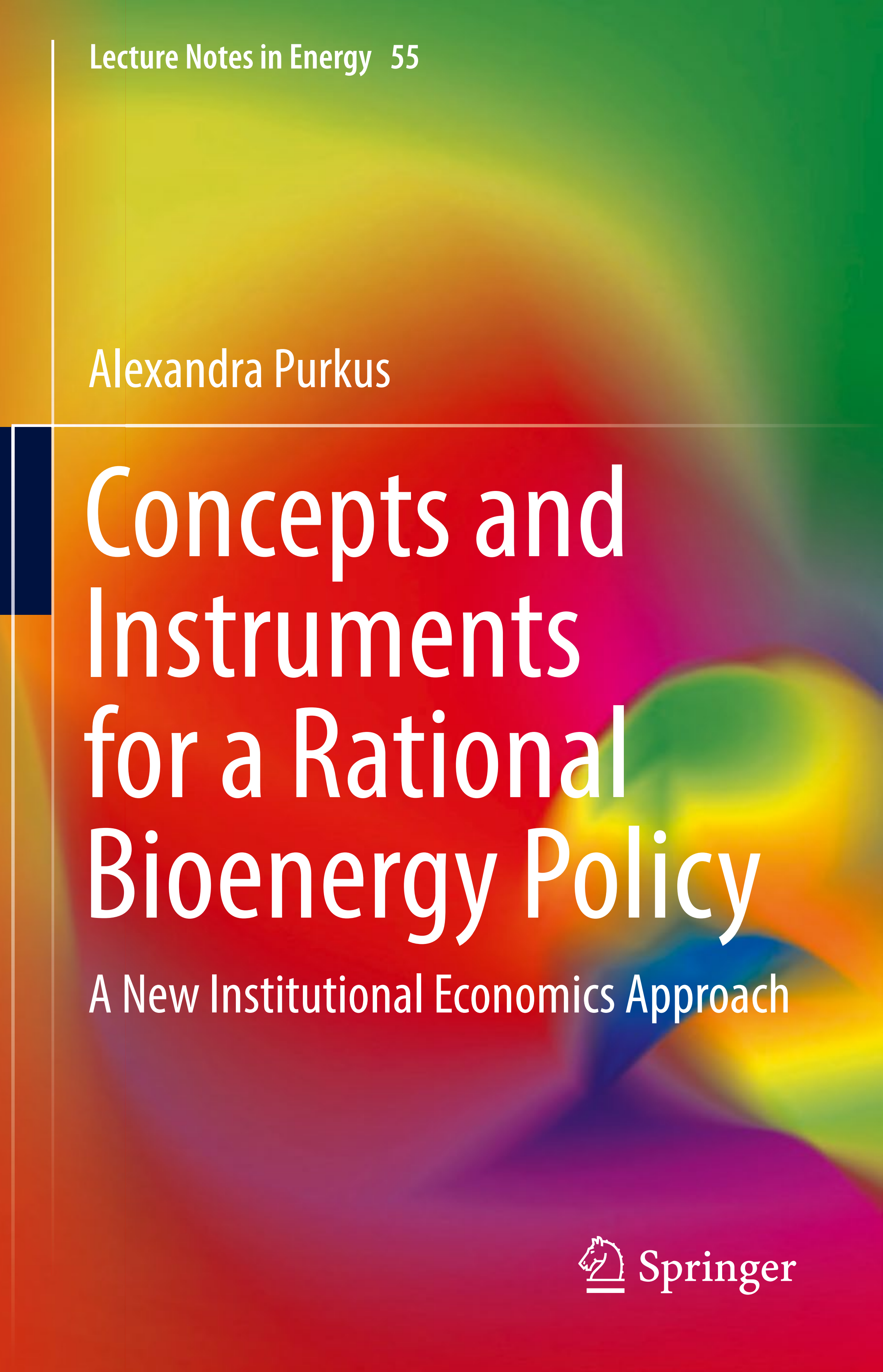

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Alexandra Purkus

Concepts and Instruments for a Rational Bioenergy Policy

A New Institutional Economics Approach

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Foreword

The use of renewable energies from biomass is connected with many hopes. In terms of climate policy, it promises a reduction of greenhouse gas (GHG) emissions in the context of satisfying a growing worldwide energy demand. At the same time, bioenergy provides urgently needed additional renewable energy sources, which are—in contrast to renewables from solar and wind—available on demand and can be used in a diverse manner: for electricity and heat production as well as for fuels. Additionally, it reduces the import dependency on scarce fossil fuels. Traditional agriculture and forestry expect a new surge in demand from bioenergy markets, and national economic policy sees export opportunities for biomass technologies as well as new sources of value creation for structurally weak areas. Against this background, it is no surprise that German and European policy heavily promoted the use of bioenergy in recent years.

However, bioenergy is widely criticised for threatening the food security of a growing global population due to the redirection of agricultural production factors towards the purpose of energy supply. Moreover, uncontrolled provision of bioenergy may result in global land-use changes, which may affect important ecological assets like biodiversity, hydrologic balance and soil integrity as well as socio-economic living conditions of people in the bioenergy regions. Even the supposed carbon neutrality of biomass use is undetermined if the change in land use for the cultivation of energy plants and their subsequent processing releases more CO_2 than the saving in energetic use compared to fossil fuels. In addition to ecological criticism, there is also economic critique concerning a policy that is too expensive for climate protection targets, as the cost for GHG reduction via bioenergy promotion may be unnecessarily high for society (compared to other means of GHG reductions). The reaction of German and European bioenergy policy to this criticism was a reduction of expansion goals and a modification of promotion instruments (e.g. sustainability requirements).

It is obvious that there are significant trade-offs between climate, energy and agricultural policy goals, and a reorientation of bioenergy policy on a scientific basis is urgently required. Between neoclassical concepts of a technology-neutral policy strictly focused on climate protection with the aim of least avoidance costs of GHG, which makes the specific promotion of bioenergy practically obsolete, and an unsteady "muddling through" approach of practical politics, a simultaneously scientifically substantiated and practice- and reality-oriented concept for a "rational bioenergy policy" is still missing.

With her dissertation, Alexandra Purkus aims to fill this research gap. She uses new institutional economic approaches, which are particularly suitable for this purpose. The overarching research goal of her PhD thesis is to bring together different strands of theory and literature to develop an analytical framework from which recommendations can be derived for a "rational bioenergy policy" that strives for efficiency and sustainability under various constraints (such as uncertainties, institutional path dependencies, transaction costs, etc.). In this way, policy recommendations are derived from an institutionally "enlightened" theory of economic policy, to identify solutions which deal with the constraints outlined above in a rational manner, and set dynamic incentives for efficiency and sustainability improvements over time. This is what is understood as "rational bioenergy policy" in the context of this work. Moreover, the issues are specified for the German bioenergy policy as a case study in the scope of the thesis.

On the one hand, the thesis covers a very relevant and current scientific issue, which is of high importance for German and European climate, environmental, energy, and agricultural policy. On the other hand, this methodological approach develops innovative theoretical perspectives of economic policy in a new policy field. They are scientifically very advanced compared to the present discussion and at the same time—especially because of the German case study—application relevant for practical bioenergy policy. This thesis is one of the few dissertations that clearly tries to cover a field of policy in its real complexity based on the example of bioenergy and under these aggravated institutional real-life conditions seeks to redefine the concept of a "rational economic policy" and to refine it for practical decisions in this policy field by using different new institutional economic theory approaches. Alexandra Purkus presents a very thorough, knowledgeable and strongly problem-oriented analysis, which is a great enrichment of the academic and policy-oriented debate, and will therefore reach a hopefully large readership.

Leipzig, Germany Erik Gawel
January 2016

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Contents

Abbreviations

a	Annum
AltholzV	Altholzverordnung (Waste Wood Ordinance)
BAFA	Bundesamt für Wirtschaft und Ausfuhrkontrolle (Federal Office of Economics and Export Control)
BBodSchG	Bundes-Bodenschutzgesetz (Federal Soil Protection Act)
BImSchG	Bundes-Immissionsschutzgesetz (Federal Immission Control Act)
Biokraft-NachV	Biokraftstoff-Nachhaltigkeitsverordnung (Biofuel Sustainability Ordinance)
BiomasseV	Biomasseverordnung (Biomass Ordinance)
BioSt-NachV	Biomassestrom-Nachhaltigkeitsverordnung (Biomass Electricity Sustainability Ordinance)
BMELV	Bundesministerium für Ernährung, Landwirtschaft und Verbraucher (Federal Ministry of Food and Agriculture and Consumer Protection); changed in December 2013 to BMEL—Bundesministerium für Ernährung und Landwirtschaft (Federal Ministry of Food and Agriculture)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety); changed in December 2013 to BMUB—Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
BMWi	Bundesministerium für Wirtschaft und Technologie (Federal Ministry of Economics and Technology); changed in December 2013 to BMWi—Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development)
BNatSchG	Bundesnaturschutzgesetz (Federal Nature Conservation Act)
BtL	Biomass to liquid

BWaldG	Bundeswaldgesetz (National Forest Act)
CAP	Common Agricultural Policy
CBA	Cost–benefit analysis
CHP	Combined heat and power
CO_2-eq.	Carbon dioxide equivalent
DüngG	Düngegesetz (Fertilisers Act)
DÜV	Düngeverordnung (Fertilisers Ordinance)
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act)
EEWärmeG	Erneuerbare-Energien-Wärmegesetz (Renewable Energy Heat Act)
EJ	Exajoule
el	Electric
EnergieStG	Energiesteuergesetz (Energy Tax Act)
EnEV	Energieeinsparverordnung (Energy Saving Ordinance)
EU	European Union
EU-ETS	European Emissions Trading System
FIP	Feed-in premium
FIT	Feed-in tariff
FQD	Fuel Quality Directive
GenTG	Gentechnikgesetz (Genetic Engineering Act)
GHG	Greenhouse Gas
GJ	Gigajoule
GWh	Gigawatt-hour
ha	Hectare
ILUC	Indirect land use change
KfW	Kreditanstalt für Wiederaufbau
KrWG	Kreislaufwirtschaftsgesetz (Closed Cycle Management Act)
ktoe	Kilotonne of oil equivalent
kWh	Kilowatt-hour
KWKG	Kraft-Wärme-Kopplungsgesetz (Combined Heat and Power Law)
LCA	Life cycle analysis
LUC	Land-use change
MAC	Marginal costs of abatement
MAP	Marktanreizprogramm (Market Incentive Programme)
MaPrV	Managementprämienverordnung (Management Premium Ordinance)
MB	Marginal benefits
MC	Marginal costs
MD	Marginal damage costs
Mio.	Million
MPS	Market premium scheme
MRS	Marginal rate of substitution
MRT	Marginal rate of product transformation
MRTS	Marginal rate of technical substitution

Mtoe	Megatonne of oil equivalent
MW	Megawatt
MWh	Megawatt-hour
N_2O	Nitrous oxide
NawaRo	Nachwachsende Rohstoffe (Renewable resources)
NIE	New institutional economics
NREAP	National Renewable Energy Action Plan
PFCs	Perfluorocarbons
PflSchG	Pflanzenschutzgesetz (Crop Protection Act)
PJ	Petajoule
PV	Photovoltaics
R&D	Research and development
RED	Renewable Energy Directive
REDD	Reducing Emissions from Deforestation and Forest Degradation
REH	Rational expectation hypothesis
RES	Renewable energy sources
SNG	Synthetic natural gas
SRC	Short rotation coppice
SRU	Sachverständigenrat für Umweltfragen (German Advisory Council on the Environment)
StromStG	Stromsteuergesetz (Electricity Tax Act)
t	Tonne
TCE	Transaction cost economics
TWh	Terawatt-hour
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
W	Watt
WBA	Wissenschaftlicher Beirat für Agrarpolitik (Scientific Advisory Board on Agricultural Policy)
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change)
WHG	Wasserhaushaltsgesetz (Federal Water Act)
WTO	World Trade Organization

Chapter 1
Introduction

1.1 Opportunities and Challenges of Bioenergy Use

In the European Union as well as on a global level, biomass constitutes the most widely used renewable energy source (BMU 2013). Given its convertibility into solid, gaseous and liquid energy carriers, biomass can be used in the electricity, heating and transport sectors; moreover, bioenergy carriers are easily storable, allowing for a better alignment of energy supply with demand than is the case for intermittent renewables such as wind or photovoltaics, which are subject to natural fluctuations. As a result, the expansion of modern energetic biomass uses is considered an important component of transitioning to a low carbon energy system (COM 2005; BMU and BMELV 2009; Chum et al. 2011). Apart from reducing carbon emissions in the energy sector, bioenergy is expected to make contributions to the security of energy supply, while simultaneously offering opportunities for rural income generation and development (COM 2005; GBEP 2007). This combination of aims from environmental, energy, economic and agricultural policy arenas has made bioenergy attractive for political support—consequently, many governments have adopted ambitious expansion plans, among them the European Union, the United States, Brazil, and China (GBEP 2007; REN21 2014: 32ff.). For the EU, bioenergy plays an important part in realising renewable energy targets for 2020, as laid down in the Renewable Energy Directive (COM 2009). In order to achieve a 20 % share of renewable energy sources (RES) in community energy consumption and a 10 % share in transport, EU-27 member states expect energy production from biomass to more than double compared to 2005 levels, from 61 million tonnes of oil equivalent (Mtoe) in 2005 to 140 Mtoe in 2020 (cf. ECN 2011).

However, the rapid expansion of bioenergy use entails sustainability risks and increases competition between various alternative uses for land and biomass resources (Thrän et al. 2011a; Bringezu et al. 2008; WBGU 2008: 57ff.). Additional demand for biomass increases pressures on agricultural land use, thereby

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incentivising the conversion of natural land and increases in agricultural intensification (Berndes et al. 2010; Edwards et al. 2010). Apart from conflicts with conservation aims, emissions associated with land use change (LUC) can significantly deteriorate the greenhouse gas (GHG) balance of bioenergy (Fargione et al. 2008; Stehfest et al. 2010; Lange 2011; Sterner and Fritsche 2011). Moreover, displacing food and feedstock production with energy crop cultivation results in rising price levels for agricultural commodities, which may in turn negatively impact food security and cause indirect land use changes (ILUC) (FAO 2008; WBGU 2008; Searchinger 2009; Kampman et al. 2010; Nuffield Council on Bioethics 2011). Studies show that significant biomass potentials could be developed for energetic uses without increasing pressures on biodiversity, soils and water resources or negatively impacting global food security (Wiesenthal et al. 2006; WBGU 2008). However, for this to be the case, appropriate regulative measures and economic incentives need to be in place. Furthermore, it needs to be taken into account that not only various energetic uses increase the demand for agricultural biomass resources, wood and organic wastes and residues, but that interest in substituting fossil fuels for biomass is also growing in the material and chemical industry sectors (BMELV 2013; COM 2012a; OECD 2009). At the same time, bioenergy applications compete with other climate change mitigation options for public support, research funds and investment capital.

In a market framework, competition between various uses for scarce biomass and land resources would be coordinated by price signals. Neoclassical economic theory predicts that under conditions of perfect competition, markets will bring about an allocation that is efficient according to the criterion of Pareto optimality—in this case, all given resources are allocated in such a way that no one can be made better off by reallocations without making somebody else worse off (Mansfield 1994: 513f.; Fritsch 2011: 23ff.; see Sect. 2.1.1). The precondition for such a welfare-optimal allocation is that all relevant markets are in a state of general equilibrium (Mansfield 1994: 489ff.; Gawel 2009: 472ff.). However, in the case of bioenergy, allocation decisions are distorted by a number of market failures, leading to allocative outcomes which are no longer efficient and do not maximise welfare (see Sect. 2.2.3). In energy markets, technology decisions are distorted by GHG externalities associated with fossil fuel-based energy production, as well as other environmental externalities which arise, for example, in the course of uranium and coal mining or radioactive waste storage (cf. Krewitt and Schlomann 2006; Nitsch et al. 2004; Owen 2006; Breitschopf et al. 2011). These externalities interact with knowledge and learning spillovers, which are generated by investments in research, development and the diffusion of innovative technologies (Jaffe et al. 2005; Newell 2010; Arrow 2008; Lehmann 2013); these prevent market actors from capturing the full economic benefits of their investments. As a result, investments in innovative technologies which are associated with low levels of carbon emissions and other environmental externalities will be lower than socially optimal, increasing abatement costs from a dynamic perspective. Furthermore, a secure and reliable energy supply is associated with positive externalities, and energy producers may fail to undertake sufficient investments to prevent short- and long-term security of supply risks, for example by increasing the diversity of energy sources (Jansen and Bakker 2006: 40; Rader and Norgaard 1996: 40; Abbott 2001: 32; Langniß et al. 2007: 17). Lastly, energy sector investments have long lifetimes and require highly specialised investments in physical capital and skills and knowledge; this interacts with increasing returns and network externalities to create a technological path dependency (Arthur 1989, 1994). This path dependency is reinforced not only by market power on the side of incumbents, but also by institutional path dependencies, because existing institutions which shape energy markets and regulation have co-evolved historically alongside dominant technologies (Unruh 2000; Lehmann et al. 2012; Lehmann and Gawel 2013; Neuhoff 2005). In combination, this results in a "carbon lock-in" (Unruh 2000) into a fossil fuel-based energy system.

These market failures interact to distort competition between low carbon energy technologies, such as bioenergy pathways and other RES, and fossil fuel-based and nuclear incumbent technologies. However, they also distort competition between heterogeneous bioenergy pathways—particularly because GHG and other environmental externalities also cause market failures in the land use sector. The GHG emission reductions associated with bioenergy use depend not only on which energy carriers are substituted by bioenergy, but also on emissions caused by land use changes and during primary biomass production (WBGU 2008: 170ff.; Lemoine et al. 2010; Sterner and Fritsche 2011). In general, the use of residues and wastes, but also of wood, tends to perform better in terms of GHG mitigation than the use of agriculturally produced energy crops (WBGU 2008: 170ff.; Sterner and Fritsche 2011). However, using the latter can significantly expand the technical biomass potential available for energetic uses (cf. Chum et al. 2011: 17ff.; Thrän et al. 2010a). Simultaneously, energy crop-based pathways can show significant differences in GHG performance and other environmental impacts, depending on associated land use changes, crop choices, cultivation methods and specific spatial contexts (WBGU 2008: 57ff.; SRU 2007: 42ff.; Thrän et al. 2010b; Rossi 2012). Furthermore, the degree of knowledge and learning spillovers differs significantly between bioenergy technologies; options such as biogas and solid biofuel-based combined heat and power (CHP) production are comparatively mature (Thrän et al. 2011b: 42ff.; Gross 2004), while others, such as second generation biofuels, have high innovative potential (Eggert and Greaker 2013; Carriquiry et al. 2011; Sims et al. 2010). If left to markets, allocation decisions along bioenergy value chains would therefore be distorted in favour of options with low private costs and a high compatibility with the current, fossil fuel-dominated path in the energy system, while differences in greenhouse gas and other environmental externalities as well as positive externalities from investments in knowledge generation and learning were neglected.

According to neoclassical welfare economics, the existence of market failures in the energy and land use sectors provides a rationale for state interventions. These should restore the functionality of the price mechanism by internalising all relevant externalities and removing market power. Once the private costs and benefits of allocation decisions equalled the social costs and benefits and perfect competition was re-established, allocative efficiency would be restored—interventions such as these, which bring about a Pareto-optimal, welfare-maximal allocation, can be termed first-best interventions (Luckenbach 2000: 141). In practice, however, policy makers who intervene in bioenergy allocation decisions risk replacing market failures with government failures; these come about if interventions fail to correct market failures, or if they decrease efficiency even further compared to the market outcome (Fritsch 2011: 370). Government failures can result from a number of sources, such as: (i) conflicts between policy aims which seek to improve economic efficiency and distributive aims; (ii) information problems, for example, concerning the GHG balances and environmental impacts of bioenergy pathways; these are subject to significant uncertainties, particularly once indirect land use changes are taken into account (e.g. Reap et al. 2008; Cherubini and Strømman 2011; Edwards et al. 2010; DG Energy 2010; Adams et al. 2013); (iii) transaction costs of regulation, which may lie above the transaction costs of using even imperfect markets as coordination mechanisms; (iv) coordination problems between local, regional, national and transnational governance levels in governing bioenergy value chains which are increasingly transnational in character, as market actors make use of different countries' comparative cost advantages in biomass and bioenergy carrier production (Junginger et al. 2011; Lamers et al. 2011, 2012); and (v) conflicts between political and economic rationality.

Indeed, as interventions in energy markets with far-reaching consequences for biomass resource markets and land use markets, German and European bioenergy policies have attracted fierce criticism (see Sects. 3.1.4 and 4.4). Economists criticise that instead of relying on first-best measures for the correction of market failures, a number of technology-specific targets and deployment support instruments are employed (e.g. Frondel and Peters 2007; Frondel et al. 2010; Frondel and Schmidt 2006; Weimann 2008: 118f.; Sinn 2008: 161ff; Kopmann et al. 2009)—the latter are moreover fragmented across the electricity, heating and transport sectors, with little coordination between them (WBA 2007: 177ff.; SRU 2007: 88ff.; WBGU 2008: 325). The resulting policy mix reflects a range of efficiency-oriented and distributive policy aims with unclear prioritisation, so that in the end, bioenergy does not make cost-effective contributions to any of them (Isermeyer and Zimmer 2006; Henke and Klepper 2006). In particular, however, a failure to align allocation decisions with GHG mitigation as a priority aim is criticised (Henke and Klepper 2006; WBA 2007: 175ff.; Kopmann et al. 2009; Isermeyer and Zimmer 2006; SRU 2007: 80ff.; WBGU 2008: 274). Especially biofuels support policies are named as very expensive means of achieving GHG emission reductions (Frondel and Peters 2007; Henke et al. 2003; Henke and Klepper 2006; WBA 2007:177; Kopmann et al. 2009). Moreover, the sustainability of bioenergy policies is called into question—if introduced by several major economies, bioenergy support instruments increase pressures on land use globally, thereby exacerbating existing market and government failures in the land use sector (cf. WBA 2007: 180f.; WBGU 2008: 209; SRU 2007: 43ff.; Gallagher 2008: 29ff.; Miyake et al. 2012). Existing environmental framework conditions are found to be inadequate to safeguard against adverse environmental and socio-economic impacts of an additional, policy-driven biomass demand, both in non-EU biomass export countries (SRU 2007: 68ff.; Nuffield Council on Bioethics 2011: 90; Wunder et al. 2012) as well as within the EU (SRU 2007: 60ff.; Hirschfeld et al. 2008; Oppermann et al. 2012; Ammermann and Mengel 2011). At the same time, existing deployment support measures and instruments such as sustainability certification are found wanting when it comes to differentiating between bioenergy pathways according to environmental externalities and distributive impacts (WBA 2007: 181f.; SRU 2007: 60ff.; WBGU 2008: 318ff.; German and Schoneveld 2012; Schlamann et al. 2013).

1.2 Economic Advice for Bioenergy Policy: Between an “Ideal World” and “Muddling Through”?

Economic policy advice can make a valuable contribution towards assessing the manifold criticisms raised against existing bioenergy policies, and developing recommendations for a more rational policy design. Theory-based, economic contributions to the debate have been primarily based on neoclassical economics, with a focus on integrating bioenergy policy into a cost-effective GHG mitigation strategy: adopting GHG mitigation as the sole relevant aim with which bioenergy policy should be aligned allows for the identification of first-best interventions for the internalisation of GHG externalities. Once a GHG mitigation target has been set, the question becomes one of identifying an individual instrument which can implement this target effectively and cost-effectively; this approach follows the Tinbergen rule, which states that solving a certain number of targets requires at least an equal number of instruments (Tinbergen 1952; see Sect. 3.1). As a result, neoclassical economists recommend moving away from a sectorally fragmented policy mix which relies on technology-specific deployment support, and coordinate bioenergy allocation decisions through an extended emissions trading scheme instead (Frondel and Peters 2007; Klepper 2010; WBA 2007: 177f.; Kopmann et al. 2009). For optimising bioenergy’s contribution to GHG mitigation targets, the instrument would need to span the electricity, heating, transport and, ideally, land use sectors, to account for GHG emissions associated with land use changes (Klepper 2010; Isermeyer and Zimmer 2006; Kopmann et al. 2009). Furthermore, to ensure an efficient allocation of abatement efforts and prevent leakage effects, the scheme would preferably need to be global in scope (Kopmann et al. 2009). With an extended emissions trading scheme, bioenergy pathways would only be adopted if they turned out to be competitive on the basis of GHG mitigation costs. Interdisciplinary policy recommendations, meanwhile, tend to be tempered by political feasibility considerations, but even here, the ideal of steering bioenergy allocation decisions through a cross-sectoral emissions trading system can be found as a long-term point of orientation, which is to guide the short-term alignment of sectoral policy instruments (cf. SRU 2007: 97f.; WBA 2007: 177ff.).

However, the applicability of these first-best recommendations rests on several highly idealised assumptions, which prove problematic when confronted with the multiple sources of market and government failures which are relevant in the bioenergy context (see Sect. 3.1.5):

1. The first-best approach to policy advice assumes that market failures can be considered individually when formulating policy recommendations, and that instruments can be optimised according to one policy aim. However, the theory of second-best emphasises the importance of interactions between multiple market failures (Lipsey and Lancaster 1956; Bennear and Stavins 2007; Lehmann 2012). If not all relevant market failures can be solved simultaneously by first-best solutions, the correction of one market failure in isolation may not necessarily increase economic welfare, because other, unresolved market failures may be exacerbated by the corrective intervention. A “second-best” intervention may consist of measures which address symptoms of interacting market failures, rather than first-best cures of their causes (Luckenbach 2000: 144). With a sector-spanning emissions trading system, for instance, abatement technology choices would remain distorted by knowledge and learning spillovers, so that efficiency can be improved by combining it with technology policy measures (Jaffe et al. 2005; Newell 2010; Bennear and Stavins 2007; Lehmann 2012).
2. First-best recommendations abstract from the transaction costs associated with the implementation, monitoring and enforcement of instruments, as well as with political decision making processes (Williamson 2005; Dixit 1996; Krutilla and Krause 2011). These would impose considerable limits on the feasibility and also the efficiency of a cross-sectoral, global emissions trading scheme (Lehmann and Gawel 2013).
3. Problems arising from uncertainty are considered only to a very limited degree, for example, in the choice between price and quantity instruments (Weitzman 1974), or target setting under uncertainty (Baumol and Oates 1971). However, the coordination of allocation decisions through an emissions trading scheme presumes an accurate accounting of GHG emissions (cf. Haberl et al. 2012), which is problematic given far-reaching uncertainties about GHG balances of bioenergy pathways.
4. By focussing on the efficiency rationale for state interventions in market processes, neoclassical theory neglects the relevance of distributive aims in political decision making. In the bioenergy context, distributive aims like rural value creation or employment generation in the RES industry play an important role; because they emerge from a democratic decision making process, they cannot justifiably be neglected (Sijm et al. 2014: 8).
5. Neoclassical recommendations view policy makers as disinterested welfare maximisers who design instruments with efficiency in mind; instead, policy making can be more accurately modelled as a negotiation and bargaining process, where self-interested policy makers attempt to maximise political support (Dixit 1996: 8ff.; Erlei et al. 1999: 323f.; Tullock 2008: 723). Political

rationality considerations can favour deviations from the Tinbergen rule; by attempting to address several efficiency-oriented and distributive aims with one instrument, the political feasibility of measures can be increased (cf. Gawel et al. 2014).

6. Neoclassical theory abstracts from the institutional context in which policy decisions and allocation decisions are taken. Institutions can be defined as "a rule or system of rules, a contract or a system of contracts (including enforcement mechanisms), which channel the behaviour of individuals" (Erlei et al. 1999: 23–25, own translation). Rules can be formal or informal in nature, and form an interacting, multi-layered system which has evolved over time (North 1990: 3; Williamson 2000; Richter and Furubotn 2003: 7). By constraining the interaction of boundedly rational individuals with imperfect information, institutions decrease the complexity of the decision making environment and economise on transaction costs (North 1990: 3). However, a given institutional framework may not be efficient and enact multiple distortions on allocation decisions—at the same time, institutional change is path dependent and mostly incremental in nature (North 1990: 92ff). By interacting with technological path dependencies, this can result in a lock-in into inefficient production and consumption structures, which cannot be overcome by an internalisation of externalities alone (Unruh 2000; Lehmann et al. 2012; Lehmann and Gawel 2013; Neuhoff 2005).
7. Lastly, even allocative outcomes which are efficient need not be sustainable, if normative requirements of inter- and intragenerational justice are applied (e.g. Daly 1992; Woodward and Bishop 1995; Padilla 2002; Krysiak 2009).

These considerations impose significant limits on the adequacy of neoclassical recommendations for bioenergy policy. By comparing existing market imperfections and policy interventions with solutions which would be ideal from a theoretical viewpoint, neoclassical policy advice risks following a "nirvana approach" (Demsetz 1969): practitioners of this approach "seek to discover discrepancies between the ideal and the real and if discrepancies are found, they deduce that the real is inefficient" (Demsetz 1969: 1). The actual feasibility of recommended measures, meanwhile, is neglected, considerably constricting the practical applicability of said advice.

As an alternative to the identification of optimal solutions based on theory, the term "muddling through" has been coined to describe a non-theory based decision and policy making strategy closer to the realities of the political process (Lindblom 1959, 1979). Here, policy choices are made on the basis of successive comparisons of alternatives which differ only incrementally, aided by experience about the differences in consequences that have been associated with incremental differences in policies in the past. Such an incremental approach allows not only for a simplification of the set of alternative policy options and consequences considered, but does not even require the definition of a clear hierarchy of policy aims—"agreement on policy thus becomes the only practicable test of the policy's correctness" (Lindblom 1959: 84).

However, a “muddling through” approach removes policies from a normative assessment. The German bioenergy policy mix, for instance, represents what has been chosen and agreed on by policy makers, and yet it has been widely criticised from an efficiency- and sustainability perspective—for evaluating these criticisms, a theoretical basis is necessary, to assess whether there may be feasible alternatives which perform better according to these criteria. Moreover, normative concepts like efficiency and sustainability are required to provide a counterweight to political rationality considerations. Public choice theory points out that it can by no means be assumed that incremental changes in policies will lead to improvements in their performance over time—instead, policy choices might reflect a redistribution of rents from less well organised groups in society to well organised interest groups (Olson 1965; Becker 1983; McCormick and Tollison 1981; Orchard and Stretton 1997: 412f.).

Furthermore, in the case of climate change policy, there is wide agreement between policy makers and scientists that a drastic reduction of GHG emissions is required in order to avoid global temperature increases with potentially catastrophic consequences (cf. IPCC 2013; UNFCCC 2014). Particularly industrialised countries which have a historical responsibility for high atmospheric carbon stocks face the challenge of undertaking a path transition away from the current technological and institutional carbon lock-in (Unruh 2000; Lehmann et al. 2012; Berkhout 2002). However, a wide range of actors and interest groups have invested specialised capital and skills into the existing “techno-institutional complex” (Unruh 2000: 818)—these would seek to influence incremental policy changes in their favour (Unruh 2002: 320f.; North 1990: 82; Kiwit and Voigt 1995; Leipold 1996: 107), thus reinforcing the lock-in.

Interactions between technological breakthroughs, social movements and exogenous focussing events (such as environmental catastrophes) can generate demand for more far-reaching policy changes, which propel innovative GHG mitigation technologies such as RES towards a market breakthrough (Unruh 2002). But, in designing these policies, there is limited experience on which an evaluation of incremental alternatives could build. European and member state-level targets for RES expansion and associated deployment support are fitting examples of this. Given the uncertainties surrounding such measures, the a priori identification of an optimal policy option which takes all relevant consequences into account is unrealistic—as the ongoing debate about how to address or even measure direct and indirect land use change effects as unintended consequences of bioenergy policies illustrates (Broch et al. 2013; Di Lucia et al. 2012; Gawel and Ludwig 2011; Van Stappen et al. 2011). On the other hand, ex post changes in bioenergy policy measures, which are implemented as part of a learning process, lead to an increase in policy uncertainty, which can compromise investors’ willingness to respond to future climate policy initiatives.

Under such circumstances, a theory-based policy analysis which operates on assumptions closer to reality than those of a first-best neoclassical approach can make an important contribution towards more rational policy making. The focus here is not on the identification of optimal solutions, but on the systematic assessment of what policy alternatives may be better able to deal with relevant uncertainties and result in comparatively more efficient (and sustainable) outcomes than others (Demsetz 1969: 1; Dixit 1996: 8ff.; Williamson 2000). This approach has been successfully applied by new institutional economics (NIE), which can be described as the systematic, positive analysis of the effect that institutions have on human behaviour and social outcomes, as well as the normative analysis of their design (Erlei et al. 1999: 42; see Sect. 3.5).

While institutional change as a whole, which involves different nested layers of formal and informal institutions, is found to be incremental in nature (North 1990: 92ff.), individual institutions such as policy instruments can be amenable to more active design. For bioenergy policy, and climate change policy in general, NIE offers important theoretical insights regarding the design of such institutions, and their interactions with institutional layers which are more resilient to change. In placing economic policy recommendations for the bioenergy context on a more realistic footing, several NIE approaches seem particularly relevant—these are transaction cost and contract economics which compare the performance of governance structures between market and hierarchies in reducing uncertainties and economising on transaction costs (e.g. Williamson 2005; Dixit 1996; Krutilla and Krause 2011; see Sect. 3.5.2); the principal-agent approach which allows for an analysis of the implications of asymmetric knowledge between regulators and regulated market actors (Arrow 1984; Noth 1994; Haberer 1996; see Sect. 3.5.3); the theory of institutional change which examines the role of path dependencies and strategies for overcoming techno-institutional lock-in situations (North 1990, 1995; Brousseau et al. 2011; see Sect. 3.5.4); and the public choice approach which focuses on the role of interests in policy making (McCormick and Tollison 1981; Olson 1965; Mueller 1989; Orchard and Stretton 1997; see Sect. 3.5.5).

Besides NIE approaches, there are a number of other theories which examine the implications of realistic assumptions for policy making, making important contributions to economic policy advice that lie between the "muddling through" of day-to-day politics and the "ideal world" recommendations of neoclassical economics. For bioenergy policy, the following approaches have been identified as particularly relevant: the theory of second-best, which as mentioned above allows for a structured analysis of interactions between market failures (Lipsey and Lancaster 1956; Bennear and Stavins 2007; Lehmann 2012; see Sect. 3.2); information economics (e.g. Hayek 1945; O'Driscoll and Rizzo 1996; Young 2001; see Sect. 3.3) and the theory of economic order (Hayek 1945; Eucken 1952/1990; Wegner 1996; see Sect. 3.4), which both offer insights into political decision making and policy design under different forms of uncertainty; and ecological economics, with relevant findings regarding sustainability constraints and the handling of associated knowledge problems in policy making (Costanza et al. 1991; Costanza and Cornwell 1992; Funtowicz and Ravetz 1991; see Sect. 3.6).

These approaches have been fruitfully applied to a number of fields, including economic policy, organisation economics, and problems of environmental policy making. For climate and renewable energy policy issues, second-best theory and NIE have made significant contributions to the evaluation of policy mixes (for overviews see Lehmann and Gawel 2013; Sijm et al. 2014; Lehmann 2013) and instrument design (Menanteau et al. 2003; Finon and Perez 2007). In the bioenergy context, however, insights from relevant theories have been applied only to very specific questions so far, such as the role of information asymmetries in sustainability certification (Schubert and Blasch 2010), or the use of a post-normal science approach for dealing with sustainability-related uncertainties in bioenergy policy making (Upham et al. 2011). What is still missing is a systematic evaluation of where problems of bioenergy allocation and policy making show relevant deviations from neoclassical assumptions, and an assessment of how insights from theories that go beyond these assumptions can be combined to form a framework from which coherent economic recommendations for bioenergy policy can be derived. This book aims to address this gap.

1.3 Research Objectives

This study pursues two primary objectives. The first is to gain additional economic insights into the governance of complex environmental policy problems characterised by high uncertainty, multiple interacting market failures, institutional path dependencies and conflicting policy aims. The second objective is to use these insights to develop economic recommendations for the case of German bioenergy policy, which are closer to political realities than those based on the neoclassical construction of the problem, wherein the focus is on a single policy aim which strives for the correction of a single market failure, which can be addressed by a single first-best instrument in a way that allocative efficiency is restored (see Sects. 1.1 and 1.2). Drawing on NIE, second-best theory and the other approaches specified above, it is of interest whether neoclassical economists' rejection of technology- and sector-specific bioenergy deployment support instruments can be confirmed, or whether conclusions indicate a justification for their inclusion in a policy mix. In that case, the question would be how the existing policy mix could be improved on in terms of efficiency and sustainability.

In answering these research questions, three broad strands of relevant literature can be defined, which themselves draw on various theories. However, each of these strands shows limits when applied to the problems of bioenergy allocation, making it necessary to apply a synergetic approach.

First, there is the policy mix literature which focuses on the implications of multiple interacting market failures and multiple, potentially conflicting policy aims (Sect. 3.2). Besides insights from second-best theory, this strand of literature frequently incorporates NIE tenets such as the relevance of transaction costs, the embeddedness of policy instruments in a wider institutional framework and the existence of institutional path dependencies (Bennear and Stavins 2007; Goulder and Parry 2008; Ring and Schröter-Schlaack 2011; Lehmann 2012). For bioenergy policy, policy mix literature focussing on the interaction between climate and renewable energy policy instruments is particularly relevant. In contrast to neoclassical theory-based recommendations, it is shown that a coordinated policy mix consisting of an internalisation instrument, R&D subsidies and deployment support can improve efficiency compared to an individual instrument (see Lehmann and Gawel 2013; Sijm et al. 2014; Lehmann 2010, 2013 for comprehensive reviews). However, existing studies focus primarily on interactions between the EU-ETS or emissions taxes and a national-level feed-in tariff or another RES support instrument in the electricity sector (ibid.). In the case of bioenergy, the relevant policy mix needs to encompass the dimension of land use governance, as well as interactions between policy mixes in different energy sectors; moreover, given the transregional character of value chains, interactions between different governance levels need to be taken into account. Furthermore, there are various relevant aims that make demands on bioenergy use, plus the normative criterion of sustainability. Focussing in detail on a subset of interactions would, by necessity, involve neglecting other interactions: instead, this book aims to provide a structured account of relevant instruments, market failures and policy aims and their complex interactions. To be able to do this, a qualitative rather than a quantitative approach is chosen.

The second strand of relevant literature is made up of studies focussing on environmental policy making under uncertainty. This encompasses environmental economics contributions of instrument choice under uncertainty based on findings by Weitzman (1974) (see Sect. 3.1.2), NIE-based contributions focussing on asymmetric information problems (Sect. 3.5.3) or institutional learning and adaptation processes (Sect. 3.5.4), applications of information economics insights on decision making under various types of uncertainty to environmental problems (Sect. 3.3), and ecological economics approaches focussing on handling sustainability constraints under uncertainty (Sect. 3.6). For the application to bioenergy policy, limits arise from the diverse character of contributions, which use different sets of assumptions and frequently focus on very specific policy or decision making problems. Here, this book's contribution is to examine and synergise insights for the formulation of a bioenergy concept which takes the role of uncertainty in different stages of the policy making process into account, from decision making to institutional design and implementation.

Thirdly, transaction-cost economics-based literature on respective advantages of hierarchical governance structures and governance structures close to markets proves relevant (Sect. 3.5.2). Originally applied in an organisation economics context (Williamson 1975, 1985), findings have since been transferred to problems of policy making (Dixit 1996; Krutilla and Krause 2011; McCann 2013). Moreover, the topic has also been the focus of works on economic policy based on the theory of economic order (Eucken 1952/1990; Hayek 1967/2003; Wegner 1996; see Sect. 3.4). While the latter emphasise the advantages of decentralised allocation decision making, transaction cost economics findings imply that under some conditions, hierarchical governance structures can perform better than market-based ones; this has also been found for the problem of instrument choice in renewable energy policy, for example, when comparing quota schemes close to markets with more hierarchical feed-in tariffs (Finon and Perez 2007; Menanteau et al. 2003).

Differentiating between various climate change mitigation options or renewable energy technologies is difficult enough for policy makers, but the heterogeneity of bioenergy pathways adds a degree of complexity. In the electricity sector, for example, it is not only a matter of differentiating between say, bioelectricity, wind power, photovoltaics and so on, but differences in GHG balances and other environmental and socio-economic impacts raise the question of how to differentiate within the bioelectricity technology group. The same is true for different biomass-based pathways in the transport and heating sectors. This study adds to the literature on the governance of technology choices between market-based and hierarchical approaches by analysing the question of technology differentiation within a heterogeneous technology group.

The overall approach of this study, therefore, is to bring together different strands of theory and literature to develop an analytical framework from which realistic, yet theory-based recommendations for bioenergy policy can be derived. The central question is what characterises a "rational", economic theory-based bioenergy policy, which acknowledges efficiency and sustainability as normative guidelines, while navigating a path between various interacting market failures and potential government failures. In this context, it is the task of economic policy advisors to offer recommendations which are closer to reality than a first-best nirvana approach, but avoid the arbitrariness of a "muddling-through" approach.

Meanwhile, given the scope of the topic and the regulative problems involved, the aim of this book is not to provide detailed recommendations for each aspect of bioenergy policy. Instead, guidelines for a rational bioenergy concept will be developed, which can then be applied to different contexts. However, even on a conceptual level, the institutional environment that bioenergy policy making is embedded in is an important factor that needs to be taken into account when formulating recommendations. Here, for reasons outlined below, German bioenergy policy has been chosen as a case study. Also, the focus is on national-level policy making and design, although interactions with other governance levels are taken into account. This focus has been selected because currently, major incentives for bioenergy use originate from national level policy decisions and instruments. Additionally, to explore its applicability to more detailed instrument recommendations, the analytical framework developed in this study is applied to the specific question of how bioelectricity support schemes should be further developed under the German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG).

1.4 Relevance of the German Case Study

The German case study is highly relevant for a number of reasons. Germany was among the early movers in supporting the expansion of biofuels and bioelectricity pathways on a significant scale (cf. Beurskens and Hekkenberg 2011; Thornley and Cooper 2008; Londo and Deurwaarder 2007). Biomass use in heating applications is an established practice in a large number of countries, but the simultaneous expansion of biomass use in all three energy sectors (see Sects. 4.1.3 and 4.1.4) is particularly interesting from an allocative point of view because it amplifies competition for biomass resources and increases coordination requirements between sectoral policy measures. Given that a number of EU and non-EU countries plan to expand their bioenergy use in several sectors (GBEP 2007; Beurskens and Hekkenberg 2011), important lessons can be learned from the German case.

Moreover, the comparability of Germany's bioenergy policy mix to other EU member states is high—all of them apply a policy mix of EU-ETS and national instruments for renewable energy support, which are mostly designed in a technology- and sector-specific manner (Winkel et al. 2011; RES LEGAL 2015). Some elements of national renewable energy policy design, such as minimum sustainability standards for biofuels and bioliquids, or RES targets in the transport sector, are harmonised by EU regulations (see Sect. 4.1.2). Moreover, member states share the Common Agricultural Policy (CAP), and national environmental framework regulations have to be aligned with EU requirements. The transferability of general findings from the German case study is therefore likely to be high, although more specific recommendations, for example, concerning instrument choice and design, would have to be adjusted to national contexts.

Finally, German bioenergy policy is an interesting case study because over the last decade, clear changes can be observed in its strategic orientation. In the mid-2000s, political commitment was expressed for an expansion of bioenergy use and renewable resource cultivation (Federal Government of Germany 2005: 42f.; BMELV 2007). The use of energy crops for electricity production was specifically incentivised through a renewable resource bonus introduced in the EEG 2004 (cf. Witt et al. 2012: 100; Delzeit et al. 2012), while tax incentives for biofuels and later the biofuel quota supported the expansion of energy crop-based first generation biofuels (FNR 2012; Naumann et al. 2014: 31ff.). In 2009/2010, policy makers continued to emphasise support for an expansion of bioenergy use in all three energy sectors, but further energy crop potentials were increasingly regarded as limited, placing the focus for further expansion on wastes and residues and technical efficiency increases (BMU and BMELV 2009: 8; Federal Government of Germany 2010: 94ff.; BMWi and BMU 2010: 10). In 2014, bioelectricity policy in particular has been revised with a strong emphasis now being placed on cost-effectiveness aspects, shifting away from energy crops as well as from remaining high-cost waste and residues as potential energy sources (Federal Government of Germany 2013: 39; BMWi 2014: 11f.). In the transport sector, the shift towards a GHG-based biofuel quota, which entered into force in 2015, likewise places greater emphasis on waste and residues-based concepts (Naumann et al. 2014: 3f.). The turn away from energy crop-based bioenergy concepts is also mirrored on the EU policy level, where deliberation on direct and indirect land use change impacts (COM 2010, 2012b) has resulted in the recent introduction of a cap on food-based biofuels in EU-level biofuel policy targets (European Parliament 2015). Meanwhile, shifts in strategic orientation have been accompanied by changes in instrument design which have at times been abrupt, leading to no small degree of policy uncertainty on the part of investors. For countries which have yet to implement comprehensive bioenergy strategies or still wider bioeconomy strategies, an analysis of these developments in the light of theoretical insights on policy adjustments can yield useful insights.

1.5 Structure and Contents

This book is divided into six chapters, Chap. 1 being the introduction. Chapter 2 conducts an economic analysis of the allocative challenges associated with bioenergy use. More specifically, it examines what problems arise when allocation decisions are coordinated by market forces alone (Sect. 2.2), and what challenges apply to regulative interventions in the market mechanism (Sect. 2.3). As such, the analysis provides the basis for subsequent chapters which examine responses to these challenges. As central normative criteria for evaluating the allocative outcome of market processes or government interventions, the requirements of efficiency and sustainability are discussed (Sect. 2.1). It is shown that when allocative problems such as the steering of biomass flows and technology choices, the setting of incentives for dynamic efficiency and innovation, and the steering of location choices and sourcing decisions are solved by the market mechanism alone, the outcome will not be efficient (Sect. 2.2). Several market failures are identified which distort allocation decisions (Sect. 2.2.3), namely environmental externalities, security of supply externalities, knowledge and learning externalities, the occurrence of market power in the energy sector, and dynamic market failures that inhibit market adjustment processes. Moreover, interactions between market actors are subject to information problems and transaction costs. Meanwhile, the analysis points out that even if the market outcome was efficient, it need not be sustainable. Policy interventions, on the other hand, are also unlikely to bring about an outcome which meets efficiency and sustainability criteria, because of the relevance of conflicting aims (Sect. 2.3.1), information problems and transaction costs (Sect. 2.3.2), the multi-level governance nature of the regulative problem (Sect. 2.3.3), and conflicts between political and economic rationality considerations (Sect. 2.3.4). Indeed, German and European bioenergy policy making shows clear empirical evidence for the relevance of these sources of government failure (Sect. 2.4). For assessing policy interventions in allocation decisions, requirements for a rational bioenergy policy are defined, which take the constraints imposed by imperfect information and political feasibility into account (Sect. 2.1.3). However, the analysis demonstrates that the multiplicity of relevant, interacting market failures and sources of potential government failures makes compliance not only with sustainability and efficiency criteria, but also with rational bioenergy policy requirements a challenging task.

Chapter 3 develops the analytical framework which is used in Chap. 5 to derive recommendations for German bioenergy policy. First, neoclassical theory implications for bioenergy policy, as well as their limits, are discussed (Sect. 3.1). To move towards more realistic theory-based policy recommendations, the analysis draws on the theory of second-best (Sect. 3.2), information economics (Sect. 3.3), the theory of economic order (Sect. 3.4), and new institutional economics (Sect. 3.5), and gives an outlook on ecological economics implications (Sect. 3.6). For each of these theories, relevant findings are discussed and applied to bioenergy policy, leading to the derivation of theoretical guidelines for bioenergy policy design (Sect. 3.7.7). It is demonstrated that when developing a comprehensive framework for bioenergy policy analysis, no individual theory addresses all relevant aspects, and that a combination of theoretical approaches is necessary to generate recommendations which adequately reflect the complexity of the policy problem. However, among the theories considered, new institutional economics approaches are found to be particularly fruitful for the generation of valuable insights for bioenergy policy recommendations. Here, the matrix of institutions which jointly influence allocation decisions by bioenergy actors is at the centre of the policy analysis. Among new institutional economics approaches, transaction cost economics (Sect. 3.5.2), the principal-agent approach (Sect. 3.5.3) and the theory of institutional change (Sect. 3.5.4) provide valuable insights for generating policy design recommendations in the presence of uncertainty and transaction costs in the various stages of decision making and policy implementation. Furthermore, the theory of institutional change and the public choice approach (Sect. 3.5.5) help explain the persistence of inefficiencies, and highlight the importance of political constraints when assessing the feasibility of policy recommendations. Because of the central insights that an institutional perspective offers for the analysis of bioenergy policy, new institutional economics is chosen as the overall framework into which insights from other theories are integrated.

Chapter 4 moves on to the German case study. While the analyses undertaken in Chaps. 2 and 3 are not specific to Germany, but generate general theoretical insights that apply to bioenergy allocation and policy making, the development of concrete recommendations requires that the institutional context be taken into account. Chapter 4 therefore provides an overview of relevant political framework conditions for German bioenergy policy. As a focus, European and national policy levels are chosen, because it is here that major incentives for bioenergy use originate (Sects. 4.1 and 4.2). It is shown that bioenergy policy affects a wide range of policy aims from diverse policy areas, and that the political prioritisation of aims has changed over time (Sect. 4.1.1). Also, the strategic long-term focus of bioenergy policy is the subject of ongoing discussions (Sect. 4.1.3). Meanwhile, alongside diverse policy aims, there is also a complex mix of policy instruments that influence bioenergy allocation decisions (Sect. 4.2). Instruments identified as the most relevant for bioenergy allocation include command-and-control instruments and market-based incentive instruments, which can be further divided into indirect instruments which increase the costs of fossil fuel substitutes and direct instruments which set positive incentives for bioenergy use. Direct, sectoral instruments such as the EEG in the electricity sector (Sect. 4.2.3), the Renewable Energy Heat Act (Erneuerbare-Energien-Wärmegesetz, EEWärmeG) and the Market Incentive Programme in the heating sector (Sect. 4.2.4), and the biofuels quota in the transport sector (Sect. 4.2.5) are found to be the most relevant policy drivers for bioenergy expansion in Germany. Besides setting incentives for bioenergy use in the utilisation sphere, they also—to varying degrees—influence the choice of conversion technologies and feedstocks.

Following the overview of political framework conditions and the identification of primary drivers, Chap. 4 assesses the German bioenergy policy mix in relation to the market and government failures discussed in Chap. 2 (Sect. 4.3) and reviews major strands of critique in the public debate (Sect. 4.4); in particular, these refer to the lack of cost-effectiveness in realising contributions to GHG mitigation and the limited effectiveness of sustainability safeguards. The chapter concludes with a review of comprehensive recommendations for reforming the German bioenergy policy mix, which have been proposed by interdisciplinary expert panels (Sect. 4.5), to allow for a comparison to the NIE-based policy advice developed in this book.

Chapter 5 addresses the research objective of developing concrete recommendations for bioenergy policy, applying the theory-based analytical framework developed in Chap. 3 to the German case study. The focus is on recommendations for a rational bioenergy policy concept, which encompasses the definition of a system of consistent policy aims, the choice of allocative principles for bioenergy governance, and the identification of suitable instrument types to implement aims (Sect. 5.1). As such, conceptual recommendations do not intend to solve every detailed question of policy formulation, but act as a reference system for individual policy decisions. Moreover, to demonstrate the applicability of the study's analytical framework to more specific questions of instrument choice and design, recommendations for the bioelectricity sector are developed in greater detail (Sect. 5.4). For each element of the bioenergy concept, neoclassical solutions are outlined, to act as a baseline against which NIE-based findings can be compared; then, there is a discussion of which theoretical insights from Chap. 3 are particularly relevant for analysing the system of policy aims, the choice of allocative principle, and instrument choice and design (Sects. 5.2–5.4). These insights are used to evaluate current German bioenergy policy, and derive recommendations for the three elements of a bioenergy concept.

Given the conflicting nature of policy aims, the establishment of a complete and coherent system of policy aims is found to be of particular importance, although public choice theory highlights the difficulties of such an endeavour (Sect. 5.2). Also, requirements concerning the operationalisation of aims are discussed. The choice of allocative principle determines what allocation mechanism is used primarily to implement aims—basic allocative principles are the use of governance structures comparatively close to markets, which leave technology choices to market actors, and the use of governance structures with a more hierarchical steering of allocation decisions (Sect. 5.3). Different allocative principles are found to be recommendable for governing different transactions in bioenergy value chains, depending on their specific characteristics. In contrast to neoclassical recommendations, a theoretical case is established for a bioenergy mix combining governance structures close to markets with more hierarchical interventions. Also, the work examines what types of interventions are most promising when it comes to addressing interactions between interventions which increase bioenergy demand, unresolved market failures and conflicting policy aims. Based on the analysis of what allocative principles are recommendable for different allocative challenges, perspectives for the further development of the German policy mix are discussed (Sect. 5.3.3).

For a more detailed analysis of instrument choice and design, a further focus is necessary; direct bioenergy support in the electricity sector is chosen as an example, because here, a major reform process is currently underway (Sect. 5.4). For addressing the allocative challenges of bioelectricity use, three elements of instrument choice and design are identified as particularly important: (1) the choice between price, quantity and hybrid instruments; (2) the design of a mechanism for technology differentiation; and (3) the design of an adjustment mechanism, which is strongly interwoven with the two previous questions of instrument choice and technology differentiation. For these three elements, theoretical insights are discussed and applied to an evaluation of the current feed-in tariff/feed-in premium scheme as well as relevant instrumental alternatives. Based on a comparative institutional analysis, recommendations are derived.

Chapter 6 concludes with a summary of major findings (Sect. 6.1), discusses the transferability of the study's analytical framework to other policy contexts (Sect. 6.2), and provides an outlook (Sect. 6.3).

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Chapter 2
Allocative Challenges of Bioenergy Use

Characterised by heterogeneous and transregional value chains, bioenergy use constitutes a complex problem of allocation. Biomass that can be used energetically includes a wide range of resources, such as wood and forestry residuals; agricultural crops as well as agricultural and animal by-products; organic wastes and waste wood; and even photosynthetic micro-organisms such as microalgae and bacteria (Bauen et al. 2009: 6ff.). These resources can be employed in a variety of different thermochemical, biochemical and chemical conversion routes (Bauen et al. 2009: 8; Chum et al. 2011: 40ff.), leading to an energetic end use as power, combined heat and power, heat, or transport fuels (Chum et al. 2011: 43ff.).

In this book, bioenergy use is adopted as an umbrella term which encompasses all energetic conversion routes based on any type of biomass, and all energetic end uses. A bioenergy pathway is understood as a specific combination of end use, conversion technology and biomass type (e.g. the anaerobic digestion of a mix of maize and slurry, followed by biogas combustion for combined heat and power generation). A bioenergy value chain, on the other hand, describes how the delivery of bioenergy as an end product is organised—it encompasses all "activities that are performed to design, produce, market, deliver, and support" a product (Porter 1985: 36), including the primary production or collection of biomass, conversion activities, combustion and the marketing of fuels or energy end products. The activities along a value chain can be carried out by a single economic actor or be undertaken by different actors; moreover, they may occur in spatial proximity to each other, or, at the other end of the spectrum, they may be distributed across the globe.

Normative requirements demand that bioenergy use needs to be "efficient and sustainable" (e.g. BMU and BMELV 2009a: 10). However, these requirements are exceedingly challenging in their implementation. Economic, environmental and social impacts of bioenergy use depend on the bioenergy pathway in question and on the organisation of value chain activities (see Sect. 2.2.1). Moreover, impacts differ not only according to how, but also according to where value chain activities take place—for example, environmental impacts of primary biomass production depend on the characteristics of the affected ecosystem (Thrän et al. 2010a),

A. Purkus, *Concepts and Instruments for a Rational Bioenergy Policy*, Lecture Notes in Energy 55, DOI 10.1007/978-3-319-31135-7_2

whereas indirect land use change impacts depend on the regulatory framework in place in the country of production (cf. Scarlat and Dallemand 2011: 1643). Along bioenergy value chains, market actors' allocation decisions are distorted by multiple market failures, while policy interventions aimed at their correction are complicated by severe information problems, transaction costs, the existence of conflicting policy aims, and challenges of multi-level governance. This multiplicity of pathways, value chains, impacts, market failures and sources of government failures gives rise to the complexity of the bioenergy allocation problem, and causes it to differ clearly from a "standard" economic allocation problem where biomass would act as a homogeneous input in a single good production function.

The following chapter contains an economic analysis of the allocative problems of bioenergy use. Section 2.1 interprets "efficiency" and "sustainability" for the bioenergy context and explores the implications of imperfect information in achieving these demands, leading to the derivation of requirements for "rational" bioenergy use. Section 2.2 explores the market mechanism's solution to the allocative problems occurring along bioenergy value chains, and discusses its limits in providing efficient and sustainable outcomes. Section 2.3 examines sources of government failure, before Sect. 2.4 concludes with a summary.

2.1 Normative Demands on Bioenergy Allocation and Bioenergy Policy

The allocative problems of bioenergy use reflect the central problem of welfare economics—how to allocate scarce resources in the face of a multiplicity of human wants? As such, they are specific instances of fundamental problems of economic allocation (cf. Common and Stagl 2005: 308ff.; Gawel 2009: 13 and 525f.), such as: (i) Which commodities should be produced with scarce inputs, and in what quantities? (ii) With what combination of inputs should commodities be produced? (iii) How should the division of labour be organised among producers, that is, what should be produced by whom? (iv) How should commodities be allocated among the members of society? (v) How should consumption and production be distributed over time?

Standard welfare economics focuses on the efficiency of allocative outcomes, and calls for policy interventions to correct market failures (Sect. 2.1.1). Another important normative demand on bioenergy allocation, which may require additional interventions, is that it should be sustainable (Sect. 2.1.2). However, the presence of uncertainty, transaction costs and political feasibility constraints complicate the attainment of both requirements. Section 2.1.3 therefore attempts to define the requirements for a rational bioenergy policy which strives for efficiency and sustainability under these constraints.

2.1.1 Efficiency

According to the concept of Pareto optimality, an allocation is efficient when given resources are allocated in such a way that no one can be made better off by reallocations without making somebody else worse off (Mansfield 1994: 513f.; Fritsch 2011: 23ff.). In solving the problem of bioenergy allocation, a multitude of interlinked markets need to be considered, for example, energy markets, markets for bioenergy carriers, markets for substitutes, agricultural commodity markets, land markets, and markets for inputs. It can be proven that, under perfect competition, the requirement of allocative efficiency in a Paretian sense is met if all relevant markets are in a state of general equilibrium (Mansfield 1994: 489ff.; Gawel 2009: 472ff.). To achieve a Paretian solution of the allocation problems in a general equilibrium context, three marginal conditions for allocative efficiency have to be met (Mansfield 1994: 514ff.; Gawel 2009: 525ff.):

1. *Exchange and consumption optimum*: The marginal rate of substitution between any two commodities, that is, the ratio at which a consumer is willing to give up one good in order to gain one more unit of another, must be the same for any two consumers ($MRS_i = MRS_j$ for all i, j = 1,. . ., n individuals); it is not possible for any one individual to improve his or her lot through further exchange, without making another individual worse off.
2. *Production optimum*: The marginal rate of technical substitution between any two inputs must be the same for any pair of producers ($\mathrm{MRTS}_{\mathrm{x}}^{\mathrm{ij}} = \mathrm{MRTS}_{\mathrm{y}}^{\mathrm{ij}}$ for all i, j = 1,. . ., n input factors and x, y = 1,. . ., m commodities); with a given quantity of inputs and given production technologies, it is not possible to increase the production of one good without producing less of another good.
3. *Simultaneous production and consumption optimum*: The marginal rate of product transformation between any two commodities must be the same as the marginal rate of substitution between these commodities ($MRS_i^{xy} = MRS_j^{xy} = MRT^{xy}$ for all i, j = 1,. . ., n individuals); it is not possible to improve consumer satisfaction by reallocating inputs among the production of any two commodities.

Accordingly, in standard welfare economics, government interventions are only called for if these marginal conditions for allocative efficiency are violated, and market failures arise—in a first-best world, interventions should address the causes for the conditions' violation, so that a welfare optimum can be achieved (Luckenbach 2000: 140f.).

For actual policy making, however, the Pareto criterion is of limited usefulness. For one thing, situations fulfilling its condition are exceptionally rare (Stavins et al. 2003); for another thing, policy interventions aimed at establishing a welfare optimum are associated with unfeasibly high information requirements (cf. Baumol and Oates 1971). To counter the first problem, public policy advice often employs the Kaldor-Hicks compensation test to evaluate whether a change in allocation improves efficiency—this would be the case if a change from one allocation to another results in gains that exceed the losses, so that winners could potentially compensate losers and still be better off (e.g. Common and Stagl 2005: 311).[1] As such, the Kaldor-Hicks criterion forms the basis for benefit-cost comparisons between policy alternatives (Stavins et al. 2003).

The second problem, which has been discussed particularly in the context of environmental policy, refers to the fact that it usually remains unknown what a welfare-optimal state would be (Baumol and Oates 1971, 1988: 159ff.). For instance, an optimal level of GHG emission reduction is defined by the point where marginal costs of emission abatement (MAC) equal the marginal benefits of abatement, i.e. the marginal damage costs of emissions (MD). As marginal damage costs of pollutants are often unknown, the widely followed pricing and standards approach developed by Baumol and Oates (1971) suggests focussing on the cost-effective, i.e. least-cost implementation of pre-defined aims which need not satisfy the condition of optimality (Gawel 1999: 242). Two dimensions of efficiency are relevant: static efficiency, which requires an aim to be achieved at least costs at a certain point in time, and dynamic efficiency, which calls for decreasing costs of aim achievement over time; the latter requirement can be realised by setting incentives for technological progress (Michaelis 1996: 42).

In the bioenergy context, the pricing and standards approach's sense of "efficiency without optimality" (Baumol and Oates 1988: 159) is more suitable than Pareto efficiency. Given the existence of diverse externalities and other market failures in the various interlinked markets relevant to bioenergy allocation, defining policy aims so as to achieve a welfare optimum must be regarded as virtually impossible. However, even if not optimal, the process and outcome of aim setting is still of significant relevance for an economic analysis (Gawel 1999: 243ff.). Moreover, information problems are not limited to choosing optimal aims, but also apply to assessing the costs and benefits of alternative means of implementation, including side effects on other societal aims (Berg and Cassel 1992: 208f.). As a normative requirement for bioenergy allocation, efficiency therefore needs to be supplemented—this is discussed in Sect. 2.1.3.

2.1.2 Sustainability

The second major normative demand on bioenergy allocation is that it should be sustainable. But what exactly does a sustainable bioenergy allocation entail? In its most basic sense, sustainability can be understood as the survival or persistence of "the global socioeconomic system in the context of its ecological life support

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[1] If all such reallocations were undertaken, the outcome would be Pareto efficient, making the Kaldor-Hicks criterion a necessary condition for Pareto optimality (Stavins et al. 2003; Common and Stagl 2005: 311). However, the criterion's focus on potential compensations which need not actually occur is subject to criticism, particularly in an intergenerational setting (Woodward and Bishop 1995; Azar 2000; Padilla 2002).

system" (Costanza and Patten 1995: 194). While attempts to define the characteristics that make up a sustainable system abound (e.g. World Commission on Environment and Development 1987; Howarth 1997; Heal 1998; Padilla 2002), most definitions encompass the following elements (based on Daly 1992; Costanza and Patten 1995): (i) a sustainable scale of the economy that does not exceed environmental carrying capacity over time; (ii) an equitable inter- and intragenerational distribution of resources and opportunities; and (iii) an efficient allocation, which ensures that resources are not wasted. In economic terms, sustainability is often formalised as the condition that, given an initial stock of resources, the highest constant level of utility is realised over time (Solow 1974; Heal 1998: 5).

It can be argued that even an allocation that is efficient in the sense of Pareto optimality, i.e. an optimal intertemporal allocation of consumption and investment, need not necessarily be sustainable (e.g. Daly 1992; Woodward and Bishop 1995; Padilla 2002; Common and Stagl 2005: 350ff.; Norgaard 1992; Endres 2013: 378ff.). The main divergence between the two concepts arises from equity considerations (ibid.): efficiency alone makes no statements about whether resources and opportunities are distributed equitably, either between those belonging to the current generation, or between the current and future generations. For example, an intertemporally efficient consumption path may entail increasing consumption for early generations, followed by a decline and persistently low levels of consumption for generations in the distant future (Common and Stagl 2005: 351). Such a pathway would not be sustainable, because the requirement of intergenerational equity demands that future generations should be able to realise at least the same level of utility as current ones; to achieve this, they require at least the same endowment of resources and opportunities (Endres 2013: 380; Woodward and Bishop 1995: 101). In effect, sustainability acts as a constraint on the choice between efficient pathways of economic development—among all intertemporally efficient pathways, only the subset that leads to an intergenerationally equitable distribution of endowments is sustainable (Woodward and Bishop 1995: 105; Norgaard 1992: 95). The distinction between efficiency and sustainability is further discussed in Sect. 2.2.3.7.

Consequently, to ensure the sustainability of bioenergy use, policy interventions going beyond the correction of market failures may be required. In particular, future generations' rights to a non-deteriorated socioeconomic and ecological capacity need to be protected (Padilla 2002: 76). However, this presupposes a definition of what exactly these rights should entail. Here, a major distinction can be made between the perspectives of weak and strong sustainability (cf. Neumayer 2003).

Proponents of weak sustainability assume far-reaching substitutability between natural capital, which encompasses all stocks in the environment that provide services to the economy, and forms of human-made capital, such as manufactured capital, human capital, as well as social and organisational capital (Ekins et al. 2003; Common and Stagl 2005: 374f.). Under such conditions, according to the Hartwick rule, a country can achieve the highest constant level of utility over time if it saves and invests all of the rent arising from the depletion of natural resources, even if the resource in question is non-renewable (Hartwick 1977; Heal

1998: 5).[2] In effect, future generations' rights would be considered protected if the total stock of capital remained constant over time (cf. Padilla 2002: 75f.). From this perspective, the conversion of, for example, a high-conservation value forest for energy crop production would be deemed acceptable, if resulting rents were invested in capital which generated utility for future generations (e.g. by investing in energy infrastructure or education as a form of human capital accumulation).

The strong sustainability perspective, on the other hand, views stocks of human-made and natural capital as complementary, rather than substitutable (e.g. Ozkaynak et al. 2004). Accordingly, maintaining the total natural capital stock at or above current levels is regarded as a "minimum necessary condition for sustainability" (Costanza and Daly 1992: 37). In order to ensure this, Costanza and Daly (1992) suggest that for renewable natural capital, resource consumption should be limited to sustainable yield levels, whereas non-renewable natural capital should be exploited only at a rate equal to the creation of renewable substitutes (see also Common and Stagl 2005: 378).

As a resource stream from the environment, whose extraction can impact other functions of the environment (cf. Ekins 2003), the role of energetic biomass production as natural capital is twofold—on the one hand, it substitutes non-renewable natural capital, i.e. fossil fuels; on the other hand, it may deplete other forms of natural capital (e.g. natural forests, or grasslands) or deteriorate ecosystem quality [e.g. by intensifying forestry management or agricultural production (e.g. Stehfest et al. 2010)]. From a strong sustainability perspective, only those forms of bioenergy would be deemed desirable which do not negatively impact natural capital stocks and their functions, or even contribute to environmental improvements, for example by increasing agricultural biodiversity (Ammermann and Mengel 2011; Fletcher et al. 2011). However, while desirable from an environmental viewpoint, this bioenergy allocation requirement neglects politically relevant trade-offs with the social and economic dimension of sustainability. For example, bioenergy demand-driven investments in the extension and intensification of agriculture in developing countries may yield socioeconomic development benefits (cf. Kampman et al. 2010: 36); also, the costs of second generation bioenergy pathways employing inputs that are considered environmentally more beneficial are, at least so far, often significantly higher than pathways based on established crops and agricultural production systems (Carriquiry et al. 2011).[3]

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[2] However, apart from perfect substitutability of the resources in question, the Hartwick rule requires that several other far-reaching assumptions hold, such as constant population, technology and preferences, and an intertemporally optimal allocation of resources which requires perfect foresight (Howarth 1997).

[3] Moreover, it can be argued that bioenergy use always implies trade-offs with other forms of natural capital formation—a hectare of land used for energetic biomass production may contribute to the substitution of fossil fuels and GHG mitigation, and may possibly even enhance agricultural biodiversity, yet environmental benefits associated with a renaturation of the same area are foregone [cf. Jakubowski et al. (1997: 18), who find that, under scarcity, any form of environmental conservation is associated with environmental costs, if only in the form of opportunity costs].

These trade-offs are reflected in the critical natural capital perspective, which allows that some parts of natural capital can be substituted by other forms of capital, while for others substitution is not possible (De Groot et al. 2003; Ekins 2003). Such critical natural capital can be defined as “natural capital which is responsible for important environmental functions and which cannot be substituted in the provision of these functions by manufactured capital” (Ekins et al. 2003: 169). In accordance with the strong sustainability principle, critical natural capital should be absolutely protected (Ekins 2003).

In the following, this work adopts the critical natural capital perspective: in order to be sustainable, bioenergy allocation must not compromise the conservation of critical natural capital.[4] In the setting of bioenergy policy aims and their instrumental implementation, policy makers have to ensure that “guard rails” delineating non-tolerable damage limits are not exceeded (SRU 2007: 59ff.; WBGU 2008: 27ff.). However, the identification of critical natural capital and the quantification of guard rails are associated with considerable problems, given imperfect knowledge about substitution possibilities, and about the potentially irreversible impacts of interventions in complex, interlinked ecosystems (Padilla 2002; Ekins 2003; Brand 2009). As a result, attempts to operationalise bioenergy sustainability criteria either formulate indicators which leave the definition of thresholds to context-dependent analyses and political deliberation processes (cf. GBEP 2011), or combine estimates for thresholds with qualitative requirements (cf. SRU 2007: 59ff.; WBGU 2008: 27ff.). Under uncertainty, sustainability criteria always retain the character of predictions, whose adequacy can only be fully assessed ex post (Costanza and Patten 1995). For bioenergy policy, adherence to the precautionary principle therefore becomes an important precondition for sustainability (Costanza and Cornwell 1992). Also, it seems that dynamic incentives should prioritise innovations in bioenergy pathways which avoid a deterioration of natural capital altogether and realise synergies with conservation aims. In this way, an alignment of bioenergy allocation with the strong sustainability perspective could be realised in the long run.

Lastly, to reflect not only intergenerational but also intragenerational justice, bioenergy allocation shall only be considered sustainable when an overall maintenance or increase in total capital stock does not imply that the opportunities of certain parts of the population are eroded. As an ethical requirement this implies, for example, that bioenergy production should not harm people’s essential rights like the right to be protected from threats to life, health and wellbeing and the right to be able to subsist, and that costs and benefits arising from bioenergy production should be shared equitably (Nuffield Council on Bioethics 2011: 64ff.).

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[4] Given that sustainability implies a “macro-perspective” (Woodward and Bishop 1995), it can be argued that sustainable bioenergy use is of limited usefulness, if the overall sustainability of the agricultural land use system is not ensured (for sustainability risks of agricultural production in general, see e.g. Henle et al. 2008; Hirschfeld et al. 2008; Oppermann et al. 2009). However, public incentives for bioenergy use add to existing sustainability problems, so that a “micro-perspective” can be justified, at least in the shorter term.

2.1.3 Rationality

In attempting to define the meaning of efficiency and sustainability for the bioenergy context, the pervasive importance of information problems has already become clear. In particular, the presence of uncertainty, which, unlike risk, does not allow for the calculation of expected utility by assigning probabilities to a finite number of possible outcomes (cf. Knight 1921; Voigt 2002: 29), severely limits attempts at welfare maximisation and the definition of secure sustainability guard rails (see Sects. 2.2.3.5 and 2.3.2). Moreover, the political system follows its own inherent rationality, so that it cannot be assumed that the setting of policy aims is an expression of general welfare maximisation, or consistent with sustainability requirements (Gawel and Lübbe-Wolff 1999). Following public choice theory, political actors rather tend to maximise individually rational variables such as political support or administrative budgets (Endres and Finus 1996; Gawel and Lübbe-Wolff 1999).

In the following, "rational bioenergy policy" shall be understood as a policy approach, which strives for efficiency and sustainability under the constraints imposed by uncertainty and political feasibility. Three dimensions of rationality can be distinguished (based on Gawel 1999).

1. *Rational setting of aims*: Even if aims are not set according to the principle of welfare maximisation, an economically rational allocation of resources presupposes that a system of policy aims complies with certain requirements (Jakubowski et al. 1997: 48ff.; Gawel 1999: 244ff.; Welfens 2013: 655ff.). Jakubowski et al. (1997: 48ff.) and Gawel (1999: 244ff.) distinguish between formal requirements which seek to safeguard the functionality of the steering mechanism, and economic or material requirements which aim to ensure that scarce resources are employed rationally (see Table 2.1 for an overview).[5]
2. *Alignment of aims and measures*: The requirement of rationality demands that policy measures are aligned with the system of policy aims, and are suitable for achieving those aims (i.e. that they are effective); in particular, it is necessary to avoid shifting conflicts between aims to the level of instrumental design, instead of solving them at the level of aim setting (Gawel 1999: 248ff.).
3. *Rational choice of allocation mechanisms and instruments*: For the implementation of aims, policy makers should strive for the most cost-effective solution among those alternatives that can be considered feasible under uncertainty and political constraints (cf. Williamson 1996: 195; Voigt 2002: 260). In assessing cost-effectiveness, transaction costs have to be taken into account, which arise

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[5] Jakubowski et al. (1997: 51) name "elasticity" as a third economic requirement, which calls for an elastic design of decisions about aims and their incremental implementation, in order to reflect uncertainty and the risk of incurring irreversibilities. However, elasticity entails trade-offs with the creation of constant framework conditions and planning security for economic actors, which shall be discussed in more detail in Chap. 3. For this reason, the requirement is neglected in the overview.

Table 2.1 Requirements for a rational setting of policy aims (based on Jakubowski et al. 1997: 48ff.; complemented by Gawel 1999: 244ff.; Welfens 2013: 655ff.)

	Requirements	Content
Formal requirements	Completeness	A system of aims for a particular policy context (e.g. bioenergy policy's system of aims) should reflect all relevant societal aims. If this is not the case, there is a risk that inconsistencies arise and trade-offs between aims remain neglected
	Consistency	Aims need to be consistent: as part of a vertical hierarchy, lower level aims must contribute to higher level aims. Aims of the same hierarchical level must not contradict each other; if conflicts arise, prioritisation is necessary to maintain consistency
	Operationalisation and measurability	It should be possible to substantiate the content, scale, temporal and spatial reach of aims; this is a prerequisite for defining indicators that make it possible to measure the extent to which aims are achieved
	Controllability and feasibility	Aims must be defined in such a way that suitable means for their achievement are controllable by a responsible agency. Moreover, the level of aims must be chosen so that they remain politically and economically feasible
Economic requirements	Balancing of costs and benefits	The setting of aims should reflect trade-offs in the use of scarce resources; even under uncertainty, decision makers should make use of the available knowledge and use benefit-cost-optimisation as a guiding principle
	Transparency and acceptance	Aims and their interactions must be transparent, in order to be comprehensible for policy makers and stakeholders alike. Furthermore, the process of aim setting and its result must be acceptable for the members of society

both in the use of the market and the political system (Häder 1997: 92ff.; Gawel 1999: 250ff.; Richter and Furubotn 2003: 55f.; see Sects. 2.2.3.5 and 2.3.2.3). Moreover, if uncertainty prohibits a comprehensive benefit-cost assessment of alternatives and a reliable definition of sustainability guard rails, an assessment of alternatives should pay particular attention to dynamic effects of alternatives, and the effectiveness of incentives for innovations which improve efficiency and sustainability of allocative outcomes over time (cf. Gawel 1999: 257).

In sum, normative demands on bioenergy allocation are understood here as comprising the following elements:

1. Policy aims, which seek to achieve certain allocative outcomes, should be consistent with the requirements of economic rationality and sustainability, understood here as the protection of critical natural capital and people's opportunities.
2. Allocation mechanisms and instruments should be suitable for effectively addressing the chosen policy aims; in choosing between feasible alternatives,

policy makers should strive for cost-effectiveness, taking all relevant cost categories into account, including transaction costs.

3. Given imperfect knowledge about what constitutes critical natural capital, optimal allocative outcomes, and the costs and benefits of alternative allocation mechanisms and instruments, special emphasis should be placed on the dynamic perspective; particularly relevant are incentives for innovations which decrease the costs of aim achievement over time, and avoid adverse impacts on natural capital, therefore aligning bioenergy allocation with a strong sustainability perspective in the long run.

2.2 Bioenergy Allocation by Markets

The outcome of bioenergy allocation is the result of a complex interaction of numerous allocation decisions along bioenergy value chains. These decisions can be coordinated either by markets or by regulative interventions. As a marketable, private good, for which both excludability and rivalry in consumption apply (cf. Gawel 2009: 742), bioenergy is in principle amenable to allocation by the market mechanism. The following section therefore examines what the market solution to the allocative problems of bioenergy use would look like in the absence of government intervention.

The section starts with a description of relevant allocation decisions along bioenergy value chains and the allocative problems arising from their coordination (Sect. 2.2.1). Following this, the characteristics of the Pareto-optimal outcome of a perfectly competitive, perfectly functioning market are examined (Sect. 2.2.2). However, various market failures are relevant in the bioenergy context, as well as violations in the assumptions of the model of perfect competition, in particular pertaining to imperfect information and transaction costs. Moreover, even a Pareto-efficient allocation may fail to meet the normative requirement of sustainability. The market mechanism's limits in coordinating bioenergy allocation decisions are discussed in Sect. 2.2.3.

2.2.1 Allocative Problems Along Value Chains

The problem of optimising bioenergy production and use is characterised by a high degree of complexity, because cost characteristics, as well as the environmental and wider socio-economic impacts of bioenergy pathways are influenced by the interplay of a variety of allocation decisions taken along heterogeneous and transregional value chains (see Fig. 2.1; Gawel and Purkus 2012). At the production, conversion and utilisation stages, actors' decisions are influenced not only by political and economic framework conditions, but also by technological constraints—specific sectoral applications demand specific bioenergy technologies,

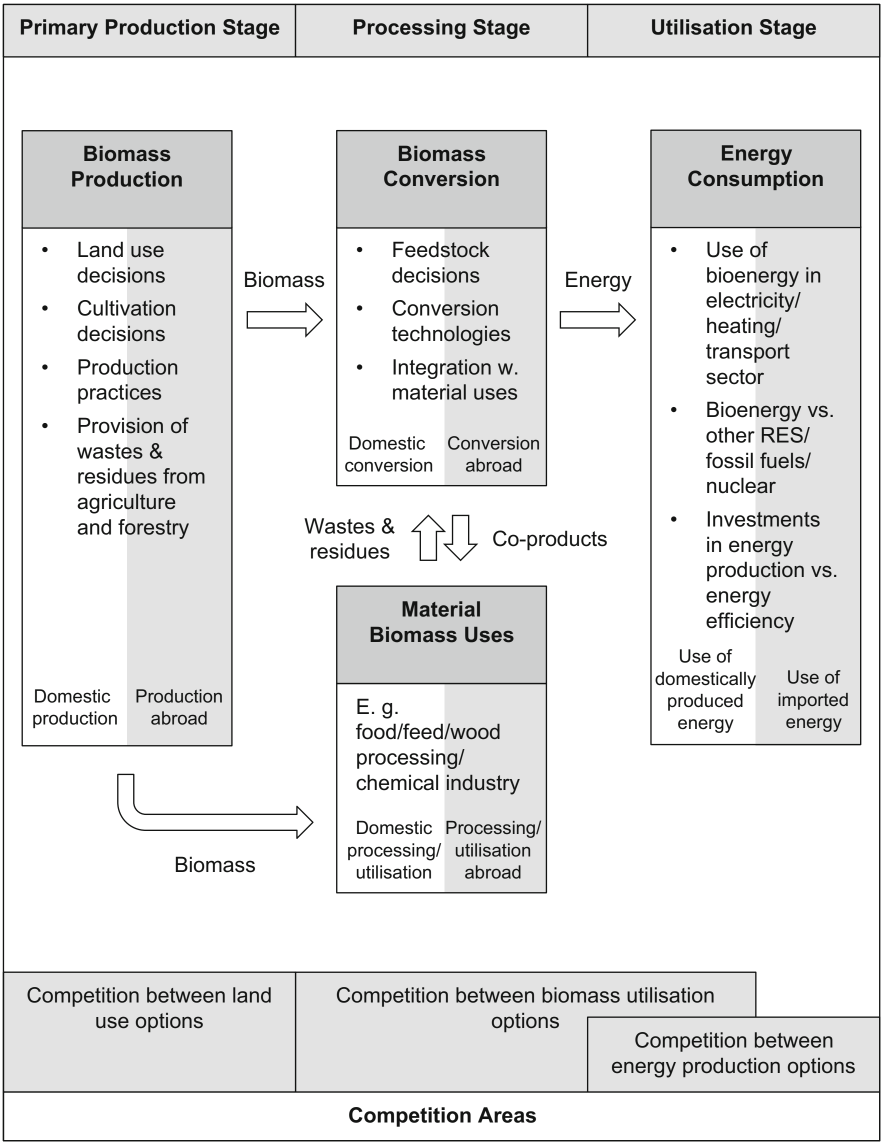

Fig. 2.1 Allocation decisions and areas of competition along a bioenergy value chain (based on Purkus et al. 2012: 9)

which in turn determine what types of biomass can be used. In the following, the problems of coordinating allocation decisions in bioenergy value chains are identified for the production, processing and utilisation stages. In all three stages, allocation decisions take place on both the supply and the demand side: their coordination requires an understanding of under what conditions relevant actors demand biomass resources, technologies and biomass-based heat, electricity or transport fuels, and under what conditions other actors supply them.

2.2.1.1 Allocative Problems in the Primary Production Sphere

Demand for biomass-based heat, electricity or transport fuels originates from the utilisation stage, and translates into an increased demand for biomass resources such as waste and residues, wood and agricultural crops; in the case of the latter two categories, this in turn increases demand for agricultural and forested land. What kind of biomass resources and land types are used for primary biomass production depends on the type of bioenergy demanded; as different bioenergy technologies require different types of biomass, decisions in the production sphere are closely interlinked with allocation decisions in the processing and utilisation spheres. Meanwhile, land use decisions and decisions relating to the collection and further treatment of waste and residues do not only depend on the relative prices that different primary biomass uses (e.g. energetic uses, material uses, use as food or feed) command. Further demand-side specifications also play a role, such as sustainability criteria that are only applied to specific biomass uses, or different demands regarding other aspects of resource quality. Besides the costs of producing different feedstocks and meeting different quality-related standards, regulatory requirements also have to be taken into account in land use or waste-related allocation decisions. In the production sphere, allocative problems can be summarised as follows:

1. *How to solve competition between alternative land uses, and how to avoid undesirable land use changes?* Among the various resources available for bioenergy production, energy crops are estimated to have the largest potential for meeting the globally increasing bioenergy demand (Chum et al. 2011: 17ff.). However, given the limited availability of arable land, the growing of energy feedstocks has to compete for suitable areas not only with the production of other commodities, but also with land use options like extensive grazing, afforestation or the conservation of natural ecosystems (Kampman et al. 2010). With an increase in biomass demand, agricultural biomass producers may change production patterns and expand the area under cultivation, either by intensifying production, or by restoring degraded land, developing marginal land or converting natural areas. Forestry actors may intensify forest management and can also respond by expanding the managed area, either through afforestation or use of previously unmanaged forests. Moreover, agricultural, forestry and waste sector actors may respond to increasing biomass prices by making wastes and residues available for energetic uses. In response to land use, cultivation and waste management decisions, scarcity relations and prices on commodity markets change, causing further market adaptation processes.
2. *How to coordinate decisions about crops, production practices and the use of waste and residues?* Besides the nature of former land uses, the choice of crops,

agricultural production practices or forestry management practices has a significant influence on the environmental and socio-economic balance of bioenergy. In the case of energy crops, crop yields combined with production systems' requirements for fertilisers, pesticides and irrigation are relevant variables (Rossi 2012). Furthermore, the use of wastes and residues from agriculture and forestry can limit the land requirements for bioenergy production, but costs and logistical barriers to making these resource categories available have to be taken into account, as well as the possible environmental impacts of residue extraction (Thrän et al. 2011a: 134). In energy crop production, agri-environment measures may provide environmental benefits (Rossi 2012), while decisions on, for example, labour conditions and wages affect the socio-economic balance (Beall and Rossi 2011).

3. *Where to locate production?* Location decisions influence cost characteristics, but can also have impacts on the socio-economic and environmental balance of biomass production, given differences in local governance frameworks (Bauen et al. 2009: 26). Moreover, environmental impacts are influenced by ecosystem characteristics and existing land use patterns (Thrän et al. 2010a). Socio-economic impacts, meanwhile, also depend on the nature of former land uses, besides the distribution and protection of property rights. For example, cultivating appropriate crops on marginal land can improve ecosystem quality and rural income opportunities, but if marginal lands were formerly used for subsistence farming with unclear property rights, the rights and opportunities of subsistence farmers might be at risk (Liu et al. 2011).

2.2.1.2 Allocative Problems in the Processing Sphere

In the processing sphere, producers of bioenergy carriers respond to energy demand from the utilisation sphere, while themselves acting as consumers on technology markets and markets for biomass resources. As such, they represent an important link for responding to demand-side cost pressures, sustainability and other quality-related requirements, which are passed on to technology developers and primary biomass producers. Different degrees of integration between value chain stages are possible—for example, an on-farm biogas producer may carry out energy crop production, biogas processing, biogas combustion as well as electricity feed-in and marketing, while a pellet producer might rely on bilateral contracts or commodity markets to source primary biomass resources and sell pellets on to utilisation stage actors. The processing sphere encompasses the following allocative problems:

1. *How to solve (and reduce) competition between material and energetic biomass uses?* On commodity markets, producers of bioenergy carriers compete for biomass resources with material applications, such as food and feed production, wood processing, and chemical industries (Ericson 2009). In particular, competition between crops which can be used both for food and energy production is criticised for its problematic impacts on global food price developments (FAO 2008; WBGU 2008; Nuffield Council on Bioethics 2011). Also for other

material uses, the importance of developing renewable resources is rising (COM 2012).

2. *How to coordinate decisions about conversion technologies?* For the conversion of biomass into gaseous, solid or liquid bioenergy carriers and—eventually—energy, a variety of technologies can be employed, which differ in their stage of development, costs, conversion efficiencies, and range of suitable feedstocks (Bauen et al. 2009; Chum et al. 2011: 39ff.; JRC-IET 2011). Depending on the technology-feedstock combination adopted, producing co-products for material applications may be possible. Likewise, wastes and residues from material biomass uses can be converted to bioenergy carriers. For relaxing competition between material and energetic biomass uses, the development of integrated solutions, such as cascading uses and biorefinery concepts, is seen as an important option (Cherubini 2010a; BMELV et al. 2012; COM 2012).
3. *How to coordinate sourcing decisions for raw materials and bioenergy carriers?* There are two types of sourcing decisions that bioenergy producers have to make. When producing bioenergy, actors can decide whether to source bioenergy carriers externally or undertake the processing of raw materials or intermediate biomass products (e.g. vegetable oils) themselves. Different degrees of integration between value chain components are possible, with trade on commodity markets, bilateral supply contracts, foreign direct investment and on-farm processing representing some of the options. In general, biomass or bioenergy carriers can be sourced regionally, domestically or be imported. Liquid biofuels and wood pellets are particularly suitable for transporting over long distances due to their high energy densities (Junginger et al. 2011).

2.2.1.3 Allocative Problems in the Utilisation Sphere

In the electricity, heating and transport sectors, demand for bioenergy is determined by the competitiveness of bioenergy pathways, and regulatory measures. Depending on the bioenergy pathway in question, producers and consumers can be extremely heterogeneous. In the transport sector, biofuel consumers range from individual car owners to industrial fleet or public transport operators; producers encompass agricultural actors producing biofuels for their own use as well as operators of multi-product biorefineries. In the heating sector, combustion of bioenergy carriers may take place in household-operated small-scale installations, or heat may be self-produced in larger industrial installations; likewise, consumers can in principle acquire a mix of natural gas and biomethane through the gas grid or purchase biomass-based cogenerated heat through district heating grids. In the electricity sector, self-production of electricity is an option, but so far it is mainly relevant for photovoltaics or fossil fuel-based plants, due to more favourable investment and operating cost characteristics (cf. Neuhoff et al. 2013: 7f.; Krampe and Peter 2014). However, electricity consumers can choose between suppliers with different portfolios of generation capacity or traded electricity, allowing them to choose, for example, “green electricity” providers. On the side of bioelectricity producers, options range from small-scale, decentralised biogas plants to co-combustion in coal power plants owned by vertically integrated energy companies.

The utilisation sphere not only determines the willingness to pay for different bioenergy pathways; sustainability and other quality-related requirements are also defined here, and passed down the value chain. The following allocative challenges can be identified:

1. *How to allocate biomass resources to different energetic utilisation options in the electricity, heating and transport sectors?* As biomass resources available for energetic uses are limited, different applications in the electricity, heating and transport sectors compete for bioenergy carriers; associated increases in production costs reduce the competitiveness of bioenergy relative to other energy sources. Substituted energy sources differ depending on whether biomass is used for the generation of electricity or heat, or as a transport fuel, significantly influencing the GHG balance of respective bioenergy pathways (e.g. Cherubini and Strømman 2011: 442f.; Sterner and Fritsche 2011: 4803f.; Thornley et al. 2015: 39f.). Also, depending on available alternatives for renewable energy production in the different sectors, the importance of bioenergy under security of supply aspects varies.
2. *How to coordinate sourcing decisions for energy in the electricity sector?* In the case of the electricity sector, imports of electricity from other countries via interconnected grids are an alternative to domestic production.
3. *How to coordinate investment decisions between bioenergy, other energy production options and efficiency measures?* In a given energy sector, bioenergy technologies compete with alternative energy production options, such as other RES, fossil fuels, or nuclear power for market shares, investments and research and development (R&D) capital. Bioenergy’s competitiveness is primarily influenced by the costs of energy carriers, characteristics of conversion technologies and the scale of operations (Chum et al. 2011; JRC-IET 2011). Additionally, the implementation of energy efficiency measures to reduce total energy demand constitutes an alternative option.

2.2.1.4 Categorisation of Allocative Problems

Across the bioenergy value chain, the diverse allocative problems that arise can be subsumed under three major categories:

1. *Steering biomass flows and technology choices:* This category encompasses the allocation of biomass resource streams to different uses, for example, material and different sectoral energetic uses. Technology choices in the energy sector, but also in material sectors have an important impact on biomass flows, and are therefore grouped in the same category; for example, choices between different electricity production technologies determine the electricity sector’s demand for

biomass. Also, the choice of technologies has implications for the type of biomass streams demanded, due to technology-specific substrate requirements (e.g. of biogas and solid biomass plants).

2. *Setting incentives for dynamic efficiency and innovation:* Beyond technology choices and the allocation of biomass among different uses at a given point in time, the setting of dynamic incentives and the steering of innovation efforts forms another relevant category of allocation problems.
3. *Steering location choices and sourcing decisions:* This category is concerned with two distinct sets of allocative problems—one, coordinating the international division of labour, i.e. whether to produce biomass and bioenergy carriers domestically or import them; second, locational decisions within a given country are relevant.

Solutions to these problems should, in accordance with Sect. 2.1, strive to bring about outcomes which are cost-effective in achieving policy aims and sustainable, i.e. outcomes which do not erode critical natural capital, and do not negatively impact the opportunities of actors involved in the bioenergy value chain or bystanders.

2.2.2 The Market Solution to Bioenergy Allocation Decisions

In order to understand how the market mechanism coordinates bioenergy allocation decisions, it seems useful to start from a simple model of perfect competition.[6] Although employing very abstract assumptions, the model helps one to understand what an "optimal" bioenergy allocation would look like (in the sense of Pareto efficiency), and at which points in the value chain exactly the market mechanism fails to satisfy the normative requirements defined above, providing a rationale for policy interventions.

In the market context, the price mechanism fulfils the role of coordinating the individual plans of all actors involved in the bioenergy value chain. Relative prices of commodities indicate their relative scarcity; as such, they ensure that input factors like land, labour, capital or biomass (as an intermediate input) are first directed towards those usages that are valued most highly by consumers, as indicated by their willingness to pay (cf. Gawel 2009: 29; Fritsch 2011: 7). Besides

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[6] Employing the following assumptions (Fritsch 2011: 26): (i) The set of resources is given; (ii) No process and product innovation; (iii) Preferences are given and unchanging; (iv) Producers and consumers are free to choose between alternatives; (v) Products are homogeneous; (vi) Numerous buyers and sellers with small market shares; (vii) Perfect information and market transparency; (viii) Unlimited mobility of input factors and goods; (ix) Unlimited divisibility of input factors and goods; (x) Adjustment is infinitely quick; and (xi) No externalities, i.e. private costs equal social costs.

Table 2.2 Functions of the price mechanism (based on Streit 2005: 37f.; Gawel 2009: 30f.)

Balancing function	Prices balance supply and demand in different markets, so that in a stationary equilibrium the market is cleared
Information function	Prices allow for a comparison between different competing uses of a good. Relative prices show the exchange ratio between goods, i.e. how much of one good must be given up in order to gain one unit of another good; as such, changes in relative prices indicate changes in scarcity relations
Rationing of demand	Scarce commodities are allocated to the demand-side actors that are willing to pay the market price, i.e. demands are served according to their urgency (in terms of expressed willingness to pay)
Rationing of supply	In the long term, only those suppliers stay in the market that can at least cover their average costs at given market prices
Incentive function	Increasing prices translate into incentives to increase production, and vice versa
Steering function	Changes in the structure of demand trigger changes in price relations; production adapts to increasing or decreasing prices in the various markets, so that scarce inputs are steered towards commodities that correlate with consumers' demand

rationing demand, prices perform a number of other functions in the coordination of allocation decisions, which are compiled in Table 2.2.

As utility optimisers, consumers in the bioenergy value chain seek to fulfil their demands at least cost, while producers maximise profit and search for the least cost combination of input factors and production technology to meet these demands (Endres and Radke 2012: 53ff.). Implications for the categories of allocative problems defined above (see Sect. 2.2.1.4) are briefly outlined below:

1. *Steering biomass flows and technology choices:* On the production side, the price mechanism directs biomass towards the applications with the highest value creation. So far, material uses of biomass tend to be more profitable than energetic ones, so that for the most part, only low cost resources (e.g. some wastes and residues) would be provided for energetic uses in the absence of policy incentives (Ericson 2009). Similarly, on the utilisation side, most bioenergy pathways are unable to compete with conventional energy technologies, mainly due to biomass costs and lack of technological maturity (JRC-IET 2011). An important exception are heating applications, where market price increases for fossil energy carriers such as heating oil have increased the competitiveness of biomass-based heating applications in recent years (BMU and BMELV 2009b: 32; FNR 2012: 12). Overall, market allocation processes can be expected to yield only low levels of bioenergy use in the electricity and transport sector, but higher levels in heating applications.
2. *Setting incentives for dynamic efficiency and innovation:* Bioenergy technologies compete with other forms of energy production along two dimensions—the

costs and the quality of energy services provided.[7] Cost competition results in pressure to reduce investment costs and operating costs over time, including feedstock acquisition and processing costs. Also, innovation efforts would be directed at quality improvements, if these were able to command a price premium on energy markets or were perceived to be a precondition for competing successfully with other energy technologies. What defines the quality of bioenergy provision has to be defined separately for different energy sectors. In the electricity sector, bioenergy producers can increase profits by shifting production to hours with high electricity prices and by participating in balancing markets. As a result, there are incentives to invest in the flexibility of bioenergy provision. However, with limited peak/off-peak spreads and volatile balancing market prices, current market framework conditions set only limited incentives for the provision of flexible capacities, even though their systemic importance is growing as shares of volatile RES increase (Arnold et al. 2015; BMWi 2014; Rohrig et al. 2011: 17). In the heating sector, manufacturers of biomass heating applications and suppliers of bioenergy carriers would have incentives to improve ease of handling and maintenance, and reduce emissions with direct impacts on customers (e.g. particulate matter emissions). In the transport sector, fuel quality would have to be at least comparable to fossil fuel alternatives, for example, regarding motor compatibility. On the other hand, in an unregulated market context bioenergy producers would have few incentives to invest in innovations with reduced external costs and improved GHG balances. Even though demand exists for environmentally beneficial energy products, research indicates that the additional willingness to pay for "green" quality characteristics is limited (Pacini et al. 2013; Schubert and Blasch 2010: 2800f.).

3. *Steering location choices and sourcing decisions:* Location decisions concerning conversion processes (e.g. biofuel refineries, pellet production plants) and bioenergy plants would be driven by economic considerations such as access to sufficient resource quantities at profitable prices, substrate transport costs, or proximity to heat customers in the case of bioelectricity cogeneration or heating plants. Likewise, decisions on whether to produce domestically or whether to import energy, energy carriers or raw materials would be determined by cost considerations and the transport worthiness of the substrates employed. Assuming perfect factor mobility in an open economy, the price mechanism would bring about an optimal division of labour among producer countries, as producers would make use of comparative advantages (e.g. advantageous climate conditions for growing energy crops).
4. *Safeguarding sustainability:* If the assumptions of the perfect competition model hold (particularly concerning the absence of market failures and perfect information), markets can be shown to achieve a Pareto-optimal intertemporal

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[7] Strictly speaking, innovation is not considered in the perfect competition model's static perspective—with perfect information and infinite adjustment speed, innovations would be taken up instantaneously by competitors, resulting in few incentives to invest in them (Mansfield 1994: 536f.).

allocation of consumption and investments (Common and Stagl 2005: 317; Gawel 2009: 535). However, as discussed under Sect. 2.2.3.7, there is no guarantee that the resulting intertemporal consumption pathway fulfils the requirement of sustainability.

Overall, in a competitive general market equilibrium, it would be guaranteed that bioenergy pathways that are part of this equilibrium are efficient from an allocative perspective, both in the production sphere (efficient allocation of input factors) and in the consumption sphere (efficient allocation of commodities). However, if current market prices were assumed, the overall significance of bioenergy pathways would likely be small.

2.2.3 Limits of the Market Allocation Mechanism

In reality, markets fail in bringing about an optimal allocative outcome because of the highly abstract nature of the perfect competition model's assumptions (Bator 1958: 377; Fritsch 2011: 57). In the bioenergy context, violations of assumptions concerning the absence of externalities and other market failures prove particularly problematic, as does the neglect of information problems, transaction costs, dynamic adjustment processes, and sustainability requirements. Market failures arise primarily in the form of environmental externalities, externalities in relation to the security of energy supply, knowledge and learning externalities which affect technology choices and investments in innovation, as well as market power in the energy market; an additional complication arises from interactions between these market failures, information problems and transaction cost problems. Below, the limits of the market mechanism in solving the allocative problems of bioenergy use are discussed.

2.2.3.1 Environmental Externalities

Environmental externalities arise in a number of activities in the production, processing and utilisation spheres of bioenergy as well as its renewable and non-renewable energy substitutes; they can be distinguished according to the spatial scale on which external costs and benefits accrue (Owen 2006: 635).[8]

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[8] Externalities arise when an actor engages in an activity that influences the well-being of a bystander and yet neither pays nor receives any compensation for that effect (cf. Baumol and Oates 1988: 17f.). Externalities cause private costs which determine private allocation decisions to deviate from social costs: In the presence of negative externalities, more of a good is produced than is socially optimal, while with positive externalities, too little is produced. Public goods, which are characterised by non-rivalry in consumption and/or non-excludability of potential consumers (Head 1962), are closely connected to externalities, in that many externalities arise from the public character of goods (e.g. investments in public goods knowledge or biodiversity produce external benefits) (Bator 1958: 18f.; Baumol and Oates 1988). Consequently, market failures arising from externalities and public goods are treated jointly here.

The atmosphere as a sink for GHG emissions constitutes a global public good, and so does biodiversity. If bioenergy pathways reduce GHG emissions compared to fossil fuel substitutes, they are associated with a positive externality (cf. WBGU 2008; Sterner and Fritsche 2011). In principle, biomass combustion releases the same amount of CO_2 that plants absorb during their growth; however, several sources of GHG emissions occur along bioenergy value chains, so that it cannot truly be termed "carbon-neutral" (WBGU 2008; Haberl et al. 2012).[9] Depending on the bioenergy pathway in question, GHG emissions can arise from conversion processes (e.g. through methane leakage in biogas plants), biomass transports, fertiliser and agricultural machinery use as part of intensive energy crop cultivation, and land-use changes; particularly the conversion of natural land for biomass production causes significant GHG emissions, by releasing the carbon stored in vegetation and soils into the atmosphere. Depending on the ecosystem in question, such land-use change emissions can cause the GHG balance of bioenergy to be negative for centuries (Fargione et al. 2008; Gibbs et al. 2008; Kampman et al. 2010). But also GHG emissions from agriculture, such as nitrous oxide from nitrogen fertilisation, may have significant impacts on GHG balances of energy crops (Crutzen et al. 2008; Stehfest et al. 2010; Popp et al. 2011).

Moreover, the conversion of natural ecosystems can entail significant biodiversity losses with associated external costs. For existing agricultural areas and also forestry production systems, different crop and management system choices can either positively or negatively impact biodiversity; for example, a location-adapted choice of crops and crop rotation patterns can enhance agricultural biodiversity relative to a scenario without bioenergy use, whereas an expansion of intensively managed monocultures would aggravate existing negative biodiversity externalities of agricultural production (Webb and Coates 2012: 52).

Apart from these direct effects, demand for bioenergy can also have indirect impacts on the global climate and biodiversity. If energy crops are cultivated on existing agricultural areas, they displace the production of other commodities, causing their prices on international agricultural markets to rise; in reaction to these macroeconomic price effects, producers increase their output of these commodities, either by intensifying production or by extending the area under cultivation (FAO 2008).[10] Due to their temporal and spatial dynamics, these indirect land use effects of bioenergy can only be quantified through modelling efforts, but results are subject to significant uncertainties (Edwards et al. 2010).

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[9] Moreover, "carbon neutrality" succumbs to a baseline error, in that the carbon sequestration that would occur if plants were not harvested and continued to absorb carbon from the air is neglected (Haberl et al. 2012).

[10] In industrialised countries, where agricultural systems are already highly intensified and the agriculturally used area cannot easily be extended, additional biomass demand can primarily be met through the reactivation of fallow land, conversion of extensively used grassland, and productivity increases. In developing countries, where capital for an intensification of agricultural production is scarce relative to natural land availability, it is more likely that additional demand is met by expanding the agricultural area (FAO 2008; Kampman et al. 2010; Meyer et al. 2010).

On the regional or local scale, bioenergy production can be associated with further external costs arising from the emission of pollutants from combustion, processing and biomass cultivation (e.g. sulphur oxides, oxides of nitrogen, or ammoniac) (Nitsch et al. 2004; Ashworth et al. 2013). Among the impacts which are not fully reflected in bioenergy producers' private costs are eutrophication, acidification, and—in the case of airborne pollutants—negative impacts on health, agricultural production and materials (Nitsch et al. 2004; Krewitt and Schlomann 2006; Owen 2006). Bioenergy-induced extensions of the agricultural area or changes in forest management can also have wider impacts on local and regional ecosystem services (e.g. regional water and climate regulation, and erosion control), resulting in further external costs. "Landscape externalities" (cf. Meyerhoff et al. 2010) can arise when changes in land use patterns diminish the attractiveness, leisure and cultural value of landscapes, for example, through the extension of large-scale maize production or, in German, "*Vermaisung der Landschaft*" (cf. Linhart and Dhungel 2013). On the other hand, depending on the crops employed and the existing agricultural land use characteristics, the cultivation of energy crops can also increase agricultural diversity, with benefits for biodiversity and landscape attractiveness (Thrän et al. 2011a: 85ff.; Meyer et al. 2010: 145ff.). Also, price increases for wood provide incentives for afforestation and the uptake of forest management practices with environmental benefits (Thrän et al. 2011a: 88). Lastly, on a local scale, bioenergy combustion or conversion plants may inflict external costs on neighbouring residents, for example, in the form of noise or odour emissions.

Of course, pollution- and landscape-related externalities also arise from fossil fuel, nuclear and other renewable energy technologies. The overall cost-benefit balance of bioenergy compared to other energy technologies varies between bioenergy pathways, necessitating comprehensive Life Cycle Analysis (LCA) efforts covering entire value chains. However, LCA estimates for individual bioenergy pathways vary considerably, and significant uncertainties and unsolved issues remain (Reap et al. 2008; Cherubini and Strømman 2011; McKone et al. 2011). Likewise, an overall quantification of the external costs associated with fossil fuel use and other RES is in many cases difficult; in general, estimates indicate that avoidance of GHG emissions can be regarded as the most significant external benefit of RES use (Nitsch et al. 2004; Krewitt and Schlomann 2006; Breitschopf et al. 2011).

2.2.3.2 Security of Supply Externalities

Security of supply can be defined as the "availability of energy at all times in various forms, in sufficient quantities, and at affordable prices" (UNDP 2004: 42). As an essential good, energy provides the basis for an unobstructed functioning of economic processes (Erdmann 2010: 7). As all energy consumers benefit from the prevention of short-run emergencies and long-run security of supply risks (Jansen and Bakker 2006: 40), and both non-rivalry and non-excludability apply to these benefits, security of energy supply can be regarded as a public good (Rader and Norgaard 1996: 40; Abbott 2001: 32; Langniß et al. 2007: 17). Bioenergy use can provide external security of supply benefits along two dimensions.

First, bioenergy can serve as a substitute for "insecure" energy sources like mineral oil and gas (Isermeyer and Zimmer 2006: 10; Berndes and Hansson 2007: 5972ff.; Gillingham and Sweeney 2010). For both of those energy carriers, Germany is highly dependent on imports from a small number of producer countries, parts of which are located in politically unstable regions (cf. Tänzler et al. 2007). Bioenergy can contribute to energy security either by substituting imports for domestically produced biomass, or in the context of an import diversification strategy (Isermeyer and Zimmer 2006: 10). However, due to incentives for free-riding, market forces alone are unlikely to provide an optimal degree of diversification of energy sources (Rader and Norgaard 1996: 40; Springmann 2005: 3).

Second, as a dispatchable RES, bioenergy could help to mitigate reliability risks in the electricity system by providing balancing and peak load power (Bofinger et al. 2010; Leprich et al. 2012: 40ff.). Here, the reliability of power supply and the provision of adequate capacity in a market with low demand flexibility are important aspects of energy security that markets may fail to provide at a socially optimal level (Cramton and Ockenfels 2012: 115f.). Moreover, on the basis of market prices, without an internalisation of environmental and import dependency-related security externalities, markets would choose fossil fuels to provide these services.

2.2.3.3 Knowledge and Learning Externalities

Further positive externalities arise in bioenergy value chains from investments in innovation and diffusion of new production, conversion and combustion technologies.

Resulting from the public good characteristics of knowledge, producers investing in R&D cannot prevent other market actors from benefitting from their new insights—other firms can adopt the innovation, while consumers benefit from prices lower than the innovative product's value, as prices get driven down by competition (Jaffe et al. 2005; Gillingham and Sweeney 2010; Newell 2010). As a result, the innovating firm is unable to fully capture the benefits of its investment, and innovation efforts are lower than what would be socially optimal.[11]

Moreover, as producers gain experience with the production of new technologies, learning by doing occurs, causing production costs to fall (Jaffe et al. 2005; Jamasb 2007; Arrow 2008). As future investors can benefit from these learning effects, current investments in capacity are associated with a positive externality

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[11] The divergence between marginal social and private rates of return on R&D investments can be significant—typical estimates of marginal social rates of return range from 30 to 50 %, while private marginal rates of return on investments in physical capital typically lie between 7 and 15 % [see Pizer and Popp (2008) for an overview of studies].

and are likely to be below the socially optimal level (Arrow 2008). The magnitude of learning effects is technology specific and can be estimated using learning curves, which typically set reductions in the unit cost of a product in relation to the experience gained from an increase in cumulative capacity or output (Jamasb 2007). For energy technologies, the focus of analyses are commonly changes in the costs of a unit of capacity (Watt) or a unit of electricity produced (kWh) in relation to cumulative production (Junginger et al. 2006).

While knowledge externalities are likely to be very relevant for research-intensive bioenergy technologies at an early stage of their development (cf. Hermeling and Wölfing 2011: 84), the magnitude of learning externalities has to be assessed on a case-by-case basis for different bioenergy technologies (cf. Gillingham and Sweeney 2010). For established technologies, like steam turbine-based cogeneration plants for solid biomass or biogas plants, learning curve effects are estimated to be small (Thrän et al. 2011b: 42ff.). Studying learning curves in biogas production from 1984 to 2001, Junginger et al. (2006) find that from 1990 onwards production costs stayed relatively constant while cumulative capacity continued to increase. Meanwhile, technological learning is not only relevant for conversion technologies, but also for feedstock production, where significant future cost reductions may be achievable (van den Wall Bake et al. 2009; de Wit et al. 2010, 2013).

2.2.3.4 Market Power in the Energy Sector

Market power in the energy sector is another form of market failure that distorts bioenergy allocation decisions. In particular, market power is relevant in the gas, mineral oil and electricity markets (Bundeskartellamt 2011; Bundeskartellamt and Bundesnetzagentur 2013). As market actors with large market shares are able to influence prices, static allocative efficiency is no longer given (cf. Gawel 2009: 725); prices are set higher than socially optimal, while output is lower.[12] While high prices make investments in alternative energy sources such as bioenergy more attractive, incumbents which have invested in fossil fuel-based energy production systems have incentives to erect entry barriers for new market participants supplying substitutes (Gillingham and Sweeney 2010). [13] By ignoring sunk costs of past

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[12] Moreover, gas and electricity grids constitute classic natural monopolies; market failures arising from, for example, limited access and uncompetitive transmission prices shall be neglected here, given that natural monopolies are typically heavily regulated (cf. Bundeskartellamt and Bundesnetzagentur 2013).

[13] In the German electricity sector, for example, large-scale fossil fuel and nuclear plants are traditionally the domain of four major electricity generating companies with a high combined market share (E.ON, RWE, Vattenfall, and EnBW), a structure going back to before the liberalisation of the electricity market. However, regulatory interventions, the expansion of renewable energies and the decommissioning of eight nuclear plants in 2011 have caused the market share of these companies to decline significantly in recent years (Bundeskartellamt and Bundesnetzagentur 2013: 19).

investments in their price setting, incumbents can outcompete new market entrants (Streit 2005: 183f.).

Moreover, market power might impact dynamic allocative efficiency by affecting innovation efforts and the direction of technological change. One the one hand, if companies are under low competitive pressure, incentives to invest in innovation to gain competitive advantages may be low; on the other hand, firms with high market shares are more likely to appropriate a higher share of their investments' benefits than under perfect competition (Gillingham and Sweeney 2010). Even when innovating, however, firms profiting from indivisibilities and increasing returns to scale have little incentive to invest in technologies that reduce these obstacles to competition, such as small-scale decentralised renewable energy technologies (Streit 2005: 180).

In an unregulated market, market power on the side of incumbents would therefore be likely to lead to an underinvestment in bioenergy capacity and innovation.

2.2.3.5 Information Problems and Transaction Costs

The presence of market uncertainty severely limits producers' and consumers' ability to maximise their respective utilities. In reality, no decision maker in the bioenergy value chain knows who demands which goods under what conditions, what alternatives are on offer to meet demand, how demand will develop over time, what the optimal production technologies and input combinations are, what production locations would be optimal, and so on (cf. Richter and Furubotn 2003: 59). Gaining information for making allocation decisions is costly, and the optimal level of information search activities is unknown; moreover, individuals face cognitive limitations in processing this information and formulating plans, and are prone to making errors (Simon 1955). Under such conditions of bounded rationality, inefficient allocative outcomes can be regarded as the norm (Richter and Furubotn 2003: 53).

Transaction costs result from these inefficiencies (Richter and Furubotn 2003: 53), and can be defined as the costs that individuals have to incur for search and information, bargaining and decision making, as well as monitoring and enforcement (Dahlman 1979: 148). As such, they result largely from dealing with the consequences of imperfect information (Dahlman 1979: 148). Alternatively, transaction costs can be characterised as the costs of establishing, exchanging and enforcing property rights (Eggertsson 1991: 14). However, given that in a world with perfect information such transactions would be costless (cf. Coase 1937), the two concepts are closely related; in the following no distinction shall be made between information costs and transaction costs as separate categories (cf. Krutilla and Krause 2011: 271).

Transaction costs also play an important role in addressing information asymmetries between actors, as a special case of the problem of imperfect information. While these may occur at different points in the bioenergy value chain, it is worth highlighting information asymmetries between producers and consumers about the environmental and social quality of goods. If, among consumers, a preference for sustainable bioenergy is assumed, it follows that the environmental and social impacts of substrate production would influence the purchase decisions of bioenergy carriers. However, bioenergy carriers are a "credence good", in that they bear no information as to their associated external costs and other socioeconomic impacts. As a result, goods with a higher environmental and social quality get crowded out of the market (cf. Akerlof 1970; Schubert and Blasch 2010). The establishment of a voluntary certification scheme would be an option for privately internalising the resulting market failure; however, the relatively limited willingness to pay for public good characteristics of products limits the applicability of this solution to niche applications (Schubert and Blasch 2010).

2.2.3.6 Dynamic Market Failure

Imperfect information and transaction costs also give rise to inefficiencies in the dynamic perspective. Unlike in the perfect competition model, market adjustment processes are not infinitely quick, nor are they without costs (Gawel 2009: 546f.; Fritsch 2011: 305f.). For example, rising prices for heating oil and gas can make a change from a fossil fuel-based to a biomass-based heating system economic, but transaction costs may prevent it from actually occurring—house owners have to search for cost-effective solutions, overcome information asymmetries with suppliers, change existing heating contracts, and so on. Moreover, technical substitution barriers have to be overcome; existing capital stock in the form of heating installations can normally not be redeployed for bioenergy use, necessitating investments in a new biomass-burning appliance.

Indeed, in the energy sector in general, past investments in long-lived fossil fuel plants, mineral oil refineries, and other elements of the fossil fuel-based technological system are often highly specialised, and cannot be easily redeployed to a new purpose (Unruh 2000). The specialised nature of investments in physical capital, but also in skills and knowledge interacts with increasing returns and network externalities to create a technological path dependency (Arthur 1989, 1994).

As a result, markets would continue to favour fossil fuel-based energy technologies even if they do not constitute the most efficient option, for example, once climate change externalities have been internalised.

Furthermore, technological path dependencies in the energy system are reinforced by a co-evolutionary development of the fossil fuel-based technological system with infrastructures, interdependent industries (e.g. car industries in the transport sector), users, and private and public institutions, giving rise to a carbon lock-in which can be extremely difficult to overcome (Unruh 2000, 2002). Compared to other RES, some bioenergy pathways have the advantage that they are compatible with the existing technological system, for example, co-firing biomass in coal power plants or blending biofuels with conventional petrol or diesel fuels (cf. Bauen et al. 2009: 55; Bento 2010). In a market context, it can therefore be expected that allocation decisions between bioenergy and other RES, but also between different bioenergy pathways would be distorted in favour of these compatible options.

Transaction costs also play a role in dynamic adjustment processes in the agricultural sector. In particular, agricultural production factors (i.e. land, labour and capital) are rather inflexible at least in the short term, limiting the sector's ability to adapt to structural change (Henrichsmeyer and Witzke 1994: 352f.). Barriers to factor mobility prevent an equalisation of factor products and factor incomes across sectors (Henrichsmeyer and Witzke 1991: 384); for example, if incomes in the agricultural sector dropped relative to other sectors in reaction to decreasing prices for agricultural commodities, actors may nonetheless be prevented from moving to other sectors by the transaction costs associated with liquidating capital, acquiring new skills while forsaking highly specialised ones, and so on. Yet, if supply fails to adapt to decreasing prices, factor incomes remain low in relation to other sectors. Policy interventions aimed at increasing factor mobility can improve the efficiency of structural adjustment processes—however, actual interventions tend to focus on increasing agricultural factor incomes, which may in turn prevent structural changes from occurring (Henrichsmeyer and Witzke 1994: 353f.).[14] From this perspective, it is debatable whether support for energy crop production is justifiable from a dynamic efficiency perspective, in that it enables farmers to branch out into different sectors and diversify their incomes, or whether it inhibits structural adjustment processes.

2.2.3.7 Sustainability

All along the value chain, allocation decisions have implications for the environmental and socioeconomic balance of bioenergy. As Table 2.3 illustrates, sustainability risks are associated particularly with the production stage; accordingly, energy crop cultivation and associated land use changes are at the centre of the bioenergy sustainability debate (cf. SRU 2007; WBGU 2008; Bauen et al. 2009; Kampman et al. 2010; Meyer et al. 2010).

In the presence of environmental externalities (see Sect. 2.2.3.1), natural capital is likely to be overused. However, even if Pareto-efficient levels of GHG mitigation, conservation of biodiversity and other ecosystem services were implemented, this does not necessarily imply that the allocative outcome would be sustainable. As discussed in Sect. 2.1.2, a key requirement of sustainability is that resources and opportunities are distributed equitably between generations, so that future generations can realise at least the same levels of utility as current ones. Efficiency, however, does not guarantee that the distribution is equitable, neither from an intergenerational nor from an intragenerational perspective (Common and Stagl

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[14] Inter alia, this can be due to a normative value being assigned to the maintenance of existing agricultural structures (cf. Gawel 2009: 547).

Table 2.3 Sustainability impacts of allocation decisions in bioenergy value chains (based on Gawel 2011; Gawel and Purkus 2012)

Stage of value creation	Allocation decisions	Environmental and socio-economic impacts
Production stage	Energy crops (e.g. cereals, oil plants, lignocellulosic energy crops), wood (e.g. forest biomass, short rotation coppice), or wastes and residues (e.g. harvesting residues from agriculture and forestry) Cultivation and harvesting methods Location of biomass production Transport or local conversion of biomass	GHG emissions from land use changes Impacts on biodiversity, soil and water quality, local water availability, and other ecosystem services GHG emissions from agricultural production (e.g. fertiliser and machinery use) and transport Social impacts (working conditions, access to land, food prices)
Processing stage	Conversion processes (physico-chemical, biochemical, thermochemical) Conversion into solid, liquid or gaseous bioenergy carriers Use of organic household waste, or by-products from material biomass uses Production of by-products Transport of bioenergy carriers or local combustion	Emissions of pollutants in conversion processes Substitution of animal feed for by-products (reduction of land use requirements) GHG emissions from transport
Utilisation stage	Utilisation in electricity, heating or transport sectors	Substitution of energy carriers with different GHG emission balances and environmental impacts (e.g. gas, coal, mineral oil, renewable energies) Emissions of non-GHG pollutants during combustion Impacts on energy prices

2005: 352f.; see also Daly 1992; Woodward and Bishop 1995; Padilla 2002; Norgaard 1992; Endres 2013: 378ff.). From a static equilibrium viewpoint, the optimal level of environmental pollution (e.g. GHG emissions) results from balancing aggregated marginal damage costs of pollution and aggregated marginal abatement costs, which include foregone benefits from the polluting activity (more precisely, the optimal pollution level can be found at the intersection of the aggregated marginal damage cost and marginal abatement cost curves) (Endres 2013: 40f.). However, this aggregated perspective does not consider the distribution of costs and benefits of emissions between economic actors—in the optimum, some actors may benefit from the polluting activity, while others bear the damage costs of pollution. Similarly, some actors may benefit from abatement activities, while for others, the costs of abatement may outweigh the benefits. In the bioenergy case, for instance, distributive impacts arise from changes in scarcity relations on agricultural commodity and land markets. In particular, the impact of bioenergy demand on food prices and the affordability of food for poor consumers in import-dependent countries is an important concern (FAO 2008). Impacts on food prices are a pecuniary externality, and as such, not a market failure (Streit 2005: 81; Gillingham and Sweeney 2010): they reflect changing scarcity relations and result in adjustments in the allocation of biomass and land resources which are desirable from an efficiency perspective, but problematic under distributive aspects.[15]

If the optimal internalisation level of an environmental externality has not yet been reached, the Kaldor-Hicks criterion states that efficiency can be improved as long as winners of an increase or a reduction of polluting emissions could potentially compensate losers and still be better off—but from an efficiency perspective, it is not necessary that this compensation actually takes place (see Sect. 2.1.1). This negligence of distributive impacts becomes particularly problematic when an intergenerational perspective is adopted—actors of the current generation can at least in principle lobby for a certain distribution of costs and benefits and seek representation in political markets; this is not possible for future generations (Padilla 2002: 70). This lack of representation tends to be expressed in the choice of discount rates: in economic decision making, benefits and costs occurring closer to the present tend to be valued higher, while future costs and benefits are discounted (Norgaard 1992: 94; Padilla 2002: 72). Discounting future damage costs of pollution, however, disadvantages the interests of future generations, who cannot express their demand for the conservation of ecosystems in either economic or political markets (Padilla 2002: 69).

As argued in Sect. 2.1.1, only efficient pathways where the rights of future generations are protected can be considered sustainable.[16] However, even if advocates for the rights of future generations can be found, the definition of these rights remains a fundamental problem, because the preferences of future generations are unknown (Common and Stagl 2005: 352f.; Padilla 2002: 72; Krysiak 2009). The weak sustainability perspective with its requirement of a constant total capital stock, the strong sustainability perspective with its demand that the natural capital stock remain constant, and the critical natural capital perspective (see Sect. 2.1.2) all are attempts of the present generation to define the rights of future generations. In the end, it remains unknown whether future generations would prefer higher stocks of natural or of man-made capital. Given the irreversibility involved with the loss of certain types of natural capital, a precautionary perspective argues at least for the protection of critical natural capital (Padilla 2002: 76).

Equity issues can therefore lead to a divergence between efficiency and sustainability criteria. Further divergences can arise from the problem of ensuring a sustainable scale of economic activity (see Daly 1992; Costanza et al. 2001:

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[15] Of course, current levels of bioenergy use are determined by policy interventions, which distort resource allocation between food and energetic uses; nonetheless, if future fossil fuel price developments were to endow energetic uses with a higher ability to pay than food-related uses (following e.g. a comprehensive internalisation of external costs), the consequences for food security would be problematic.

[16] Dynamic efficiency is a prerequisite for sustainability, in as far as that it ensures that the highest feasible constant level of utility is realised over time (Stavins et al. 2003).

98ff.). The question here is, whether the efficiency perspective with its focus on internalising environmental externalities in order to achieve optimal pollution levels can reflect the ecological limits of ecosystems' carrying capacity. In many cases, assuming a "well-behaved", i.e. continuous and smoothly increasing marginal damage function, proves inadequate—rather, the relationship between pollution and an ecosystem's ability to carry out its functions is characterised by complex and imperfectly understood ecological interactions, discontinuities, and uncertain thresholds, beyond which the ecosystem may undergo irreversible changes (Daly 1992: 190; Padilla 2002: 73f.; Woodward and Bishop 1995: 106; Mäler 2000). Before a threshold is crossed, marginal damage costs of emissions may well be zero, but beyond it they might, in an extreme case, lead to the irreversible loss of the natural capital contained in the ecosystem, accompanied by a steep increase in the marginal damage cost curve at the point of the threshold (Daly 1992: 192). In many cases, it is not only impossible to ascertain the position of the threshold with certainty, but the probability distribution of emissions leading to thresholds being exceeded is also unknown (cf. Dovers et al. 2001). Furthermore, the internalisation approach typically neglects the spatial allocation of environmental damages (Streit 2005: 13), which is of high relevance for the protection of ecosystem functionality (e.g. Thrän et al. 2010a). Additionally, the identification of efficient pollution levels presupposes a monetary valuation of environmental damages, to allow for an aggregation and comparability of private and external costs and benefits of polluting activities. However, the monetary valuation of environmental damages, which encompass the degradation and loss of marketable ecosystem services but also of non-market values, presents significant problems (Norgaard 1992: 94; Bartkowski et al. 2015; Hattam et al. 2015).

To summarise, it is the presence of uncertainty and ignorance regarding discontinuous marginal damage cost curves and thresholds, but also problems regarding the monetary valuation of costs and benefits of pollution abatement, that impose severe limits on the efficiency concept's ability to sustain environmental carrying capacity. However, uncertainty and ignorance apply not only to the sustainable scale of economic activity, but also to the identification of pathways which can be described as intergenerationally equitable: what rights future generations should be entitled to, or what can be described as critical natural capital, is ultimately decided by current generations based on current preferences. This leads to the question of how to rationally deal with respective uncertainties (see Sect. 2.1.3) and how to move the economy in the right direction, even if optimal or assuredly sustainable solutions cannot be identified with certainty at the outset (Woodward and Bishop 1995: 106).

2.3 Bioenergy Policy as a Problem of Regulation Between Market Failures and Government Failures

As discussed in the previous section, multiple market failures may cause the level of bioenergy use to be lower than socially optimal. By introducing a policy-driven demand for bioenergy, however, policy makers accept responsibility for a complex allocation problem. As discussed in Sect. 1.2, it is not adequate to assume that regulative interventions can succeed in repairing all relevant market failures, leading to a welfare-optimal allocative outcome. Rather, interventions come with costs and risks of failure of their own, with important consequences for policy analysis: not only does the achievement of optimal outcomes become unlikely, but interventions may not even necessarily improve welfare compared to a situation in which market failures were left unaddressed. To avoid replacing market failures by government failures, it is therefore necessary to carefully assess where in the value chain government interventions are likely to perform "better" (i.e. more efficiently, sustainably, and rationally) than the market mechanism. As a first step towards such an analysis, major sources of government failure in fulfilling efficiency and sustainability requirements on bioenergy allocation are outlined below: these are problems concerning the establishment of a consistent system of policy aims, imperfect information, and the transaction costs of regulation; moreover, the allocation problems of bioenergy value chains reach across several scales and regulative jurisdictions, turning bioenergy policy into a multi-level governance problem. Lastly, conflicts can occur between economic and political rationality.

2.3.1 Conflicting Aims as Barriers to Rational Bioenergy Policy

When arguing for bioenergy support, policy makers in Germany and the EU, but also in countries such as the US, China or Brazil emphasise GHG mitigation, security of energy supply, and rural value creation and development as major policy aims that bioenergy use could make positive contributions to (COM 2005; GBEP 2007: 22; BMU and BMELV 2009a; Thrän et al. 2011a: 5). However, a range of other aims are also of relevance; these include technological development, the mitigation of non-GHG-related environmental impacts of fossil or nuclear energy technologies, or the development of a domestic bioenergy industry and contributions to domestic growth (COM 2005: 4; GBEP 2007: 22; BMU and BMELV 2009a: 10, BMWi and BMU 2010: 3).[17] This multiplicity of aims turns bioenergy into a complex policy field, spanning policy areas like energy policy, climate and environmental policy, technology policy, agricultural policy and

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[17] For a more detailed analysis of relevant aims in the German and European case, see Sect. 4.1.1.

industrial policy. Depending on the policy area in question, different aims take precedence which cannot easily be reconciled with each other (van der Horst 2005; Isermeyer and Zimmer 2006; SRU 2007: 80ff.).

From an economic rationality perspective, the broad range of aims that policy makers use to justify bioenergy support poses two major problems. One stems from interactions between conflicting aims, which necessitate the formulation of a hierarchy of policy aims (Welfens 2013: 655); this is discussed further below. First of all, however, a distinction is necessary between different rationales that underly the various policy aims. Neoclassical economic theory distinguishes between aims which are based on an efficiency rationale and those based on other rationales, such as distributive concerns, fairness or democratic participation (Luckenbach 2000: 135 and 173; Sijm et al. 2014: 8). Aims aligned with the efficiency rationale seek to ameliorate market failures to improve the allocative efficiency of market processes. In the case of bioenergy policy, GHG mitigation is an example of an efficiency-based aim, because it strives to internalise GHG externalities. Further efficiency rationales exist for the protection of the environment, in as far as the aim addresses further environmental externalities; security of supply, which seeks to address negative externalities from insecure resource imports or intermittent energy supply; and technological development, which encompasses an internalisation of positive externalities from knowledge generation and learning (see Sect. 2.2.3; cf. also Sijm et al. 2014: 5). Market failures caused by market power, information problems, transaction costs and imperfect adjustment processes can provide further efficiency rationales for policy interventions (see Sect. 2.2.3).

Aims such as rural value creation or domestic industry development, on the other hand, have a strong distributive component, because they aim to enhance income opportunities for certain societal groups. However, interventions in market processes which seek to alter their distributive outcome are likely to impact the efficiency of the allocative outcome (Luckenbach 2000: 188f.). For example, if bioenergy use is to contribute to domestic rural value creation, the use of domestically produced energy crops and domestic forest resources performs best. However, for a cost-effective substitution of fossil fuel resources, domestic biomass producers should be exposed to competition with international suppliers, which have comparative cost advantages particularly in the production of biofuels (Henke and Klepper 2006; Isermeyer and Zimmer 2006; Berndes and Hansson 2007; WBA 2007: 176f.). For contributions to GHG mitigation or security of energy supply, it would likewise be unimportant whether technologies were manufactured domestically or imported from abroad. As a result, neoclassical economists reject rural value creation as a “valid” aim for bioenergy policy, recommending instead an alignment with efficiency rationales (Isermeyer and Zimmer 2006; WBA 2007: 183ff.; Hermeling and Wölfing 2011: 82; Henke and Klepper 2006). From this perspective, contributions to aims based on distributive rationales would be considered mere co-benefits.

Meanwhile, even among aims that follow an efficiency rationale, prioritisation is necessary. This is because the contribution of different bioenergy pathways to different relevant aims varies strongly. Consequently, different priorities imply different support strategies for bioenergy, resulting in a diverse range of allocative outcomes. From a climate policy perspective, for example, it would be rational to employ a biomass utilisation strategy focussing on pathways with high GHG mitigation potentials and, at least in the mid-term, low GHG mitigation costs. Following these criteria, bioenergy should be employed primarily for the substitution of coal in the electricity sector in combined heat and power applications, whereas the use of biofuels in transport constitutes the least favourable option (WBA 2007: 192ff.; WBGU 2008: 326f.; König 2011; Sterner and Fritsche 2011; Hennig and Gawor 2012). However, under security of energy supply aspects biofuels are of particular interest, because they can act as a substitute for mineral oil with its high dependency on a limited number of export countries and its tendency towards strong price increases (cf. Henke and Klepper 2006; Isermeyer and Zimmer 2006; Berndes and Hansson 2007). To indicate major lines of conflict between aims, Table 2.4 provides an overview of support focuses that would result from different prioritisations—including aims based on efficiency and distributive rationales. That notwithstanding, an important question is whether the promotion of bioenergy use would be a cost-effective means of implementing these aims. This is further discussed in Sect. 3.1.

In actual policy making, however, situations with unclear hierarchies between multiple aims and unsolved trade-offs abound (cf. Thacher and Rein 2004; Wieliczko 2012). There are many reasons for this. Keeping priorities unclear is a rational strategy for policy makers attempting to maximise political support, because different aims can be emphasised when addressing different interest groups (Streit 2005: 277; Kay and Ackrill 2012: 299). For the same reason, mixing distributive and efficiency rationales in justifying policy interventions can be politically expedient. On the other hand, information problems may lead to an incomplete understanding of policy effects and interrelations between aims, making it difficult to anticipate conflicts ex ante and assess them correctly even once they occur (Eggertsson 1997: 1191f.; Streit 2005: 314). Another possible reason for a lack of prioritisation is that policy aims may be considered to be not commensurate, leaving policy makers unwilling to trade off one aim against the other, for example, higher security of energy supply against lower GHG mitigation benefits (Thacher and Rein 2004: 457f.).

Furthermore, trade-offs can arise between short-term and long-term perspectives. Although stationary bioenergy applications perform better in terms of GHG mitigation than biofuels, there are several renewable alternatives in the heating and electricity sectors; whereas the transport sector's most important low carbon alternative to biofuels, electromobility, will only be available in the medium term, as it necessitates significant changes in infrastructure and user behaviour (WBGU 2008: 190ff.; Dallinger et al. 2011). For heavy load transport, shipping and aviation, biofuels may even constitute the only feasible option in the long run (cf. JRC-IET 2011). As a result, the expansion of biofuels in transport is sometimes also supported from a GHG mitigation perspective, while highlighting the role of

Table 2.4 Focus of bioenergy support according to different political priorities (based on Isermeyer and Zimmer 2006; Berndes and Hansson 2007; WBGU 2008; Kampman et al. 2010; Sijm et al. 2014)

Dominant policy perspective	Priority aim	Rationale	Focus of support
Climate policy	Climate change mitigation	Efficiency (internalisation of GHG externalities)	Pathways with the highest GHG mitigation potentials and lowest GHG mitigation costs
Environmental policy	Protection of the environment	Efficiency (internalisation of energy-related environmental externalities)	Pathways that do not increase pressures on land use, avoid a deterioration of environmental quality, or provide environmental benefits beyond GHG mitigation
Technology policy	Technological development, innovation	Efficiency (internalisation of positive knowledge and learning externalities)	Innovative pathways with a large potential for knowledge and learning spillovers
Energy policy	Security of energy supply	Efficiency (internalisation of security of supply externalities)	Substitution of energy carriers with a high import dependency (primarily mineral oil and natural gas)
Agricultural policy	Rural value creation, rural development and rural employment	Distributive (increase and diversify income of agricultural producers)	Domestic production of energy crops
Industrial policy	Sectoral development, domestic economic growth and employment	Distributive (income opportunities in bioenergy technology industries and associated manufacturing industries)	Innovative value chains and exportable products

technological progress and second generation biofuels in delivering improved GHG balances (BMU and BMELV 2009a; COM 2009).

Incomplete knowledge and political rationality also impose problems on the implementation of other requirements for a rational setting of policy aims, such as operationalisability, transparency and the balancing of costs and benefits (see Table 2.1). However, the establishment of a complete and consistent system of policy aims can be considered of particular importance, as it is a prerequisite to other requirements of rationality, not only concerning the setting of aims but also the choice of effective and cost-effective instruments. Conflicts between aims cannot be solved on the instrumental level, as any form of bioenergy support will cause trade-offs (Gawel 1999: 248ff.; see Sect. 2.1.3). As such, a prioritisation of aims becomes the prerequisite for a rational design of bioenergy policy.

2.3.2 Incomplete Knowledge and Transaction Costs as Sources of Government Failure

The complexity of bioenergy value chains imposes considerable information requirements on policy makers, when attempting to steer bioenergy use so as to achieve certain aims. Whereas in a market context, the effects of "inefficient" decisions by individual actors are limited, the incentive framework set by national or EU-level policy makers affects entire transregional value chains, limiting the scope for trial-and-error processes (cf. Hayek 1945). Consequently, a rational handling of imperfect information in decision making processes becomes an important element of a rational bioenergy policy, as does the acknowledgement of transaction costs of regulation.

2.3.2.1 Different Forms of Incomplete Knowledge

At this point, it seems useful to refine the distinction between different forms of imperfect knowledge. Knowledge can be incomplete concerning the probability that certain outcomes may arise, or concerning the outcomes and their magnitudes themselves (Smithson 1989; Stirling and Mayer 2004; Common and Stagl 2005: 385). Based on this, four types of imperfect knowledge can be distinguished, which are summarised in Table 2.5.

In the case of *risk*, decision makers are able to assign probabilities to a finite number of possible outcomes. This is the case in classic gambling situations, when the underlying properties of the gamble are known, but also if probabilities can be derived from past experiences (Perman et al. 2003: 445). For example, an experienced biomass project investor may be able to calculate a probability distribution for profits of a new investment based on the performance of past projects with the same characteristics. Using this information, the investor can calculate the expected net present value of the project. Furthermore, based on data about the past and causal relationships, probabilities can also be derived from models (Perman et al. 2003: 445).

In the case of *ambiguity*, decision makers can ascertain the probability that a certain state may come about, but they do not know for certain what characteristics this state might have. For example, modellers who wish to assess future regional potentials for biomass production may know that with a high likelihood, climate change will impact the productivity of agricultural systems, without being able to establish what form this impact will take (cf. Stirling and Mayer 2004: 162).

Table 2.5 Types of incomplete knowledge (based on Common and Stagl 2005: 386)

	Knowledge of outcomes	
Knowledge of probabilities	Well defined	Poorly defined
Yes	Risk	Ambiguity
No	Uncertainty	Ignorance

Under *uncertainty*, following the definition introduced by Knight (1921), decision makers know what outcomes are possible, but not their probabilities. For instance, bioenergy production and use has impacts on complex environmental systems, like the global climate, or ecosystems and biodiversity, which are incompletely understood (Funtowicz and Ravetz 1990; Dovers et al. 2001; Wesseler et al. 2003). Young (2001: 46ff.) distinguishes between ecological uncertainty about ecosystem dynamics and the consequences of human-induced ecological change, and valuation uncertainty which arises when attempting to estimate the value of ecosystem services and functions and implications of ecological changes for human welfare. Models can yield probabilities that human activities (e.g. different GHG emission scenarios) will give rise to certain changes (e.g. in global or regional temperature levels), but due to the complexity of the modelled systems these probabilities are themselves uncertain.[18] Some types of uncertainty can be quantified (e.g. modelling uncertainty is frequently expressed by using different models to generate probability density functions for key variables, and providing policy makers with relative likelihoods of different future outcomes), while for others this is not possible (Jenkins et al. 2009: 14ff.; IPCC 2013: 15ff.).

In a situation of *ignorance*, finally, it is neither feasible to define a full set of possible outcomes, nor to assign probabilities. Inherent to ignorance is the possibility of being surprised by unforeseen consequences, or “unknown unknowns” (Wynne 1992; Stirling and Mayer 2004). For example, environmental systems can be subject to critical thresholds and tipping points, whose position or even existence may be unknown; the dynamic nature of ecosystems and the lack of past experiences can make it extremely difficult to predict the changes which may occur as a consequence of passing such thresholds (Young 2001: 48ff.).

2.3.2.2 The Role of Incomplete Knowledge in Bioenergy Policy Making[19]

Incomplete knowledge about the costs and benefits of various pathways is a central problem in the design of bioenergy policy. While the phenomenon of incomplete information about the private cost characteristics of RES plants and future learning curve effects has been well-researched (Menanteau et al. 2003; Finon and Perez 2007), the heterogeneity of bioenergy pathways and their dependency on biomass and land resources adds several dimensions to the problem of policy design. In particular, many decision problems that policy makers face when intervening in bioenergy allocation processes do not allow for the assignment of probabilities to

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[18] Uncertainties in climate models, for example, arise mainly from natural climate variability, an incomplete understanding of earth system processes and imperfections in their modelling representation, and uncertainty about future levels of anthropogenic GHG emissions (Jenkins et al. 2009: 14ff.).

[19] Some parts of this section have been used in Purkus et al. (2015).

well-defined outcomes, and can therefore be characterised as decisions under uncertainty or ignorance (for the sake of simplicity, the following discussion shall refer to the term uncertainty only, including the possibility that not all outcomes may be known). Table 2.6 summarises the major types of uncertainty that bioenergy policy makers have to face.

On the cost side, policy makers face uncertainties regarding private as well as external costs. *Static cost uncertainty* concerning the private costs of bioenergy production arises from information asymmetries between bioenergy producers and policy makers. *Dynamic cost uncertainty*, on the other hand, applies to both policy makers and market actors: the future costs of bioenergy provision depend on the extent of cost reductions that can be realised by technological progress and learning by doing, but also on resource cost developments. The future availability of biomass resources for energetic uses depends in turn on the demand for competing biomass uses, but also on factors such as agricultural productivity developments, population and economic growth, and societal preferences, all of which are inherently uncertain (Thrän et al. 2010b: 201f.; Chum et al. 2011: 26ff.). As a result, the future competitiveness of bioenergy pathways can be associated with large uncertainties (cf. Thrän et al. 2011a). Moreover, uncertainties apply to the *external environmental costs* of bioenergy production (e.g. through negative impacts on biodiversity, soils, water quality and availability), which depend on the pathway in question as well as on local and regional circumstances (Gabrielle et al. 2014; Thrän et al. 2010a).

On the benefit side, there are *uncertainties about GHG mitigation benefits* to contend with: not only the level and slope of the aggregate marginal benefit function of GHG mitigation is uncertain (Pizer 1999; Newell and Pizer 2003), but also the extent of emission reductions associated with different bioenergy pathways (see Adams et al. 2013 for an overview). Emission reductions and GHG mitigation costs depend crucially on the type of fuels replaced by bioenergy use (Cherubini and Strømman 2011: 442f.; Sterner and Fritsche 2011: 4803f.; Thornley et al. 2015: 39f.). Moreover, GHG accounting requires numerous assumptions about allocation decisions in bioenergy value chains and their direct and indirect impacts, which are associated with significant uncertainties. The same holds true for wider environmental impact assessments, which are required to produce comprehensive estimates of external environmental costs and benefits.

Life Cycle Analysis (LCA) techniques are used to establish GHG balances and environmental impact balances for representative pathways; however, the results of LCA calculations often vary significantly, making it difficult to state with confidence that a selected pathway will show a certain GHG balance or certain other environmental impacts with a certain likelihood (Cherubini 2010b; Cherubini and Strømman 2011; Rowe et al. 2011; Adams et al. 2013). Rowe et al. (2011) and Whitaker et al. (2010) identify three main reasons for this: (i) “real” variations in input data, which are due to the large number of assumptions that need to be made concerning variables in heterogeneous and complex value chains and the amount of required data; (ii) an incomplete understanding and inaccurate assumptions concerning the GHG emissions associated with certain process steps, for example,

Table 2.6 Major types of uncertainty in bioenergy policy making (based on Purkus et al. 2015: 66)

Stage of political decision making	Type of uncertainty	Dimensions
Rationale for bioenergy support and design of support mechanism	Static cost uncertainty	Uncertainty about private costs of bioenergy production, i.e. the position and shape of the aggregated marginal cost curve of bioenergy producers is not known to policy makers
	Dynamic cost uncertainty	Uncertainty about cost reductions through learning curve effects and economies of scale
		Uncertainty about resource cost developments
	Uncertainty about external environmental costs of bioenergy production	Uncertainty about negative externalities associated with a specific bioenergy pathway (arising from e.g. negative impacts on soils, water quality and availability, biodiversity, particulate emissions during bioenergy conversion and use)
	Uncertainty about GHG mitigation benefits	Uncertainty about aggregate marginal damage function of GHG emissions
		Uncertainty about GHG balances of bioenergy pathways
		Uncertainty about indirect land use changes and associated GHG emissions
	Uncertainty about security of supply benefits	Uncertainty about benefits of import substitution
		Uncertainty about future competitiveness of bioenergy's contributions to security of supply
	Uncertainty about how to balance multiple externalities	Uncertainty about what weight should be given to which external benefits and costs
	Uncertainty about optimal biomass allocation	Uncertainty about current and future conditions of reference systems in different energy and bioeconomy sectors

(continued)

Table 2.6 (continued)

Stage of political decision making	Type of uncertainty	Dimensions
Implementation of support scheme	Uncertainty about the response of actors to policy incentives	Uncertainty about the correctness of behavioural assumptions (e.g. concerning rational behaviour)
		Uncertainty regarding interactions between bioenergy policy incentives and other policies and macroeconomic framework conditions
		On the side of market actors, uncertainty about the credible commitment of policy makers (policy uncertainty)

regarding the relationship between fertiliser use and N_2O emissions from soils (Cherubini and Strømman 2011: 443f.); and (iii) methodological variations, including different definitions of system boundaries and the use of different allocation procedures for co-products. Moreover, many impacts are dependent on spatial and temporal contexts (McKone et al. 2011: 1754). These factors combine to make the assignment of "risk profiles" to bioenergy pathways very difficult, so that policy making which is based on LCA results can be characterised as decision making under uncertainty (Upham et al. 2011: 513ff.; Thornley and Gilbert 2013). The complexity of estimating GHG mitigation benefits grows, once indirect land use changes (ILUC) caused by an increased biomass demand are taken into account (Di Lucia et al. 2012; Broch et al. 2013)—due to structural differences between models and uncertainties regarding the assumptions used to estimate key parameters, modelling estimates of net land use change effects including ILUC vary significantly (DG Energy 2010; Edwards et al. 2010).[20]

To make matters more complicated, uncertainties arise not only from the interaction of bioenergy with ecological systems, but also from technological and societal systems. Not only is policy makers' knowledge about the costs and learning curve potentials of existing innovative technologies limited, but future innovations which cannot be anticipated can cause significant changes in technological and even societal framework conditions (cf. North 2005: 21f.). This makes it difficult to assess the external benefits of improvements in the *security of energy supply*; those relating to the substitution of imports depend on which fuels are replaced by bioenergy, whereas the value of the systemic benefits of providing flexible bioenergy depends on the future availability of low carbon alternatives and their competitiveness. For example, whether bioenergy will turn out to be a cost-

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[20] Especially important for net land use change results are assumptions concerning the crop mix used to produce biofuels and the integration of co-products, yield growth, the allocation of production changes to region and land type, and consumption changes in response to changes in relative prices (Keeney and Hertel 2009; Edwards et al. 2010; Laborde 2011; Broch et al. 2013).

effective option for balancing intermittent electricity generation by wind and photovoltaics, or whether storage technologies and demand-side management will prove more promising is still being debated (cf. Leprich et al. 2012). Likewise, even though biofuels currently appear to be the only feasible low carbon substitute for storable carbon-based fuels in aviation and heavy load transport (cf. Bauen et al. 2009: 12; Kampman et al. 2010: 52), alternatives may yet be developed.

Given the existence of *multiple externalities*, policy makers additionally face the challenge of weighing the external costs and external benefits of a given pathway against each other and solving associated trade-offs. Moreover, uncertainties apply not only to bioenergy pathways, but also to material biomass applications in the growing bioeconomy. The dynamics of technological change prevent reliable predictions of future sectoral developments, causing problems for policy makers seeking a strategic focus for bioenergy support—the *optimal future allocation of scarce biomass resources* remains unknown, because the future availability of alternative, non-biomass GHG mitigation options in the different sectors determines where biomass use would generate the largest benefits.

In the implementation phase, a further dimension of uncertainty applies to the *response of actors to policy incentives*. Actors' responses may differ from the expected because behavioural assumptions may prove incorrect, or because incentives set by bioenergy policy interact with other policy or macroeconomic framework conditions in an unforeseen fashion. Moreover, the degree of policy uncertainty which market actors perceive constitutes an important influencing factor on their behaviour: the profitability of investments depends heavily on policy incentives, so that market actors will only be willing to carry them out if they have sufficient safeguards and confidence in their continued existence (Finon and Perez 2007; Foxon and Pearson 2007: 1546; Meijer et al. 2007).

Over time, some decision problems characterised by uncertainty can be ameliorated by acquiring new information, for example, through scientific research, or learning. In the case of information asymmetries, knowledge may already be available to some elements of society, so that uncertainty could be "cured" by uncovering such knowledge and transferring it to policy makers (e.g. knowledge about private bioenergy production costs) (Common and Stagl 2005: 388). In other cases, however, uncertainty may be an expression of Hayek's constitutive lack of knowledge (cf. Hayek 1945)—the complexity of the decision problem, information costs, the potential of future developments to surprise, and cognitive limits of decision makers combine to make an accurate assessment of the impacts of a given bioenergy policy intervention impossible. Moreover, policy makers face a trade-off: while new information becomes available over time, the flexibility to adapt the policy results in an increase in policy uncertainty. The higher the degree of policy uncertainty market actors face, the higher the uncertainty for policy makers that market actors will respond to policy measures.

To help deal with uncertainties, scenario and sensitivity analysis are established methods for exploring the consequences of varying assumptions about probabilities or outcomes (Goodwin and Wright 2001; French 2003; Volkery and Ribeiro 2009). Both methods can be used to demonstrate causal relationships, explore contingencies and identify potential conflicts between stakeholders or between policy aims; also, they can be applied to test the robustness of different policy strategies under uncertainty, by analysing how well they perform across scenarios (Stewart et al. 2013). As such, sensitivity and scenario analyses are important methods for supporting decision makers under conditions of imperfect knowledge, but ultimately subjective judgements are required to select between alternative courses of action (Common and Stagl 2005: 382). Moreover, the communication of uncertainty to policy makers is associated with significant challenges (Volkery and Ribeiro 2009; Gibbs et al. 2012; Enserink et al. 2013). As a result, the problem of how to make rational decisions under uncertainty remains, and is compounded by the presence of ignorance about the set of possible outcomes of a course of action.

Ultimately, different economic theory approaches differ significantly in their assessment of how well policy makers are able to deal with uncertainty. Hayek's contributions to the theory of economic order, for instance, emphasise the risk of government failure when intervening in markets, given the central decision makers' constitutive lack of knowledge (Hayek 1945/2005; see Sect. 3.4.1). Under uncertainty about the allocative effects, direct interventions on behalf of certain bioenergy pathways would have to be assessed as unfavourable, because they would result in a spiral of corrective interventions as knowledge about impacts of policy measures becomes available (cf. also von Mises 1929). In this light, even partial improvements of the degree to which external costs were reflected in market prices would appear preferable, to allow for a use of the market mechanism as a decentralised means of discovering information and adapting to changing framework conditions (cf. Streit and Wohlgemuth 2000: 468). On the other hand, theories such as transaction cost and contract economics take a more balanced stance on the respective advantages of government interventions and market processes in handling uncertainties (see Sect. 3.5.2). Chapter 3 therefore explores contributions from different theories to the problem of policy making under uncertainty.

2.3.2.3 Transaction Costs of Regulation

Efforts to increase the available knowledge of decision making give rise to transaction costs. But also other aspects of regulation are associated with costs—just as market transaction costs represent the costs of using the market mechanism (Sect. 2.2.3.5), political transaction costs can be regarded as the costs of using the political system (Voigt 2002: 210). Comparable to the market context, transaction costs of regulation result from the search for information, decision making, and the implementation, monitoring and enforcement of policies (Richter and Furubotn 2003: 63f.).[21] However, as Krutilla and Krause (2011) point out, the transaction

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[21] Political transaction costs also encompass the costs of establishing, operating and changing the order of the political system itself, for example, through constitutional reforms and the creation of new administrative bodies (cf. Richter and Furubotn 2003: 63). As the political system can be assumed as given in the bioenergy context, these shall be neglected here.

Table 2.7 Transaction costs of environmental regulation (based on Krutilla and Krause 2011: 275)

	Transaction costs	
Policy stage	Public sector	Private sector
Policy formulation and decision making	Policy formulation and decision costs	Lobbying costs
Policy implementation	Costs of regulatory development and legal actions	Lobbying and legal costs
Policy operation	Administration, monitoring and enforcement costs	Administration, monitoring and enforcement costs; legal costs

costs of regulation differ from market transaction costs both in their source and level; whereas market transactions are typically characterised by the voluntary transfer of property rights, policy making often implies the creation of new property rights or changes in existing property rights, and involves coercion. As a result, higher levels of negotiation costs, and most likely also monitoring and enforcement costs, are to be expected (Krutilla and Krause 2011: 268). The "value of rights", or content of policy aims and regulative interventions emerges in political markets, and actors have incentives to attempt to influence these outcomes, making the costs of lobbying an important transaction cost component in regulation; the same can apply to political decisions over the use of revenues created by regulation, for example, newly introduced taxes (Krutilla and Krause 2011: 269). Table 2.7 gives an overview of the different types of transaction costs arising throughout the environmental policy process, as defined by Krutilla and Krause (2011: 275). Meanwhile, it is important to distinguish between costs arising from administering, monitoring and enforcing policies, which count towards the transaction costs of regulation, and costs incurred in executing policies—the costs of adapting technologies, changing production processes etc. constitute production costs of achieving policy aims, not transaction costs (Krutilla and Krause 2011: 268).

In devising and implementing policy interventions, government failure arises if the transaction costs of regulation decrease welfare compared to a situation where market failures were left unattended (Demsetz 1969; North 1990; Dixit 1996; Williamson 1996). Consequently, in deciding about the desirability of interventions at specific points in the bioenergy value chain, it is necessary to compare the respective costs and benefits of alternative institutional arrangements.

2.3.3 *Bioenergy Policy as a Multi-level Governance Problem*

Yet another problem of bioenergy regulation arises from the transregional character of value chains and the fact that externalities and socioeconomic impacts occur on different spatial scales. For example, importing biofuels to meet European RES quotas implies an export of local and regional externalities associated with energy crop production; whereas the conversion of natural land for agricultural production affects the global public goods climate and biodiversity, no matter in which country it takes place.

Interdependencies in bioenergy regulation occur both vertically between local, regional, national, supranational and transregional institutions, and horizontally between actors of the same governance level, for example, different national governments, but also different European directorates or national level ministries responsible for the various affected policy fields (Knill and Tosun 2008: 149; Benz 2009: 21). No isolated governance actor can solve the allocative problems associated with bioenergy use; rather, a multi-level governance framework with an effective interaction and coordination of governance levels is required (Benz 2009: 21). This framework need not be limited to public actors, but can also include private actors, for example from the business sector or NGOs, which especially in the transregional context have emerged as important actors alongside non-coercive forms of governance (Conzelmann 2008: 11ff.).

Multi-level governance, meanwhile, is associated with several challenges of its own; in particular, these refer to the institutional design of the multi-level governance framework, its coordination and its legitimation (cf. Benz 2009: 18f.).

The first question that needs to be answered is which governance levels should fulfil which functions in governing bioenergy allocation decisions. Both centralised and decentralised solutions are associated with costs and benefits, making a context-dependent assessment of trade-offs necessary (Benz 2009: 27ff.).[22] For example, defining sustainability standards for bioenergy on a national rather than a higher order level has the advantage that both specific spatial contexts and preferences of national constituencies can be taken into account; moreover, negotiation and decision making costs may be significantly lower than in the case of European or even transregionally valid standards. On the other hand, the smaller the area to which sustainability requirements apply, the more relevant the external effects on other government levels and leakage effects will be. While affecting a significant share of global biofuel demand, the effectiveness of the EU's unilaterally adapted sustainability standards is still limited by producer countries' ability to redirect trade-streams to regions with lower or no such requirements (Di Lucia 2010; van Dam et al. 2010; Van Stappen et al. 2011). Likewise, while biofuels destined for the EU might be produced sustainably, no guarantee exists that displaced agricultural production was not compensated for elsewhere by converting natural land (e.g. Searchinger 2009). Clearly, the appropriate governance level to address problems related to ILUC, GHG mitigation and biodiversity would be the global one, but transaction costs associated with negotiations are likely to prove prohibitive in the foreseeable future (cf. Gallagher 2008: 11; WBGU 2008: 320; Scarlat and Dallemand 2011; Frank et al. 2013).[23]

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[22] In allocating responsibilities for environmental policy, the EU has adopted the principle of the appropriate level of action and the subsidiarity principle (Knill and Tosun 2008: 152). Nonetheless, in applying these principles to actual problems, considerable room remains for interpretation (Benz 2009: 27).

[23] The spatial governance of the energy transition in Germany's federal system provides another example of trade-offs between centralised and decentralised forms of governance (cf. Klagge 2013).

Moreover, the allocation of responsibilities to different governance levels is complicated by the fact that it does not result from a disinterested balancing of costs and benefits, but that different governance actors pursue their own interests in competing for competencies and resources. In this context, either lobbying for functions which might have been more efficiently addressed on other governance levels or avoiding new tasks can be rational strategies (Pappenheim 2001; Benz 2009: 33ff.).

Once responsibilities are defined, the coordination of different governance levels and actors becomes the second major challenge. Just as in national policy making, transaction costs of gathering information and decision making arise, as well as of monitoring and enforcing negotiated agreements. Coordination of multi-issue topics like bioenergy may be especially difficult, as the distribution of responsibilities is highly fragmented, and actors from different policy areas and governance levels may have very different perspectives on how problems can be solved, or what problems are even about (Heinelt 2008: 66; Poocharoen and Sovacool 2012). Likewise, prioritisation of policy aims is likely to differ between participants of such governance networks (ibid., cf. Sect. 2.3.1).

Furthermore, coordinating decision making on global public goods may fail due to an inability to overcome the prisoner dilemma characteristics of negotiations, in which each party has incentives to free ride on the mitigation efforts of others (e.g. Helm 2008). Also, government failure on lower governance levels can complicate coordination. For instance, national governments may choose not to internalise the external costs of biomass production in their jurisdiction, in order to gain competitive advantages in international trade (Common and Stagl 2005: 460ff.). In such situations, non-governmental actors can play important roles, either as participants in voluntary initiatives [e.g. roundtables on sustainable biomass production, such as RSB (2013) or RSPO (2013)], or as “watchdogs” pointing out government failures (Heinelt 2008: 60).

Finally, European and national-level bioenergy policy decisions have impacts on the citizens of other jurisdictions, without decision makers being accountable to them. As a result, questions of legitimacy of policy making in multi-governance contexts arise (Benz 2009: 19; Di Lucia 2010).

2.3.4 Conflicts Between Political and Economic Rationality

In neoclassical economic theory, the rationale for policy interventions is derived from the correction of market failures (cf. Sect. 2.3.1). In a first-best perspective, it is implied that policy makers choose instruments which implement efficiency-based policy aims and targets in a cost-effective manner (see Sect. 3.1 for a more detailed discussion). However, when contrasted with actual policy making, a fundamental question is whether parliamentary democracies are actually able to produce policies which correct market failures and establish an efficient allocation process (Gawel 1995: 14). After all, policy making is not a welfare maximisation process by a “benevolent dictator”, expressing a society’s aggregated welfare function. Rather, it can be described as a political and social negotiation and bargaining process, where politicians, bureaucrats, voters and organised interest groups attempt to maximise individual welfare (Dixit 1996: 8ff.; Erlei et al. 1999: 323f.; Tullock 2008: 723; McCormick and Tollison 1981; see Sect. 3.5.5 for a more detailed discussion). In the political process, two major types of government failure can arise (Gawel 1995: 31ff.; Helm 2010: 185f.): policy makers can fail to optimally address market failures because of the political rationale inherent in the voting system, or because policies are captured by rent-seeking interest groups.

First of all, political priorities and policies are not chosen to ensure an efficient functioning of market processes and Pareto-optimal welfare outcomes, but with the aim of maximising voter support and winning elections. For this purpose, a rational strategy can be to not focus on one policy aim and find a cost-effective means of addressing it, but to present an instrument or policy package which is intended to address several aims at once (cf. Gawel 1995: 21). For instance, only few voters might have a strong preference for cost-effective GHG mitigation in itself, but combining GHG mitigation with green growth, green jobs and improved security of energy supply could prove to be a strategy for gaining political majorities. In particular, a combination of efficiency-based and distributive aims in policies can prove attractive: one example is the design of environmental tax reforms in several EU member states, where revenues from taxes on energy carriers are used to reduce the costs of labour (e.g. by lowering social security contributions) in order to stimulate employment (cf. Helm 2010: 188; Fujiwara et al. 2006: 6). Gearing aims and policies towards maximising voter support and gaining political majorities may result in outcomes which are not efficient from an economic viewpoint, but it does reflect societal preferences; as such, it can be understood as an expression of the democratic principle (Gawel 1995: 31).

The second source of government failure is rent-seeking by interest groups, which attempt to influence the political decision process to gain political rents. Any regulative intervention in market processes creates rents and burdens—for example, subsidies act as direct rents, taxes create burdens and reduce rents, and permit systems establish new property rights (Helm 2010: 186). In competing for rents, small and comparatively homogeneous interest groups have an advantage compared to large groups with diffuse interests, because costs of organisation are lower and free-riding can be more effectively prevented (Olson 1965; Becker 1983; Orchard and Stretton 1997: 412f.; Erlei et al. 1999: 350ff.). Interest groups can make strategic use of information asymmetries to influence political decision making in their favour (Helm 2010: 187), e.g. by over- or understating GHG mitigation costs, depending on their interests. Moreover, political bargaining power can be used to organise resistance against unfavourable policy decisions; for example, to avoid regulatory burdens, GHG emitters may threaten to relocate production to regions with less stringent GHG mitigation targets. The effects of rent seeking can be observed in the adoption and design of the EU-ETS, for instance (Helm 2010: 189; Gawel et al. 2014): other than taxes, the emissions trading scheme creates an income effect for participating emitters who can sell surplus permits, in particular if emission allowances are initially allocated free of charge. But also, there is high political resistance to changes which affect existing rents, such as those arising from direct and indirect subsidies for fossil fuels and nuclear power (Gawel and Lehmann 2011: 26; Köder et al. 2014).

For bioenergy policy this implies that allocation decisions are taken in a regulatory framework which is shaped by past and present competition for rents by interest groups. In the energy sector, fossil fuel and nuclear-based incumbents have been very successful in gaining such rents, which continue to distort competition with renewable energies as innovative market entrants (Gawel and Lehmann 2011: 26). On the other hand, introducing subsidies for renewable energy sources is likely to garner much higher political support than increasing the stringency of emissions caps in the EU-ETS or implementing emissions taxes, because new rents are created and costs of the scheme are borne by the public, i.e. energy consumers or tax payers, with diffuse interests.

2.4 Empirical Evidence for Government Failure in German and European Bioenergy Policy

The preceding discussion of potential sources of government failure gives rise to the question whether evidence for such failure can be found in German and European bioenergy policy making. This section provides exemplary evidence for cases where conflicting policy aims, information problems, transaction costs, multilevel governance problems and conflicts between political and economic rationality have stood in the way of an efficient correction of market failures.

Conflicting aims have been identified as a major source of government failure in German bioenergy policy. Economists strongly criticise that interventions on behalf of bioenergy are not aligned with GHG mitigation as a priority efficiency rationale, but are intended to address a range of policy aims, and thus fail to make cost-effective contributions to any of them (cf. Henke and Klepper 2006; WBA 2007: 175ff.; Kopmann et al. 2009; Isermeyer and Zimmer 2006). Strategic policy documents like the National Biomass Action Plan (BMU and BMELV 2009a) do not undertake a prioritisation of aims, and fail to provide a transparent balancing of trade-offs. In practice, distributive rationales such as rural value creation play an important role—after all, the very beginnings of European and German bioenergy policies where strongly influenced by policy makers' desire to create additional outlets for agricultural products and provide income opportunities on set-aside land (cf. Londo and Deurwaarder 2007). The use of individual policies to address several efficiency-based and distributive aims at once follows political rationality considerations—it reflects vote maximising behaviour as well as the influence of interest groups, such as lobbying organisations of agricultural producers.

Also, the effects of uncertainty and ignorance as forms of *incomplete knowledge* can be observed clearly in German bioenergy policy. For example, although scientists (Thrän and Pfeiffer 2015; Majer et al. 2013; Thrän et al. 2011a) and policy makers (Federal Government of Germany 2013: 39; BMWi and BMU 2010: 10) alike acknowledge the necessity of setting a strategic focus and clear GHG mitigation criteria for the energetic use of limited biomass resources, an explicit and well-founded focus has not yet been forthcoming. However, making decisions about strategic prioritisations between different sectoral biomass uses and bioenergy pathways is complicated by uncertainties about GHG mitigation potentials and costs, the scope of dynamic cost reductions and potential improvements in GHG balances, and the development of technological alternatives to bioenergy. Also, balancing trade-offs between bioenergy's contributions to different aims is complicated by uncertainties about the extent of external costs and benefits. In all these cases, incomplete information on the side of policy makers can be used by interest groups to argue for or against the political support of certain bioenergy applications. Another example of government failure in the face of incomplete knowledge is the ILUC debate, where uncertainty about the extent of ILUC impacts of bioenergy policies and associated GHG emissions has contributed to stalling decisions about policy responses (Gawel and Ludwig 2011; Di Lucia et al. 2012).

However, addressing ILUC is also a *multi-level governance problem*: Just as GHG mitigation in general, reducing GHG emissions and biodiversity losses from land use changes is a global problem which ideally requires a global solution (cf. Gallagher 2008: 11; WBGU 2008: 320; Scarlat and Dallemand 2011; Frank et al. 2013). National or regional approaches, such as sustainability certification, but also regional emissions trading schemes, remain subject to leakage problems, i.e. GHG emissions or land use changes are displaced to regions that are not subject to these regulations. Existing approaches such as the EU-ETS or the EU Renewable Energy Directive's sustainability standards are limited to a regional scope, while global systems remain out of reach; in explaining this, transaction costs of negotiating, implementing and enforcing a global system play an important role, in the same way as resistance against surrendering political responsibilities to higher governance levels (cf. Sect. 2.3.3). The latter effect can also be observed in EU member states' energy policies: if RES expansion is supported as a means of improving the security of energy supply, it would be cost-effective to understand security of supply in a European perspective and expand RES production wherever it is cheapest (Söderholm 2008; Unteutsch and Lindenberger 2014). However, the perspective of an integrated European approach clashes with member states' sovereignty over their energy policies, which include national targets and strategic decisions concerning the energy mix (Strunz et al. 2014a: 247, b: 13).

Transaction costs of regulation, meanwhile, place not only constraints on optimising the choice of governance level, but also on the choice and design of instruments intended to address market failures. An example is the EU-ETS with its limited sectoral scope—focussing mainly on CO_2 emissions from major point sources and aviation (DG CLIMA 2014, see Sect. 4.2.2.1) reduces transaction costs compared to a more comprehensive coverage of GHG emissions, but prevents a truly cost-effective allocation of mitigation efforts (cf. Sect. 3.1.1). Moreover, internalisation levels are likely to remain below what would be economically efficient, because they are politically negotiated—a more comprehensive internalisation of external costs, however, would give rise to significant political transaction costs due to lobbying activities (Gawel et al. 2014; Gawel and Lehmann 2011: 26).

Consequently, conflicts between political and economic rationality can provide effective explanations for deviations between economic policy recommendations and the existing design of German and EU bioenergy policy (see Sect. 3.1.4). This applies not only to the system of policy aims, but also instrument choice and design. The EU-ETS with its various concessions to political rationality (Lehmann and Gawel 2013: 600; Gawel et al. 2014) and energy taxes with far-reaching exemptions and concessions (Gawel and Purkus 2015) are examples of market-based instruments which address market failures, at best, only partially. Instead of increasing the costs of fossil fuels, support for low carbon technologies in the energy sector predominantly takes the form of technology-specific subsidies, for example, in the form of the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) in the electricity sector, the biofuel quota in the transport sector, or the Market Incentive Programme (Marktanreizprogramm, MAP) in the heating sector (see Sect. 4.2). Biofuel quotas and earlier tax incentives for biofuels, but also the EEG, have attracted criticism for supporting bioenergy technologies with high GHG mitigation costs (Frondel and Peters 2007; Henke and Klepper 2006; Isermeyer and Zimmer 2006; Kopmann et al. 2009; WBA 2007: 175ff., 2011; SRU 2007: 88ff.). Political rationality considerations imply that when support instruments are revised, decisions about technology-specific subsidies are not taken with regard to GHG mitigation costs and learning curve potentials alone, but that they are influenced by industry lobby groups which can make use of asymmetric information, thus contributing to inefficiencies (Helm 2010). On the other hand, competition between renewable energies and fossil fuel and nuclear incumbent technologies remains distorted by the availability of significant subsidies for the latter (Gawel and Lehmann 2011: 26; Köder et al. 2014).

In combination with the analysis undertaken in Sect. 2.2.3, these observations provide clear theoretical and empirical evidence for both market failures and government failures in the governance of bioenergy allocation decisions. Notably, it is not only market failures which interact with each other, but also different sources of government failure. As shown by these examples of government failures in German and European bioenergy policies, political rationality considerations exhibit particularly strong interactions with other sources of government failure, and can further decrease the efficiency of outcomes in the presence of conflicting policy aims, information problems, transaction cost constraints or multi-level governance problems.

2.5 Summary

Bioenergy use can be described as a complex problem of allocation, with economic, environmental and social impacts resulting from the interaction of numerous allocation decisions along heterogeneous and transregional value chains. Central normative demands on bioenergy allocation are that it should be efficient and sustainable, but these terms require a more precise definition. Given the unfeasibly high information requirements of achieving a Pareto-efficient, welfare-optimal allocation, efficiency is understood here as the cost-effective implementation of politically defined aims; whereas in order to be sustainable, bioenergy allocation must not compromise the conservation of critical natural capital and people's opportunities. However, information problems impose severe difficulties on a cost-effective policy implementation and on the definition of secure sustainability guard rails; in addition, it cannot be assumed that politically determined policy aims are an expression of welfare maximisation or that they are consistent with sustainability requirements. When assessing policy interventions in allocation decisions, it is therefore useful to define requirements for a rational bioenergy policy which takes into account the constraints imposed by imperfect information and political feasibility. Besides requirements pertaining to the rational setting of aims, the alignment of aims and measures, and the rational choice of allocation mechanisms and instruments, this perspective highlights the importance of dynamic incentives when striving for sustainability and efficiency.

Along the bioenergy value chain, three overarching categories of allocative problems can be distinguished; these pertain to the steering of biomass flows and technology choices, the setting of incentives for dynamic efficiency and innovation, and the steering of location choices and sourcing decisions. In principle, bioenergy is a marketable good, allowing for a use of the market in coordinating allocation decisions. In a perfectly competitive market, the price mechanism would bring about a welfare-optimal solution to the allocative problems of bioenergy use. However, several market failures arise, causing the level of bioenergy use to be lower than socially optimal, and also a distortion of resource allocation between different bioenergy pathways. Namely, the market mechanism fails to provide an efficient bioenergy allocation due to environmental externalities, security of energy supply externalities, knowledge and learning externalities which affect technology choices and innovation incentives, and market power in the energy market. Moreover, overcoming imperfect information and using the market mechanism is costly—transaction costs arise in the search for information, bargaining, decision making, and during the monitoring and enforcement of contracts, causing inefficient allocative outcomes to be the norm. Specifically, they also impose barriers on market adjustment processes, giving rise to path dependencies and other dynamic market failures. Lastly, even if an efficient outcome could be achieved, there would be no guarantee that it would satisfy the requirements of sustainability.

Meanwhile, comparing inefficient market outcomes with a situation in which ideal policy interventions re-establish a welfare optimum gives rise to what Demsetz (1969) described as the nirvana approach. Just like market transactions, policy interventions are subject to information problems and transaction costs, and are shaped by political rationality rather than disinterested efficiency considerations. Information problems are particularly relevant, because many decision problems that policy makers face when intervening in bioenergy allocation bear characteristics of uncertainty (i.e. it is not feasible to assign probabilities to outcomes of policy interventions) and ignorance (i.e. it is not even feasible to define precise outcomes of policy interventions, let alone probabilities). As policy decisions affect the entire value chain, costs of erroneous decisions can be high, but so can the costs of not intervening in market processes. At the same time, the far-reaching consequences and coercive nature of policy decisions imply higher levels of information, negotiation, monitoring and enforcement costs than is the case with market transactions.

Moreover, government failure can arise from not establishing a consistent system of policy aims, which is key among the economic requirements for a rational setting of policy aims. If conflicts between the aims of bioenergy policy are not addressed through prioritisation, a cost-effective policy implementation becomes virtually impossible given the heterogeneous nature of pathways. Among other factors, the multi-level governance nature of bioenergy policy can complicate such a prioritisation, while also implying further problems concerning the institutional design of the governance framework, its coordination and legitimation.

As a result of these regulative challenges, it seems all too easy to replace market failures by government failures when intervening in bioenergy value chains. And indeed, the German case shows that besides theoretical evidence, there is also clear empirical evidence for both market and government failures. Consequently, it is necessary to analyse what kind of institutional arrangements between markets and regulation are likely to perform most successfully in finding a rational solution for the allocative problems of bioenergy use (see Fig. 2.2).

The next chapter examines the contribution of different economic approaches, in particular new institutional economics and related theories, towards answering this question, putting special emphasis on how different institutional settings perform under uncertainty about central variables of decision making. While multi-level governance theories can also be fruitfully applied to the bioenergy context (e.g. Di Lucia 2010), the focus shall in the following be on the European and particularly the German national governance level as a case study, in order to reduce the complexity of the analysis; nonetheless, the multi-level governance context of decision making needs to be kept in mind.

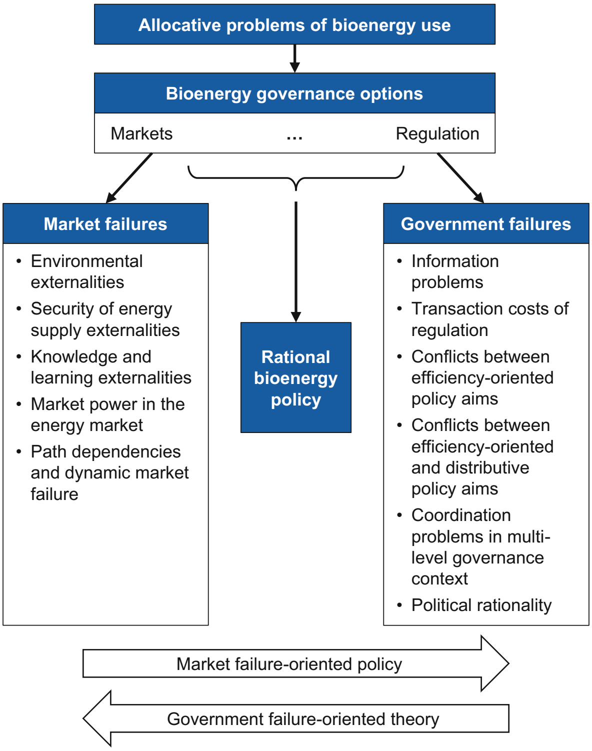

Fig. 2.2 Research framework for a rational bioenergy policy between market failures and government failures

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Chapter 3
Implications of Economic Theory for Bioenergy Policy Design

With the allocative and regulative challenges of bioenergy use outlined (see Chap. 2), this chapter's task is to develop the theoretical basis for a rational bioenergy policy. As discussed in Sect. 2.1.3, the defining characteristic of such a rational bioenergy policy is that it strives for efficiency and sustainability under the constraints imposed by multiple interacting market failures and various sources of government failures (cf. Fig. 2.2), while acknowledging the likely non-optimality of outcomes.

Given the various allocative and regulative problems involved in bioenergy policy making, there is no single theoretical approach which covers all relevant aspects. Rather, a number of theories promise important insights. The following economic theories have been identified as especially relevant to the problems of bioenergy policy making:

1. The *neoclassical economics* approach to target setting and instrument choice under perfect information as well as under uncertainty (Sect. 3.1);
2. The *theory of second-best,* which focuses on the handling of multiple market failures and other constraints on optimal policy design (Sect. 3.2);
3. *Information economics* contributions which examine the implications of incomplete knowledge for policy decision making (Sect. 3.3);
4. The *economic theory of order,* which examines more closely the constitutive lack of knowledge that policy makers face, drawing implications for the adequacy of structural or process policy measures (Sect. 3.4);
5. *New institutional economics,* which explores the consequences of imperfect information, positive transaction costs and self-interested policy makers—within this theory family, the approaches of transaction cost economics, principal-agent theory, the theory of institutional change, and public choice theory appear particularly relevant (Sect. 3.5);
6. *Ecological economics,* which focuses on the design of sustainable economics systems while taking potential sources of government failure into account (Sect. 3.6).

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While neoclassical economics tends to focus on the optimal correction of individual market failures, theoretical approaches such as the theory of economic order or public choice theory (Sect. 3.5.5) place a stronger emphasis on sources of government failures (cf. Fig. 2.2). Transaction cost economics is an example of a theory which takes a more balanced view, allowing for an analysis of the respective advantages that hierarchical, market-based, or hybrid governance options between markets and hierarchies may have when steering specific allocation decisions (see Sect. 3.5.2). The challenge therefore lies in bringing different strands of theories together to develop an analytical framework which makes it possible to derive bioenergy policy recommendations which are close to political realities. At the same time, such a framework should provide a stronger normative orientation for structured policy recommendations than the incremental improvements associated with a "muddling through" approach to policy making (cf. Lindblom 1959, 1979; see Sect. 1.2).

To identify the relevant theoretical elements of such a framework, this chapter proceeds as follows. For each theory, a short introduction of basic assumptions is complemented by a closer examination of selected aspects which promise to be of particular relevance to bioenergy policy making. This is followed by a discussion of the implications that theoretical insights have for the formulation of economic bioenergy policy advice. In doing so, neoclassical recommendations are used as a "baseline", against which contributions from other theories can be compared. To set up this baseline, Sect. 3.1 encompasses a literature review of neoclassical theory-based critiques of German and European bioenergy policy (Sect. 3.1.4), as well as a discussion of the limits of neoclassical policy recommendations, when considered in the light of the diverse allocative and regulative challenges identified in Chap. 2 (Sect. 3.1.5).

Naturally, the list of theories considered is not exhaustive. However, the named approaches offer a wealth of relevant insights and recommendations, making a limitation of the analysis to a selection of theories necessary. In particular, contributions from other social sciences disciplines, such as sociological theories about decision making under uncertainty and ignorance, are not examined, even though they hold promise in terms of their applicability to the problems of bioenergy policy design [for a discussion of relevant sociological approaches see Bleicher (2011)]. Furthermore, the aim of this chapter is not to give an exhaustive overview of the considered theories, but to present a problem-oriented examination of implications relevant to bioenergy policy design. In line with the overall focus of this work, the emphasis is placed on new institutional economics approaches.

3.1 The Neoclassical Approach: Correcting for Market Failures

German and European bioenergy policy is assessed very critically by neoclassical economists (Henke and Klepper 2006; WBA 2007: 175ff.; Frondel and Peters 2007; Kopmann et al. 2009; Isermeyer and Zimmer 2006; Hermeling and Wölfing 2011: 81f.). As discussed in greater detail in Sect. 3.1.4, bioenergy policy's lack of alignment with a cost-effective GHG mitigation strategy is a central point of critique—policy recommendations tend to focus on GHG externalities as the relevant market failure to be addressed, and on cost-effective instrument choices for their internalisation.

Neoclassical theory, however, allows for a more differentiated picture: establishing an efficient bioenergy allocation requires a correction of *all* relevant market failures. The focus of interest of policy analysis must therefore be defined more broadly, encompassing the design of interventions which internalise not only GHG externalities, but also other environmental externalities of energy production, security of supply externalities and knowledge and learning externalities (cf. Sect. 2.2.3). Also, in order to restore market functionality, neoclassical economics acknowledges that interventions may be necessary to constrain market power (see e.g. Fritsch 2011). Once prices reflect all relevant externalities and perfect competition is established in the energy market, the price mechanism would bring about an optimal level of bioenergy use and an optimal overall allocation of biomass resources. From a neoclassical perspective, the problem of bioenergy policy is therefore not one of designing dedicated bioenergy support, but of finding first-best, i.e. Pareto-optimal measures to address various market failures.

Indeed, according to Tinbergen's (1952) widely accepted findings, attempting to solve several independent aims, such as GHG mitigation, security of supply and promotion of innovation through a smaller number of instruments—e.g. support for renewable energy technologies—is bound to produce inefficient solutions (cf. Fischer 2008; Kalkuhl et al. 2013). Instead, Tinbergen found that solving a certain number of policy aims and associated targets requires at least an equal number of instruments, which must moreover be linearly independent, i.e. able to generate separate effects (Tinbergen 1952; Hughes Hallett 1989). Based on this rule, economic policy analysis frequently focuses on identifying singular policies able to optimally address individual aims (cf. Lehmann 2012: 72). Also, in neoclassical welfare economics, the correction of market failures is the only rationale for government interventions in market processes that is acknowledged (Streit 2005: 21f.; Luckenbach 2000: 135f.; Fritsch 2011: 72ff.). Policy makers may wish to change the distributive outcome of market processes, but the Pareto criterion for a welfare-optimal allocation does not allow for any conclusions as to when a distributive intervention would be economically justified; for this, normative value judgements are required (Streit 2005: 22). Indeed, distributive interventions tend to be viewed as detrimental to allocative efficiency (Luckenbach 2000: 188).

With regard to the major aims of bioenergy policy discussed in Sect. 2.3.1, a neoclassical policy analysis would therefore focus on aims based on the efficiency rationale, i.e. climate change mitigation, the protection of the environment, technological development and security of energy supply. Agricultural and industrial policy aims which are based on a distributive rationale would not be sufficient to justify interventions in market processes. If policy makers wished to correct the distributive outcome of market processes, the intervention of choice would be income transfers which minimise the distortive impact on allocation decisions; better still would be changes in market framework conditions that allow for higher market incomes, such as improvements in the economy's international competitiveness (Luckenbach 2000: 176ff.). Changing the relative prices of goods in order to increase income in certain sectors, on the other hand, would substantially reduce the efficiency of the market allocation mechanism, and is therefore not to be recommended.

The following sections outline neoclassical theory recommendations for addressing externalities, distinguishing between the cases of perfect information (Sect. 3.1.1) and imperfect information (Sect. 3.1.2). The focus on externalities is chosen because of the relevance of GHG externalities, other environmental externalities, security of supply externalities and knowledge and learning externalities in distorting bioenergy allocation decisions (cf. Sect. 2.2.3). For addressing market power in the energy sector, a first-best approach would consist in interventions which establish competitive framework conditions, for example, through market liberalisation (for a discussion of liberalisation strategies see e.g. Ringel 2003; Domanico 2007; Fritsch 2011: 195ff.). In Sect. 3.1.3, implications of neoclassical theory for bioenergy policy are derived; in Sect. 3.1.4, these are contrasted with actual bioenergy policy recommendations that have been put forward by neoclassical economists. Section 3.1.5 discusses limits of the neoclassical approach and neoclassical policy recommendations.

3.1.1 Target Setting and Instrument Choice Under Perfect Information

In order to make their achievement measureable, policy objectives need to be operationalised through targets (Jakubowski et al. 1997: 48; Streit 2005: 274ff.). If perfect information is assumed, neoclassical theory offers recommendations about what the optimal degree of a regulative intervention should be when internalising an externality. This makes it possible to derive quantitative targets, which correspond to, for example, welfare-optimal levels of GHG emission reductions or biodiversity conservation. Moreover, under perfect information, instruments can be identified that bring about Pareto-optimal outcomes efficiently and effectively. Commonly, command-and-control instruments and the market-based options of taxes, subsidies and tradable permits are considered in developing instrument recommendations, while the ‘soft’ instrumental option of moral suasion is accorded a merely supportive role due to its non-binding character (Michaelis 1996: 32f.). The following section outlines neoclassical theory recommendations for target setting and instrument choice under perfect information.

According to Pigou (1920), a Pareto optimum can be achieved by increasing private costs to social costs in the case of a negative externality, or private value to social value in case of a positive externality. The optimal level of abating negative externalities, such as those associated with GHG emissions, is found when marginal abatement costs equal marginal social damage costs, whose avoidance constitutes the marginal benefits of abatement (see Sect. 2.1.1). For positive externalities, which arise in relation to the provision of public goods such as knowledge, the optimum is characterised by the equality of the marginal costs of generating the positive externality and its marginal social benefits. If relevant costs and benefits are known to policy makers, market prices can be optimally corrected by introducing a tax which is set equal to the marginal social damage of an activity associated with negative externalities, or, in the case of positive externalities, a subsidy equal to the marginal social benefit of the activity in question (Baumol and Oates 1988: 21ff.).

While in principle, negative externalities could also be internalised through a subsidy, e.g. through subsidising GHG emission abatement instead of taxing emissions, this is not regarded as an efficient solution. Internalisation costs are borne by the general public instead of the producers and consumers of the good associated with the externality; as a result, prices and allocation decisions remain distorted (Michaelis 1996: 29). More specifically, subsidies can cause emitters to increase initial emissions in order to qualify for higher subsidies, while also encouraging excessive entry into the polluting industry and reducing incentives for innovation compared to taxes (Baumol and Oates 1988: 211ff.). Consequently, subsidies are only a first-best solution for internalising positive externalities. However, due to the reciprocal nature of externalities (Coase 1960), it may not always be clear what counts as a positive and what as a negative externality—especially in the environmental context, such definition problems are common (Thöne 2000). For example, it can be debated whether agri-environment measures aimed at increasing biodiversity generate a positive externality, thus qualifying for a subsidy, or whether they merely reduce the negative externalities of conventional agricultural production. As Coase (1960) pointed out, the distinction depends on the allocation of property rights—if the society collectively owns the right to a high degree of biodiversity, activities detrimental to it cause a negative externality and should be taxed in accordance with the polluter pays principle; whereas if farmers own the right to deplete biodiversity on their private land, compensation is called for if they abstain from making use of that right. Accordingly, the choice between taxes and subsidies requires a clear definition of property rights, but all too often property rights are only created in actuality through the selection of one over the other (Thöne 2000).

Besides the efficient setting of targets, i.e. optimal levels of GHG emissions and environmental quality, security of supply, and knowledge and learning generation, the allocation of abatement costs or public good provision costs among individual producers is of interest. The allocation is efficient, if the costs of abating an additional unit of emissions or conversely, the costs of providing an additional unit of the public good, are the same for all producers of the externality in question. If that is the case, the total costs of achieving the target are minimised (Baumol and Oates 1988: 163ff.). Pigouvian taxes and subsidies have this property, as the tax or subsidy rate is the same for all producers, who are free to choose abatement and production levels which are optimal based on their individual cost structures. Under certainty, tradable permits are equivalent to taxes—if the quantity restriction on the total number of permits available is set at an optimal level, the permit price resulting from trade will equal the Pigouvian tax (Baumol and Oates 1988: 58ff.).

At the same time, if policy makers had perfect information on producers' cost structures and transaction costs were zero, they could also achieve an efficient allocation through command-and-control instruments, e.g. by individually allocating emission standards to producers. Naturally, these assumptions are rather abstract. In the next section, the implications of imperfect information for instrument choice are explored.

Meanwhile, to achieve an efficient allocation, targets and instruments also need to be aligned with the scale on which an externality occurs, i.e. whether its impacts are local, regional or global (cf. Endres 2013: 259). Benefits of GHG mitigation occur globally, no matter where emission reductions take place. Therefore, it would be most efficient if GHG mitigation targets and a tax on emissions or an emissions trading scheme were implemented on a global level, as this would allow GHG mitigation to be realised where it is cheapest, minimising overall costs (Böhringer and Rosendahl 2010a; Stavins 1997).[1] Moreover, mitigation contributions of individual countries and regions to the overall problem of climate change would remain small (Böhringer and Alexeeva-Talebi 2011; Hoel 1991). Indeed, unilateral targets and instruments would lead to inefficient outcomes, because some regions would abate emissions at unnecessarily high costs, while others would have incentives to free-ride on their efforts (Stavins 1997).

Also, leakage of emissions may occur between regions that have stringent and less stringent emission reduction targets: this can be caused by trade, when emission-intensive industries in non-abating regions gain competitive advantages compared to producers in abating regions; but also, reductions in demand for fossil fuels in the abating regions would cause world market prices to drop, increasing consumption and emissions in other regions (Böhringer and Alexeeva-Talebi 2011; Hoel 1991; Felder and Rutherford 1993). Leakage can, however, be limited through technological spillover effects—that is, if regions with less stringent emission reduction targets can benefit from positive knowledge externalities associated with investments in GHG mitigation technologies in regions with more ambitious

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[1] Of course, the institutional constraints on the implementation of a global instrument would be massive—as an instrumental alternative for cost-effective GHG mitigation, regional or national emissions taxes could be aligned with a globally negotiated tax rate; whereas regional emissions trading systems could be linked, so that emission permits could be traded across regional systems (Stavins 1997).

targets (Barker et al. 2007). Also, according to the Porter hypothesis, industries in regions with ambitious environmental regulation may actually gain competitive advantages, because of induced investments in energy efficient production processes and innovation (Porter and van der Linde 1995)—however, empirical studies find this holds true only under certain conditions and for certain industry sectors, and that the design of unilateral policy measures plays an important role (Wagner 2004; Ekins and Salmons 2007; Ambec et al. 2013).

3.1.2 Target Setting and Instrument Choice Under Imperfect Information[2]

As discussed in Sect. 2.1.1, neoclassical environmental economists widely acknowledge imperfect information regarding the marginal costs (MC) and marginal benefits (MB) of abating damages to society or providing public goods; instead of seeking optimal solutions, the focus tends to be on minimising the costs of achieving politically set targets (Baumol and Oates 1988: 159). Whereas uncertainty about marginal benefits primarily affects the optimality of the chosen target, uncertainty about marginal costs, which are typically known to individual producers but not to policy makers, has important implications for instrument choice (Baumol and Oates 1988: 60). For the sake of simplicity, the following explanation focuses on the mitigation of negative GHG externalities.

In the absence of perfect knowledge about the individual MC of implementing GHG emission reductions, command-and-control instruments usually involve the setting of uniform abatement levels. Individual producers end up abating either more or less than optimal, so that command-and-control instruments fail to achieve cost-effectiveness (Michaelis 1996: 42ff.). Performance in terms of dynamic efficiency, which involves a decrease of emissions reduction costs over time, is also poor—once abatement standards are met, producers lack incentives for further emission reductions, whereas technology standards in particular inhibit decentralised searches for least-cost abatement options and innovation (Michaelis 1996: 48ff.). Moreover, the effectiveness of command-and-control instruments in achieving an aggregate target is only ensured if the total number of producers (in the case of absolute emission standards) or the total level of output (in the case of relative emission standards) remains constant, or if both aggregate and individual emissions are to be reduced to zero (Michaelis 1996: 36ff.).

Leaving the choice of abatement level to producers, the market-based instruments of taxes and tradable permits both meet the criterion of cost-effectiveness. Moreover, they perform better than command-and-control instruments in setting incentives for dynamic efficiency, because emitters have continuous incentives to invest in measures which reduce their abatement costs; by implementing further

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[2] Some parts of Sect. 3.1.2 have been used in Purkus et al. (2015).

emission reductions, emitters can reduce tax payments or the amount of required emission permits, allowing for spare permits to be sold in tradable permit markets (Michaelis 1996: 48ff.).

Nonetheless, since Weitzman (1974) it is well established that under uncertainty, price and quantity instruments are not equivalent in their effects. Literature based on Weitzman's findings highlights the importance of cost uncertainty in identifying the efficient instrument choice (Adar and Griffin 1976; Fishelson 1976; Baumol and Oates 1988: 60ff.). At the same time, it is usually assumed that benefit uncertainty does not affect the choice between price and quantity instruments; if policy makers make an error in assessing the MB curve's position, social costs are the same for both instrument types. Insights have been applied to the choice between tradable permit schemes and taxes as climate policy instruments (Pizer 1999; Newell and Pizer 2003), as well as to the choice between price and quantity instruments in renewable energy policy (Menanteau et al. 2003; Finon and Perez 2007)—however, the justification for separate renewable energy support instruments follows from second-best considerations (see Sect. 3.2). In the following, implications of the price vs. quantity literature are demonstrated for the case of addressing GHG externalities.

Under uncertainty about the aggregated MC curve of GHG emission reductions, quantity instruments such as a GHG emissions trading scheme assure that a given target is achieved, but the costs of doing so remain uncertain: the price of tradable emission permits is determined by supply and demand on the emissions trading market. Price instruments, such as emissions taxes, offer a higher degree of cost control; the most expensive abatement technology used will be the one whose implementation is just about profitable under the given price incentive. On the other hand, it is uncertain whether the target will be reached—an effective achievement of targets would require repetitive adjustments of tax rates in a trial-and-error process, which would seldom be feasible and increase policy uncertainty for investors (Menanteau et al. 2003: 804).

As Weitzman (1974) showed, the advantages of adopting price or quantity instruments under uncertainty depend on the relative slopes of marginal cost and marginal benefit curves. If the MC curve is comparatively steep, price instruments will achieve a better welfare result; whereas if the MC curve's slope is comparatively gentle, a quantity instrument would be the favoured solution. In the case of GHG mitigation, it is argued that the MB curve is relatively flat, at least in the short- to mid-term, favouring a price instrument (Pizer 1999; Newell and Pizer 2003); in the long run, however, a quantitative constraint may be called for (Stern 2006: 312ff.). Furthermore, instrument recommendations may change if cost and benefit uncertainties are correlated—Stavins (1996) emphasises that benefit uncertainty does matter in such cases. While a positive correlation increases the advantages of quantity instruments, a negative correlation favours price instruments.

3.1.3 Implications of Neoclassical Theory for Bioenergy Policy Advice

In sum, neoclassical theory recommends the correction of all relevant market failures which distort bioenergy allocation decisions. The selection of which market failures are considered relevant also determines which policy aims are acknowledged in the economic analysis. For aims which are directed at improving the efficiency of market processes, it is necessary to define preferably quantitative and measurable targets. Under imperfect information, these need to be set politically, given that optimal mitigation levels are not known. This follows from the pricing and standards approach's "efficiency without optimality" logic (Baumol and Oates 1988: 159, see Sect. 2.1.1). In contrast, targets for aims based on other rationales, such as a distributive reasoning, can be neglected in the analysis.

In Sect. 2.2.3, the market mechanism's limits in guiding bioenergy allocation decisions have been introduced. To what extent these limits are considered by neoclassical theory, and what first-best instrument recommendations are typically put forward in the literature is discussed in the following.

The importance of GHG externalities in distorting allocation decisions in the energy sector is well established in economic literature (e.g. Nordhaus 1993; Pearce 1996; Ekins and Barker 2001; Stern 2006). For cost-effective GHG mitigation, the use of taxes or tradable permit schemes is recommended—tradable permit schemes perform better than taxes in terms of their effectiveness for achieving a given target, while taxes imply a higher degree of control over abatement costs (see Sect. 3.1.2). In the case of bioenergy, however, it is not only GHG emissions from the combustion of fossil fuels that are relevant, but also emissions from the land use sector, which significantly influence GHG balances (cf. Fargione et al. 2008; Popp et al. 2011; Lange 2011). For an efficient allocation of mitigation efforts, neoclassical theory suggests the implementation of a common carbon price for *all* emitters, including all three energy sectors and the land use sector (cf. Kopmann et al. 2009; De Cara and Vermont 2011; Murray et al. 2009; Kindermann et al. 2008). As a GHG mitigation option, bioenergy use would therefore not only compete with other options in the energy sector, but also with alternative land use options such as afforestation and carbon sequestration in plants. Moreover, given the global nature of the externality, a global approach to setting and implementing mitigation targets is recommended (Böhringer and Rosendahl 2010a; Stavins 1997).

Other environmental externalities of energy production and use (see Sect. 2.2.3.1) can likewise be depicted in a neoclassical theory framework. For addressing the emission of pollutants in land use and energy production, neoclassical theory generally recommends the use of taxes or tradable permit schemes, an analogue to the internalisation of GHG emissions (Baumol and Oates 1988:163ff. and 177ff.). For positive biodiversity externalities, the use of subsidies has been recommended, for example, through payment for ecosystem services schemes (Robert and Stenger 2013; see Ikkatai 2013 for an overview). Of course, in a first-best scenario externalities should not only be internalised if they arise from the use of fossil fuels or nuclear power, but also if they are caused by the use of bioenergy and other RES.

Regarding security of supply externalities, there is some debate in the economic literature about how exactly they are to be defined and whether markets really fail to hedge supply risks (Abbott 2001; Metcalf 2014). With regard to negative externalities associated with fossil fuel imports from geopolitically instable regions, it can be argued that markets do not provide individual energy producers with sufficient incentives to diversify supply, because profits depend on their resource supply's diversity in relation to competitors (Rader and Norgaard 1996: 40; Springmann 2005: 3). If price shocks in resource supply affect all competitors in a similar fashion, producers do not risk losing their market share; moreover, energy producers may be able to pass on increased resource costs to consumers, if the price elasticity of demand is low (Rader and Norgaard 1996: 40). Even if this argument for the presence of an externality is accepted, the task of identifying an optimal instrument for its internalisation is still not straightforward—taxes on fuels with high import dependency might primarily transfer rents from export to import countries, rather than increase the ability to accommodate supply shocks (Metcalf 2014: 161f.). To decrease reliance on insecure imports, instruments directed at reducing overall energy demand (such as a tax on energy consumption) or increasing the diversity of fuels used for energy production might prove more effective (Metcalf 2014).

In the context of electricity markets, there is furthermore a debate about whether markets can provide for a supply which is sufficiently reliable from a social perspective and for an adequate amount of installed capacity (e.g. Cramton and Ockenfels 2012; Oren 2003; Gottstein and Skillings 2012; Lehmann et al. 2015). In the German electricity market, a specific question is whether markets provide sufficient incentives for investments in flexible capacity, which can balance fluctuations in intermittent RES supply (cf. BMWi 2014). However, the expansion of intermittent RES is promoted by government interventions rather than being the result of market mechanisms; from a neoclassical perspective, it is therefore possible to argue that increased costs for ensuring the security of electricity supply arise from a government failure rather than a market failure (Weimann 2008: 110).

Besides GHG externalities, knowledge externalities are another widely acknowledged market failure in neoclassical analyses of energy technology choices (cf. Sijm et al. 2014). For their internalisation, R&D subsidies are the focus of recommendations (Hermeling and Wölfing 2011: 84; Böhringer and Rosendahl 2010b; Frondel et al. 2010). To internalise learning externalities, a separate instrument is required, because they arise not from R&D activities but from learning by doing as a technology's cumulative installed capacity or output increases (see Sect. 2.2.3.3). In the case of innovative RES technologies for electricity generation, recommendations for their internalisation are technology-specific subsidies on either RES electricity generation (Canton and Johannesson Lindén 2010; Fischer and Newell 2008; Kalkuhl et al. 2012; Lehmann 2013); renewable generation capacity installed (van Benthem et al. 2008); investments in renewable generation capacity (Kverndokk and Rosendahl 2007); or the output of RES technology manufacturers (Bläsi and Requate 2010), depending on how learning processes are modelled (see Lehmann and Gawel 2013; Sijm et al. 2014 for an overview).

Market power in energy markets, meanwhile, is regarded as a relevant market failure in gas, mineral oil and electricity markets in particular (Zwart 2009; Bergman 2009; Kverndokk and Rosendahl 2013; for the case of Germany see Bundeskartellamt 2011; Bundesnetzagentur and Bundeskartellamt 2013). To counter it, economic proposals focus on the establishment of competitive framework conditions, for example, through market liberalisation (Ringel 2003; Domanico 2007; Fritsch 2011: 195ff.), network regulation (Vazquez and Hallack 2015) or the integration of several regional or national markets (Bergman 2009: 74ff.).

Market failures which arise from uncertainty, transaction costs, and institutional and technological path dependencies are not in the focus of the standard neoclassical analytical framework—nor are government failures, for that matter (Dixit 1996: 4ff.; see Sect. 3.1.5). The analysis of market failures which arise once these assumptions are abandoned is the domain of new institutional economics (see Sect. 3.5). Also, given the focus on efficiency as a rationale for government interventions, sustainability concerns relating to intra- and intergenerational justice are not addressed.

To sum up, a neoclassical concept for bioenergy policy would envision the implementation of first-best solutions for GHG externalities, other environmental externalities of energy production and land use, knowledge and learning externalities and market power; if and how to undertake efficiency-based interventions to internalise security of supply externalities is somewhat more contentious. Static and dynamic market failures arising from uncertainty, transaction costs, and institutional and technological path dependencies as well as distributive issues are neglected.

Moreover, it is worth stressing that a cost-effective implementation of efficiency-oriented policy aims requires targets and instruments to be defined in a technology-neutral fashion, to allow for an equalisation of emission abatement costs or costs of public good provision across all producers of the externality (see Sect. 3.1.1). For addressing externalities, market-based instruments are generally found to perform better in producing cost-effective and dynamically efficient outcomes than command-and-control instruments. Once price signals were corrected, the market allocation mechanism would determine whether bioenergy technologies could make a cost-effective contribution to efficiency-oriented policy aims. In a first-best scenario, there would therefore be no bioenergy policy or, more generally, renewable energy policy as such; if all relevant market failures were addressed optimally, market forces would bring about the welfare-optimal degree of bioenergy use and other RES deployment.

3.1.4 Critique of German and European Bioenergy Policy by Neoclassical Economists

It is important to discriminate between the basic implications from neoclassical theory outlined in the preceding section, and recommendations for bioenergy policy and wider RES policy that have been put forward by neoclassical economists. Importantly, neoclassical theory highlights that to arrive at an efficient solution to the allocative problems of bioenergy use, all relevant market failures need to be addressed; according to the Tinbergen rule, this requires at least one instrument per market failure and policy target (Tinbergen 1952). Neoclassical policy advice that is voiced in the public debate, however, tends to focus on GHG externalities as the individual market failure that has to be addressed in the context of bioenergy policy; accordingly, GHG mitigation is identified as the sole policy aim that should guide bioenergy policy design (Henke and Klepper 2006; WBA 2007: 175ff.; Kopmann et al. 2009; Isermeyer and Zimmer 2006). It is recommended that any contributions to other aims, most notably security of supply, rural value creation, employment in the bioenergy technology industry, and technological developments, should be considered as co-benefits; their consideration should not distort the integration of bioenergy into an efficient GHG mitigation strategy (ibid.).

Positive externalities associated with increases in the security of energy supply, for instance, are acknowledged as a rationale to intervene in market processes on efficiency grounds; however, the potential contribution of bioenergy to a secure energy supply is generally considered too small and too uncertain in the long run to qualify as a justification for bioenergy support (Henke and Klepper 2006: 11; Isermeyer and Zimmer 2006: 11f.). This is particularly true for the contribution of domestically produced biomass—to reduce reliance on “insecure” energy carriers such as oil and gas, a more efficient approach than domestic self-sufficiency would be an import diversification strategy which expands imports of bioenergy carriers and RES electricity produced at low cost locations (Henke 2005; Henke and Klepper 2006; Isermeyer and Zimmer 2006: 10ff.; WBA 2007: 184). Moreover, it is highlighted that under cost-effectiveness aspects, increases in energy efficiency and absolute reductions of energy consumption are likely to be more favourable means of increasing the security of energy supply than bioenergy use (Hermeling and Wölfing 2011: 81f.); in principle, another cost-effective option would be the increased use of coal instead of gas in electricity production (Böhringer and Rosendahl 2010b: 318).

Meanwhile, the use of bioenergy policy to support rural value creation and employment meets with strong criticism (Hermeling and Wölfing 2011: 82; WBA 2007: 183ff.; Isermeyer and Zimmer 2006; Henke and Klepper 2006). Increasing the prices for bioenergy and biomass inputs as a means of enhancing rural income opportunities would not serve the correction of a market failure, but reflect the distributive rationale for government interventions. Structural problems of the agricultural sector, such as a lack of international competitiveness, would not be adressed—rather, allocation decisions in the biomass production sphere and also the utilisation sphere would be distorted, resulting in efficiency losses. Also, the net rural employment effects of increased biomass production for energetic uses are associated with significant uncertainties, given that to a certain degree, other agricultural production systems and associated jobs would be displaced (Isermeyer and Zimmer 2006; Berndes and Hansson 2007; Nusser et al. 2007).

For promoting technological development and addressing knowledge externalities, contributions by neoclassical economists recommend public R&D support, with the added co-benefit of employment creation in innovative bioenergy technology industries (Frondel and Peters 2007; Isermeyer and Zimmer 2006; WBA 2007: 224; Hermeling and Wölfing 2011: 84). Learning externalities are usually neglected.

Following this assessment, neoclassical contributions to the bioenergy policy debate criticise the diversity of policy aims and lack of prioritisation that has been displayed in German and European bioenergy policy, as well as the resulting policy design, which is assessed as extremely inefficient from a GHG mitigation perspective. First of all, it is emphasised that separate targets and support instruments for RES in the electricity, transport and heating sectors prevent an equalisation of GHG mitigation costs across emitters (Frondel and Peters 2007; Isermeyer and Zimmer 2006; Kopmann et al. 2009; Hermeling and Wölfing 2011: 46). As a result, there would be "too much" mitigation by RES technologies with comparatively high mitigation costs, including bioenergy options, whereas more cost-effective mitigation options like efficiency improvements or a switch from coal to gas remain underutilised. This prevents GHG mitigation targets from being achieved at least costs. Biofuel support, in particular, is singled out as a case of inefficient GHG mitigation, because here, GHG mitigation costs are much higher than could be reasonably expected to emerge from an emissions trading system that equalises abatement costs across emitters (Frondel and Peters 2007; Henke et al. 2003; Henke and Klepper 2006; WBA 2007:177; Kopmann et al. 2009). A further point of criticism is that sectoral, technology-specific support instruments for bioenergy not only lead to an inefficient allocation of GHG mitigation investments, but also distort the allocation of biomass and arable land as scarce resources (WBA 2007: 177; Kopmann et al. 2009).

Furthermore, it is pointed out that the costs of using bioenergy as a GHG mitigation option are further increased by focussing on the domestic production of biomass and bioenergy carriers. This is particularly prevalent in the case of biofuels, which are subject to significant import tariffs (see Sect. 4.2.1.4 for details). To increase cost-effectiveness, economists recommend the abolishment of such tariffs, and the use of international comparative cost advantages through trade (Henke 2005; Henke and Klepper 2006; Klepper 2010; Isermeyer and Zimmer 2006; WBA 2007: 176). Moreover, biofuel imports should be viewed in the context of a global climate policy strategy—as Henke (2005) points out, the costs of achieving global GHG mitigation targets could be reduced if biomass was used directly in export countries, for example, for electricity and heat production, rather than being converted and exported as biofuels.

Based on this critique, neoclassical economists recommend integrating bioenergy policy into a comprehensive emissions trading scheme that allows for open competition (in terms of technology) between mitigation options, using the European Emissions Trading System (EU-ETS) as a starting point (Frondel and Peters 2007; Klepper 2010; WBA 2007: 177f.; Kopmann et al. 2009). To reflect the global nature of GHG externalities, however, the scheme's reach would need to be widened to enable participation by as many countries as possible (Kopmann et al. 2009); at least it should be embedded in a global GHG mitigation strategy (WBA 2007: 218f.). Optimally, a first-best emissions trading scheme should also span all emitting sectors, to achieve an efficient allocation of mitigation efforts (Klepper 2010; Isermeyer and Zimmer 2006; Kopmann et al. 2009). To account for GHG emissions associated with land use changes and agricultural production, this should not only include the energy and industrial sectors, but also the land use sector (Klepper 2010; Kopmann et al. 2009). If the realisation of a sector-spanning instrument turns out to be unfeasible, Hermeling and Wölfing (2011: 83) recommend implementing carbon taxes in sectors which remain outside the emissions trading scheme, which would need to be aligned with competitively determined emission permit prices.

With a comprehensive emissions trading scheme in place, the use of instruments directed at RES support in specific sectors and countries would result in additional costs, but not in additional emission reductions—it would merely cause the price of emission certificates to drop, allowing other emitters to expand their emissions (Böhringer and Rosendahl 2010a, b; Sinn 2008: 176f.; Weimann 2008: 54f.; Weimann 2009).[3] While some policy advisors view the integration of bioenergy policy and RES policy in a sector-spanning emissions trading scheme as something to be achieved in the long term (WBA 2007: 177ff.; SRU 2007: 97f.), others adopt a strong and more direct position against additional targets and support instruments for RES (e.g. Frondel et al. 2010; Frondel and Schmidt 2006; Weimann 2008: 118f.; Weimann 2009; Sinn 2008: 161ff). Even more pronounced is the rejection of technology-specific bioenergy support—if separate targets for RES use exist, then cost-effectiveness considerations lead to recommendations of technology-neutral instruments, which allow targets to be reached with the cheapest RES technologies (Frondel et al. 2013; Monopolkommission 2011; Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung 2011; Acatech 2012; Jägemann 2014).

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[3] See Lehmann and Gawel (2013) for a review of studies which analyse this effect.

3.1.5 Limits of Neoclassical Theory and Neoclassical Policy Advice

The preceding sections have shown an important distinction between implications of neoclassical theory (Sect. 3.1.3), and prominent neoclassical policy recommendations as put forward in the public debate (Sect. 3.1.4). According to neoclassical theory, GHG externalities are not the only relevant market failure in the bioenergy context; these failures should be addressed through market-based, technology-neutral instruments that allow market processes to find the most cost-effective solutions. If market failures remain unaddressed, bioenergy allocation decisions would remain distorted, and the resulting outcome would not be efficient—this would be the case even if GHG externalities were internalised to an optimal degree (cf. Lipsey and Lancaster 1956).

For example, GHG externalities interact with market failures in technology markets. The emissions trading scheme proposed by neoclassical economists, which spans multiple sectors and countries, would result in cost-effective GHG mitigation only from a static perspective. Investments in invention, innovation and the diffusion of innovative GHG mitigation technologies would remain below the socially optimal level, because of the positive knowledge and learning externalities associated with them (see Sect. 2.2.3.3; Jaffe et al. 2005; Newell 2010; Lehmann and Gawel 2013; Sijm et al. 2014 for an overview). If knowledge and learning spillovers are not internalised, innovative technologies would progress down their learning curves more slowly than would be efficient from a dynamic perspective, increasing future costs of emissions abatement. Moreover, knowledge and learning externalities are exacerbated by dynamic market failure (Sect. 2.2.3.6): the energy sector is characterised by strong technological path dependencies, because of the long-lived nature of investments in generation capacity, the competitive advantage that incumbents can achieve by ignoring sunk costs in price setting, and interdependencies between generation capacity and energy system infrastructure, for example (Lehmann et al. 2012; Unruh 2000; Kalkuhl et al. 2012; Neuhoff 2005).

Further interactions arise between GHG externalities and other environmental externalities (see Sect. 2.2.3.1). If market failures relating to biodiversity losses or the emission of pollutants such as sulphur oxides, nitrogen oxides, or ammoniac remain at least partially unaddressed, then price signals from GHG emissions taxes or an emissions trading scheme could result in higher levels of bioenergy use than the welfare-optimal level. Also, if allocation decisions were aligned with GHG mitigation costs alone, distortions between bioenergy pathways with different environmental costs and benefits beyond climate change impacts would remain. Likewise, security of supply externalities are not independent from GHG externalities—for instance, fuel switching from coal to gas would reduce the GHG emission intensity of electricity production (Bruckner et al. 2014: 541), but would increase dependency on a limited number of geopolitically sensitive export countries (see Sect. 2.2.3.2).

These examples show that interactions between unresolved market failures are a political reality, and need to be considered in target setting and instrument design—therefore, policy recommendations which focus on one market failure alone remain of limited practical applicability. In overcoming this constraint, a neoclassical theory-based first-best approach is of limited help—one can demand that a GHG emissions tax or emissions trading scheme is accompanied by first-best solutions for all other relevant market failures, but in practice this is unlikely to be feasible due to a number of constraints. What these constraints are, and how to address this problem, is analysed by the theory of second-best (see Sect. 3.2).

Besides this *lack of consideration of interactions between multiple market failures*, comparing neoclassical theory implications and policy recommendations to the allocative and regulative challenges identified in Chap. 2 shows a number of further shortcomings:

1. *Limited consideration of uncertainty:* Even though uncertainty about the marginal costs and benefits of target implementation is acknowledged, information requirements for instrument choice and design remain high: for example, the relative slopes of MC and MB curves must be known to decide between price and quantity instruments, which in the GHG mitigation case is complicated by the existence of uncertain thresholds in the MB curve (Perman et al. 2003: 256). More fundamentally, putting a price on GHG emissions will only result in a cost-effective contribution of bioenergy to GHG mitigation targets if the actual GHG emission reductions achieved by different bioenergy pathways can be calculated accurately. As Sect. 2.3.2.2 has shown, however, these are subject to large uncertainties, because they depend on (a) what energy sources have been substituted, and (b) numerous allocation decisions taken along value chains (such as decisions about feedstocks, land use or conversion technologies; see Adams et al. 2013 for an overview). Moreover, uncertainties apply also to other externalities associated with bioenergy use, for example, net biodiversity losses due to direct and indirect land use changes. This complicates the balancing of trade-offs between different policy aims.
2. *Neglect of transaction costs:* Transaction costs of instruments are not considered for the implementation, monitoring and enforcement phase nor for the negotiation and decision making phase. However, these costs can be significant for market-based instruments and may, in some cases, make a reassessment of the stated inferiority of command-and-control options necessary (Dixit 1996: 40 ff.; Häder 1997; Gawel 1999; Coggan et al. 2010). For example, the transaction costs for an emissions trading scheme which encompasses the electricity, transport, and heating sectors as well as the land use sector would be considerable. In the transport, heating and land use sectors, the large number of emitters and the small scale of many emission sources drive up the transaction costs associated with calculating and monitoring emissions, as well as the costs of participation in emissions trading. Moreover, a first-best instrument would not only have to account for CO_2 emissions but also for other greenhouse gases like methane or

nitrous oxide, particularly if the land use sector was included (cf. Osterburg et al. 2009). This would further increase transaction costs.

3. *Distributive rationale for policy aims is neglected:* For developing realistic policy recommendations, the focus of neoclassical economic theory on policy aims based on the efficiency rationale is problematic. In practical political decision making, distributive aims like employment generation in the manufacturing sector or rural value creation are of immense importance (see Sect. 2.3.1). As part of the sustainability discourse, inter- and intragenerational justice also plays an important role as an aim motivated by the distributive rationale (see Sect. 2.1.2). Distributive aims such as these emerge from the democratic decision making process, and can therefore not be justifiably neglected (Sijm et al. 2014: 8). From a positive analytical perspective, political rationality considerations reinforce the practical relevance of distributive aims, given policy making's nature as a political and social negotiation process (see Sect. 2.3.4). If self-interested policy makers attempt to maximise political support, it can be rational for them to adopt distributive aims which benefit their constituents and influential interest groups.

Of course, there is a need to discuss whether bioenergy policy would be a cost-effective means for achieving distributive aims, a question that is answered in the negative by contributions from economic policy advisors (cf. Hermeling and Wölfing 2011: 82; WBA 2007: 183ff.; Isermeyer and Zimmer 2006; Henke and Klepper 2006). Nonetheless, if aims derived from, for example, industrial policy or agricultural policy are set politically, they still need to be taken into account when formulating policy advice, in order to ensure the practical relevance of said advice (cf. Matthes 2010; Lehmann and Gawel 2013). If achieving high shares of RES in the energy system is politically set as a target to promote the development of innovative industries alongside climate change mitigation and energy security improvements (cf. COM 2009; Federal Government of Germany 2010), the GHG abatement costs of different RES options are no longer the only relevant criterion to guide technology choices.

4. *Political feasibility constraints of the "one aim—one instrument approach" are neglected*: Given policy making's nature as a bargaining process, combining the GHG mitigation aim with further aims in the political discourse can be a rational strategy to increase the political feasibility of measures (cf. Gawel et al. 2014). Just as in other policy fields, it is possible that the implementation of climate policy measures to address GHG externalities may only gain political majorities if distributive aims and interests are considered in instrument choice and design. Examples are the free initial allocation of emission allowances in an emissions trading scheme (Oates and Portney 2001: 15), or exemptions for energy intensive production processes in energy taxes (Anger et al. 2006). Also, the argument that additional RES targets and RES support do not lead to additional emission reductions in the presence of an emissions trading scheme's emissions cap does not necessarily hold, once political feasibility constraints are considered: given that emissions caps are not set optimally, but negotiated, additional support for innovative technologies can help to make stricter emissions caps

politically feasible (Lehmann and Gawel 2013: 601; Gawel et al. 2014). Meanwhile, political feasibility can not only be increased by combining aims based on efficiency and distributive rationales, but also by the simultaneous invocation of multiple efficiency-based aims—this is the case, if different interest and voter groups stand to benefit from different aims, and their combined consideration results in an advocacy coalition which supports a specific policy intervention (cf. Lehmann et al. 2012: 344). In such cases, trade-offs need to be weighed between the political feasibility of implementing at least a partial cure for a market failure, and the risk of introducing new allocative distortions.

5. *Neglect of the institutional context*: Neither policy decisions nor allocation decisions are taken in an institutional vacuum. Instead, both are influenced by a multi-layered system of formal and informal rules that have evolved over time (North 1990a: 3; Williamson 2000). The implementation of new instruments has to take existing institutions into account—this includes interactions of a new instrument with the existing policy mix, but also the consistency with higher-level institutions, like constitutional laws. This shows problems of "ideal" instrument recommendations such as those concerning a global emissions trading scheme—an instrument with a global scope would presuppose a legitimate global organisation that could enforce compliance (cf. Stavins 1996: 8; Schmalensee 1998), a precondition that would meet with considerable political feasibility constraints and might require considerable adjustments in national policy and legal regimes. Moreover, policy recommendations need to consider the path-dependent, mostly incremental nature of institutional change (North 1990a: 92ff). The existing institutional context may not be efficient and enact multiple distortions on allocation decisions—given the interests aligned with it, however, the radical changes associated with the implementation of a first-best instrument would seldom be feasible (e.g. the abolishment of any direct support measures for GHG mitigation technologies). Moreover, institutional path dependencies interact with and reinforce technological path dependencies (see Sect. 2.2.3.6), because institutions have co-evolved with incumbent technologies. This can lead to a technological lock-in, which severely inhibits the diffusion of innovative technologies and structural change (Unruh 2000; Lehmann et al. 2012; Lehmann and Gawel 2013; Neuhoff 2005). Policy recommendations therefore need to consider strategies for implementing path changes.

Taken together, these considerations considerably limit not only the likelihood of implementation, but also the adequacy of first-best neoclassical recommendations for bioenergy policy. In comparing imperfect existing institutional arrangements with solutions which would be ideal from a theoretical viewpoint, neoclassical policy advice risks following a "nirvana approach" (Demsetz 1969: 1), where the actual feasibility of recommended measures is neglected. In the following, the contribution of selected theoretical approaches that could contribute to economic bioenergy policy advice which is closer to political realities shall be explored.

3.2 Policy Design in the Presence of Constraints: Implications of Second-Best Theory

The point of departure of second-best theory is a critique of the "piecemeal" policy recommendations of neoclassical welfare economics, which—focussing on market failures one at a time—assume that fulfilling Pareto optimality conditions in a problem-specific context will unambiguously lead to increases in welfare, without paying attention to whether or not they are fulfilled elsewhere (Lipsey and Lancaster 1956; Bohm 2008). Instead, if there is a constraint which prevents the attainment of a Pareto optimum, arriving at a second-best optimum which attempts to maximise welfare subject to that constraint may in fact require deviations from other Pareto optimality conditions—this is the core of the second-best problem, as defined by Lipsey and Lancaster (1956). Merely reducing the number of market failures does not necessarily increase economic efficiency, compared to a situation where no Pareto optimality conditions are fulfilled (Lipsey and Lancaster 1956; Markovits 2008). As a result, for example, it is not possible to state a priori that a perfect internalisation of GHG emissions is desirable, as long as market failures related to other externalities or market power remain in place.

3.2.1 Nature and Consequences of Unresolvable Constraints

Relevant constraints that prevent a first-best optimum may arise from either market or policy failures that cannot be resolved. The reasons for this can be manifold, and may be either technical or behavioural in nature (Bennear and Stavins 2007; Bohm 2008; Lehmann 2012). Examples of the former are prohibitively high transaction costs of correcting failures, the presence of uncertainty preventing optimal policy design, or budget constraints that make interventions unfeasible. Behavioural constraints arise when it is technically possible to resolve constraints, but suitable measures are not at the government's disposal, e.g. due to a lack of political feasibility, lack of political jurisdiction, legal constraints or traditions limiting instrument choices. Further, a distinction can be made between cases where there is one constraint which cannot be overcome, and situations where several constraints apply simultaneously and only some of them can be addressed at any given time (Meade 1955; Lipsey and Lancaster 1956; Bennear and Stavins 2007).[4]

Given the variety of relevant market and also policy failures, bioenergy policy can be seen as a prime example of the second-best problem. Whether it is welfare-improving to correct an individual market failure depends on whether this would

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[4] What constitutes an unresolvable constraint, meanwhile, can change with time—first-best instruments that are considered unfeasible due to high transaction costs of monitoring, for example, may become practicable with advances in monitoring technology (McCann 2013).

ameliorate welfare losses from other market failures, exacerbate them, or not affect them either way (Bennear and Stavins 2007).

For example, GHG externalities in the land use sector and biodiversity externalities can be jointly ameliorating. If internalising climate change costs of deforestation prevents deforestation, biodiversity losses are also mitigated, an approach pursued by instruments such as the UNFCCC's Reducing Emissions from Deforestation and Forest Degradation programme (REDD+) (FAO et al. 2009). On the other hand, if GHG and biodiversity externalities in the land use sector cannot be effectively addressed, because of factors such as high transaction costs for monitoring and enforcement or political feasibility constraints, then perfectly internalising GHG externalities in the energy sector may reinforce these market failures, by promoting higher than optimal levels of bioenergy use. Similarly, adopting the reasoning employed by Viner (1950) and Meade (1955), removing trade barriers for biofuels while tariffs for other agricultural commodities remain in place may not necessarily lead to free trade-related efficiency improvements in global production; import demand for biofuels would increase relative to the import demand for, for example, food or feed commodities, risking further distortions of international trade and land use patterns.

3.2.2 Use of a Policy Mix to Address Multiple Market Failures[5]

In principle, solving second-best optimisation problems requires identifying the welfare-maximising deviations from optimal states for all relevant Pareto imperfections, subject to the relevant constraints. The two preceding examples may serve to illustrate the complexity of such an undertaking, and unfeasibly high information requirements limit the usefulness of attempts to define "first-best rules for second-best problems" (Bohm 2008: 382) for practical policy making (cf. also Lipsey and Lancaster 1956). For that reason, case-by-case identification of relevant constraints and instrumental solutions is regarded as more feasible than the identification of general conditions for second-best optima (Bohm 2008).

In particular, in a second-best setting, policy mixes with several instruments addressing a single market failure can improve efficiency compared to single instrument strategies; for example, a mix of instruments can be employed to limit reinforcing effects on other market failures, decrease transaction costs of implementation, or increase the political feasibility of interventions (Gawel 1992; Bennear and Stavins 2007; Lehmann 2012). Also, hybrid instruments that combine price and quantity elements can, in some cases, help deal with uncertainty and ignorance. In climate policy, for instance, hybrid instruments have been suggested as a means of protecting against the possibility of unexpectedly high marginal

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[5] Some parts of this section have been used in Purkus et al. (2015).

damage or abatement costs, when there is a lack of knowledge concerning the relative position of MC and MB curves (Roberts and Spence 1976; McKibbin and Wilcoxen 2002; Pizer 2002; Jacoby and Ellerman 2004).

Interactions between environmental externalities and knowledge and learning externalities in technology markets are a well-researched example of a situation with multiple market failures, in which a policy mix can prove superior to an individual instrument (Jaffe et al. 2005; Newell 2010; Lehmann 2012, 2013). Accompanying internalisation efforts with a technology policy which supports R&D and diffusion of innovative technologies through "demand-pull" measures can lower the costs of GHG mitigation over time, and thereby improve overall welfare (Jaffe et al. 2005; Newell 2010; Lehmann 2012). In contrast, addressing technological spillovers by setting an emissions tax rate or cap in an emissions trading system above what would be optimal from an internalisation perspective would not lead to a dynamically efficient outcome, unless all GHG mitigation investments had the same potential for innovation (Grubb and Ulph 2002: 94; Lehmann 2012: 77).

Moreover, the presence of both knowledge and learning spillovers means that combining GHG internalisation with a subsidy on R&D expenditure alone will not result in optimal outcomes either. Rather, welfare is improved if these two instruments are complemented with targets and support instruments that promote the diffusion of innovative GHG mitigation technologies, such as RES (Fischer and Newell 2008; Sijm et al. 2014; Lehmann and Gawel 2013 for an overview). Technological path dependencies which benefit fossil fuel-based energy technologies (see Sect. 2.2.3.6) also provide arguments for supporting the diffusion of innovative GHG mitigation options, such as RES technologies (Unruh 2000; Kalkuhl et al. 2012; Neuhoff 2005; Lehmann et al. 2012; Lehmann and Gawel 2013).

In a second best context with innovation and diffusion barriers for RES technologies, it is not only specific RES support that can be justified, but also the use of technology differentiation within RES policies. In the same way as a technology-neutral GHG mitigation policy, technology-neutral RES support incentivises the use of RES technologies with the lowest costs. However, when respective potentials are exhausted, there is a sharp increase in marginal production costs, because the next cheapest technology is still at a market introduction stage and hasn't benefitted from learning curve effects yet (Menanteau et al. 2003: 801; Finon and Perez 2007: 79f.). Dynamic efficiency considerations therefore argue for a differentiation of support, to move a portfolio of RES technologies down the learning curve and reduce the costs of RES production in the long term. Moreover, differences in the maturity of technologies and technology-specific knowledge and learning spillovers argue for a differentiation in R&D and deployment support (Lehmann et al. 2012; Foxon et al. 2005; see Braun et al. 2010 and Noailly and Shestalova 2013 for empirical evidence on differences in knowledge spillovers associated with RES technologies). Finally, path dependencies might distort competition between RES in favour of those compatible with the predominant fossil fuel-based energy system.

3.2.3 Implications for Bioenergy Policy Advice

Rather than identifying first-best solutions for the individual market failures which are relevant in the bioenergy context, second-best theory shifts the focus to the question of how a policy mix could be designed which improves overall efficiency compared to the status quo, by taking interactions between unresolved market failures and other constraints into account. This has several major implications for economic recommendations for bioenergy policy.

Firstly, it proves inadequate to optimise bioenergy policy with regard to an individual aspect, such as GHG mitigation in neoclassical bioenergy policy advice. The persistence of other market failures implies that even if a perfect internalisation of GHG externalities were feasible, e.g. through an "ideal" version of an emissions trading system, the outcome would not be efficient. For example, with persistent market failures in the land use sector, a GHG-oriented policy which increased demand for bioenergy would need to be accompanied with additional safeguards, to prevent the aggravation of, for example, biodiversity or soil and water quality-related market failures. Simultaneously, market failures such as knowledge and learning spillovers, market power or path dependencies would continue to distort market signals for the choice of GHG mitigation options.

A further argument against the "one aim—one optimal instrument" approach of neoclassical economics is that policy aims which follow rationales other than the efficiency-based one, such as distributive aims, may turn out to be important constraints for efficiency-based interventions: in the bioenergy context, particularly the distributive aim of rural value creation is stressed by policy makers (see Sect. 2.3.1). The second-best perspective therefore emphasises the need to take into account the full scope of relevant market failures, efficiency-based aims directed at their alleviation, as well as distributive aims, which have important implications for the political feasibility of first-best (or even second-best) measures.

Further implications arise out of the heterogeneous nature of bioenergy pathways. The electricity, heating and transport sectors pose different challenges when it comes to addressing market failures. For example, GHG emission sources in the heating and transport sectors are more decentralised than in the electricity sector, which proves to be a relevant constraint for implementing an emissions trading system in these sectors. Also, interest coalitions which affect the political feasibility of interventions may differ between sectors (see Sect. 2.3.4). This argues for a sector-specific analysis to determine what market failures and political constraints are relevant; accordingly, recommendations for a policy mix that takes interactions between relevant market failures into account may differ between sectors. Interactions between GHG externalities and knowledge and learning externalities exist in all three energy sectors, leading to an underinvestment in innovative GHG mitigation options. As discussed in Sect. 3.2.2, this argues for a combination of an instrument which internalises the external costs of GHG emissions not only with R&D support, but also some form of deployment support for innovative technologies. However, the appropriate degree of technology differentiation in designing deployment support may depend on sectoral characteristics, such as the technological maturity of available GHG mitigation options, and interactions with further market failures which distort competition between technologies.

Another relevant question is what degree of technology differentiation is sensible within the technology group of bioenergy in the different energy sectors. Again, interactions between market failures and political constraints have to be taken into account, because different bioenergy pathways are associated with different external costs and benefits, and different types and levels of uncertainty (cf. Purkus et al. 2015; Sect. 2.3.2.2). Here, an interesting question is where is it sensible to account for interactions between market failures and political constraints by differentiating between bioenergy pathways in a single instrument, and where can a policy mix perform better, combining, for example, diffusion support with sustainability certification.

Using insights from the case study analysis of German bioenergy policy (Chap. 4), questions relating to technology differentiation are analysed further as part of Chap. 5. Section 5.3 discusses under which conditions there is a rationale for differentiating between bioenergy and other RES technologies as GHG mitigation options. Also, the rationale for differentiating between different technologies within the bioelectricity, bioheat or biofuel technology groups is discussed. Section 5.4 encompasses a more specific analysis of design options for a technology differentiation mechanism for the case of bioelectricity deployment support.

Lastly, the second-best perspective suggests that policy recommendations should include a critical assessment of which constraints may be resolvable over time. For example, implementing a second-best option, such as accounting for indirect land use effects in biofuel regulation, should not reduce efforts to find general solutions for addressing market failures in the land use sector, even if these might only seem feasible in the long run (Zilberman et al. 2010). Given the increased complexity of the considered problem, second-best implications for policy recommendations are necessarily less clear-cut than in a standard neoclassical setting, but are nonetheless likely to be of greater relevance for actual policy making (Bennear and Stavins 2007; Lehmann 2012).

3.3 Policy Making Under Incomplete Knowledge: Insights from Information Economics

As an extension of neoclassical theory, information economics examine the consequences of relaxing the assumptions of perfect information and perfect foresight. Building on the distinction between different forms of incomplete knowledge established in Sect. 2.3.2, the following section discusses economic contributions to handling complex decision making problems characterised by uncertainty and ignorance, and the implications that can be derived for the design of bioenergy policy. Also, insights regarding the allocation of risks and uncertainties between different actors are discussed. Precautionary and deliberation-based approaches for decision making under environmental uncertainty, meanwhile, will be discussed in the context of ecological economics contributions (Sect. 3.6), as they are often applied in conjunction with an assumption of critical environmental limits and limited substitutability of natural capital (cf. Wätzold 2000; Dovers et al. 2001; Young 2001; Perman et al. 2003: 444ff.; Stirling and Mayer 2004).

3.3.1 Probabilistic Approaches and Decision Theory-Based Decision Rules

In information economics, information is typically integrated into the microeconomic analysis by treating it as a commodity, whose production and acquisition is associated with costs (Schumacher 1994: 8ff.; Svetlova and van Elst 2013). Conventional applications relate to determining the optimal degree of information efforts under imperfect information about prices and quality, which is realised when the marginal costs of information search efforts equal their marginal expected benefits (e.g. Stigler 1961; Akerlof 1970; Stiglitz 1975). While the costliness of information implies that a state of perfect information is generally not optimal, it is still considered to be feasible in principle—individuals are widely assumed to have perfect stochastic knowledge, i.e. knowledge about probability distributions of prices, quantities, events et cetera (O'Driscoll and Rizzo 1996: 3f.). Consequently, although individuals may not know the relevant probability distribution from the outset, it is assumed that it exists objectively and is knowable in principle, through gradual discovery.

As a consequence of this assumption, large parts of information economics focus on the maximisation of expected utility under risk [see Perman et al. (2003: 446ff.) for an overview of risk analysis concepts].[6] As discussed in Sect. 2.3.2, however, many of the decision problems that bioenergy policy makers face are characterised by uncertainty and ignorance. While economists such as Knight (1921), Keynes (1921) and Hayek (1945) stressed the importance of these forms of incomplete knowledge early on, the discussion of their implications has mainly remained outside of mainstream economic theory (Köhn 2013; Svetlova and van Elst

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[6] In the environmental context, for example, methods for estimating option value and quasi-option value (in the presence of irreversible impacts) have been applied to decisions involving the conversion of natural land; these attempt to correct the expected net benefits of the planned (e.g. industrial) development for the loss of options the associated conversion would entail, as uncertain future benefits of natural land are foregone (Perman et al. 2003: 448ff.; Weikard 2003). However, given extremely high information requirements about outcomes, probabilities, or the prospect of gaining additional information about conservation benefits in the future, calculated option values are rarely formally taken into account in decision making, although they generally imply lower levels of conversion than would otherwise be the case (Perman et al. 2003: 459).

2013).[7] Instead, economists have tended to incorporate uncertainty and ignorance into a probabilistic framework, following work by Ramsey (1931), de Finetti (1951) and Savage (1954) on subjective probabilities. According to their assumptions, decision makers will subjectively assign a probability distribution to all possible consequences of an action on the basis of beliefs, even if it is not possible to establish an objective probability distribution (Young 2001: 68f.; Köhn 2013: 16f.).[8] Using empirical observations of actors' behaviour, the subjective probability distribution can then in principle be derived a posteriori (Svetlova and van Elst 2013: 46). Further, subjective probabilities were integrated into Muth's (1961) rational expectation hypothesis (REH), which proved very influential on the economic theory of choice. According to the REH, agents have rational expectations about the future, allowing for a convergence of subjective probabilities with objective probabilities in the long-term (Young 2001: 68; Svetlova and van Elst 2013: 16).

While subjective probabilities and the REH opened up all forms of uncertainty to the quantitative approaches of risk analysis, the adequacy of this approach has been severely criticised (see Young 2001: 68ff.; Köhn 2013: 17f.; Svetlova and van Elst 2013: 47ff. for an overview of arguments). For one, subjective probabilities presuppose that a complete set of outcomes can be hypothesised for each action, which is, by definition, not the case for decision problems under ignorance (Shackle 1969). If it were possible to have full knowledge of all available alternatives for action and their consequences, decision making would be reduced to a "mechanical application of the personal utility-maximisation rule" (Svetlova and van Elst 2013: 49), which appears certainly inadequate to complex decisions under multi-dimensional uncertainty and ignorance as occurring in the bioenergy context. Moreover, Woodward and Bishop (1997: 506f.) question the rationality of assigning "ad hoc probabilities" when well-defined objective probability distributions are not available, and warn against basing policy advice on such assumed probabilities. Meanwhile, experimental evidence indicates that real-world decision making seldom complies with the rational expectation hypothesis and its predictions (e.g. Simon 1955; Kahneman and Tversky 1979).

A different approach that manages to do without probabilities is offered by decision theory rules for decision making under uncertainty. Examples of these include maximin, maximax and minimax regret rules (Dixit and Nalebuff 1993; Perman et al. 2003: 460 f.).[9] These rules require policy makers to estimate the

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[7] Recently, this neglect in mainstream economic theory has come under criticism in the wake of the global financial crisis (cf. Priddat and Kabalak 2013).

[8] If any information or belief about probabilities is lacking, it is assumed that decision makers can at least apply the "principle of insufficient reason", which involves the assignment of equal probabilities to mutually exclusive outcomes. Following this, decision makers should adopt the strategy that yields the pay-off with the greatest expected value (Perman et al. 2003: 461).

[9] Another example of a decision rule which has been applied to environmental uncertainty is Shackle's (1969) model, which replaces probabilities with a measure of surprise, and attempts to balance best case against worst case scenarios for possible courses of action (Wätzold 1998: 96ff.; Young 2001: 88ff.).

pay-off (i.e. the net present value) that different strategies would generate under different possible states of nature. Since under uncertainty, the probability of different states is unknown, decision rules focus on comparing the potential outcomes of alternative strategies across different states (Perman et al. 2003: 460f.). According to the *maximin rule*, policy makers should focus on adverse outcomes and choose the strategy with the least bad of the worst possible outcome. The more optimistic *maximax rule*, on the other hand, recommends choosing the strategy with the best of the best case outcomes. The *minimax regret rule*, finally, focuses on identifying the strategy with the least costly mistake, i.e. the lowest "regret" when a state of nature comes to pass which would have favoured a different strategy (Perman et al. 2003: 461). Decision rules can be used as an input for decision making, to present to policy makers trade-offs between what Iverson (2012) and Iverson and Perrings (2012) call "environmental mistakes" (in hindsight, environmental damages are higher than optimal) and "growth mistakes" (too much environment has been protected at the cost of economic development) across a range of plausible outcomes. However, none of the rules can guarantee that the strategy with the highest welfare outcome is chosen: depending on the decision rule adopted, different strategies would be recommended, and which rule would be considered adequate under specific circumstances requires a value judgement from decision makers (Perman et al. 2003: 461). Moreover, even though the theory does not rely on probabilities, the ability to describe all possible states of nature and estimate pay-offs for them imposes high information requirements on policy makers.

Overall, for deriving bioenergy policy recommendations, neither probabilistic approaches nor decision theory rules offer promising avenues. If it were possible to calculate welfare outcomes for different strategic focuses of bioenergy support and different instrument combinations, and assign probabilities to them, providing economic policy advice would be easy—the task would simply be to identify policy alternatives that maximise expected utility. As discussed in Sect. 2.3.2.2, the reality of bioenergy policy making looks very different; indeed, imperfect knowledge about outcomes and their respective likelihoods is not limited to GHG benefits of different policies, but extends to other environmental costs and benefits associated with land use changes as well as to security of supply benefits, which depend on substituted energy carriers and the future availability and costs of alternatives to bioenergy. The use of subjective probabilities would obscure the challenges associated with handling uncertainty and ignorance, rather than address them. For example, in the early stages of bioenergy policy, policy makers neglected that GHG mitigation benefits of bioenergy pathways could be significantly reduced by direct and indirect land use changes (cf. COM 2005, 2006). Rather than deriving subjective probabilities from policy makers' behaviour, economic policy advice needs to incorporate recommendations for how to deal with unexpected consequences of policies.

Given the complexity of bioenergy's allocative problems, the usefulness of decision rules for deriving policy recommendations is also very limited: besides the problems associated with choosing a case-adequate rule, the assessment of outcomes under different states of nature remains highly speculative. For example, if policy makers wished to compare the pay-off of a policy that rewarded energy crop cultivation on set-aside land compared to one that required set-aside land to be left fallow, decision rules would require a quantification of private and external costs and benefits associated with both approaches under different states of nature. Resulting values would in themselves be associated with high uncertainties.

Consequently, economic policy advice requires a more comprehensive approach to dealing with the challenges posed by uncertainty and ignorance. This requires a more fundamental revision of theoretical assumptions about how decision makers, and policy makers in particular, handle imperfect knowledge when taking allocation and regulation decisions. Key contributions are discussed in the following.

3.3.2 The Challenge of Handling Uncertainty and Ignorance

The implications of uncertainty and ignorance go beyond not being able to specify probability distributions and enumerate all possible outcomes in policy assessment. Hayek stresses the importance of being aware of what he calls a constitutional lack of knowledge, which follows from the subjective nature of all knowledge as well as from the unattainability of a state of perfect information (Hayek 1967/2003). Individuals filter and interpret perceptions of their environment on the basis of individual cognitive structures, resulting in knowledge which is subjective and heterogeneous across actors (Schumacher 1994: 56), and actions which are not completely determined by external factors, but allow room for creative and autonomous choices (O’Driscoll and Rizzo 1996: 1). At the same time, knowledge remains necessarily incomplete, as it is not only made up of scientific knowledge which may be gathered by a limited number of experts, but also of “knowledge of the particular circumstances of time and place” (Hayek 1945: 521), which is dispersed across individuals and is frequently contradictory. According to Hayek, it would be impossible for decision makers to possess all the knowledge relevant to a decision “in concentrated or integrated form” (Hayek 1945: 519). Reasons for this are not only the costliness of information acquisition, but also the limited cognitive capacity of the human brain, and the complexity of an environment which constantly changes over time (Schumacher 1994: 62f.; O’Driscoll and Rizzo 1996: 2f.). Moreover, the consequences of decisions depend on the choices made by other individuals, which can never be perfectly predicted due to the subjective quality of their knowledge (Hayek 1937). This effectively renders the future unknowable, given that the overall societal outcome of individual actions is extremely unlikely to correspond to the intentions of any individual. Economic theory, according to Hayek, is therefore constrained to predicting the type of structure or pattern that will emerge from the interaction of decision-making individuals, rather than particular outcomes (Hayek 1961/2007, 1968a).

Taking the subjectivity and incompleteness of knowledge into account also has important implications for the economic rationality assumption. Uncertainty and ignorance prevent individuals from selecting the utility maximising option among all available alternatives (Simon 1955; Williamson 1975: 21ff.; Loasby 1976: 217). Moreover, preferences may be incomplete, inconsistent and subject to change (Simon 1955). Simon (1955) proposed bounded rationality as an alternative concept to the globally rational behaviour generally assumed by economic theory, in order to better reflect the limited information access and computational capacities that characterise human decision making. While in the utility maximisation model, rationality of behaviour is measured in terms of its appropriateness for achieving given aims under certain constraints (i.e. substantive rationality), under uncertainty and ignorance the rationality of the decision making process itself becomes the centre of interest (i.e. procedural rationality) (Simon 1976; Young 2001: 62f.). As a more realistic model of decision making, Simon (1955) suggested replacing individual utility maximisation by satisficing. According to this concept, individuals form aspiration levels, and only start searching for new, alternative courses of action which deviate from routine behaviour when they find themselves below these levels (cf. Voigt 2002: 30). Authors such as Heiner (1983) and Nelson and Winter (1982) stress the importance of rule-following behaviour and routines in dealing with uncertainty and ignorance, with successful rules being selected over time in an evolutionary process. Accordingly, the development of the economy is presented as a dynamic process characterised by trial and error, rather than a progression of equilibrium states (Loasby 1976: 217; Nelson and Winter 1982).

Meanwhile, rules not only play an important role in individual or organisational decision making, but also in coordinating the behaviour of boundedly rational actors. Here, institutions, as systems of formal and informal rules, play a central role: by constraining the choices available to individuals they introduce regularity into their behaviour, thereby enabling the forming of reliable expectations and reducing uncertainty for all members of society (Hayek 1967/2003; North 1990a: 25) (see Sects. 3.4 and 3.5). Further, Hayek stressed the role of markets—which themselves are embedded in the system of institutional constraints (cf. Ménard and Shirley 2005: 2)—as an important mechanism for coordinating the actions of different individuals through prices (Hayek 1945), and for discovering time- and space-dependent knowledge (Hayek 1968a).

These considerations reveal two important implications for economic bioenergy policy advice. Firstly, Hayek's findings imply that it is not possible to predict that a certain policy incentive results in a certain allocative outcome, shifting the emphasis to predictions about the structural impact that policies are likely to have (cf. Hayek 1961/2007, 1968a). If, for example, an emissions tax or emissions trading system established a price for GHG emissions, boundedly rational actors would not necessarily choose the most cost-effective mitigation options; rather, they would search for mitigation options within the bounds imposed by information availability and behavioural routines, until a utility level was achieved that could be considered at least temporarily satisfactory. Consequently, even a market-based policy intervention following neoclassical recommendations would not necessarily result in the establishment of a new equilibrium in which GHG mitigation aims would be achieved cost-effectively—instead, it would trigger an ongoing trial-and-error process, while actors would extend their information, adjust their satisficing levels and continue searching for less costly GHG mitigation options. Meanwhile, similar to behavioural routines, institutional and technological path dependencies can constrain such search processes—to counter these and broaden the set of avenues explored, additional policy interventions may be necessary.

Secondly, Hayek in particular warns policy makers not to assume too much knowledge. While for individual market actors, trial-and-error processes are an effective way of learning and generating new knowledge, errors in centralised decision making would affect a large number of actors and result in high welfare costs. This leads to the conclusion that policies should leave as much room for decentralised search processes as possible, with a coordination of activities through markets and competition (Hayek 1945/2005: 45, 1960).

3.3.3 Allocation of Risk and Uncertainty Between Market Actors and the State[10]

Besides the problems of decision making under different forms of incomplete knowledge, policy makers are faced with the problem of how to allocate risks and uncertainties between different actors. Actors are characterised by different preferences regarding risks and uncertainties, which has implications for instrument choice. If bioenergy investors, for example, are risk averse, then they will ask for higher price premiums, the more risky they perceive an investment to be (Pahle et al. 2014). Under price-based feed-in tariffs, where policy makers set a guaranteed remuneration per kWh, investors' income is fairly certain; under quantity instruments such as RES quotas, where remuneration is determined by supply and demand for tradable certificates, investors face much higher risks. As a result, quantity instruments tend to result in higher prices for RES provision than feed-in tariffs (Mitchell et al. 2006; Klessmann et al. 2008; Diekmann et al. 2012).

In the case of bioenergy, not only income risks are relevant, but a range of uncertainties (see Sect. 2.3.2.2), including, for example, dynamic cost uncertainties and uncertainties regarding GHG mitigation benefits of pathways. Accordingly, the question is which of the relevant uncertainties should be borne by the state, which by market actors, and which should be shared. Here, the theory of risk allocation can provide useful insights—employed primarily to the allocation of investment risks in infrastructure projects (Irwin et al. 1997: 8ff.; Beckers and Miksch 2002), findings also prove relevant for the handling of uncertainties in bioenergy policy (cf. Purkus et al. 2015).

According to Irwin et al. (1997: 8ff.), the following criteria should be taken into account when allocating risks [see also Beckers and Miksch (2002: 10f.)]:

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[10] Some parts of this section have been used in Purkus et al. (2015)

1. *Degree of control over risky outcomes*: Risk should be allocated to actors who can best control the risky outcome, i.e. actors who can influence the risky variable or can at least limit risk.
2. *Ability to bear risks*: Risk should be allocated to actors who can bear it at the lowest costs; for example, because they are less risk-averse, because they can hedge risks and insure against them, or because they can spread risks among many people.
3. *Transaction costs*: The transaction costs (including information, negotiation, contract implementation and monitoring costs) of allocating risks among parties must be taken into account.

Who can bear risks at the lowest costs is discussed controversially in the literature; while the state can spread out risks among tax payers, inefficient incentives in public administration can lead to a less effective management of risks (Kerf et al. 1998: 121; Beckers and Miksch 2002: 12). The transaction costs of allocating risks, meanwhile, depend on their current allocation (which need not be efficient), and are therefore strongly context-dependent. Focussing on the control over risky, or—phrased more generally—uncertain outcomes, Table 3.1 gives an overview of respective advantages of market actors and the state.

In general, the ability to use dispersed knowledge gives market actors an advantage in dealing with private cost uncertainties, particularly those of a static nature that can be described as "normal market uncertainties" (e.g. uncertainties about price and resource cost developments). In the case of external costs and benefits, market actors have some information advantages compared to the state, because their level depends on specific investment, production and supply chain decisions. However, in assessing externalities the state has the advantage of acting from a systems perspective, and is able to promote "objective" improvements in understanding. While only the state can decide about the weighting of externalities, the optimal current and future allocation of biomass resources is unknown to market actors and policy makers alike; however, the latter can account for cross-sectoral interactions of policy and market incentives which influence the allocation of biomass resources when designing policies.

In neoclassical policy analysis, the implications of different allocations of risk and uncertainty tend to be neglected—works on target setting and instrument choice under imperfect information focus on social costs of errors, not on costs associated with risk allocation (cf. Sect. 3.1.2). Indeed, many of the problems discussed in this section do not arise within the neoclassical analytical framework. If the focus is on addressing one individual externality, then uncertainties related to externalities other than GHG emissions can be neglected, as can the question of how to balance several externalities and how to allocate investment risks that result from a shift in political priorities. But even with GHG externalities, neoclassical bioenergy policy advice (cf. Sect. 3.1.4) tends to abstract from the inability to calculate certain, accurate GHG balances for complex bioenergy pathways (see Sect. 2.3.2.2). Given the relevance of uncertainties for many dimensions of bioenergy allocation (cf. Sect. 2.3.2.2), the ability to handle them in a rational

Table 3.1 Allocation of uncertainties between market actors and the state—differences in the degree of control over uncertain outcomes (reproduced from Purkus et al. 2015: 70)

	Ability to control outcome	
Type of uncertainty	Market actors	State
Static costs	(+) Control planning of investments and operation of bioenergy plants	(−) Can only indirectly influence investment decisions; information asymmetry between state and producers
Dynamic costs	(+/−) Control R&D investment decisions and sourcing decisions, but learning curve effects depend on aggregated market developments	(+/−) Can set incentives for innovation and diffusion of specific technologies
External environmental costs of bioenergy production	(+/−) Production decisions affect external costs, but their extent may not be understood, and incentives are needed to take them into account	(+/−) State can promote improvement in scientific understanding, but impacts can be strongly context-dependent
GHG mitigation benefits	(+/−) Production decisions affect GHG balance, but impacts may not be understood, and incentives are needed to take them into account	(+/−) State can promote improvement in scientific understanding, and assess ILUC impacts; but actual GHG balance is determined by supply chain decisions
Security of supply benefits	(+/−) Production mode (flexible/inflexible) influences system benefits	(+/−) Benefits are determined by framework conditions (e.g. share of volatile RES, security of imports), but also depend on production and investment decisions
Uncertainty about how to balance multiple externalities	(−) Externalities affect wider public, not bioenergy producers	(+) Requires democratic decision making process
Uncertainty about optimal biomass allocation	(−) Allocation results from aggregated demand and supply, as influenced by market and political framework conditions	(+) State influences allocation by setting policy incentives; cross-sectoral coordination of policy instruments required

Note: (+) comparatively high degree of control over outcomes; (−) comparatively low degree of control; (+/−) control over some aspects of outcomes, not over others

manner becomes crucial for bioenergy policy—accordingly, economic policy advice needs to encompass insights on how to allocate different types of uncertainty between market actors and the state.

3.3.4 Implications for Bioenergy Policy Advice

It has become apparent that more traditional approaches of information economics which rely on—either objective or subjective—probabilities and attempt to maximise expected utility under risk are of limited applicability to the problems of bioenergy policy, where decisions have to be made under incomplete knowledge of probabilities and outcomes. If outcomes can be hypothesised and expressed in a commensurable fashion (e.g. in monetary terms), then decision rules from decision theory can help to structure the problem, but the high degree of complexity of the allocative problems associated with bioenergy use severely limits their applicability. Indeed, the impossibility of deriving unequivocal recommendations for achieving utility maximising outcomes under uncertainty—and more so, under ignorance—has important repercussions for the rationality assumption applied to economic actors; for developing economic bioenergy policy advice, it seems more appropriate to adopt the bounded rationality concept and focus on the role of institutions as uncertainty-reducing constraints. Moreover, when accounting for Hayek's "constitutive lack of knowledge", it can no longer be assumed that it is possible ex ante to identify optimal policy options based on an accurate understanding of how market actors will react to them and the outcomes that will result from these reactions. Rather, both policy making and actions of market actors are better understood as trial-and-error processes in a dynamically changing environment. Implications from these insights have been examined in-depth by the theory of economic order (Sect. 3.4) and new institutional economics (Sect. 3.5), while ecological economists have stressed the importance of policy learning, the precautionary principle and deliberative decision making processes in the presence of uncertainty and ignorance about environmental limits to economic activity (Sect. 3.6).

Viewing actors as boundedly rational has important implications for economic advice on bioenergy policy. When taking information problems into account, neoclassical recommendations focus on the case of imperfect information on the side of policy makers (see Sect. 3.1.2): when setting a price or a quantity constraint on GHG emissions, they are unaware of the real position of marginal cost and benefit curves, leading to non-optimal outcomes. However, the pricing and standards approach assumes that market actors choose least cost GHG mitigation options to bring about—in the case of a quantity instrument, at least—a cost-effective attainment of targets; this cannot be taken for granted under bounded rationality. Rather, policy makers have to take constraints that limit market actors' search processes into account, such as path dependencies. Also, in addition to knowledge and learning externalities, myopic behaviour may further reduce incentives to invest in innovation (Pavitt and Patel 1988: 51). As a result, combining an internalisation instrument like an emissions trading system or an emissions tax with further instruments, like deployment support and information instruments, may be necessary to address constraints on search processes.

Moreover, as the theory of risk allocation shows, the allocation of uncertainties between market actors and the state has important implications for the costs of implementing targets, and also for the incentives that actors face. Neoclassical policy recommendations only provide answers regarding the allocation of static and dynamic cost uncertainties; uncertainties regarding the actual impacts of different bioenergy pathways on policy aims and the balancing of trade-offs are neglected. As far as static cost uncertainties about market actors' production costs are concerned, the theory of risk allocation agrees with the neoclassical analysis, in that market actors are better able to control these costs than the state. With dynamic cost uncertainties, however, the situation is more complicated, because learning curve effects depend on aggregated investments in innovative technologies, a factor that can be influenced through policy incentives for R&D and the deployment of these technologies. Rather than letting market actors bear these cost uncertainties entirely, a shared allocation where the state provides a degree of planning security for investments in innovative technologies may result in a comparatively more efficient outcome, by reducing GHG mitigation costs over time.

Moreover, bioenergy policy makers have to deal with uncertainties about GHG balances and other environmental externalities of bioenergy pathways. These uncertainties can be allocated to market actors, for example by requiring them to provide certification about GHG balances and environmental impacts according to latest scientific knowledge.[11] However, new information about the environmental impacts of allocative decisions along the value chain might devaluate investments, for example, if GHG mitigation contributions turned out to be much smaller than expected. This might lead to investments not being undertaken at all, or being associated with high risk premiums. Under these circumstances, it can be appropriate for the state to take on some of the uncertainties, for example by committing to a GHG accounting methodology for a certain amount of time.[12] For security of supply benefits, a shared allocation of uncertainties may likewise prove beneficial. What kind of production, investment and R&D decisions yield the highest benefits for the security and stability of the energy system depends on the long-term development of framework conditions (such as the share of volatile RES), which can be influenced by policy makers. Meanwhile, the theory of risk allocation suggests that the state is better equipped to deal with solving trade-offs between externalities, and influence the overall allocation of biomass resources by setting political and market framework conditions. Here, uncertainty for market actors could be reduced by (i) committing to a hierarchical ranking of policy aims, and (ii) providing a well-coordinated policy mix for influencing biomass allocation.

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[11] GHG accounting methodology and environmental impacts would have to be verified externally—otherwise there would be a high risk that market actors would make use of asymmetric information advantages (see Sect. 3.5.3) to produce beneficial environmental balances. In that case, uncertainties about the social costs of bioenergy use would rest largely with the state.

[12] As practiced, for example, in UK sustainability certification for bioelectricity (cf. DECC 2013).

In designing a policy mix and individual instruments, these findings highlight the challenge of limiting the social costs of errors and maintaining incentives for innovation and improvements in the balance of external costs and benefits of bioenergy production, while providing an adequate degree of planning security. These aspects will be further addressed in Sects. 5.3 and 5.4, where theoretical insights are applied to the case study of German bioenergy policy.

3.4 Structural Versus Process Policy: Implications of the Theory of Economic Order

As one of the precursors of new institutional economics, the theory of economic order examines the implications of a constitutional lack of knowledge (see Sect. 3.3.2) for policy making, and the role that institutions, as enforceable rules, play in shaping an economic order (Oberender and Christl 2000; Streit 2010). In particular, the theory is concerned with the comparison of government interventions where policy makers attempt to steer market allocation processes towards certain results (process policy), and interventions which limit themselves to the design of market framework conditions (structural policy or “Ordnungspolitik”) (Pütz 1979: 108ff.; Wegner 1996: 368). The knowledge problem that policy makers face has been especially a focus of Hayek’s work (Hayek 1945; 1945/2005) and other contributions that build on it (e.g. Wegner 1996; Pahl 2001). Moreover, limits of policy interventions have also been addressed by Eucken and work based on his principles of economic policy (Eucken 1952/1990: 254ff.), although here the focus is on problems of power rather than knowledge (Streit and Wohlgemuth 2000). After a short introduction of both approaches, implications for bioenergy policy are discussed.

3.4.1 Policy Making and the Problem of Knowledge

In designing interventions in the economic process, policy makers lack relevant knowledge along two major dimensions (Wegner 1996: 373f.). When a policy measure is employed to influence actors’ behaviour, policy makers cannot foresee the reallocation effects of the policy, because possible substitutive or innovative actions of actors are determined by their individual time- and space-dependent knowledge (cf. Sect. 3.3.2). Not only is this knowledge not accessible to policy makers in its entirety, it is also changeable. When competing in markets, actors’ continuously expand their knowledge about possible actions, while at the same time, the market’s selection process devaluates other possibilities.

This lack of knowledge poses problems if policy makers undertake process policy interventions to steer market allocation processes towards certain results, instead of adopting a structural policy approach; here, policy makers would focus on formulating framework conditions which safeguard the functioning of market allocation processes, accepting whatever allocative outcome results (Pütz 1979: 108ff.; Wegner 1996: 368). With process policy interventions, intended results are likely to be missed, necessitating further corrective interventions. In the worst case, this can lead to an "intervention spiral" (cf. von Mises 1929), which destroys self-coordinating market forces and restricts personal freedom of society's actors (cf. Hayek 1945/2005). This applies especially to prescriptive command-and-control instruments which directly control elements of actors' plans (e.g. through direct quantity or price controls, prescribed production processes etc.), rather than merely changing the data that actors face, as is the case with indirect measures (e.g. by altering relative prices, or—more generally—through monetary or fiscal policy measures) (Pütz 1979: 146f.; Luckenbach 2000: 368f.). While indirect process policy interventions leave decisions about plan elements to individual actors, prescriptions forego the benefits of using competition as a discovery mechanism for new knowledge and the possibility of learning from trial-and-error processes (Hayek 1945, 1968/2002); instead, policy makers have to adapt centrally to new information and changing circumstances, necessitating frequent corrections of interventions.

While centrally planned interventions are viewed as doomed to fail, the theory of economic order stresses the prime importance of the price mechanism in coordinating the use of dispersed knowledge, with competition as a means of discovering new information (Streit and Wohlgemuth 2000: 468). However, the theory's approach differs distinctly from the neoclassical model of equilibrium markets with perfect competition (Hayek 1937). First, it is stressed that individuals labouring under incomplete knowledge require rules to form stable expectations—designing these rules is the task of structural policy (Streit 2010). According to Hayek (1968b), they should have the character of "abstract rules of just conduct" (ibid.: 27), which should allow individuals to pursue their own goals using their personal knowledge and skills and form reliable expectations about other people's actions, define areas in which individuals can act with private autonomy, and keep open the scope for innovative behaviour (see also Streit and Wohlgemuth 2000: 471f.).

On the basis of rules, an order emerges spontaneously in the economy (Hayek 1969). However, this does not take the form of an equilibrium state that can, in principle, be calculated by a process of optimisation, but of an ever changing and not foreseeable evolutionary process (Wegner 1996: 372). Consequently, Hayek sees only very limited potential for consciously influencing the emerging order (cf. Wegner 1996: 372; Streit and Wohlgemuth 2000: 468; Pahl 2001: 176). An environmental structural policy that follows this logic would most likely focus on defining property rights and liability rules, rather than attempting to bring about certain levels of environmental quality (Pahl 2001: 176).

More recent approaches, on the other hand, acknowledge both the need for interventions and their limits (Wegner 1996; Gerken and Schick 2000; Pahl 2001); here, the focus tends to be on designing interventions which are consistent with the economic order (Wegner 1996: 375f.; Streit 2010). Wegner (1996: 375ff.) emphasises that it is possible for policy makers to intervene in market processes without destroying their evolutionary potential, and reach an outcome that is compatible with intended policy aims. For this, policies need to be designed so as to limit the set of potential actions, while offering incentives for innovative processes that contribute towards policy aims (Wegner 1996: 378; Pahl 2001: 194). Similarly, environmental policy applications of evolutionary economics suggest the creation of a selection environment that steers innovations in certain environmentally compatible directions by applying pressure on options with undesirable characteristics (van den Bergh 2007). For "devaluating" options (cf. Wegner 1996: 378), market-based instruments such as taxes can be employed, but also command-and-control instruments such as proscriptions can be consistent with the economic order (ibid.: 379).

On the other hand, attempts to increase the value of certain actions, e.g. by offering subsidies for specific technologies, are regarded as having little chance of success (Wegner 1996: 380). Not only would they stifle innovation, but there would be no guarantee that supported technologies would ultimately be successful given market dynamics. But even with interventions which limit the admissible set of actions, innovation and substitution effects can occur which are not compatible with policy aims; the degree to which this happens can potentially be influenced by the perceived legitimacy of aims (Wegner 1996: 382ff.).

However, even if interventions are consistent with policy aims, there is no guarantee that defined targets are effectively and efficiently reached, as foreseen by the pricing and standards approach (see Sect. 2.1.1). Making concessions to the constitutive lack of knowledge, the demerit goods approach gets by entirely without targets, focussing instead on how politically defined price signals can initiate structural changes towards more sustainable consumption or production patterns (cf. Gawel 1995a; Budzinski 2000: 232ff.).

3.4.2 Policy Making and the Problem of Power

The theory of economic order views the creation of an institutional framework not only as necessary for enabling stable expectations, but also for limiting concentration processes and the build-up of private power in markets, which would restrict individual freedom (Gerken and Schick 2000: 21; Oberender and Christl 2000: 531; Streit and Wohlgemuth 2000: 463). On the other hand, institutions are also required to protect individuals from public power. Like the consideration of knowledge problems, the theoretical focus on the problems of power in policy making also leads to a preference for structural policy which constrains itself to setting market framework conditions for market actors, rather than process policy interventions which directly interfere with elements of actors' plans. In sum, structural policy is seen as protecting actors' freedom, while also limiting the state's scope for influence (ibid.).

Table 3.2 Eucken's constitutive and regulative principles of economic policy (based on Cassel and Kaiser 2000: 85f.; Eucken 1952/1990: 254ff.; van Suntum et al. 2011: 7f)

Constitutive principles	
Fundamental principle of economic constitution	Establishment of a functional price mechanism with perfect competition
Primacy of monetary policy	Realisation of a stable price level, avoidance of inflation or deflation
Open markets	Safeguarding of an open market access for all market actors, prevention of public or private actions to close markets
Private property	Decentralised economic decision making requires private property rights concerning the means of production
Freedom of contract	Competition requires the freedom to choose contract partners and the content of contracts
Liability	Complementary to freedom of contract and private property; owners of property rights have to bear responsibility for potential damages to third parties
Continuity of economic policy	Economic policy needs to be consistent and of a certain permanency, to reduce market actors' uncertainty
Regulative principles	
Regulation of monopolies	Monopolies should be regulated and made to act as if perfect competition existed
Income policy	Progressive taxation should be used to correct allocative outcomes for distributive aims
Correction of national accounting	State interventions are necessary to correct for external effects which distort the price mechanism
Correction of anomalous supply behaviour	State interventions are necessary if supply increases with decreasing prices or wages

As a central representative of this line of reasoning, Eucken emphasises the role of the price mechanism as the economy's central coordination mechanism, but compared to Hayek, he foresees a more active role for the state in guaranteeing its functionality (Eucken 1952/1990: 253; Oberender and Christl 2000: 533; van Suntum et al. 2011: 8). According to Eucken, several guiding principles of economic policy can be identified, which need to be put into practice as a coherent whole to guarantee the functioning of a competitive economic order (Eucken 1952/1990: 254ff.). These can be divided into constitutive principles, which are required to establish a competitive economic order, and regulative principles, whose implementation keeps it functional (ibid., see Table 3.2). Generally, Eucken's principles are still regarded as practically relevant for economic policy today, although with some limitations and specifications (e.g. concerning conclusions about perfect competition and monopoly control) (Cassel and Kaiser 2000; van Suntum et al. 2011).

While most of Eucken's principles yield implications for the constitution of the economy as a whole, several principles also apply to the more specific field of bioenergy policy. Besides the general demand that a functioning price mechanism and competitive framework should be established, the requirement of a continuous policy framework has major implications for bioenergy policy design. According to Eucken (1952/1990: 288), frequent policy changes can increase the uncertainty of market actors to such a degree that investments would no longer be undertaken unless they had very short payback periods. The demand for stable political framework conditions does not necessarily mean that policies need to be unchangeable, making them unable to react to changing developments; rather, policy changes must not be discretionary, but designed so that they can be anticipated by market actors well in advance (Budzinski 2000: 254ff.). Moreover, a clearly defined and reliable hierarchy of policy aims contributes to a constant policy framework, as changing political priorities can be a major cause of abrupt policy changes and a source of uncertainty for market actors (Hamm 2000: 108; Gawel and Hansjürgens 2013).

Regarding the case for state interventions in support of bioenergy, the regulative principle of correcting national accounting calls for interventions to address external effects; however, given the general formulation of the principles, implications for instrument choice are not entirely clear. While a preference for market-based instruments seems probable, as these maintain a greater scope for individual freedom of action (Pahl 2001: 128), Eucken's regulatory principles could, in principle, also be used to justify discretionary interventions (Cassel and Kaiser 2000: 86). Furthermore, similar to an environmental structural policy concerned with the problem of knowledge, the constitutive principles emphasise the importance of property rights and liability rules (Pahl 2001: 133f.). From the principle of open markets, meanwhile, the implication can be derived that policy should be designed in a way that does not obstruct competition, either between technologies or between national and international market actors.

3.4.3 Implications for Bioenergy Policy Advice

In contrast to neoclassical economics, the theory of economic order places a strong focus on government failures and formulates requirements for policy design under uncertainty. The theory of economic order highlights the limits of steering knowledge and warns policy makers against overestimating it, which appears very relevant for a complex issue with numerous side effects and interactions such as bioenergy policy. Instead of attempting to bring about certain outcomes, such as the uptake of certain bioenergy technologies or the use of certain feedstocks, the theory recommends focussing on the design of framework conditions in relevant sectors that are conducive to competition, and incentivise dynamic innovative processes and structural changes compatible with social aims (Pahl 2001: 171). In a similar way to neoclassical economics, this implies technology-open policies rather than support for specific bioenergy technologies, although in this case, the prime motivation is not the assumption that the lowest cost options get selected in an optimisation process, but rather the wish to enable trial-and-error processes and the discovery of new knowledge. Nonetheless, even approaches that recognise the need for process policy interventions are adamant that policies supporting specific technologies as a means of reaching policy aims are more likely to lead to an intervention spiral than be successful (cf. Wegner 1996). Consequently, a structural policy approach to the aims of bioenergy policy would consist of discouraging the use of high carbon options or options with low security of supply. Another important element of such a policy would be to abolish existing process policy interventions that limit competitiveness and create barriers to the diffusion of low carbon technologies in relevant sectors, for example by correcting taxes and phasing out environmentally harmful subsidies.

Moreover, a central requirement that also applies to the—from the theory of economic order perspective—suboptimal case where a specific bioenergy policy exists, is the insight that policies should have a certain continuity, which also requires a reliable hierarchy of policy aims.

Nonetheless, the structural policy approach displays certain limits, which need to be considered when drawing implications for bioenergy policy. For one, transaction costs and the incompleteness of contracts in a world of imperfect knowledge is not sufficiently taken into account; as explained further in Sect. 3.5, this may prevent socially desirable transactions from occurring, if only structural policy is employed (Oberender and Christl 2000: 533ff.). For example, a strict application of the liability principle endorsed by both Hayek and Eucken is likely to prevent a fair number of investments, because bearing the liability for environmental damages which are as yet unknown would prove too risky. Moreover, in the bioenergy context the implementation of liability rules faces limits because of the cumulative and long-term nature of damages, the relevance of the spatial dimension, and the existence of indirect effects (Pahl 2001: 169). More generally, bioenergy policy recommendations need to take into account that the existing economic order is shaped by process policy interventions and lock-in effects which can cement inefficient institutional frameworks (ibid.: 259). As a result, structural policy measures may be out of bounds for political feasibility or transaction cost reasons, for instance. Importantly, incentives that policy makers face tend not to support structural policy interventions, but process policy ones (Cassel and Kaiser 2000: 91). Addressing this would require constitutional reforms, which is out of bounds for the formulation of bioenergy policy advice. In short, second-best constraints which limit the practical applicability of neoclassical "optimal" policy recommendations also apply to the theory of economic order's primacy of structural policy (cf. Sect. 3.2). Such constraints are taken into account by new institutional economics approaches, which are therefore examined in greater detail in the following section.

3.5 Why Institutions Matter: Contributions from New Institutional Economics

The school of new institutional economics (NIE) seeks to fill the institutional vacuum that is left by the neoclassical equilibrium analysis. As outlined in Sect. 1.2, NIE encompasses both the positive analysis of the effects that institutions have on human behaviour and social outcomes, as well as the normative analysis of their design (Erlei et al. 1999: 42). An institution can be understood as a set of rules (including instruments for their implementation), which aim to steer individual behaviour in a certain direction (Richter and Furubotn 2003: 7f.; Erlei et al. 1999: 23ff.; Schotter 1986: 117). Institutions can be formal, such as rules of private or public law, or informal, such as conventions; also, they may be self-enforcing, or enforced through external coercion (Richter and Furubotn 2003: 7f.). The institutional perspective significantly reduces the degree of abstractness of economic analysis, as compared to the neoclassical approach (cf. Sect. 3.1). For example, viewing markets as institutions, rather than as mechanisms for bringing demand and supply in equilibrium, has important implications for policy analysis—the problem of addressing market failures now goes beyond the matter of correcting prices, but involves a change of institutions that govern economic exchange, including formal and informal rules of cooperation, legal framework conditions, and policy instruments (cf. Richter and Furubotn 2003: 339ff.).

Exploring the implications of bounded rationality, uncertainty and ignorance play an important role in both the positive and normative analysis of institutions (Williamson 2000; Dequech 2006).[13] At the same time, assumptions of scarcity and competition, which Ménard and Shirley (2005: 2) term the "successful core of neoclassical economics", remain accepted, as does the perspective of methodological individualism, which places the behaviour of human actors with diverse preferences in the focus of the analysis (Richter and Furubotn 2003: 3). In this respect, NIE differs from old institutional economics, while making it easy to apply to the allocative problems of bioenergy use as examined in Chap. 2. Moreover, by taking transaction costs, the incompleteness of private and public contracts, the determinants of political decision making processes and institutional path dependencies into account as central parts of the analysis, NIE allows for a more differentiated analysis compared to the economic theory of order.

In the following, principles of NIE and its different theoretical strands are analysed for insights regarding the design of bioenergy policy.

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[13] Although, given the diversity of theoretical approaches that fall under NIE, the degree to which these forms of "strong" uncertainty (cf. Dequech 1997) and the bounded rationality assumption are incorporated into analyses differs (Dequech 2006).

3.5.1 Principles of New Institutional Economics

At a fundamental level, institutions can be understood as humans' attempt to deal with uncertainty in a physical and social environment which is constantly evolving (North 2005: 14f.). By defining and limiting the choice sets of individuals, institutions decrease the complexity of the environment in which decision making takes place and allow for the creation of stable expectations as to other people's actions (Langlois 1986; North 1990a: 3f.; North 2005: 48f.). By acting as the "rules of the game" (North 1990a: 3), institutions provide structure to the environment, and make it more predictable (North 2005: 15).

Following Williamson (2000), it is useful to distinguish between several levels of institutional analysis, according to the degree to which institutions are amenable to change and the purpose displayed in their design (Fig. 3.1). Socially and culturally embedded informal institutions make up the top level, followed by the formal rules which constitute the institutional environment, such as the legal framework and the allocation of property rights.[14] Governance structures in organisations and policies emerge as the "game" is played within the existing formal rules and institutional environment (Dixit 1996: 30f.), and in turn affect the incentives that players face, as expressed in prices and quantities on markets. Neoclassical analysis traditionally focuses only on this last level. While higher order levels place constraints on subsequent levels, feedbacks act in the opposite direction. For example, an emissions tax enacted on the governance level not only affects prices and quantities, it also implicitly changes existing property rights (cf. Sect. 3.1.1). Likewise, formal rules may over time lead to changes in informal institutions (Williamson 2000).

In decision making, individuals are constrained by all four nested levels of institutions simultaneously. However, while the institutional environment and informal institutions have been found to have a significant impact on economic performance and development (cf. North 1990a, 2005), they are difficult to change intentionally, as they tend to emerge in an evolutionary process over timescales of decades to centuries (Williamson 1996: 4f.). Governance structures are more amenable to purposeful design, although they too might have evolutionary origins, and design options are constrained by higher-level institutions (Williamson 1996: 4f.). Nonetheless, the scope for purposeful design on manageable timescales is what makes governance structures (such as individual policy instruments) and their interplay a useful focus for bioenergy policy analysis. The institutional environment and informal institutions, on the other hand, can be taken as given, at least in the medium term.

Meanwhile, although institutions reduce uncertainty, they do not succeed in eliminating it; given the complex and constantly changing nature of the human

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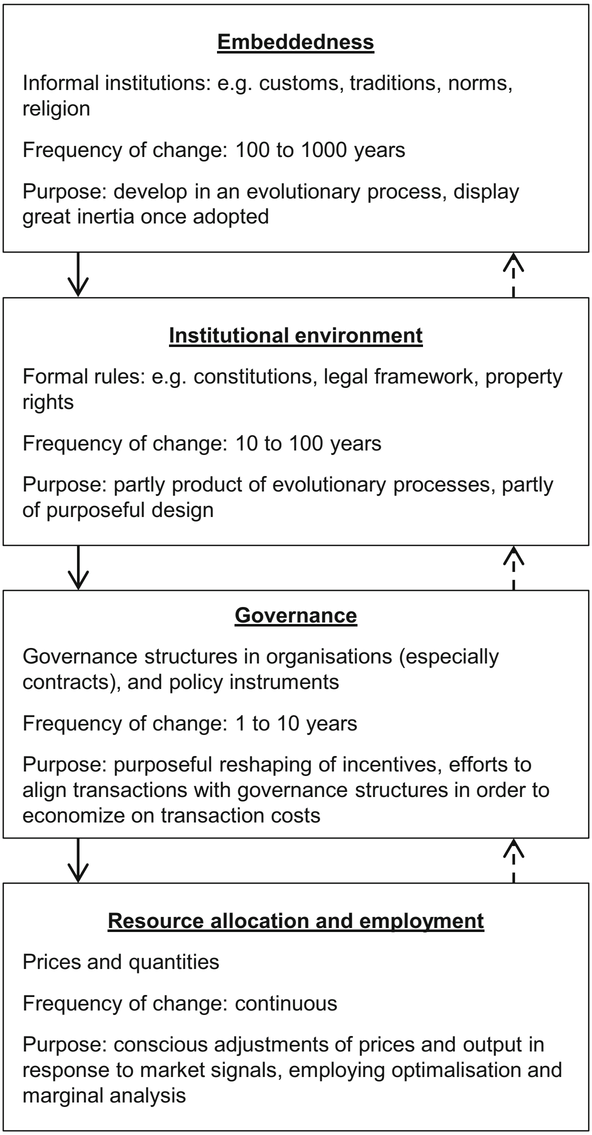
[14] Property rights encompass a bundle of rights, such as the right to use a good and draw income from it, the right to change and transform a good, or the right to transfer a good (Richter and Furubotn 2003: 90).

Fig. 3.1 Williamson's nested institutional framework (based on Williamson 2000: 597, complemented by Dixit 1996: 51ff. Note: solid arrows indicate constraints, dashed arrows indicate feedback)



environment and the transaction costs involved in planning for contingencies, contracts established through rules and other institutional arrangements remain necessarily incomplete (Dixit 1996: 30f.; North 2005: 2). Moreover, there is no guarantee that the institutional framework is efficient. Evolving from a process of social interaction, institutions reflect the interests of social groups with the power to change rules (North 2005: 15). For some parts of society, institutions can even become a source of uncertainty in themselves, depending on "who makes the rules and for whom" (North: 2005: 15), and with what objectives. This has important implications for policy making. Even though, as part of the governance level, policies and policy instruments can be purposefully designed, they do not typically emerge from a perfectly informed process of welfare maximisation, but rather from a political bargaining game between different interest groups under uncertainty (Dixit 1996: 11). Focussing on feasible institutional options, which take transaction costs and political constraints into account, NIE therefore deals with alternatives which are all flawed (Dixit 1996: 8ff.; Williamson 2000). To choose between alternatives, Williamson proposes the remediableness criterion, according to which "an outcome for which no feasible superior alternative can be described and implemented with net gains is presumed to be efficient" (Williamson 1996: 195).

To varying degrees, all of NIE's major strands (cf. Erlei et al. 1999; Voigt 2002; Richter and Furubotn 2003)—transaction cost economics, contract theory, principal-agent theory, the theory of institutional change, public choice theory, property rights theory—have been applied to problems of policy making and, more specifically, environmental governance (e.g. Balks 1995; Paavola and Adger 2005; Vatn 2005; Paavola 2007; Gerber et al. 2009; Ménard 2011; Gawel 1995b).[15] In the following, the first five of these theoretical strands shall be examined more closely regarding their implications for bioenergy policy; property rights theory shall be neglected, because as part of the institutional environment, the definition and basic allocation of property rights is taken as given. Notwithstanding this, policy instruments affect and alter existing property rights, which has repercussions for the transaction costs and political feasibility of instrumental alternatives (Balks 1995: 24f.; Krutilla and Krause 2011: 287). Meanwhile, NIE insights have also been successfully applied to the economic analysis of law (for an overview, see Picot and Dietl 1993; Kirstein 2003; Polinsky and Shavell 2008), and—more specifically—environmental law (e.g. Eide and Van den Bergh 1996; Gawel 1999; Gawel and Lübbe-Wolff 1999). Findings on the design of legal rules are incorporated into the subsections of this chapter, depending on the branch of NIE they are primarily related to. Moreover, the law and economics perspective proves relevant in Chap. 5, when it comes to the analysis of impacts that German legal rules (especially those pertaining to renewable energy law) have on bioenergy allocation.

3.5.2 The Transaction Cost and Contract Perspective

The costliness of all transactions is a central tenet of NIE (Richter and Furubotn 2003: 53; Ménard and Shirley 2005: 1). In a neoclassical world with perfect information, transaction costs would be zero, and individuals could organise their

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[15] An early focus was placed on the governance of natural resources under common property regimes (Ostrom 1990), but the formation of a new institutional environmental or ecological economics framework is still a work in progress (Paavola and Adger 2005; Ménard 2011).

transactions by setting up complete contracts that cover all future contingencies and whose implementation could be flawlessly controlled and enforced (Richter and Furubotn 2003: 13). With costless contracting, the need for economic organisation, for example in hierarchically structured firms, would vanish (Williamson 1979), and even policy interventions to correct market failures would in many instances become superfluous. In the case of externalities, the Coase theorem states that in a zero transaction cost world, producers of externalities and parties affected by them can arrive at a Pareto-optimal outcome through bargaining—the precondition for such a private internalisation of externalities being the existence of well-defined property rights (Coase 1960).[16]

In reality, however, imperfect information and positive transaction costs are the norm, and in many cases prevent individual bargaining solutions. By acting as constraints on individual behaviour and channelling individual actions towards certain social outcomes, institutions reduce uncertainty, and economise on the costs of transactions (Schotter 1986: 117; Erlei et al. 1999: 23ff.). As defined in Sect. 2.2.3.5, transaction costs encompass search and information costs, bargaining and decision making costs, as well as monitoring and enforcement costs and arise both in market transactions and in policy making (Dahlman 1979: 148). In case of the latter, transaction costs arise both on the side of the regulators and the regulated parties in all stages of the policy process (see Table 2.7). In the choice and design of policy instruments, the challenge lies in selecting feasible options which minimise the sum of transaction costs and production costs involved in implementing a given policy aim. Between the two cost types, however, trade-offs may occur (Krutilla and Krause 2011: 284ff.; McCann 2013).[17] The magnitude of transaction costs, meanwhile, is influenced by many factors, including physical and spatial characteristics of the governance problem, the state of available technology (e.g. for monitoring purposes), the institutional environment and informal institutions [see McCann (2013) for a comprehensive review]. Transaction cost economics (TCE) focuses on how specific attributes of transactors and transactions influence transaction costs, and how distinct governance structures can be aligned with transactions in order to economise on transaction costs (Williamson 2005). According to Williamson (1999: 312), this "discriminating alignment" forms the basis for explaining the choice of governance structures between market and hierarchies in economic organisation. Governance, in this sense, can be understood as "the means by which order is accomplished in a relation in which potential conflict threatens to undo or upset opportunities to realize mutual gains" (ibid.: 312). Originally applied to problems of production coordination, such as "make or buy" decisions in firms

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[16] In the case of environmental pollution externalities, for example, individuals whose utility is negatively affected by pollution could offer emitters compensation for reducing emissions, or they could agree on a compensation for accepting some level of pollution. Independent of the initial distribution of property rights, the resulting level of emissions would be Pareto-efficient (Coase 1960).

[17] For example, while tradable permit schemes for emissions deliver lower overall abatement costs (cf. Sect. 3.1.2), transaction costs can be comparatively high (e.g. Ofei-Mensah and Bennett 2013).

(e.g. Coase 1937; Williamson 1979, 1981), the concept has been extended to policy design (e.g. Dixit 1996; Finon and Perez 2007; Coggan et al. 2010), and indeed the organisation of the political decision making process itself (e.g. North 1990b; Dixit 1996). In all three contexts, the basic unit of analysis is a transaction or a "contract" (Dixit 1996: 48; Williamson 2005: 47). In the context of public policy, parties to contracts are, on the one hand, regulators, i.e. politicians and administrative agents, and the regulated, for example, producers and consumers. On the other hand, a contractual relationship also exists between regulators and citizens, wherein the contract can be described as a "promise of a policy (or program) in return for votes" (Dixit 1996: 48). This last dimension shall be discussed further in Sect. 3.5.5. Whereas economic contract theory is generally concerned with the effects that different contract structures have on incentives and human behaviour, TCE focus specifically on transaction cost implications (Richter and Furubotn 2003: 171f.).[18] Below, key attributes of transactors, transactions and governance structures are described and applied to the bioenergy context, before drawing implications for bioenergy policy design.

3.5.2.1 Attributes of Transactors

Human actors who execute transactions are described as far-sighted but boundedly rational, resulting in contracts which strive to account for future contractual hazards but remain unavoidably incomplete (Williamson 2005: 46). Contractual incompleteness, however, can be taken advantage of by actors who are opportunistic. Described by Williamson as "self-interest seeking with guile", opportunism as the second major behavioural assumption of TCE may cause actors to strategically break commitments, disguise their own characteristics or preferences, and withhold or falsify information in order to gain a personal advantage (Williamson 1981: 554). Consequently, contracts are not self-enforcing and need to be supported by credible commitment and mechanisms for monitoring and enforcement (Williamson 2000: 601).[19]

3.5.2.2 Attributes of Transactions

Regarding transaction attributes, Williamson (1979, 1981) identifies uncertainty, the frequency with which transactions recur, and asset specificity as central

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[18] The principal-agent approach is another strand of NIE which makes major contributions to contract theory, focussing on problems which arise from information asymmetries between contracting parties (see Sect. 3.5.3).

[19] Trust and shared preferences between contractual parties can reduce the scope for opportunism, in the same way as social connectedness through membership in a common community or network can (Coggan et al. 2013: 225).

dimensions. In the bioenergy context, most relevant transactions are recurrent in nature, so that the focus here is placed on uncertainty and asset specificity.

Given the impossibility of covering all possible contingencies in contracts, uncertainty gives rise to disturbances in contractual relationships, which require adaptive responses (Williamson 1985: 56ff.). More specifically, sources of disturbances are found in behavioural uncertainty concerning the actions of opportunistic parties, institutional uncertainty about what a party may be contracted to do, and biophysical uncertainty regarding the future state of the natural environment (Williamson 1985: 57ff.; Coggan et al. 2013: 224). While the relevance of behavioural and biophysical uncertainty for bioenergy governance is obvious, institutional uncertainty is directly influenced by the institutional environment and institutions of the governance level (Coggan et al. 2013: 224). When transactions are surrounded by high uncertainty in any or all of these dimensions, the capacity for effective adaptation becomes a key requirement that efficient governance structures have to meet (Williamson 1985: 56).

Asset specificity describes the degree to which a transaction requires durable, specialised investments, which "cannot be redeployed to alternative uses except at a loss of productive value" (Williamson 1996: 377). Transaction-specific investments can take various forms—using bioenergy as an example, specialised physical assets (such as biogas plants), site-specific assets (e.g. investments in local heating grids), human assets (e.g. training in specific conversion technologies and learning by doing), dedicated assets (e.g. long-term contracts for the purchase of bioenergy carriers), and organisational assets (e.g. trade and other relationships, established business practices) all seem particularly relevant (Williamson 1985: 55). Again, the incompleteness of contracts can give rise to contractual hazards if parties which have specialised for each other act opportunistically to take advantage of bilateral dependencies (Williamson 1996: 377). If a party undertakes a transaction-specific investment, they become subject to hold-up risks, as their partner might opportunistically attempt to renegotiate contract terms in the knowledge that the asset's economic value would be lower in the next best alternative utilisation option. Against the risk of being expropriated of quasi-rents (i.e. the surplus in economic value derived from specialised asset employment compared to the next profitable utilisation), contractual safeguards have to be provided; otherwise specialised investments would not take place (Williamson 1985: 52ff.; Finon and Perez 2007: 81).

3.5.2.3 Attributes of Governance Structures

Williamson (1996: 4f.) distinguishes between institutions that belong to the institutional environment (such as constitutions, the legal framework, and property rights) and institutions of governance, i.e. governance structures (see Fig. 3.1). Governance structures cover the spectrum from market to hierarchy, with hybrid forms in-between (Williamson 1996: 103f.). Other than the institutional environment, which acts as a composite on macro-variables such as economic growth or development, governance structures operate at the level of individual transactions (Williamson 1996: 5). In the bioenergy context, governance structures can be interpreted as different forms of private or regulatory contracts that affect allocation decisions in bioenergy value chains. For example, a biofuel producer can source feedstocks via an "anonymous" market, or contract bilaterally with a primary biomass producer, establishing quality-oriented criteria and some form of monitoring scheme. In this example, mandatory sustainability certification would act as a regulatory contract, which would change the incentives biofuel producers face, and force them to adapt their private contracts. When it comes to firms organising their production decisions, hierarchy, as the opposite pole of markets, is commonly interpreted as vertical integration; the regulatory context finds its equivalent in the administration of allocation through public bureaucracies (Dixit 1996; Williamson 1999; Ménard 2011: 117). Policy instruments, however, predominantly fall into the category of hybrid governance structures, with the balance between the polar modes market and hierarchy being determined by their contractual design (Williamson 1996: 104).

Each governance structure can be described as a number of "internally consistent" attributes, which have different strengths and weaknesses when it comes to adapting to disturbances arising from the various relevant uncertainties (Williamson 1996: 103ff.). Markets provide high-powered incentives, because actors directly bear the consequences of their own actions. In this way, they support autonomous adaptation to disturbances, as each party attempts to find cost-efficient solutions using the time- and space-dependent knowledge available to them (Hayek 1945; Williamson 1999: 312). However, with increasing bilateral dependency between parties, there is a need for coordinated responses to disturbances. In orchestrating cooperative adaptation with a greater systems orientation, hierarchies perform better than markets; this comes at the cost of lower incentive intensity, because gains and losses associated with actions are no longer the sole responsibility of each party, and their distribution is subject to negotiation (Williamson 1996: 103, 1999: 312). As incentive intensity decreases, the need for administrative controls grows, and market incentives are replaced by monitoring mechanisms, penalty schemes and other administrative enforcement mechanisms which are associated with bureaucratic costs (Williamson 1996: 103f.). Besides incentive intensity and administrative controls, the predominant contract law regime forms the third central governance attribute, with disputes in markets being open to court ordering, whereas the options for court appeals in case of hierarchic governance are more limited (Williamson 2005: 48).

Hybrids, on the other hand, possess intermediate values for the three governance attributes and their adaptive performance. By combining ownership autonomy with long-term contracts, contractual safeguards, and administrative support delivered by bureaucratic agencies, they allow for a balance between the advantages of autonomous and cooperative adaptation (Williamson 1996: 104f.). It falls to the specific contractual design to solve trade-offs between the respective strengths and weaknesses of different hybrid modes (cf. Finon and Perez 2007). While markets and hierarchies can be considered as extreme ends of the spectrum of governance structures, different forms of hybrids form the focus of interest in the context of bioenergy policy analysis.

3.5.2.4 Aligning Transactions with Governance Structures: The Case of Bioenergy

Among the different attributes of transactions, asset specificity is regarded as the most important one for explaining the alignment of transactions with governance structures (Williamson 1996: 105ff.). As asset specificity deepens, the degree of bilateral dependency between parties increases, and with it the need for safeguards and coordinated responses to disturbances. One option for dealing with bilateral dependency are relational contracts; these are long-term agreements, which do not attempt to address all possible contingencies, but arrange for procedures which are to be followed when future problems and adaptation needs arise (Macneil 1974: 753; Williamson 1985: 70; Richter and Furubotn 2003: 185). However, there is a limit to the legal bindingness of such incomplete, relational contracts, so that mechanisms of private ordering need to be in place to guard against opportunistic behaviour (Richter and Furubotn 2003: 185ff.). As the need for binding safeguards increases, the preferred governance mode for transactions involving highly specialised investments tends to shift towards hierarchy (Williamson 1996: 106ff.).

In the bioenergy case, the degree of asset specificity and bilateral dependency differs greatly between bioenergy pathways and specific allocation decisions along value chains. On the utilisation side in particular, asset specificity is significant—here, capital intensive investments in highly specialised equipment are required, be it biomass-fuelled electricity or heating plants, biofuel refineries, or—on a smaller scale—domestic heating installations. The further removed a biomass utilisation is from commercial competitiveness, the higher the degree of bilateral dependency and the greater the need for contractual safeguards—if a biogas plant, for example, is reliant on public support to sell its electricity, the difference between specialised asset deployment and the next profitable employment may amount to its entire income streams (cf. Williamson 1985: 52f.). Between primary biomass producers and bioenergy producers, on the other hand, the degree of bilateral dependency is moderate—primary producers can sell their biomass to numerous purchasers in different biomass utilisation sectors, and adapt land-use decisions according to demand at least in the mid-term.[20] Likewise, bioenergy producers have a choice of biomass suppliers to enter into contracts with, although dependency on suppliers increases with growing competition for feedstocks.

According to Williamson's discriminating alignment hypothesis (Williamson 1996: 105ff.), it is sensible to govern allocation decisions with low asset specificity

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[20] Nevertheless, perennial, specialised energy crops result in higher asset specificity than, for example, maize, with multiple utilisation options, exemplifying the diversity of transactions involved even at one specific stage of the value chain.

and multiple actors on the supply and demand side by markets or hybrid instruments close to the market governance mode, and introduce hybrid instruments which lean more strongly towards hierarchical governance as bilateral dependency becomes more pronounced. In particular, in the electricity and transport sectors, where very few biomass applications are competitive, the government effectively acts as a monopsony, determining demand for bioenergy through regulation. In order to incentivise highly specific investments, the existence of reliable safeguards is therefore critical (cf. Finon and Perez 2007). On the one hand, relevant safeguards relate to the level of income and price risks, which can be controlled through the choice and design of price, quantity or hybrid instruments for deployment support (Finon and Perez 2007; Menanteau et al. 2003). On the other hand, profitability of investments is also determined by the costs that bioenergy producers incur, including technology-specific investment costs and, importantly, feedstock costs. Safeguards relating to the cost-side of bioenergy production can be provided by offering technology- and feedstock-specific cost-based support (cf. Scheftelowitz et al. 2014: 127). At the same time, allocation decisions regarding the choice of technology-feedstock combinations are highly complex, and have multiple impacts upstream and downstream in the value chain (see Chap. 2). Therefore, the benefits of safeguards and cooperative adaptation to changing framework conditions (e.g. technology and feedstock cost developments) have to be balanced with the high information requirements and bureaucratic costs hierarchical governance modes would entail. The overarching challenge for bioenergy policy design, consequently, is how to provide sufficiently secure safeguards, while still retaining an appropriate degree of market incentives and autonomous adaptation.

3.5.2.5 Credible Commitment

Even if safeguards are implemented in the regulatory contract (e.g. by guaranteeing feed-in tariffs for 20 years, as in the case of the German Renewable Energy Sources Act), they need to be accompanied by credible long-term commitment of policy makers in order to be effective (Dixit 1996: 62ff.; Williamson 1996: 335f.).[21] If credible commitment is lacking, the risk remains that contractual safeguards will be broken and quasi-rents expropriated (Finon and Perez 2007: 83). In order to be credible, Dixit (1996: 62) states that commitment must be clear and observable to all ex ante, and irreversible ex post; this comes, however, at the price of reduced flexibility to react to future disturbances. Also, credible commitment may be difficult to establish for a number of reasons, of which Williamson (1996: 335f.) and Weingast (1993) highlight three:

Firstly, politicians may prefer the use of discretionary over rule-based interventions, in order to realise short-term benefits and respond to shifts in power relations. In the interest of long-term efficiency, commitment to rules which limit the degrees

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[21] Highlighting the importance of long-term political commitment, the concept shows strong parallels to Eucken's "continuity of economic policy" principle (see Sect. 3.4.2).

of freedom that policy makers have would be beneficial (cf. Kydland and Prescott 1977). To maintain flexibility, Dixit (1996: 64) recommends the use of conditional contingent-response rules, given that inflexible, unconditional rules may perform just as badly as discretionary interventions. Of course, taking into account the complexity of the environment and the limited foreseeability of the future, contingent-response rules will always remain incomplete contracts.

Second, the democratic system with its election cycles poses challenges for the time consistency of policies. Politicians may not be able to bind their successors to promises made; as a result, they may give preference to policies and projects whose benefits are concentrated in the early implementation period, rather than accrue over the long-term.

Third, rather than maximise overall welfare by committing to a course of action, politicians may adopt a looting strategy to secure a "big (and certain) piece of a small pie" (Williamson 1996: 336) for favoured constituencies in the short-term.

In the light of these challenges, establishing mechanisms for delivering credible commitments which limit the scope for opportunistic actions ex post is challenging (cf. Williamson 1996: 336). Dixit (1996: 65ff.) proposes locking-in actions in institutional design, the delegation of authority to independent agencies (as practiced in monetary policy with independent central banks), and making use of reputation as a valuable capital asset with long-term benefits in repeated games. Also, safeguards in the higher order institutional environment and mechanisms for punishing deviations from regulatory contracts play an important role (Dixit 1996: 74). For example, in German law the protection of legitimate expectations ranks as a constitutional principle, and infringements can be brought before the courts (Schwarz 2002). In this way, certain safeguards are provided against a sudden termination or renegotiation of existing regulatory contracts (Langniß 2002: 6; Finon and Perez 2007: 88).

3.5.3 Asymmetric Information and the Principal-Agent Approach

Principal-agent problems arise in the presence of asymmetric information between the parties involved in a contract. Information asymmetry exists when an agent, who is charged with carrying out some task for a principal, has an information advantage over the principal or can carry out unobserved actions (Arrow 1984; Stiglitz 2008). If there is at least a partial conflict of interest between principal and agent, the agent has an incentive to use these advantages to further his own interest, i.e. to behave opportunistically (Dixit 1996: 51f.). Principal-agent theory provides insights for dealing with opportunistic behaviour ex ante, i.e. before the contract is finalised, and ex post in the implementation period. In general, the policy process is characterised by multiple principal-agent relationships; voters can be cast as principals and politicians as their agents, just as legislative authorities are principals of bureaucratic agencies charged with implementing policies (Dixit 1996: 51f.). In regulation, politicians and public agencies can be described as principals, whereas the regulated parties act as agents (Haberer 1996: 109). Here, the focus shall be on this latter form of principal-agent relationships.

Principal-agent theory distinguishes two major problems which can arise in the presence of asymmetric information. Adverse selection can occur if the agent possesses hidden information before a contract is closed, leading the principal to select contractual partners with unfavourable characteristics. If, on the other hand, principals cannot observe the agent's actions during contract implementation, and outcomes are influenced by stochastic factors so that the agent's performance cannot be reliably inferred from them, there is a risk of moral hazard such as shirking, non-compliance with contractual agreements, etc. (Arrow 1984; Voigt 2002: 103f.). To address these problems, principal-agent theory examines the design of schemes relying on incentives, penalties, monitoring or cooperation, which attempt to entice agents to reveal hidden information or align their interests with those of their principal when taking hidden actions (Miller 2005).

Different from other branches of NIE, principal-agent theory widely relies on the assumption of full rationality, relaxing it only as far as information asymmetries are concerned; both principals and agents are modelled as taking optimal decisions in view of the given constraints, resulting in complete—and often highly complex and context-specific—contracts (Arrow 1984; Haberer 1996: 111; Erlei et al. 1999: 166f.). While this limits the practicality of normative recommendations for real-life applications (Haberer 1996: 111f.; Erlei et al. 1999: 166f.; Richter and Furubotn 2003: 238f.), the theory's focus on information asymmetries nevertheless yields useful insights for bioenergy policy. Bearing these limits and partial contradictions with transaction cost economics in mind, the problems of adverse selection and moral hazard as well as theoretical starting points for solutions are discussed using two examples: the selection of technologies in renewable energy support schemes, and attempts to ensure the sustainability of primary biomass production practices.[22]

3.5.3.1 Adverse Selection in the Governance of Bioenergy Technology Choices

In market-based instruments such as GHG emissions taxes and tradable permit schemes, the problem of asymmetric information about abatement costs is solved by leaving technology choices to emitters (cf. Sect. 3.1.2). However, if policy makers wish to encourage investments in specialised equipment, like renewable energy plants, findings from transaction cost economics imply that governance

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[22] Among the major types of uncertainty in bioenergy policies making (cf. Table 2.6), information asymmetries appear most relevant in the case of technology costs and primary production conditions. While adverse selection is discussed for technology governance and moral hazard for primary production choices, in practice both forms of asymmetric information problems are relevant in both cases, often showing some overlap (cf. Erlei et al. 1999: 166).

modes close to the market end of the spectrum may not be appropriate; in the absence of safeguards which ensure planning security, few transactions involving policy-specific investments would take place (cf. Sect. 3.5.2). Hybrid instruments which are closer to the hierarchy side of the governance spectrum can be used to solve this problem. Feed-in tariffs (FIT), for example, which offer guaranteed prices to energy producers, offer a high degree of planning security for investors (Mitchell et al. 2006; Klein et al. 2010; Haas et al. 2011). As a result, risk premiums are found to be lower than under quantity instruments for RES support, such as quota schemes, leading to lower overall costs of achieving RES targets (Menanteau et al. 2003; Finon and Perez 2007). In FIT schemes, policy makers have to set prices based on the costs of the technologies they wish to see participating in the market, at a level that is consistent with reaching RES expansion targets. Meanwhile, producers of each technology group, such as bioenergy, have an incentive to overstate their costs, in order to increase their profits—a problem which is also well known from the regulation of monopolies, although in the multiple agent-case of RES producers, wider opportunities for comparing performance and establishing benchmarks exist (cf. Arrow 1984; Noth 1994: 270f.). If FIT rates are set too high, high cost producers are pooled with low cost ones, and windfall profits accrue for the latter; but if FIT rates are set too low, RES expansion targets will be missed. The challenge, therefore, is to design schemes which give producers incentives to truthfully reveal their costs.

Generally, principal-agent theory suggests three options for separating high cost from low cost producers: screening, signalling and the design of contracts which support self-selection (Noth 1994: 269ff.; Balks 1995: 92f.; Dixit 1996: 55). Firstly, policy makers can incur costs to screen technologies, for example by funding research projects which establish benchmarks. Secondly, they can attempt to design support schemes so that RES producers have incentives to signal their true costs, for example by auctioning off contracts for a predefined quantity of energy produced from renewable sources (Groscurth and Bode 2011). Differentiated targets for different RES technologies are possible, forcing, for example, bioenergy producers to compete with each other by price and reveal their costs. In practice, the design of auction schemes for renewables is a complex undertaking, and tendencies to underbid competitors with unfeasibly low prices have resulted in high failure rates among projects in the past (e.g. Finon and Perez 2007; Batlle et al. 2012). Alternatively, if regulatory activities such as the setting of FIT rates are understood as a political process (cf. Dixit 1996: 93), representatives of technology groups may have incentives for not overstating true costs too much, in order not to jeopardise public support for their technologies.

In the third case, principals can offer agents a choice between several distinct contracts, leading them to indirectly reveal their type by picking the contract that is most advantageous to them (Balks 1995: 92 f.). This idea has, for example, been applied to the design of regulatory contracts with monopolies (cf. Laffont and Tirole 1993). In renewable energy policy, an option would be to offer low-risk FIT in parallel with an instrument that leaves producers with a larger share of the price risks, but also offers them the chance to gain higher profits, such as a fixed feed-in premium (cf. Klessmann et al. 2008). In this example, the expectation would be that producers with low costs and technologies that are closer to commercial competitiveness would choose the latter instrument.

In all of these solutions, the presence of asymmetric information gives rise to agency costs, which cause the allocative outcome to be second-best compared to a situation with perfect information (Dixit 1996: 52ff.). Compared to a first-best outcome in the perfect competition model in which profits are driven to zero, under asymmetric information agents have to be allowed positive profits of a level sufficient to give them incentives to reveal their true costs (Noth 1994: 270; Dixit 1996: 86). Hybrid renewable energy support schemes relying on the revelation of asymmetric cost information, therefore, have to figure in information rents.

3.5.3.2 Moral Hazard Risks in the Governance of Primary Biomass Production

Insights from principal-agent theory have been fruitfully applied to the implementation of environmental standards and financial incentives for the production of public goods in agricultural policy (e.g. Ozanne et al. 2001; Fraser 2002; Yano and Blandford 2011). If adherence to schemes' requirements is costly and cannot be perfectly monitored, farmers have an incentive for non-compliance, and moral hazard risks arise. This problem can be transferred to the implementation of minimum sustainability requirements for bioenergy production, which have been introduced for biofuels and liquid biomass in the electricity sector (see Chap. 4).

Information asymmetries are particularly high for non-point source pollution where it is not possible to unequivocally identify the source of environmental impacts (cf. Chambers and Quiggin 1996). An example of this is the excessive or inappropriately timed application of fertilisers and fermentation residues in fields, resulting in nutrient run-off and nitrate pollution of groundwater resources (cf. COM 2013). Direct land use changes (e.g. conversion of grasslands or forests for energy crop production) are more easily attributable to biomass producers, but monitoring is associated with costs. Besides other environmental and also socio-economics impacts, information asymmetries between primary biomass producers, biomass purchasers upstream in the value chain and policy makers also affect the calculation of credible GHG balances; for example, fertiliser use can have significant impacts on a bioenergy pathway's life cycle GHG emissions (e.g. Crutzen et al. 2008; Stehfest et al. 2010).

In general, moral hazard problems are addressed through a combination of monitoring schemes with penalties for non-compliance and attempts to align the incentives of agents and principals in contractual design (cf. Miller 2005). Again, every solution is associated with agency costs, making achievable outcomes second-best compared to a case with symmetrical information (Ozanne et al. 2001; Richter and Furubotn 2003: 218). Linking compensation payments—or, as the case may be, price premiums for sustainable production—to a measurable output results in high-powered incentives for the generation of environmental benefits (Balks 1995: 109). For example, proving via certification schemes that local biodiversity or water quality safeguards were not exceeded in energy crop production could be made a prerequisite for receiving public support for bioenergy. However, such a scheme would involve high risks for biomass producers, given that the outcomes are influenced by stochastic factors and the actions of other producers, and are therefore partly beyond their control. Risk averse biomass producers are likely to prefer less high-powered incentives, such as tying eligibility for support to the adoption of certain agricultural practices, even if the compensation received was lower (cf. Dixit 1996: 87). In the absence of a direct link between outcomes and remuneration, however, the implementation of monitoring schemes is necessary, and a trade-off exists between compliance and environmental benefits on the one hand, and monitoring costs on the other (Ozanne et al. 2001).

In this situation, principal-agent theory directs its attention to identifying optimal levels of pollution abatement or external benefit generation, compensation payments, monitoring efforts and penalties (Ozanne et al. 2001; Fraser 2002; Yano and Blandford 2011). Risk attitudes of biomass producers can be identified as an important determining factor of the optimal balance. If producers are risk averse and face uncertainty regarding the likelihood of detection and the output prices for their product, compliance is likely to be higher than for risk neutral producers; on the other hand, if the production practices they are required to adopt increase production uncertainty, risk aversion may also lead to a decrease in compliance (Yano and Blandford 2011). This can have important implications for the design of bioenergy sustainability requirements. For example, especially on marginal land, reducing fertiliser input may increase the variability of yields, which may lead to a higher risk of non-compliance by energy crop producers and higher monitoring requirements (Yano and Blandford 2011: 153).

Furthermore, if compensation payments (or price premiums) just cover additional costs of sustainable production practices, the incentive to cheat increases the higher these payments are (Ozanne et al. 2001: 337). If, however, compensation exceeds additional costs, risk averse producers may be inclined to higher levels of compliance even if monitoring and penalties are held constant, because the costs of detection in terms of rent foregone increase—the same logic finds application in the concept of efficiency wages (Miller 2005: 358). Additionally, qualifying for bioenergy support is not a one-off but a repeated game—if non-compliance at one point in time has negative implications for producers' utility in further plays of the game (e.g. by denying certification to repeat offenders), this acts as yet another deterrent against moral hazard (cf. North 1990a: 55; Miller 2005: 361f.).

3.5.4 The Theory of Institutional Change

Representing the choice and design of policy instruments as an optimisation exercise in empty space would be misleading. Decision making and policy implementation take place in the context of the existing institutional matrix, with manifold interlinkages between institutions of the various institutional levels (cf. Fig. 3.1). Moreover, policy analysis has to take into account the dynamics of institutional change. Not only does the existing institutional framework constrain choices of present actors, but the historical process that has shaped current institutions also constrains future opportunities for change (North 1990a: 92ff.). Centrally, institutional change is found to be path dependent and mostly incremental in nature. Following North's theory of institutional change, the defining characteristics of the process are outlined below, before the implications of path dependence are further explored and applied to the case of bioenergy policy.[23] To conclude, options for breaking institutional lock-in situations and for improving the adaptive efficiency of institutions are discussed.

3.5.4.1 The Dynamics of Institutional Change

Organisations, which can be defined as "groups of individuals bound together by some common objectives" (North 1995: 1), act as the agents of institutional change according to North (1990a: 82ff.; 1995). They constitute the players of the game, whose opportunities are defined by the interaction of institutions as the game's rules and other economic constraints, such as technology, income and preferences (North 1990a: 73). Responding to the incentive structure embodied in the existing institutional framework, organisations invest in those skills and forms of knowledge that are perceived to have the highest pay-off, in order to gain an edge over competitors (North 1990a: 82). While this behaviour reflects the problem of choosing efficient governance structures under given constraints, as analysed by Williamson's transaction cost economics (see Sect. 3.5.2), North (1990a: 79) stresses a second strategy that organisations can adopt: by altering the institutional framework, organisations can increase the pay-off to their specific skills and knowledge sets. Interactions between competing organisations and the political realm therefore form an endogenous source of institutional change (North 1995). But also, exogenous factors such as changes in relative prices, changing preferences or technological innovations create new opportunities which are taken up by economic and political entrepreneurs, eventually resulting in alterations of existing institutions or in the creation of new ones (North 1990a: 82ff.; Brousseau et al. 2011: 11). To be sure, changing institutions is costly, the more so the higher the institutional level at which efforts are directed (cf. Fig. 3.1). Organisations that have adapted to the existing institutional framework will resist changes, particularly if the investments undertaken

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[23] In North's perspective, institutional change is regarded as the result of intentional efforts by humans to control their environment and reduce pervasive uncertainty (North 2005: 1ff.). A second major branch of theories on institutional change follows Hayek's view (Hayek 1969) that institutions and order evolve spontaneously, as the unintentional product of human actions and interactions; whether or not this process leads to efficient outcomes, is the subject of some debate (cf. Leipold 1996; Brousseau et al. 2011). North's perspective is adopted here due to its better applicability to problems of intentional policy design.

have a high degree of asset specificity and would be devalued by the proposed alterations (Kiwit and Voigt 1995; Leipold 1996: 107). As a result, the institutional matrix at any point in time reflects the relative bargaining strengths of coalitions that promote or oppose changes (North 1995; Brousseau et al. 2011: 11).

3.5.4.2 Path Dependence, Institutional Efficiency and the Carbon Lock-in

It is, however, not only the efforts of status quo-oriented organisations that makes institutional change path dependent and overwhelmingly incremental in nature (North 1995). Adapting the concept of technological path dependency (cf. David 1985; Arthur 1989) to the institutional context, North (1990a: 94ff., 1995) finds that the existing institutional matrix benefits from increasing returns, positive network externalities and complementarities between institutions, which add stability to a current path. Table 3.3 summarises and contrasts the “self-reinforcing mechanisms” (Arthur 1988) at work in technological and institutional change.

In the case of technological path dependence, inefficient solutions may gain the upper hand because of small chance events at the outset; once the reinforcing mechanisms kick in, competitors are permanently disadvantaged and a lock-in to an inefficient path may develop (Arthur 1989). In institutional change, chance events are less important; instead, a greater role falls to bargaining power and

Table 3.3 Self-reinforcing mechanisms in technological and institutional change (based on Arthur 1988; North 1990a)

Mechanisms	Technological change	Institutional change
Increasing returns to scale	Given large set-up or fixed costs, unit costs fall with increasing output	Institutions have large initial set-up costs, but besides economies of scale, economies of scope matter
Learning effects	Product quality improves and/or product costs fall as production technology and products become more prevalent	Organisations evolve to take advantage of the opportunity set offered by the institutional framework, and benefit of learning effects as they acquire those skills and knowledge consistent with it
Coordination effects	Cooperating with other agents taking similar actions yields advantages	Mutual acknowledgement of an institution reduces uncertainty; there are direct coordination benefits, if institutions act as contracts between organisations; and indirect coordination benefits, if organisations invest in institutions with complementary characteristics
Adaptive expectations	Increased prevalence of products and/or technologies in the market gives rise to expectations of further prevalence	Increased prevalence of contracting based on a specific institution gives rise to expectations about the permanence of that institution

incomplete political and economic markets. Institutions are not designed with efficiency and welfare maximisation in mind, but evolve as the product of bargaining games between those powerful enough to change the rules (North 1990a: 16). Moreover, decision makers apply subjective mental models to interpret information and handle complex situations, which may well be erroneous (North 1990a: 98ff., 1995). In a zero transaction cost world with perfect competition and complete information, one could expect an efficient path to emerge in the long-run; given market imperfections, significant transaction costs and incomplete information feedbacks, this clearly need not be the case (North 1990a: 98ff.). Again, increasing returns produced by the existing institutional framework reinforce the current path. For example, if current institutions reward redistributive efforts more highly than productive ones, organisations will invest in associated skill sets (North 1990a: 99). In this way, a long-term lock-in into an inefficient path is possible.

Lock-in situations can be particularly pervasive, if technological path dependencies interact with institutional ones, as is the case with the carbon lock-in of the fossil fuel-based energy system described by Unruh (2000, 2002) (see Sect. 2.2.3.6). Policy makers wishing to promote the diffusion of renewable energies not only have to implement support schemes to counterbalance the increasing returns to scale that fossil fuel technologies were able to benefit from over the course of decades, they also have to address various institutional, infrastructural and behavioural barriers, as current demand patterns on the side of consumers, grid and storage infrastructures, legal norms and administrative procedures have co-evolved to match prevalent fossil fuel-based energy technologies (cf. Lehmann et al. 2012). At the same time, the theory of institutional change suggests that resistance to a change of path may go well beyond incumbents of the energy sector; rather, the circle of organisations who have invested in skills and knowledge consistent with what Unruh (2000: 828) calls the "carbon based techno-institutional complex" has to be drawn wider to include consumers and associated industries as well as members of public agencies and politicians. Options for breaking persistent lock-in situations are briefly discussed below (Sect. 3.5.4.3). Compared to other RES technologies, some bioenergy pathways have the advantage that they are compatible with fossil fuel-based infrastructures and consumption patterns (cf. Sect. 2.2.3.6). For example, liquid biofuels can be easily blended with conventional petrol or diesel fuels and used in most vehicles without technical adjustments (up to a certain share in the blend, see Naumann et al. 2014: 22ff.). Another example is biomethane, which can make use of the existing natural gas grid and is interchangeable with natural gas in applications such as combustion in gas power plants, gas-based heating systems or natural gas-fuelled vehicles (Thrän et al. 2014: 15). If bioenergy policy aims to break the carbon lock-in and initiate a comprehensive energy transition, however, there is the added complication that bioenergy support needs to avoid reinforcing the existing lock-in. At the same time, even if a path change can be implemented, the question is how to prevent a new, inefficient lock-in from occurring. This moves the focus to normative recommendations concerning the process of institutional change (Sect. 3.5.4.4).

3.5.4.3 How to Implement Path Changes?

Unruh (2002) distinguishes policy measures according to the disruption they cause to the current techno-institutional complex. End-of-pipe approaches directed at the treatment of emissions show the highest compatibility with the existing system, while continuity approaches promote incremental innovations or changes of individual system components; discontinuity approaches, meanwhile, aim to replace the system and switch to a different path of technological and institutional change. In this classification, RES deployment can be part of either a continuous or discontinuous approach, depending on whether it builds upon existing infrastructure, consumption patterns, business models and so on, or whether comprehensive system reforms are undertaken (Unruh 2002: 319). Barring major exogenous shocks or crises, the self-reinforcing mechanisms of institutions will resist radical changes (North 1990a: 89); but also approaches that are continuous from a systems perspective may bring major disruptions for some of the system's components and associated organisations, giving rise to opposition (Unruh 2002: 319). Consequently, reform opportunities are subject to a number of political constraints, which, when manifesting ex ante, can prevent policy proposals from being accepted, and, when coming to bear ex post in the implementation period, can lead to a lack of effective enforcement or policy reversals (cf. Brousseau et al. 2011).

Consequently, the question is, how can reforms that prove discontinuous to the current pathways be implemented at all? The literature on institutional change draws a distinction between long-term, bottom-up processes of institutional transformation which may eventually trigger path changes, and top-down reforms implemented by policy makers (Brousseau et al. 2011). The focus here shall be on the latter, as they seem more relevant for the time horizon adopted for the analysis of bioenergy policy.

For easing political constraints, three main strategies emerge (Brousseau et al. 2011). First, policy makers promoting a reform can integrate it into a reform package which includes transfers to compensate losers. However, transfers have to be financed by taxes with associated allocative distortions, and increase incentives for organisations to invest in redistributive efforts, such as lobbying. Moreover, in order to increase the chances of ongoing compensation payments, interest groups are likely to prefer indirect compensation to direct transfer payments. For example, compared to direct income transfers, import restrictions on agricultural commodities create less transparent benefits for domestic farmers and tend to be politically more acceptable, even though distortions of allocation decisions and efficiency losses are more severe (Erlei et al. 1999: 363).

Second, reforms can be designed partially and gradually to reduce opposition and allow interest groups or "advocacy coalitions" (Jacobsson and Lauber 2006; Lehmann et al. 2012: 344) to develop which have a stake in the reforms (Dewatripont and Roland 1995; Wei 1997). In gradual reform processes, appropriate sequencing of reform steps gains crucial importance—implementing policy measures with low transaction costs and low adaptation costs first can increase support for the overall reform, but if initial impacts are too small, support may wane (McCann 2013: 260). Under uncertainty, sequencing can also be used to provide room for learning and adaptive management responses in policy design (Batie 2008: 1184f.). In renewable energy support, supporting the creation of niches provides an example of a gradual approach (see also Sect. 3.6) which reduces disruptions to the dominant system and can be used to promote a step-by-step path change (e.g. Kemp et al. 1998).

However, gradual reforms take time to implement, which in the case of urgent problems may not always be available. A strategy to reduce opposition to more comprehensive reforms consists in using the windows of opportunity that crises provide (Unruh 2002). Nonetheless, rapid path changes do not necessarily produce better outcomes than gradual ones, as decisions which prove erroneous in hindsight may lead to new inefficient lock-ins, and reforms may still be captured by interest groups (Brousseau et al. 2011: 16).

Overall, each of the alternatives discussed has certain drawbacks, making the choice of appropriate strategies—or strategy mixes—to overcome opposition against reforms very much context-dependent. By analysing the dynamics of political processes, public choice theory sheds further light on the role of political constraints (see Sect. 3.5.5). Before turning to it, however, the problem of normatively evaluating institutional change shall be discussed.

3.5.4.4 Evaluating Institutional Change: The Concept of Adaptive Efficiency

Williamson's remediableness criterion evaluates the efficiency of alternative institutional solutions at a point in time, taking into account feasibility constraints (see Sect. 3.5.2). The theory of institutional change, on the other hand emphasises the dynamic properties of institutional choice, framing it as a problem of adapting to unforeseen circumstances under informational and cognitive restrictions (North 1990a: 80 ff.). Focussing on how institutions influence the development of an economy through time, North (1990a: 80) introduces the concept of adaptive efficiency. Given uncertainty about "the correct answer" to problems of social and economic organisation or technology choices, an institutional framework can be described as adaptively efficient, if it encourages innovation, trials and experiments, knowledge acquisition and learning (North 1990a: 80ff.).

While a comprehensive operationalisation of the criterion and the dynamic capabilities of institutional frameworks remains problematic (Brousseau et al. 2011: 7f.), some conclusions for bioenergy policy can be drawn. Building on Hayek (1960) (see Sect. 3.3.2), North finds that permitting decentralised decision making and trial-and-error processes is a characteristic of an adaptively efficient framework, as this encourages the discovery of innovative solutions (North 1990a: 81). A central steering of, for example, technology choices would perform worse in this regard, because choices and innovative opportunities would be more strongly constrained, increasing the risk of lock-ins.

Moreover, the adaptive efficiency criterion stresses the importance of learning in policy design. For one, it is vital to establish effective feedback mechanisms which allow the identification of relatively inefficient solutions, be they the result of erroneous mental models, rent-seeking activities or changes in external circumstances (North 1990a: 26f. and 99f.). And second, institutions should be so designed as to be amenable to changes, when new information of altered circumstances make inefficiencies apparent (North 2005: 4). As discussed under Sect. 3.5.2, however, trade-offs between institutional adaptability and planning security for investors have to be considered. Likewise, allowing for a “maximum generation of trials” (North 1990a: 81) may increase adaptive efficiency and responsiveness to future problems, but it need not imply the most productive use of scarce resources and a cost-efficient implementation of aims; as a result, trade-offs between adaptive and allocative efficiency can arise.

3.5.5 The Role of Interests in Political Decision Making: Implications of Public Choice Theory

Placing the focus on the process of political decision making, insights from public choice theory complement the findings from the theory of institutional change discussed above. Extending the methods of economics to the political sphere, the public choice approach models policy making as the interaction between various self-interested, utility maximising actors (Mueller 1989: 1f.; Erlei et al. 1999: 319).[24] The neoclassical view of policy design as an optimal instrument choice by benevolent dictators seeking to maximise social welfare is abandoned, and rent-seeking and regulatory capture by special interest groups emerge as additional important sources of government failure besides transaction costs and imperfect information (North 1990b; Dixit 1996: 9ff.; McCormick and Tollison 1981; Stigler 1971). That said, the perspective of public choice research is often positive rather than normative—that is, the focus lies on explaining perseverant inefficiencies in existing regulation (e.g. Endres and Finus 1996; Schneider and Volkert 1999; Hansjürgens 2000). Normative recommendations for improving the efficiency of political outcomes tend to focus on the constitutional level, aiming at the design of political procedures which are less likely to incentivise unproductive rent-seeking activities and limit the risk of regulatory capture (cf. Buchanan and Tullock 1962; Voigt 2002: 125ff.; Tullock 2008: 726f.). As part of the institutional environment, these options are beyond the focus of the present bioenergy policy analysis—

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[24] In this context, it seems important to note that the assumption of self-interestedness does not preclude behaviour which can be described as altruistic—an individual’s utility function may well include the welfare of other individuals as a component (Pappenheim 2001: 63).

however, insights from positive public choice theory can be used to form hypotheses about political preferences of different relevant actors, and derive inferences for the political feasibility of alternative instrument options. In the following, basic assumptions about the interests of different actor groups and a public choice explanation of their interactions are presented, followed by a formulation of hypotheses about the preferences of bioenergy actors; in Chap. 5, these hypotheses are confronted with actual bioenergy policy instruments, testing their explanatory value.

3.5.5.1 A Sketch of the Public Choice Model of Political Decision Making

In the public choice perspective, the political decision making process is modelled as the interaction of actors in political markets, who act as suppliers and consumers of regulation or public services (Stigler 1971; Keohane et al. 1998; Erlei et al. 1999: 323f.; Tullock 2008: 723). The demand side is made up of voters and organised interest groups which represent the preferences of only a certain part of the population, whereas the supply side is represented by politicians and political parties, as well as the bureaucratic apparatus of public administration. While politicians devise policies, the bureaucracy is charged with implementing them, even though frequently they also contribute to the policy design stage (e.g. Schneider and Volkert 1999: 133f.).

Similarly to the various failures in markets for goods and services, political markets are inherently imperfect; interactions between actors form a chain of principal-agent relationships, in which divergent interests between principals and agents combine with information asymmetries and transaction costs to make a perfect control of behaviour impossible (North 1990b: 361; Erlei et al. 1999: 323). Concerning the interests or utility functions of different actors, public choice theory provides several assumptions (cf. Endres and Finus 1996: 92ff.; Orchard and Stretton 1997: 410ff.; Erlei et al. 1999: 324ff.; Hansjürgens 2000: 154ff.; Pappenheim 2001: 63ff.). On the supply side, both *politicians* (Downs 1957) and *bureaucrats* (Niskanen 1971/1994) attempt to maximize factors such as personal income, influence, and prestige, for whose attainment it is necessary to gain influence over discretionary budgets. For politicians, maximising votes and political support serves as a means towards achieving these ends. For bureaucrats, maximisation of departmental budgets is usually used as a proxy. Naturally, individual maximisation attempts are subject to constraints—politicians face competition within and between parties, whereas bureaucrats are subject to interdepartmental competition and are—albeit to an imperfect degree—controlled by their government principals (Erlei et al. 1999: 328).

On the demand side, *voters* have an interest in using elections to support the government that enacts policies which are the most beneficial for them (Downs 1957; Tullock 1967: 110ff.). However, given the costs involved in attaining information about political agendas and the small influence of each individual vote on the election result, voters have an incentive to remain “rationally ignorant” (cf. Downs 1957) and align their votes with ideological stereotypes (North 1990b: 362) and broad, simple and symbolic messages (Edelman 1964; Hansjürgens 2000: 155). For that reason, *organised interest groups* are often of higher relevance for politicians (see Olson 1965)—on the one hand, they enact political pressure regarding specific subjects and policies, while on the other, they provide resources that are helpful for winning elections, such as party financing, information about the preferences of their members, or information which may be relevant for policy implementation. The content of their utility function depends on the interest group in question—while industry interest groups strive to improve the profits and competitive position of their members, employee interest groups can be assumed to lobby for higher incomes and secure working prospects; consumer groups, meanwhile, are likely to focus on increasing the consumer surplus, whereas environmental interest groups seek a higher environmental quality, and so on (Endres and Finus 1996: 94).

Utility maximisation attempts by organised interest groups are constrained by competition for political rents among different groups (Becker 1989/1996; Erlei et al. 1999: 354). However, competition is distorted in favour of small and relatively homogeneous groups (Olson 1965; Orchard and Stretton 1997: 412f.; Erlei et al. 1999: 350ff.). The reason for this is that organised action is associated with costs. In large interest groups, particularly those lobbying for the supply of public goods or the interests of future generations, potential members balance these immediate costs against individually small, dispersed benefits which may only accrue in the long term. Hence, for each individual, free-riding on the groups' efforts is rational, and organising their interest becomes a difficult endeavour. In small and homogenous special interest groups, on the other hand, the costs of organisation are compensated by relatively large benefits for individual group members in the near future, so that these groups can be more effectively organised.

For explaining policy choices, two approaches can be distinguished within public choice theory (Endres and Finus 1996: 93). *Political-support models* (e.g. Coughlin 1982; Coughlin and Nitzan 1981) assume that politicians actively choose policies in order to maximise political support, taking the relative weights of different interests in society into account (see Mueller 1989: 199ff. for an overview). Moreover, politicians can act as entrepreneurs and develop innovative political ideas, having an active influence on the formation of opinions and interest organisation (Hansjürgens 2000: 164). *Rent-seeking approaches* (e.g. McCormick and Tollison 1981; Krueger 1974), on the other hand, see the initiative on the side of interest groups, which compete for policies that would be beneficial for them (cf. Mueller 1989: 229ff.); here, politicians act as predominantly passive brokers who transfer resources from badly to well-organised interest groups. Of course, models combining demand- and supply-side approaches also exist (e.g. Coughlin et al. 1990; Austen-Smith 1987).

Meanwhile, both approaches show the relevance of organised interest groups for policy making. The higher relative strength of small special interest groups compared to large interest groups, particularly those representing general public interests with high free-riding incentives, introduces allocative distortions into competition on political markets. Inefficient outcomes are the result, as the gains that accrue to special interest groups are unlikely to outweigh the costs imposed on the wider society (Orchard and Stretton 1997: 412; Erlei et al. 1999: 352f.). Moreover, further rent-seeking costs result from the unproductive use of resources for merely redistributive purposes (Olson 1965; Buchanan 1980; cf. also North 1990a: 99).

3.5.5.2 Relevant Actors in Bioenergy Policy

According to the general classification introduced above, relevant actors in bioenergy policy making fall into the classes politicians, voters, bureaucrats, and interest groups. For the latter two, some specifications seem necessary (see Fig. 3.2). Relevant bureaucracies are the various ministries and ministerial departments involved in bioenergy policy, for example, departments responsible for topics such as the environment, energy, climate change, agriculture, industrial affairs, research and development, and so on. These departments represent the

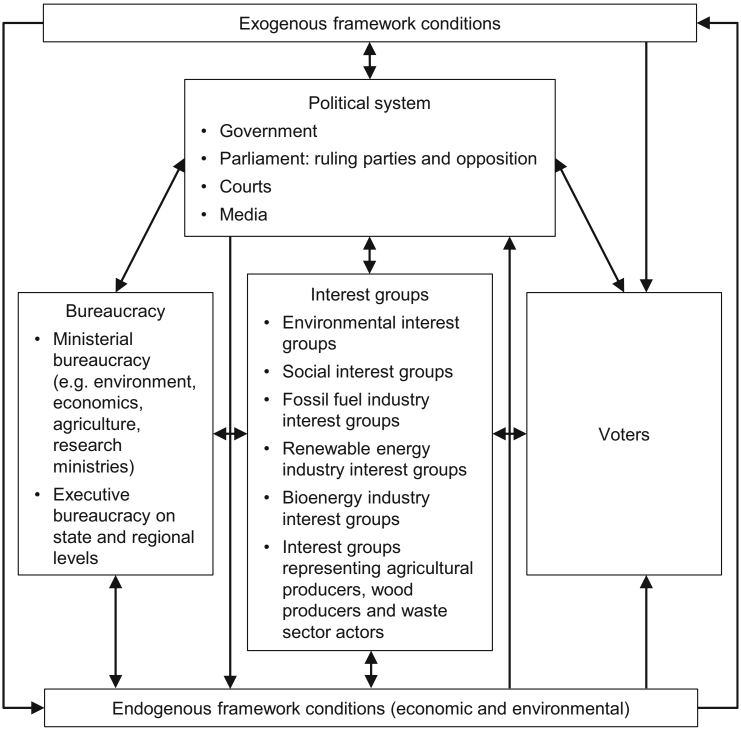

Fig. 3.2 Relevant actors and influences in bioenergy policy decision making [adapted from Endres and Finus (1996: 91) and Schneider and Volkert (1999: 125)

multiple, competing aims of bioenergy policy (cf. Table 2.4), and will attempt to promote the aim which is most relevant for their sphere of influence in the political decision process. Moreover, bureaucracies at state and regional levels charged with executing policy decisions are relevant, such as federal state level ministries, state environmental agencies or communal agencies endowed with authority on planning permissions. Not only do these agencies' interests play a role in how policies are implemented, but to varying degrees they may also be able to exert influence on the decision making process.

Relevant interest groups are likewise very varied. Environmental interest groups promote the provision of public goods and focus on the environmental characteristics of bioenergy. Other interest groups focus on social impacts, which themselves cover a wide range of issues from labour conditions in producer countries to impacts on domestic consumer energy prices. Given their focus, these groups can be summarised as "public interest groups" which represent the interests of diffuse stakeholders in society and sometimes also of future generations, although in participating members act according to individual utility functions. These groups are complemented by "special interest groups" with a more focused membership, promoting, for example, the interests of agricultural producers, industries with stakes in fossil fuels, bioenergy-related and other renewable energy industries. On the whole, interests are therefore varied and frequently contradictory—all the more so as, even among these types of interest groups, interests may diverge. For example, in the case of bioenergy, actors of the electricity, heating and transport sectors compete for political support. On the other hand, different interest groups and other actors are not only able to compete, they may also join in strategic coalitions or engage in log rolling, i.e. the exchange of support (Orchard and Stretton 1997: 412).

Besides the various actors, framework conditions also influence the political decision process; these can either be of an exogenous nature, like the structure of the political system, or be determined endogenously by policy making, such as the current state of the economy or environmental quality (cf. Endres and Finus 1996: 91).

3.5.5.3 Hypotheses About Actors' Interests Concerning Bioenergy Policy

Based on public choice theory, a number of hypotheses about actors' interests in bioenergy policy can be made; these concern actors' preferences about (i) the aims that bioenergy policy should be aligned with; (ii) the policy instruments that should be used to achieve those aims; and (iii) the cost incidence of support measures. Moreover, public choice theory suggests that because of their organisational advantages, special interest groups such as agricultural and industry interest groups are likely to have a higher weight in the political process than voters or environmental and social interest groups (see Sect. 3.5.5.1).

1. *Preferences concerning the hierarchy of policy aims*: Politicians will support that hierarchy of policy aims which they feel maximises overall support; if possible, it is rational for them to stress different aims when addressing different constituents, gloss over conflicts between aims and leave hierarchies unclear (cf. Kay and Ackrill 2012). Among bureaucracies, each ministry has an incentive to emphasise the relevant policy aims for its sphere of influence in order to maximise its budget (Schneider and Volkert 1999: 133f.). On the demand side for regulation, the hierarchy between policy aims will reflect the political strength of interest groups. Among the three main stated aims of bioenergy support (see Sect. 2.3.1), climate change mitigation and security of energy supply reflect public goods with diffuse benefits; rural value creation, on the other hand, directly benefits the interest group of agricultural producers, and can therefore hope for a strong political lobby. Bioenergy and fossil fuel-based industry interest groups would be likely to support the aims most beneficial or least averse to their respective interests, but preferences for a hierarchy of aims are likely to be diverse. For example, biofuel producers with a supply chain based on waste may lobby for a climate change priority to gain a competitive advantage over energy crop-based biofuel producers, while producers with less advantageous GHG balances may stress security of supply and rural development characteristics. Given a strong political lobby with a clear preference, the public choice approach suggests a high practical relevance of rural value creation as a policy aim.
2. *Preferences concerning policy instruments:* Public choice analyses of instrument choice in environmental policy indicate preferences against the use of market-based instruments which increase the costs of resource use; subsidies are supported by specific interest groups but may be opposed by other interest groups and voters who have to bear the costs. This leaves an overall preference for command-and-control over market-based instruments, and for symbolic policy measures with an intentional lack of effectiveness (e.g. Frey 1992; Gawel 1995b; Endres and Finus 1996; Schneider and Volkert 1999; Hansjürgens 2000; Pappenheim 2001: 89ff.). This is explained as follows (ibid.):

Politicians align their position with the perceived preferences of other actors, weighted by their political influence. In order to maximise voter support, symbolic, high publicity actions with immediate results are required. At the same time, there is an interest in avoiding high costs to well-organised interest groups. Command-and-control instruments are attractive on both counts, as they have a high symbolic value, but can be weakened in the implementation process, for example, through exemptions or a lack of enforcement.

Voters have an interest in measures which seem effective, but do not impose high costs on them. Command-and-control instruments have the advantage of being more easily comprehensible than market-based instruments which take effect through changes in relative prices; moreover, costs to voters are often less transparent. Market-based instruments such as taxes or emissions trading schemes which increase the costs of certain activities reduce profits for producers or purchasing power for consumers, depending on the incidence of the burden. Subsidies, on the other hand, increase profits or purchasing power for specific groups of producers or consumers, but have to be financed by tax increases or surcharges elsewhere. The associated redistribution of profits or purchasing power can give rise to political resistance in voter markets—whether this will be the case, though, depends on whether losers can be clearly identified (Tollison 1982: 590). For politicians, it can therefore be rational to transfer rents from poorly organised interest groups with diffuse interests to well-organised interest groups, to maximise overall political support (cf. Gawel 1995b: 32; McCormick and Tollison 1981: 18ff.).

In general, public choice theory further suggests that voters may place a comparatively low priority on environmental issues when deciding how to vote, because they are likely to weigh the immediate costs of environmental measures more highly than future benefits, and because these issues tend to be complex and information-intensive.

Interest groups representing interests of industries and primary biomass producers have a number of reasons to prefer command-and-control instruments over market-based instruments which increase the costs of resource use. As long as standards are not exceeded, firms can use the environment as a free production factor, and there is little competitive pressure for having to search for innovative technologies. Moreover, command-and-control instruments can be used to construct entry barriers for new competitors, if new and old emitters are treated differently. In general, command-and-control instruments are found to be more easily influenced by industry interests than market-based measures, because the prescription of technically detailed standards allows for the use of information asymmetries in the political decision process and negotiations during implementation. In instrument design, renewable energy industry interest groups provide a counterbalance to incumbent fossil fuel-based industries, but are likely to have less political weight (cf. Schneider and Volkert 1999: 131). The same applies to environmental and other public interest groups, which have a higher interest in implementing effective and cost-efficient measures, and may therefore be more open towards market-oriented instruments.

For interest groups, lobbying for subsidies which increase the income of their members can be another profitable channel for rent-seeking (Helm 2010: 186f.). However, special interest groups have an inherent interest in intransparent transfer processes. They are therefore likely to prefer allocative distortions which yield competitive advantages, if possible justified by value-based arguments, over direct income transfers; being more easily quantifiable and traceable, direct transfers are more likely to give rise to resistance among voters and competing interest groups, although allocative distortions and associated efficiency losses would be less severe (Erlei et al. 1999: 363f.).

Bureaucracies, finally, are assumed to concur with industry interest groups in supporting technically detailed command-and-control instruments, as these are labour and resource intensive and leave greater discretionary leeway for implementing agencies; as a result, they can be used to justify an increase in budgets and department sizes.

For bioenergy policy, it can therefore be hypothesised that instrument choice will be biased towards command-and-control instruments with a high symbolic value; in their design and implementation, instruments are likely to be geared towards the interests of special interest groups with a strong political lobby, i.e. particularly fossil fuel incumbents and agricultural producers. Moreover, interest groups may favour rent transfers through subsidies, but political majorities for this instrument depend on whether costs can be transferred to weakly organised interests.

3. *Preferences concerning cost incidence:* Support-maximising politicians have an incentive to design instruments so that costs are borne by actors who are unlikely to organise resistance effectively. In this regard, it is attractive to distribute costs among the general public rather than to specific groups. In climate policy, for example, applying the polluter pays principle to the financing of policy measures is bound to raise resistance among well-organised fossil-fuel interest groups; on the other hand, socialised costs are diffuse and have low visibility, and costs to the individual member of society are small, making them more politically acceptable (Schneider and Volkert 1999: 128ff.).

Besides direct policy costs, the distribution of transaction costs among actors can also have important implications for political feasibility (Krutilla and Krause 2011: 287f.). Depending on the design parameters of policy instruments, for example, the majority of transaction costs can be shouldered by public agencies or firms; firms will resist these costs, but bureaucracies may welcome them if accompanied by budget increases, leading to the expectation that transaction costs, like abatement costs, are more likely to be socialised than borne by well-organised interests.

The hypotheses formulated above are by necessity somewhat generalising and simplifying in nature—for a detailed examination of actors' interests, a case study of actors' actual behaviour, published statements and documents etc. would be required. Moreover, the complexity of the interest landscape is compounded by the multiple uncertainties surrounding bioenergy; as a result, interest groups may not always know from the outset what positions or policy measures are in their best interest (cf. North 1990b: 360f.), so that preferences and strategic coalitions may change over time. While an in-depth analysis is beyond the scope of this work, the hypotheses derived from general public choice assumptions may serve to shed light on some deviations of actual policy making from economic policy recommendations based on the normative criteria of efficiency, sustainability and economic rationality (as distinct from political rationality). In Chap. 5, the accuracy of the public choice-based theoretical predictions will be discussed.

3.5.6 Implications for Bioenergy Policy Advice

New institutional economics shifts the perspective towards the contractual details of hybrid instruments seeking a balance between market incentives and investment safeguards, as opposed to the dichotomy between market-based instruments and command-and-control instruments that dominates neoclassical policy analysis.[25] Contrary to the unequivocal recommendation of market-based instruments in neoclassical economics, NIE recognises that instrument choice needs to be aligned with the specific characteristics of the transaction in question, in particular the degree of uncertainty involved and the asset specificity of investments. Consequently, under certain conditions, command-and-control instruments—or rather hybrid instruments with hierarchical components, such as technology-specific deployment support—can have advantages over governance structures close to market allocation processes, if they are associated with lower transaction costs. Likewise, the theory of economic orders' preference for structural over process policy can be inappropriate, once transaction cost considerations are taken into account. Nonetheless, the theory of economic order highlights the risk of government failures which increase with the proximity of governance structures to the hierarchy end of the spectrum. By placing the emphasis on respective advantages of different hybrid governance modes between markets and hierarchies, NIE breaks both with the neoclassical focus on market failures and efficiency-oriented, optimum-restoring policy interventions, and the theory of economic order's focus on the pitfalls of centralised decision making. Instead, designing policy interventions becomes a question of balancing trade-offs and identifying not optimal, but comparatively more favourable—that is, efficient and sustainable—solutions.

The challenge for NIE-based economic policy advice, therefore, is to identify appropriate governance structures for specific allocation decisions in the bioenergy value chain. Acknowledging uncertainty, bounded rationality and the importance of the institutional context implies that the identification of optimal governance structures is not only an illusory undertaking, but also impractical. For one thing, the full costs and benefits of alternative options, including transaction costs, are seldom known to decision makers, or economists, for that matter. For another thing, the set of feasible options is at any point in time constrained by the existing institutional framework with its different nested layers of institutions, and by the interplay of political interests. Rather than following an optimisation approach, for bioenergy policy analysis an application of Williamson's remediableness criterion seems appropriate, which compares the current institutional set-up with feasible alternatives according to their potential to achieve policy aims with lower transaction and production costs. Transaction cost economics and principal-agent theory offer recommendations for the choice of governance structures, predominantly from a static perspective.

While the differentiated approach of NIE has the potential to generate policy recommendations with a higher degree of practical relevance, this comes at a price—compared to neoclassical economics, instrument recommendations are

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[25] Indeed, as Finon and Perez (2007) demonstrate, the choice of design parameters may cause the governance attributes of different renewable electricity support instruments to converge, even though instrument types such as feed-in tariffs, auctions and quotas with green certificate trading traditionally receive very different approval ratings by economists (e.g. Groscurth and Bode 2011; Frondel et al. 2013).

less clear cut, as numerous trade-offs are involved in designing the parameters of regulatory contracts. Moreover, the theory of institutional change and the public choice approach both highlight the persistence of inefficient institutions. In the former, inefficiencies may arise through errors in mental models and failures to adapt to a complex and constantly changing environment, and are perpetuated through a number of self-reinforcing mechanisms which lend stability to the current institutional set-up and lead to a path-dependent and incremental nature of institutional change. In particular, institutional path dependencies increase the risks of government failure when it comes to bringing about efficiency—or sustainability—enhancing institutional changes. Furthermore, both theories share the view that policy making is not the domain of benevolent welfare maximisers, but of individuals and organisations seeking to further their own interests; as a result, the institutional set-up at any point in time reflects the political bargaining strengths of different interests rather than efficiency criteria. While the public choice approach predominantly follows a positive focus, explaining institutional choices from the interaction of different actors in the political process and their interests, the theory of institutional change examines what characteristics make institutions adaptively efficient in a changing and uncertain environment, and how path transitions can be initiated.

Summing up, the following implications can be derived from NIE for the analysis of bioenergy policy:

1. *Relevance of the time frame and the institutional framework:* In the short to mid-term, the institutional environment can be taken as given, alongside informal institutions, making governance structures such as policy instruments the focus of the analysis. Nevertheless, incentives for bioenergy actors result from the institutional matrix in its entirety, so that interactions of instruments with other institutional layers have to be taken into account. In the long term, elements of the institutional environment may be subject to change as well.
2. *Differentiated policy mix instead of a "one size fits all" instrument recommendation:* Appropriate governance structures depend on the attributes of transactions, particularly on the degree of asset specificity and uncertainty involved. As these differ between the stages of the bioenergy value chain, and also between the electricity, heating and transport sectors in the bioenergy utilisation sphere, different instruments are needed for different allocation decisions. Attempting to solve the various problems of bioenergy allocation through one, sector-spanning instrument, for example, a cross-sectoral emissions trading system or emissions tax, as suggested by neoclassical theory, is unlikely to perform well from a transaction costs economics perspective. Naturally, interactions between transaction-specific instruments have to be taken into account.
3. *Alignment of governance structures and transactions:* The higher the asset specificity of investments, and the greater the need for coordinated responses to uncertainty-related disruptions in incomplete contracts, the more pronounced will be the advantages of hybrid governance structures which lean more towards the hierarchy-end of the spectrum than the market-end. In the bioenergy context,

investments with high asset specificity can be mainly found at the utilisation stage. In deployment support, safeguards can relate to the income or cost-side of investments. Utilisation-sided incentives propagate down the value chain, and influence allocation decisions in the processing and primary biomass production stages. Especially for the latter, asset specificity tends to be low, so that separate hierarchical interventions on behalf of certain biomass cultivation choices are not recommendable. Here, advantages of governance structures closer to markets prevail. But even in the utilisation sphere, there are trade-offs between different governance modes to consider—with increasing hierarchy, the benefits of high-powered market incentives and autonomous adaptation processes are lost, while information requirements for central decision makers and bureaucratic costs increase. These trade-offs need to be balanced carefully in the design of governance structures.

4. *Role of credible commitment:* In order to be credible, contractual safeguards need to be accompanied by a credible long-term commitment of policy makers. However, credible commitment can be extremely challenging to establish. Also, it should not preclude flexibility to adjust to new information or changing framework conditions—inflexible, unconditional rules can be as harmful as discretionary interventions for establishing credibility. One possible option would be to attempt to establish credible commitment at a sufficiently high policy level, for example by credibly ensuring the long-term stringency of GHG emission reduction targets, rather than committing to quantitative technology-specific targets for bioenergy with little flexibility.
5. *Information asymmetries give rise to agency costs and information rents:* Information asymmetries occur particularly in the governance of technology choices and primary production conditions, giving rise to adverse selection and moral hazard problems. In both cases, policy makers have to accept agency costs; to reduce information asymmetries, principals have to undertake screening or monitoring activities, or provide incentives for agents to truthfully reveal their costs, resulting in information rents. In contractual design, the risk attitudes of agents should be taken into account; risk averse actors are likely to prefer hierarchical solutions (e.g. technology standards, proscribed production methods, or guaranteed prices) to high-powered incentives, such as output-related compensation.
6. *Role of institutional learning and adaptation:* Under conditions of uncertainty and bounded rationality, regulatory contracts are necessarily incomplete; it is therefore crucial that learning processes be incorporated into contractual design. Moreover, institutions need to be able to adapt to unforeseen circumstances and new information. In order to be adaptively efficient, institutions should encourage innovation, trial-and-error processes, knowledge acquisition and learning on the part of all involved actors. In general, decentralised decision processes are found to have a higher adaptive efficiency than centralised ones. Especially in the governance of investments with high asset specificity, however, trade-offs between adaptive efficiency and planning security arise.

7. *Strategies for overcoming technological and institutional lock-in:* In the energy system, technological and institutional path dependencies interact to create a lock-in which benefits dominant fossil fuel-based technologies and impedes the diffusion of renewable energies. In order to promote a path transition towards an RES-based energy system, bioenergy policy should be designed so as to facilitate a path transition, while avoiding new inefficient lock-ins. At the same time, political constraints on path changes have to be taken into account. These may be eased by employing reform packages which include transfers to losers; by designing reforms in a partial and gradual manner, in order to weaken opposition and allow advocacy coalitions for reforms to evolve; and by using a crisis as a window of opportunity for more comprehensive reforms. Gradual reforms that promote incremental innovation and limit changes to individual system components have a higher political feasibility than attempts at radical system changes, but the reform process is likely to be a lengthy affair.
8. *Actors' interests are aimed at utility maximisation, not at efficient policy and instrument choices:* Public choice theory suggests that political markets are imperfect, and competition is distorted in favour of small, homogenous organisations such as agricultural and industry interest groups. From generalised assumptions about actors' interests and relative political weights, it can be hypothesised that the hierarchy of bioenergy policy aims will be biased towards rural value creation; that in instrument choice, hierarchical command-and-control instruments with high symbolic value but weak implementation performance will tend to win out, as well as subsidies, if costs can be concentrated on diffuse and weakly organised groups in society. Those same groups are also more likely to bear the costs of command-and-control instruments than members of well-organised interest groups.

Integrating public choice theory (with its aim of explaining how policy decisions are actually made) with more normatively oriented NIE approaches which seek to provide recommendations for improving the efficiency of institutional design is challenging. Does an economically rational bioenergy policy stand a chance of being implemented at all, or is the political process a mere zero sum game for the distribution of rents? To escape this dilemma, it shall be assumed here that public interest groups have some interest in rational policy design, and that, in entering coalitions with special interest groups representing environmental technology and renewable energy industries, momentum for political reforms may be created. Moreover, introducing uncertainty and ignorance into the public choice model increases the indeterminacy of political outcomes; for example, uncertainty about future market developments, environmental framework conditions and societal preferences makes it rational for fossil fuel incumbents to explore technological alternatives, resulting in interests which are more complex and diversified than in the very simple public choice model developed in Sect. 3.5.5.

3.6 Sustainability and Uncertainty: Contributions from Ecological Economics

The following section will give a brief outline of ecological economics approaches to dealing with environmental uncertainty and ignorance. Compared to the theoretical approaches discussed above, ecological economics makes a more significant break with the efficiency-based welfare concept of neoclassical economics, adopting a normative focus on sustainability instead. As Daly and Farley (2004: 426) put it, ecological economics requires the analysis of allocative efficiency to be preceded by a social determination of questions regarding distribution and the ecologically sustainable scale of economic activity (cf. also Faber 2008; Common and Stagl 2005: 354). Its normative focus on sustainability is derived from inter- and intragenerational justice considerations (Costanza et al. 1991)—an aspect which is neglected by neoclassical theory (cf. Sect. 2.2.3.7), and which is also not usually in the focus of NIE approaches or the other theories examined above. Moreover, unlike the weak sustainability perspective predominantly adopted by neoclassical economists, ecological economists view natural capital and man-made capital as complements rather than substitutes (Daly 2002: 3f.). This leads to the conclusion that as a subsystem of the natural environment, economic processes should be organised so as to not exceed critical natural boundaries and endanger the long-term ecological sustainability of societies. Sustainability is therefore regarded as the priority aim in the hierarchy of policy aims, against which short-term aims and measures for their implementation should be critically assessed (Costanza et al. 1991: 16). Importantly, it is found that instrument choices which are efficient from a neoclassical point of view but do not take ecological boundaries into account do not guarantee sustainability.

The importance of sustainability as a normative requirement in bioenergy use (see Sect. 2.1.2) lends relevance to ecological economics insights in the bioenergy context. In particular, it is of interest to determine what recommendations can be derived for dealing with uncertainty and ignorance in assessing complex human-environment interactions, because these make it very difficult to define what constitutes "sustainable" bioenergy use (see Sects. 2.1.2 and 2.3.2). Given the dynamic, non-linear, potentially unpredictable and irreversible nature of environmental changes, conventional risk analysis is widely viewed as inadequate to inform policy decisions (e.g. Funtowicz and Ravetz 1990; Wynne 1992; Young 2001; Stirling and Mayer 2004; Batie 2008). This section therefore explores implications of two approaches for handling environmental uncertainty and ignorance which have been advanced in the context of ecological economics: the application of the precautionary principle and the use of a post-normal science approach for environmental decision making.

Meanwhile, this section only intends to give a brief outline, not a comprehensive overview of ecological economics. Indeed, while ecological economics departs from central tenets of neoclassical economics, it does not provide a homogeneous theoretical and methodological framework to replace it, but rather a host of diverse approaches which differ in their distance to neoclassic theory-based environmental economics analyses (Faber 2008: 4; Venkatachalam 2007; Røpke 2005). To a certain degree, this corresponds to ecological economics' mission statement, that the intricacies of human-environment interactions require an inter- and even transdisciplinary approach, which draws on theories from various social and natural science disciplines depending on the problems analysed (Costanza et al. 1991: 3; Faber 2008; Baumgärtner et al. 2008). However, this diversity of methods and theoretical approaches poses problems for the derivation of concrete, theory-based policy recommendations, which could be described as intrinsically ecological economic in nature. As a result, this study places its focus on more narrowly defined economic theory approaches with distinct analytical tools for developing policy recommendations.

3.6.1 The Precautionary Principle: Content and Operationalisation

In its basic form, the precautionary principle states that regulators should not use scientific uncertainty about environmental consequences of economic activities as a reason for inaction, but should act in anticipation to prevent potential environmental damages (Costanza and Cornwell 1992; Common and Stagl 2005: 389). This applies particularly if "the environmental cost of economic activity is highly uncertain/ambiguous, potentially catastrophic, widespread and possibly irreversible" (Common and Stagl 2005: 389). The European Commission regards the precautionary principle as applicable in "circumstances where scientific evidence is insufficient, inconclusive or uncertain and there are indications through preliminary objective scientific evaluation that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal or plant health may be inconsistent with the chosen level of protection" (COM 2000: 10). On the one hand, the precautionary principle can be used to justify regulation which limits activities to which these characteristics apply—the EU moratorium on genetically modified organisms, which was adopted in 1999, can be cited as an example (Stirling and Mayer 2004; Common and Stagl 2005: 394). But also, the principle can be applied to modify or put on hold policy decisions with uncertain, but potentially irreversible environmental impacts. In both cases, it reflects the envisioned role of sustainability as the priority aim in the hierarchy of policy aims (Common and Stagl 2005: 389).

While the precautionary principle can be understood as an assignment to assess potential consequences of regulatory inaction or action and the uncertainties involved (COM 2000: 17), it does not provide a clear decision rule (Stirling and Mayer 2004: 159; Common and Stagl 2005: 390). In particular, it remains unclear what magnitude of threat is required to undertake precautionary action that comes with its own costs (Perrings 1991: 154). The EU Commission, for example, states that "the appropriate response in a given situation is thus the result of a political decision, a function of the risk level that is "acceptable" to the society on which the risk is imposed" (COM 2000: 16). This, however, requires a transparent and open societal discussion of associated risks and uncertainties, whereas policy makers tend to prefer clear and unambiguous decisions which can be defended on the basis of given information (Funtowicz and Ravetz 1990: 11; Costanza and Cornwell 1992). Several approaches for an operationalisation have been suggested, including the implementation of research and monitoring mechanisms for the early detection of environmental hazards; the implementation of measures aimed at reducing environmental burdens in general and promoting "clean production" and innovation; and cooperative stakeholder approaches exploring synergies between environmental aims, competitiveness and employment, for example (Common and Stagl 2005: 390). But also, characteristics of political decision making and regulation can be identified, which support the principle's application. Perrings (1991: 164f.) suggests that when applying the precautionary principle, sequential decision making processes may be adequate, where policy makers initially proceed cautiously to safeguard against unexpectedly high future costs, adapting regulation as learning takes place and provisional knowledge gets confirmed or refuted. Stirling and Mayer (2004: 164) stress the importance of dynamic properties of regulation, such as flexibility, reversibility, resilience, robustness and adaptability, as well as diversification across a range of technological or economic options (see also Godard 1992: 248)—recommendations, which share much with North's concept of adaptive efficiency (see Sect. 3.5.4.4). Lastly, the implementation of safe minimum standards (Ciriacy-Wantrup 1952: 251ff.; Bishop 1978) can be regarded as closely related to the precautionary principle (Common and Stagl 2005: 392ff.). Here, environmental standards are implemented to safeguard against potentially unacceptable social costs, although the definition of "unacceptable" again remains a case of political judgement.

3.6.2 The Post-normal Science Approach to Environmental Decision Making Under Uncertainty

The post-normal science approach was developed in the context of ecological economics as a new problem-solving framework for complex sustainability issues (Funtowicz and Ravetz 2003: 1; Luks and Siebenhüner 2007: 421). In cases where externalities are uncertain but potentially irreversible, the setting of optimal prices becomes impossible for policy makers—as a result, the setting of ecologically corrected prices is a highly politicised issue (Funtowicz and Ravetz 2003: 3). In fact, many sustainability issues can be characterised as "wicked problems", where it is not only difficult to model cause and effects because of the influence of diverse dynamic social, political and biophysical factors; often, there is not even a consensus about what the problem is exactly, because different stakeholders hold a different perspective on it and any potential problem solving strategies are characterised by trade-offs (Batie 2008: 1176). Climate change is an example of such a problem, where uncertainties cannot be resolved, but must be managed (Funtowicz and Ravetz 1993: 740ff.). According to Funtowicz and Ravetz (1990: 7ff., 1993: 740ff.), this necessitates first of all a critical discussion about the quality of scientific data, and a questioning of the reliance on "magic numbers" in policy making (Funtowicz and Ravetz 1990: 10). The latter can lead to a vicious circle—policy makers ask for straightforward information as a basis for policy making which displays the appearance of certainty; when complied with, and uncertainties become obvious, this can lead to the view that experts are not competent or biased and uncertainties become instrumentalised by special interests (Funtowicz and Ravetz 1990: 7ff.).

The post-normal science approach as developed by Funtowicz and Ravetz (1991, 1993) suggests that to deal with issues which are characterised by high system uncertainties and high decision stakes, traditional problem solving strategies as used in core science, applied science and professional consultancy are no longer adequate; instead, ensuring the quality of scientific inputs to the policy decision process requires an "extended peer community" (Funtowicz and Ravetz 1993: 745) including those with a stake in the issue. Given that with "wicked problems", the distinction between facts and values is frequently difficult, including an extended peer community is expected to help deal with ethical uncertainties and make values explicit; also, dispersed, local knowledge is included in the decision making process (Funtowicz and Ravetz 1993: 751ff.). With sustainability problems which encompass different scales, an inclusion not only of different scientific disciplines and stakeholders from society is seen as important, but also an approach that integrates global, cross-national, national, regional and local perspectives (Luks and Siebenhüner 2007: 422). While post-normal science decision making processes will not be able to resolve uncertainties, they may increase the legitimacy of outcomes, and contribute to social learning which improves the adaptive capacity of institutions (Lebel et al. 2010).

However, when confronted with insights from public choice theory (see Sect. 3.5.5) the post-normal science approach shows significant problems. Even the neoclassical pricing and standards approach acknowledges that under uncertainty, targets are the outcomes of political decision making processes, and as such a reflection of political majorities (see Sect. 3.1.2). Public choice theory emphasises that the democratic decision making process is distorted by interest groups with different political weights; this problem would also apply to post-normal science decision making processes with extended stakeholder involvement. Rather than contributing to more sustainable outcomes, such processes are likely to become new arenas for rent-seeking activities, in which different stakeholder groups will attempt to capture policies while exploiting information asymmetries. Even proponents of the approach acknowledge that stakeholder negotiation and decision processes can become dominated by special interests, making the organisation of "successful" processes a challenging task (Funtowicz and Ravetz 1993: 753; Upham et al. 2011: 515). This is particularly problematic if extended stakeholder communities do not merely fulfil a consultative function. If policy makers bind themselves to accept the outcome of a post-normal decision making process, it is possible that well-organised, homogeneous special interest groups have an even stronger impact on the decision outcome than in a conventional political process in a representative democracy—this is because in the latter, politicians who wish to be re-elected attempt to maximise voter support when taking decisions. This is likely to limit the extent to which they are willing to burden social groups with diffuse and weakly organised interests with costs arising from rent transfers.

Moreover, adopting a post-normal approach in economic policy advice would have far-reaching consequences, because it implies a shift from an outcome-oriented towards a procedural understanding of rationality: if the decision making process was accepted as legitimate, then it would have to be considered as secondary whether outcomes could in fact be described as efficient or sustainable. Certainly, there would be no guarantee that outcomes would fulfil these normative requirements.

3.6.3 Implications for Bioenergy Policy Advice

In applying ecological economics insights to bioenergy policy, the difficulties involved with defining sustainability prove a major challenge. Ecological economists recommend a clear hierarchy of policy goals with long-term sustainability as a priority aim—however, sustainability itself is commonly understood as a multidimensional concept encompassing social, economic and environmental criteria (e.g. Enquete-Kommission 1998: 17ff.), with an abundance of internal trade-offs. This makes it much more difficult to derive concrete policy recommendations than is the case for efficiency-oriented concepts in economic theory.

Given uncertainties not only about the presence of ecological boundaries, but about the definition of sustainability itself, the precautionary principle nonetheless yields important implications for bioenergy policy design. On the one hand, it suggests that despite uncertainties about optimal levels of environmental protection and mitigation costs, inaction in the face of anthropogenic climate change is not justified; on the other hand, forging ahead with political support of large-scale bioenergy expansion is also to be viewed critically given uncertainties about environmental and social impacts. Batie (2008: 1177) explicitly names biofuel production with its global, complex interactions as an example of a wicked problem, but this definition can also be applied to other forms of bioenergy production which affect the demand for arable land and trigger indirect land use effects with potentially irreversible effects.

When operationalised, the precautionary principle implies that alongside bioenergy policy decisions, monitoring and reporting mechanisms should be established, but also that a sequential and gradual approach to policy implementation should be adopted which avoids irreversible changes and allows for learning processes. This is particularly important because once policy incentives are in place and investment decisions have been taken based on them, political credibility considerations limit the reversibility of policy decisions (see Sect. 3.5.2.5). To allow scope for learning, policy decisions should avoid premature focuses of problem solving strategies to individual technologies, especially if these are associated with significant uncertainties. These recommendations show that in its applications, the precautionary principle can be considered as complementary to the NIE concept of adaptive efficiency, extending it by ecological and distributive components.

Meanwhile, involving extended stakeholder groups in consultation processes can broaden the informational basis for decision making and can help in identifying relevant uncertainties; however, a comprehensive involvement in political decision processes involving the prioritisation of policy aims, target setting and instrument choice and design is found to be not a promising solution for handling environmental uncertainties. Compared to established decision making processes in representative democracies, there seem to be even higher risks that policies are captured by influential interest groups. As such, the post-normal science approach does not solve, but can potentially even worsen the problem of uncertainties being instrumentalised in the political process. Additionally, it significantly increases transaction costs of policy making. Given these practical problems, the post-normal science approach is not considered further in the formulation of policy recommendations in Chap. 5.

3.7 Summary: Theoretical Implications for Economic Bioenergy Policy Advice

This section summarises the insights that can be derived for economic bioenergy policy advice from the theories discussed above, and evaluates them according to their applicability to the allocative and regulative problems of bioenergy use. Section 3.7.7 concludes by developing theoretical guidelines for the development of policy recommendations in Chap. 5.

3.7.1 The Neoclassical Perspective

The neoclassical perspective envisions no specific bioenergy policy as such—rather, the approach recommends correcting relevant market failures, such as market power, environmental externalities, security of supply externalities, and knowledge and learning externalities, and leaving choices about energy technologies, biomass uses, and land use options to market actors. The assumption is that once a competitive framework has been established and price signals have been corrected for external costs and benefits, the coordinating mechanism of the market would bring about a welfare-optimal outcome. Nonetheless, neoclassical theory allows for a more differentiated picture than the bioenergy policy advice frequently put forward by neoclassical economists, which focuses on GHG mitigation as the primary market failure that needs to be addressed—if other relevant market failures are not likewise corrected, bioenergy allocation decisions would remain distorted, and allocative outcomes would remain inefficient.

However, the focus of neoclassical bioenergy policy advice on GHG mitigation results in part from a methodological issue of neoclassical theory. Instrument recommendations concentrate on how to ameliorate individual market failures, without considering interactions when the implementation of first-best solutions for all relevant market failures is not feasible. At the same time, neoclassical theory acknowledges that in practice, optimal internalisation levels are seldom known, focussing instead on what instrument can bring about a cost-effective, dynamically efficient and effective achievement of politically set targets. For the internalisation of negative externalities, neoclassical theory recommends the use of market-based instruments such as taxes or tradable permit schemes, or subsidies in the case of positive externalities. Under uncertainty about the exact shape of marginal abatement cost and marginal damage cost curves, quantity instruments such as tradable permit schemes perform better in terms of effectiveness, while price instruments such as taxes offer a higher control over abatement costs. The use of command-and-control instruments, meanwhile, is generally discouraged.

For implementing GHG mitigation targets and achieving a bioenergy allocation which is efficient from a GHG mitigation perspective, this leads to the following recommendation: ideally, global GHG externalities should be addressed by a global emissions trading scheme or a global emissions tax, which would need to encompass not only CO_2 but all relevant greenhouse gases and all emitting sectors including the land use sector. Neoclassical theory implies that this instrument would need to be accompanied by further first-best measures to address other environmental externalities of energy production and land use, knowledge externalities and market power, as well as security of supply externalities and learning spillovers if they prove relevant.

However, these recommendations show a number of shortcomings, which severely limits their practical applicability:

1. Interactions between unresolved market failures need to be considered—the isolated introduction of an emissions trading scheme, for instance, would not result in dynamically efficient technology choices, because GHG externalities interact with market failures in technology markets. Here, knowledge and learning externalities need to be taken into account, as well as technological and institutional path dependencies. Other relevant market failures remain at least partially unresolved, further distorting allocation decisions.
2. The extent to which uncertainties are considered is very limited—in practice, a sector-spanning emissions trading scheme would be unable to achieve an efficient bioenergy allocation, because an accurate quantification of GHG emission

reductions resulting from bioenergy pathways remains unfeasible. Similarly, the extent of contributions to other policy aims is not known with certainty.

3. The transaction costs associated with a global, sector- and GHG-spanning emissions trading scheme would be immense—this would negatively affect the cost-effectiveness of this instrument choice compared to other alternatives. However, neoclassical theory neglects the transaction costs of instrument implementation, monitoring and enforcement, just as it also neglects the transaction costs associated with negotiation and political decision making.
4. Neoclassical theory only acknowledges policy aims which are based on the efficiency rationale as justifications for intervening in market processes. However, in political decision making, distributive aims like employment generation in the manufacturing sector or rural value creation are highly important, and need to be taken into account to ensure the practical relevance of policy advice.
5. Instruments which would be efficient from a neoclassical perspective may prove politically unfeasible—taking several efficiency-based but also distributive aims into account in instrument design may be necessary to acquire political majorities for interventions.
6. Lastly, policy decisions and allocation decisions do not take place in an institutional vacuum, but within a system of formal and informal rules that have evolved over time—as a result, instrument choices and design need to take interactions with the existing institutional framework into account. In particular, the existence of interacting institutional and technological path dependencies implies that there are limits to the reversibility of policy and technology decisions, giving rise to dynamic inefficiencies.

3.7.2 Second-Best Recommendations

Interactions between market failures are the point of departure for the theory of the second-best. The approach acknowledges that it may not be possible to resolve all relevant market failures simultaneously, for example due to the high transaction costs of doing so, information problems, budget limitations or political feasibility constraints. According to the theory's central tenet, in the presence of unresolvable constraints correcting one market failure in isolation may not necessarily increase economic efficiency and welfare. Welfare losses from other market failures might be ameliorated or not affected, but they might also be exacerbated, so that a close examination of interactions is crucial for the formulation of policy recommendations.

For the bioenergy context, this means that focussing on individual market failures and identifying a single optimal instrument for addressing each of them is no longer an appropriate approach. The perseverance of market failures and existence of various sources of government failure indicate the presence of multiple constraints which have to be considered unresolvable, at least in the medium term. While the complexity of the problem prevents an exact identification of the conditions for a second-best optimum, the approach suggests that addressing a market failure through a policy mix which combines several instruments to take effects on other market failures into account can improve welfare compared to neoclassical single instrument recommendations. Under these conditions, instruments directed specifically at the promotion of bioenergy and other renewable energy sources can have a rationale for existing as part of a policy mix, if given the tapestry of interacting market failures they improve welfare compared to the neoclassical solution. In the case of GHG mitigation and knowledge externalities, qualitative studies and modelling exercises indicate that this is indeed the case, arguing for a combination of emissions taxes or an emissions trading system with direct support for technology innovation and diffusion (Jaffe et al. 2005; Bennear and Stavins 2007; Fischer and Newell 2008; Lehmann 2013). Moreover, in a second-best context with innovation and diffusion barriers for RES technologies, dynamic efficiency considerations can justify the use of technology differentiation within RES policies. On the other hand, in using bioenergy support as part of a climate policy mix, positive and negative effects on other relevant market failures arise, so that a policy mix for bioenergy policy itself becomes necessary.

Regarding the design of such a policy mix, the following theoretical approaches provide further insights.

3.7.3 Insights from Information Economics

Information economics takes a closer look at the implications of different forms of limited knowledge in economic and political decision making. Traditional approaches focus on the treatment of risk and rely on the existence of objective or subjective probability distributions, allowing decision makers to calculate and maximise expected utility. Other decision theoretic models examine the case of uncertainty, when it is only possible to hypothesize outcomes but not their probabilities. Yet other contributions in the field have been concerned with the implications of ignorance, when neither probabilities nor the full set of possible outcomes are known.

For generating bioenergy policy recommendations, probabilistic approaches are of limited applicability, because situations abound where decision making is characterised by uncertainty or ignorance. Likewise, decision rules like the maximin, maximax or minimax regret rules imply high information requirements regarding the cost and benefits associated with potential outcomes; besides, even if this information is available, they do not result in unequivocal recommendations for alternative policies.

For the case of bioenergy policy, approaches examining the wider implications of uncertainty and ignorance are of greater relevance; these indicate the necessity of dealing with incomplete knowledge on a fundamental level of policy design. Hayek’s constitutional lack of knowledge, for example, points out the subjectivity of all knowledge as well as the impossibility of attaining a state of perfect information. Likewise, Simon's bounded rationality concept attempts to account for limited computational capacities and information access of individuals, and stresses the importance of a process- rather than an outcome-oriented understanding of rationality. Under pervasive uncertainty and ignorance, the coordination of individual actions requires a system of formal and informal rules which constrain choices and enable the forming of reliable, mutual expectations—the price mechanism alone is no longer sufficient as the sole form of coordination. As a result, merely internalising external costs and benefits and providing a competitive framework is unlikely to be appropriate for addressing the allocative challenges of bioenergy use. Instead, instruments need to be placed in an institutional context which in its entirety determines the incentives for boundedly rational individuals. Moreover, incorporating ignorance into the analysis emphasises the importance of generating room for trial-and-error processes, adaptation to unexpected occurrences, and learning in policy design.

Another relevant question with regard to the handling of imperfect knowledge is how uncertainties should be allocated between different actors, such as the state and market actors. Applying insights from the theory of risk allocation, central factors that play a role here are actors' ability to bear uncertainties, the transaction costs of allocating uncertainties, and actors' degree of control over uncertain outcomes. Focussing on the latter, it is found that market actors have an advantage in dealing with static private cost uncertainties, while the state with its system perspective and democratic decision making processes should decide on the balancing of externalities and account for cross-sectoral interactions of policy and market incentives which influence the allocation of biomass resources. However, a detailed analysis is required to assess how uncertainties about dynamic costs, external costs, GHG mitigation benefits and security of supply benefits should be allocated in instrument design.

3.7.4 Contributions from the Theory of Economic Order

The theory of economic order highlights the importance of the constitutional lack of knowledge that policy makers face when intervening in the economic process, which severely limits the foreseeability of reallocation effects of policies and resultant outcomes. As such, it focuses strongly on the risks of government failure. Instead of attempting to steer market allocation processes towards certain results (process policy), the theory recommends that policy makers limit themselves to the design of market framework conditions (structural policy), and use the price mechanism as the central mechanism for coordinating allocation decisions and knowledge creation. Besides guaranteeing the functioning of markets, structural policy measures can be used to provide a selection environment which steers the decentralised discovery of new knowledge into directions compatible with societal aims.

While older approaches of the theory point towards the definition of property rights and liability rules as central structural policy instruments of environmental policy, newer contributions acknowledge that process interventions may be necessary; here, the focus is on the design of interventions which are consistent with the economic order and keep open the evolutionary potential of market processes. For this, it is recommended that policies devaluate options with socially undesirable characteristics, thereby steering innovation and substitution effects in a direction that is compatible with intended policy aims. Attempts to increase the value of certain actions, on the other hand, are discouraged, because innovation and dynamic market selection processes are inhibited in their functionality.

Meanwhile, the theory of economic order emphasises that political framework conditions need to be stable and policies continuous, with changes implemented in a foreseeable manner, because frequent policy changes will result in high uncertainty for market actors and inhibit long-term investments. A central component of a continuous policy is a clearly defined and reliable hierarchy of policy aims, which limits the scope for abrupt policy changes and sends, in combination with policies consistent with it, reliable signals towards structural changes.

However, as findings from new institutional economics, but also second-best theory and the theory of risk allocation show, the theory of economic order's focus on the benefits of decentralised decision making may prove limited once transaction costs, path dependencies and the current institutional context are taken into account. As such, while the theory highlights the problems of overestimating policy makers' steering knowledge and the potential benefits of using market processes to guide allocation decisions, policy recommendations need to take the limitations of structural policy measures into account.

3.7.5 Implications of New Institutional Economics

Compared to neoclassical economics and the theory of economic order, new institutional economics brings a more balanced perspective to the analysis of market and government failures, by directing attention to the relative advantages and disadvantages of governance structures between markets and hierarchies as end points of a broad spectrum of alternatives. Among new institutional economics approaches, transaction cost and contract economics, the principal-agent approach and the theory of institutional change prove particularly fertile for generating specific policy design recommendations in the presence of uncertainty, ignorance, and associated transaction costs in the various stages of decision making and policy implementation. Moreover, the theory of institutional change and the public choice approach provide positive explanations for the persistence of inefficiencies, and highlight the importance of political constraints when assessing the feasibility of policy recommendations. The insight that political rationality and economic rationality can produce very different policy outcomes, meanwhile, not only has repercussions for the feasibility of instrument recommendations, but also for the setting of targets and the prioritisation of policy aims. As a result, an enquiry about characteristics of a rational bioenergy policy cannot assume that policy aims and their hierarchy are mere expressions of a general societal welfare function; rather, the influence of various actors' interests on the definition of policy aims as well as their implementation has to be taken into account, and conflicts between economic and political rationality need to be examined. Likewise, the setting of quantified policy targets is not a problem of welfare maximisation under uncertainty, but an inherently political problem.

From the examined approaches, the following implications can be drawn for bioenergy policy analysis.

3.7.5.1 Transaction Cost and Contract Economics

The transaction cost and contract economics approach understands policy instruments as regulatory contracts which are embedded in the wider institutional framework with its several nested levels. In a social market economy, these contracts tend to take the form of hybrid governance structures between the extremes of unregulated market allocation on the one hand and allocation through central directions in a hierarchy on the other. Given uncertainty and bounded rationality, regulatory as well as private contracts remain incomplete, so that the focus shifts from the optimal solutions of the neoclassical approach to a comparison of flawed alternatives; applied to the requirements of a rational bioenergy policy, the relevant question becomes whether compared to the status quo feasible institutional alternatives can be described, which would achieve policy aims at a lower sum of production and transaction costs.

In the bioenergy context, asset specificity and uncertainty are central attributes in the choice of governance structures. Based on Williamson's discriminating alignment hypothesis, transactions with low asset specificity and little need for coordinated adaptation to disruptions are well suited for governance structures close to markets, while with increasing bilateral dependency (caused by high asset specificity and large benefits of coordinated responses) more hierarchical governance structures become advantageous. With an increasing degree of hierarchy, high-powered market incentives for autonomous adaptation and the use of dispersed knowledge are lost, and need to be replaced by central information gathering and mechanisms for monitoring and enforcement which entail administrative costs. On the other hand, hierarchical governance structures provide contractual safeguards and planning certainty, without which investments in highly specific assets would not be undertaken.

Policy instruments have to solve these trade-offs according to specifics of the transaction in question; these specifics vary for different transactions along the bioenergy value chain and for different biomass utilisation options. Consequently, other than neoclassical theory, the TCE approach provides arguments for a differentiated bioenergy policy mix, where for example separate instruments for electricity, transport and heating sectors may be justified on the basis of different transaction characteristics. Overall, TCE implies that in the governance of utilisation-sided allocation decisions with high asset specificity, policy instruments with hierarchical elements may be called for; this is particularly the case in the electricity and transport sectors, where few biomass applications are competitive and the government effectively acts as a monopsony. In the production and conversion stages of the value chain, the existence of multiple actors on the supply and demand side and alternative asset utilisation options reduces the degree of bilateral dependency; moreover, the diversity and complexity of allocation decisions confers benefits upon autonomous adaptation that makes use of time- and space-dependent knowledge, while central information gathering and coordination efforts would be costly. Here, policy instruments which are balanced towards the market side of the spectrum seem more appropriate.

Lastly, TCE stresses the importance of credible political commitment, which is required to ensure the effectiveness of contractual safeguards and provide planning security for investors. Credible commitment needs to be clear and observable, as well as irreversible; as this entails costs in terms of reduced flexibility, it seems advantageous to choose as the reference of commitment higher level policy aims (e.g. climate change mitigation or renewable energy expansion) rather than specific targets (e.g. 10 % bioenergy expansion in the next five years). Even so, establishing credible commitment is rendered exceedingly difficult by the rationality of the political process.

3.7.5.2 Principal-Agent Approach

The principal-agent approach provides recommendations for the design of regulatory contracts in the presence of asymmetric information. Agents can use hidden information before contracts are finalised, giving rise to adverse selection problems, or take hidden actions in the implementation phase, generating moral hazard. In the bioenergy context, information asymmetries are particularly relevant in the governance of technology choices and primary production decisions; in the former case, producers have information advantages regarding technology costs and learning curves, whereas in the latter, asymmetric information exists regarding production decisions and the environmental and socio-economic impacts.

To avoid adversely selecting producers with unfavourable characteristics to participate in support schemes, three main options exist: screening, signalling and adopting a contractual design that promotes self-selection. To counter moral hazard, combinations of monitoring schemes, penalties for non-compliance, and attempts to align the incentives of agents and principals with contractual design, for example by tying compensation payments to outcomes, are proposed. The risk attitude of agents proves to be an important factor in determining the appropriate mix of measures. In both cases, the existence of asymmetric information gives rise to agency costs, which cause the allocative outcome to be second-best compared to a situation with perfect information; in particular, in order to provide agents with incentives for truthfully revealing information and complying with contractual requirements, they must be allowed positive profits, the so-called information rents.

3.7.5.3 Theory of Institutional Change

The theory of institutional change brings attention to the dynamics of changing institutions, with major implications for the feasibility of policy recommendations. Institutional change is found to be path dependent and mostly incremental; this is due to a number of self-reinforcing mechanisms which stabilise the current institutional path, such as increasing returns, learning effects, coordination effects and adaptive expectations regarding the permanence of existing institutions. Organisations which are well adapted to a given set of institutions will resist changes that do not increase the payoff to their acquired set of skills and other assets. These dynamics can result in an inefficient institutional lock-in, which is exacerbated further if it interacts with technological path dependencies, resulting in a co-evolving techno-institutional complex. In the energy system, the dominant path favouring fossil fuel-based technologies is reinforced by technological returns to scale as well as various institutional, infrastructural and behavioural barriers. Due to lock-in effects, correcting prices and restraining market power is not sufficient for establishing a competitive framework for non-fossil fuel technologies, as assumed by the neoclassical approach. Rather, additional policy instruments need to address the interacting barriers. Given insights from TCE, direct technology-specific support may well be needed as part of a policy mix that facilitates path changes.

At the same time, policy measures face the challenge of avoiding new lock-ins which, given uncertainties, may turn out to be inefficient in the future. The theory of institutional change introduces adaptive efficiency as a normative criterion, which demands that institutions promote innovation, trial-and-error processes, knowledge acquisition and learning on the part of market as well as policy actors. However, trade-offs may arise between adaptive efficiency and the cost-effective achievements of targets in a static perspective, and adaptive efficiency and planning security for investors in highly specialised assets.

Furthermore, the theory has implications for the political feasibility of policy options. Given the self-reinforcing mechanisms of an institutional set-up, it is to be expected that the more disruptive proposals prove to the current path, the greater the resistance to them will be. Policy recommendations have a chance of being implemented if the political weight of a coalition of winners of institutional change exceeds that of the losers. Strategies for easing political constraints include the use of reform packages that provide transfers to losers; designing reforms in a partial and gradual manner in order to weaken opposition and allow advocacy coalitions for reforms to evolve; and the use of crises as windows of opportunity for reforms. Incorporating political constraints into economic policy analysis is likely to move recommendations yet further away from optimal solutions, but increases their practical applicability.

3.7.5.4 Public Choice Approach

The public choice approach generates further insights into the nature and direction of political constraints. Based on assumptions about the utility function of different actors in the political process, hypotheses can be generated about actors' political preferences and the implementation chances of policy measures, and also about the relative weight of societal aims in policy making.

In bioenergy policy making, relevant actors fall into the classes politicians, voters, ministerial bureaucrats and bureaucrats with executive tasks at state and regional levels, public interest groups focussing on environmental or social issues, and special interest groups representing interests of fossil fuel-based industries, renewable energy industries, specifically bioenergy industries, and agricultural producers. The public choice approach suggests that political competition is distorted in favour of small, homogeneous organisations such as agricultural and industry interest groups. From generalised assumptions about actors' interests and relative political weights, it can be hypothesised that between climate change mitigation, security of energy supply and rural value creation, the hierarchy of bioenergy policy aims will be biased towards the latter; that in instrument choice, hierarchical command-and-control instruments with high symbolic value, but weak implementation performance will tend to win out; also, subsidies may prove politically advantageous if costs can be placed on diffuse and weakly organised groups in society.

While the approach can explain persistent inefficiencies in policy design, normative recommendations for lowering the risk of government failure due to rent seeking and regulatory capture by special interest groups are primarily aimed at the constitutional level. If the constitutional context is taken as given, the public choice approach's findings may prove challenging for the implementation chances of bioenergy policy recommendations inspired by economic rationality. Nonetheless, coalitions of interests may provide momentum for reforms, while the existence of uncertainty and ignorance lets interests and political preferences appear less fixed than in the public choice model.

3.7.6 Contributions from Ecological Economics

Ecological economics highlights the fact that targets for emissions or internalisation levels cannot be left to an economic optimisation process, but need to take scientific information about environmental carrying capacity into account. At the same time, the position of what would constitute safe minimum standards is often unknown given the complex and dynamic nature of sustainability problems. In these cases, application of the precautionary principle is suggested. The precautionary principle implies that uncertainties should not be used as justification to delay regulatory action to prevent environmental harm; conversely, policies with potentially irreversible environmental impacts should also adopt a precautionary approach, using sequencing of policy decisions and gradual policy implementation to allow for learning processes. Complementing the NIE concept of adaptive efficiency, the precautionary approach is found to be of high relevance for bioenergy policy.

Discursive approaches to policy design and target setting represent an alternative way of addressing environmental uncertainties and conflicting stakeholder interests; however, these are found to be less promising, because the risk of capture by rent-seeking interest groups is high. Meanwhile, the lack of a homogeneous theoretical and methodological framework proves problematic for deriving concrete ecological economic policy recommendations for bioenergy policy.

3.7.7 Theoretical Guidelines for a Rational Bioenergy Policy

The analysis undertaken in this chapter has shown the limits of neoclassical economic theory in addressing the complex allocative and regulative challenges that bioenergy policy makers face. This section draws conclusions about contributions that the theory of the second-best, information economics, the theory of economic order, ecological economics and new institutional economics can make towards addressing these limits and providing guidelines for a rational bioenergy policy design.

To begin with, neoclassical theory's focus on policy aims which can be derived from the efficiency rationale removes policy recommendations from political realities. The democratic justification of distributive aims which emerge from the political decision making process cannot be neglected; neither can political rationality considerations, which imply that policies may have to offer contributions to several efficiency-oriented and distributive policy aims at once, in order to gain political majorities. Nonetheless, the application of economic tools for evaluating policy measures' contributions to societal aims requires a prioritisation of aims. The consideration of multiple policy aims may change recommendations for instrument choice and design compared to a neoclassical first-best approach following Tinbergen's "one aim—one instrument" rule. However, without a prioritisation of aims which is based on a discussion of trade-offs, no assessment of the effectiveness and cost-effectiveness of policy measures would be possible, removing the basis for economic policy recommendations. Therefore, a rational bioenergy policy can accommodate several efficiency and distributive aims, but still requires the formulation of a hierarchy among them. Recommendations for a prioritisation will be discussed in Chap. 5, in Sect. 5.2.1.

The necessity to consider several policy aims at once follows not only from the rationale of the political decision making process, but also from the theory of second best. Constraints imposed by transaction costs, information problems, budget limitations or political feasibility frequently prevent the implementation of first-best instruments for correcting market failures. As a result, it is not sufficient to consider an intervention's impact on the priority aim it is meant to address;

interactions with unresolved market failures and distributive aims which affect the political feasibility of measures have to be taken into account as well when formulating policy advice. The theory of second-best shows that under such conditions, a policy mix may improve efficiency compared to the introduction of an individual instrument. Indeed, while neoclassical economists propose the adoption of an emissions trading scheme or emissions taxes as the single means of addressing GHG externalities, second-best contributions see a case for separate targets and instruments for RES deployment—this finding is based on an analysis of the interactions between GHG externalities, knowledge and learning externalities, security of supply externalities, market power and further environmental externalities of energy production, all of which remain at least partially unresolved.

However, the second-best approach increases the complexity of economic policy analysis considerably when compared to the neoclassical approach of focussing on one policy aim that strives to correct a market failure, its operationalisation in one quantified target and the choice of a first-best instrument for its implementation. The challenges increase, once the full implications of uncertainty are taken into account: impacts of policy mixes on relevant aims can seldom be quantified with confidence, and in many cases, trade-offs between aims may only become obvious with hindsight, as unexpected consequences of policy interventions. Probability-based information economics approaches for maximising expected utility or decision theory rules which rely on a comparison of potential outcomes offer little help in this situation—rather, a more fundamental integration of uncertainty into policy analysis is required. This includes an acknowledgement that the identification of an optimal policy mix which maximises overall welfare becomes impossible, shifting the focus to a more dynamic understanding of policy design which highlights aspects of adaptive efficiency, such as the reversibility of policy impacts and openness to learning. Moreover, when potentially irreversible impacts on critical natural capital or the opportunities of present and future generations are at stake, ecological economics advises the adoption of a precautionary approach.

For designing policy interventions in the presence of uncertainty, interacting market failures and multiple policy aims, the theory of economic order and new institutional economics lead to implications which differ in their assessment of hierarchical governance modes. The theory of economic order warns policy makers against overestimating the knowledge they possess, and stresses the importance of decentralised decision making and trial-and-error processes in coordinating economic activities. Overall, the theory emphasises the risks of government failure more strongly than the risks of market failure—even with imperfect markets, restricting policy makers to the reform of market framework conditions is considered preferable to direct interventions in market processes. New institutional economics, on the other hand, adopts a more differentiated approach: government structures close to markets are regarded as having advantages when it comes to the search for low cost solutions using dispersed information. But, under some circumstances, more hierarchical governance structures can perform more efficiently by reducing the costs of organising transactions. This shifts the focus to a comparison of a continuum of alternative governance options, with markets and hierarchies as extremes. When formulating instrument recommendations, this results in a break with the neoclassical dichotomy between market-based and command-and-control instruments; instead, the scope for instrument options widens to a range of hybrid governance structures with different combinations of market-oriented and hierarchical elements.

Given its consideration of transaction costs, uncertainty, political rationality and the institutional context of decision making, NIE is found to be the most appropriate approach for reflecting the broad scope of allocative and regulative challenges of bioenergy policy. Moreover, other than ecological economics, it provides a distinct set of analytical tools for developing economic policy recommendations. NIE emphasises the importance of viewing new policy measures in the context of the existing institutional framework, which evolves over time to reflect changing priorities among efficiency-oriented and distributive policy aims, and changes in the relative bargaining power of interest group coalitions. Policy recommendations need to take the path dependence of institutional change into account, which makes most changes incremental. In contrast, the theory of economic order's preference for structural policy interventions risks being as removed from political realities as first-best neoclassical recommendations, if it abstracts from the ubiquitous existence of process policy interventions and the manifold interests that would resist their abolishment. Here, NIE's focus on a comparison of flawed but feasible alternatives offers a much more realistic approach to economic policy advice, allowing for recommendations as to how institutional and allocative efficiency can be gradually improved, and how techno-institutional lock-in situations might be overcome despite the interests aligned with a given path.

When compared with neoclassical policy recommendations, the NIE approach yields several important insights for climate and energy policy. First of all, institutional path dependencies interact with technological ones to favour incumbent technologies and actors. This distorts competition with innovative GHG mitigation options such as RES technologies, particularly as path dependencies interact with knowledge and learning externalities. If an internalisation instrument like the emissions trading scheme were implemented as the sole measure for achieving GHG mitigation targets, allocation decisions would remain distorted in favour of incremental improvements of dominant fossil fuel technologies; from a dynamic perspective, however, suboptimal investments in innovative options would increase the costs of GHG mitigation. As a result, a combination of an indirect internalisation instrument, R&D and deployment support for innovative technologies proves more cost-effective in the long run—a combination with R&D support alone, meanwhile, would not be sufficient to internalise learning externalities and overcome path dependencies.

Moreover, the consideration of political rationality and transaction costs implies that internalisation instruments are likely to differ considerably from first-best recommendations—the EU-ETS and the design of national energy taxes serve as examples. After all, incumbent interest groups are invested in the existing institutional framework, which has co-evolved alongside fossil fuel-based energy technologies. As a result, they would likely resist the implementation of ambitious GHG mitigation targets through stringent caps in emissions trading or high emissions tax rates, using asymmetric information about GHG abatement costs in lobbying processes. Voters would also be unlikely to favour market-based instruments which set negative incentives, which would result in a reduction of purchasing power (see Sect. 3.5.5). Rather than leaving climate policy to symbolic displays, the use of deployment support as a subsidy for RES technologies could prove to be a favourable option for overcoming the lock-in in favour of carbon-intensive energy technologies. By appealing not only to efficiency-based, but also distributive aims and increasing purchasing power through direct and indirect employment stimulation, political resistance against a path transition can be lowered. Moreover subsidies for RES create new interest groups and advocacy coalitions lobbying in favour of a path transition—this reduces constraints for a more ambitious GHG mitigation policy over time, including a more stringent implementation of internalisation instruments.

Lastly, in interaction with differences in knowledge and learning spillovers and path dependencies, the high asset specificity of investments in innovative RES technologies can argue for a technology differentiation of RES support. The further removed technologies are from competitiveness, the more they depend on the continued existence of policy incentives, increasing the need for high investment safeguards. Technology-neutral instruments favour investments in low cost technologies, which are closest to commercial competitiveness—offering high remuneration rates with strong investment safeguards would do little to benefit innovative technologies with high knowledge and learning spillovers, as investments in low cost technologies would still be associated with the highest profits and lowest regulatory risks. This would result in windfall profits for low cost producers, and increase support costs compared to a remuneration which differentiates between RES technologies on the basis of their costs (cf. del Río and Cerdá 2014). Also, high safeguards would reduce incentives for comparatively mature technologies to engage in further search activities for cost reductions. Moreover, to initiate a comprehensive path transition to a low carbon energy system, it is necessary to bring a portfolio of RES technologies and other innovative GHG mitigation options down the learning curve, because otherwise abatement costs would increase sharply once low cost options were exhausted; with it, future political resistance against GHG mitigation would increase. This argues for a technology differentiation which takes not only technologies' learning curve potential into account, but also their ability to bear market risks.

Based on the case study analysis of German bioenergy policy, Chap. 5 will use these insights to develop recommendations for a rational bioenergy concept.

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Chapter 4
The Case of German Bioenergy Policy

NIE approaches in particular emphasise that policy recommendations need to take the institutional context of policies into account. Given the path dependency of institutional change, the given institutional set-up has important implications for the political feasibility and transaction costs of implementing policy changes (see Sect. 3.5.4). At the same time, the impacts of any given measure cannot be analysed in isolation because they depend on interactions with other policy instruments and the wider institutional framework (see Sect. 3.5.1). The formulation of concrete policy recommendations therefore has to be preceded by an analysis of the relevant institutional context. This chapter fulfils this role for the case study of German bioenergy policy. First, a review is undertaken of national and EU-level framework conditions which influence the strategic role of bioenergy in the transition towards a low carbon energy system (Sect. 4.1). This is followed by an identification and introduction of the major policy instruments which are relevant for bioenergy (Sect. 4.2). Section 4.3 assesses the German bioenergy policy mix in relation to the market and government failures discussed in Chap. 2. As a background for the theory-based analysis of German bioenergy policy in Chap. 5, Sect. 4.4 compiles the major strands of critique of the current policy approach found in the literature. Section 4.5 follows with a short review of existing policy recommendations, focussing on findings by interdisciplinary expert panels, to complement neoclassical theory-based policy advice outlined in Sect. 3.1.4. Section 4.6 concludes with a summary and a discussion of implications for the subsequent development of theory-based policy recommendations.

A. Purkus, *Concepts and Instruments for a Rational Bioenergy Policy*, Lecture Notes in Energy 55, DOI 10.1007/978-3-319-31135-7_4

4.1 Setting the Context: Framework Conditions for German Bioenergy Policy

This section introduces relevant framework conditions for German bioenergy policy. First among these are the political aims associated with bioenergy policy both on the national and the European level. Then, an overview is given of relevant European legislation and policy processes, which have significant implications for German bioenergy and renewable energy policy design. Also, this chapter examines what strategic role policy makers and researchers foresee for bioenergy in the wider transition to an energy system with significant shares of RES, followed by a short review of the current state of bioenergy use in Germany and estimates of future potential uses.

4.1.1 Relevant Aims of European and German Bioenergy Policy

Both in Germany and on the EU-level, climate change mitigation, security of energy supply, and the creation and protection of rural employment are the central aims that are commonly quoted as the political rationale for bioenergy support (COM 2005: 4f.; BMU and BMELV 2009a: 6; Thrän et al. 2011a: 5). While the first two aims apply to renewable energy support in general, the rural development component is particularly stressed in the bioenergy context (cf. e.g. BMWi and BMU 2010: 3; COM 2012a: 5).

Nonetheless, given the diversity of affected policy areas, the system of relevant aims for bioenergy policy has to be broadened (cf. Sect. 2.3.1). For example, aims such as the promotion of innovative industries as drivers for growth and technology exports, or the conservation of non-renewable resources provide further rationales for support (BMU and BMELV 2009a: 10f.). At the same time, potential negative side effects of bioenergy expansion on other societal aims also need to be taken into account, indicating lines of conflict between policy aims. Based on an evaluation of strategic German policy documents, Table 4.1 provides an overview of aims that are discussed in conjunction with bioenergy policy, either as beneficiaries of bioenergy expansion or potential carriers of its costs.

Over time, shifts in the relative weights of policy aims can be observed. The roots of the European bioenergy strategy, for instance, clearly lie in agricultural policy—given the necessity of reducing the significant overproduction of agricultural commodities in the EU, energy crop cultivation was seen as an alternative source of income for European farmers (cf. Londo and Deurwaarder 2007). From the end of the 1990s, the aims of climate change mitigation and security of energy supply stepped into the foreground, which can be attributed to drastic increases in oil prices on the one hand, and the growing public attention to climate change issues and the adoption of binding emission reduction targets in the Kyoto protocol on the

Table 4.1 Relevant policy areas and aims in German bioenergy policy (based on BMU 2007, 2010; BMELV 2008, 2009, 2011a, b, c; BMU and BMELV 2009a; BMWi and BMU 2010; BMWi 2012, 2013)

Policy area and responsible ministries on the federal level	Aims
Energy policy (BMWi, BMU)	Security of energy supply (import substitution and diversification)
	Economic viability (efficient energy supply at competitive prices)
	Affordability of energy prices for consumers
	Environmental compatibility of energy supply
	Social acceptability of energy supply and associated risks
Agricultural and forestry policy (BMELV)	Rural development (employment, value creation and quality of life in rural areas)
	Sustainable use of natural resources (soil, water, air, and biological diversity)
	Internationally competitive agriculture and forestry
	Domestic and global food security
	Adaptation to climate change
	Maintenance and enlargement of forested areas
Environmental policy (BMU)	Climate change mitigation
	Protection of soil fertility, air quality, water quality and availability
	Conservation of biodiversity (species diversity, habitat diversity, and genetic diversity)
	Preservation of valuable wild and cultivated landscapes
	Conservation of non-renewable resources
	Transition to a circular economy with closed loop recycling management
Macroeconomic and industrial policy (BMWi)	Growth
	Employment
	Innovation
	Security of resource supply (resource efficiency, use of renewable resources)
Development policy (BMZ)	Sustainable socio-economic development
Trade policy (BMWi)	Creation of global conditions that foster free trade and competition
	Strengthen the competitive position of German companies

other (ibid). Also, while in the early days of bioenergy policy, the emphasis was on the possibilities of energetic biomass use (cf. COM 2005), subsequent strategic policy documents are paying an increasing amount of attention to conflicts with environmental aims, such as nature conservation, and social aims like food security (cf. e.g. BMU and BMELV 2009a). More recently, potential conflicts with economic aims such as the affordability of energy prices have entered the political discourse (cf. BMWi 2014). Moreover, accompanied by increases in scientific understanding, the contribution of bioenergy to individual aims has been reassessed. Most strikingly, initially bioenergy policy was shaped by the assumption that energetic biomass use had a neutral climate impact, with the combustion of plants releasing the same amount of carbon into the atmosphere as absorbed beforehand during plant growth (for a discussion see Haberl et al. 2012). Following heavy criticism from the scientific community and civil society actors, a more differentiated, life cycle-based perspective on the climate impacts of bioenergy has been taken up by policy makers which also acknowledges the importance of indirect land use change effects (cf. e.g. BMU and BMELV 2009a; COM 2012b), although the implementation of these insights remains challenging (see Sect. 4.4.3).

4.1.2 A Sketch of European Bioenergy Policy

European climate, energy and agricultural policies play a vital part in setting the context for member states' bioenergy policy. This section gives an overview of directives, strategic declarations and policy processes that constitute the core of European bioenergy policy. EU-level instruments which affect the incentives of bioenergy market actors, such as the Common Agricultural Policy (CAP) and the Emissions Trading Scheme (EU-ETS), are discussed in Sect. 4.2, as are other directives which are relevant for bioenergy framework conditions but too general to form part of a distinct European bioenergy policy (e.g. the Waste Framework Directive).

Throughout the 1990s and 2000s, the potential contribution of bioenergy to GHG mitigation, security of energy supply and rural value creation was emphasised in strategic communications by the European Commission (e.g. COM 1997, 2007; see Thrän et al. 2009 for an overview). In the EU's 2005 biomass action plan and the subsequent EU strategy for biofuels, member states were expilicty encouraged to develop their energetic biomass potential (cf. COM 2005, 2006); additionally, the Commission recommended the use of biomass imports for bioenergy expansion, in a balanced relation to domestic supply (COM 2005: 40). Due to security of supply considerations, the transport sector received special attention—as "the only available large scale substitute for petrol and diesel in transport" (COM 2007: 7), biofuels have been supported through a European quota obligation since 2003.

4.1.2.1 The EU's 20-20-20 Targets

Binding targets for the expansion of renewables in all sectors followed in 2009 as part of the EU's climate and energy package. As key objectives for 2020, the EU committed to achieving a 20 % reduction in EU GHG emissions from 1990 levels; an increase in the share of renewable resources in EU energy consumption to 20 %; and a 20 % improvement in the EU's energy efficiency (DG CLIMA 2014a). To implement these targets, four measures were adopted: the Renewable Energy Directive (RED, see below), a reform of the EU Emissions Trading System (EU-ETS), the definition of national targets for non-EU-ETS emissions, and the creation of legal framework conditions for carbon capture and storage through a EU directive (DG CLIMA 2014a).[1] Based on the 20-20-20 targets, legally binding national targets have been defined, which provide important framework conditions for national-level climate and energy policies (see Fig. 4.1). In addition, some member states, among them Germany, have adopted further targets beyond 2020—some of these have been implemented in law, as is the case for German post-2020 electricity sector targets which are anchored in the Renewable Energy Sources Act (section 1 (2) EEG 2014); others, such as Germany's post-2020 GHG emission reduction targets, energy efficiency targets and total RES share targets, are based on strategic declarations and not legally binding (cf. BMWi and BMU 2010; Rodi et al. 2011: 42ff.).

4.1.2.2 The Renewable Energy Directive

The Renewable Energy Directive (RED) demands that the share of RES in final EU energy consumption amount to 20 % by 2020 (COM 2009a, Article 3 No 1). In addition, each member state is required to meet at least 10 % of final energy consumption in the transport sector through RES by 2020 (COM 2009a, Article 3 No 4). Although this target was formulated in a technology-neutral fashion, it was recognised that the major part of this contribution would be made by biofuels (COM 2009a: Preamble p. 18; cf. also Beurskens and Hekkenberg 2011).

Alongside its targets, the RED introduced binding sustainability criteria and certification requirements for biofuels and bioliquids (COM 2009a, Articles 17–19). The focus on biofuels and bioliquids resulted from: (a) the prominent role of biofuels in meeting the transport sector's RES target; (b) the close link between biofuel production and first generation energy crops, which have been heavily criticised for adverse land use change impacts and poor GHG balances (e.g. Fargione et al. 2008; Searchinger 2009); and (c) the relevance of biofuel imports from Non-EU countries (cf. Beurskens and Hekkenberg 2011). In order for biofuels to count towards the targets, producers have to prove via certification that raw materials do not originate from areas with high biodiversity value or carbon stocks, that agricultural cultivation within the EU adheres to environmental minimum requirements, and that biofuels have a GHG mitigation potential of at least 35 % (increasing to 50 % from 2017, and 60 % from 2018). While this includes emissions from direct land use changes, ILUC effects are considered only through monitoring and reporting duties on the side of the Commission (COM 2009a,

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[1] Energy efficiency was not addressed as part of the climate and energy package, but was covered instead by the 2011 Energy Efficiency Plan and the Energy Efficiency Directive (cf. DG CLIMA 2014a).

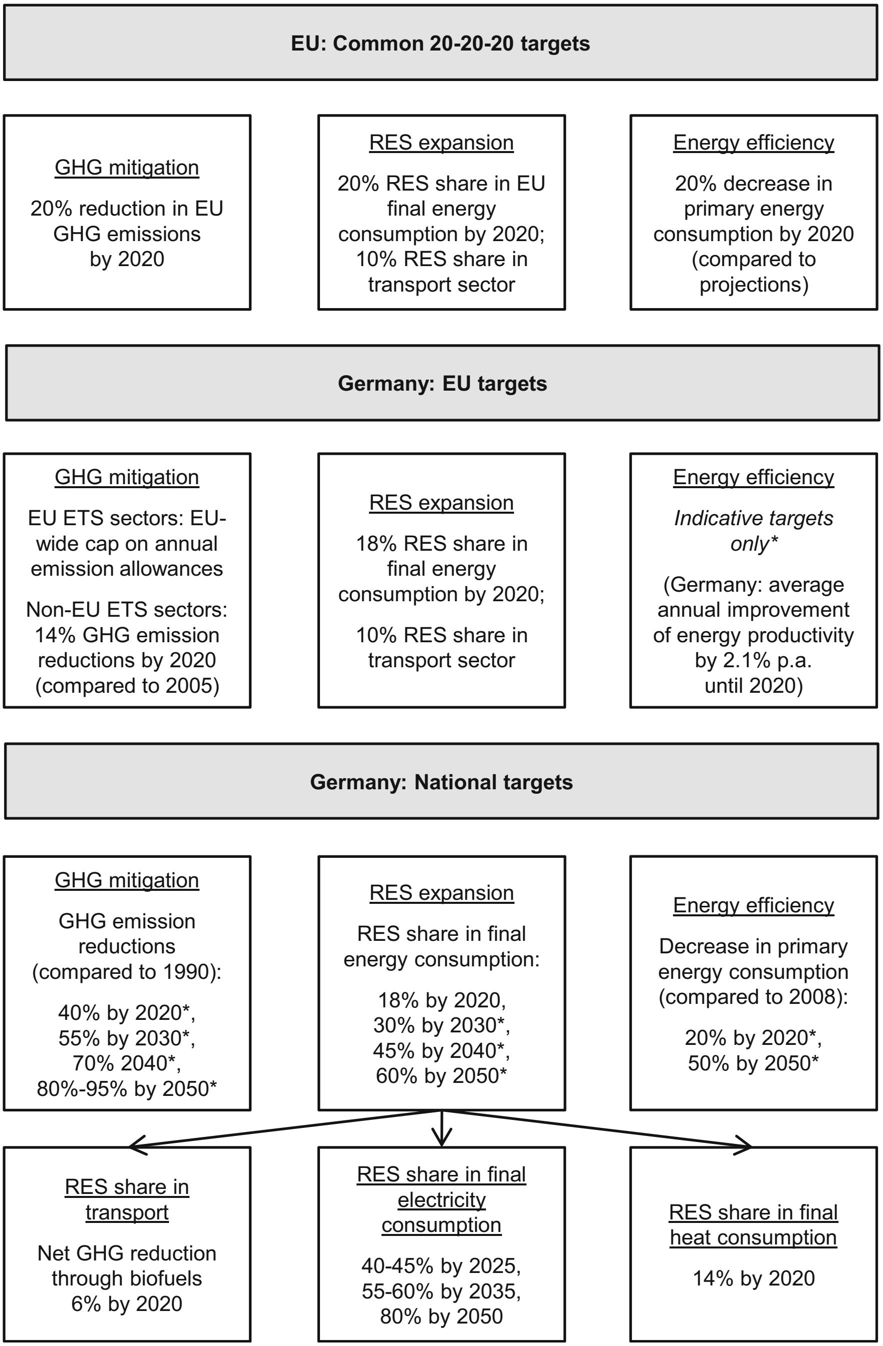

Fig. 4.1 2020 targets of European energy and climate policy and member state level targets for Germany (based on BMWi and BMU 2010; Rodi et al. 2011: 42ff.; COM 2012c; DG CLIMA 2014a, c; DG Energy 2014; EEG 2014; BImSchG 2015. *Note*: targets indicated by a (*asterisk*) are not legally binding)

Article 23). Furthermore, in order to support the diversification of feedstock and reduce competition for land and biomass, the contributions of biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material are to be counted double towards the 10 % transport sector target as well as to national renewable energy obligations (COM 2009a, Article 21).

4.1.2.3 The Fuel Quality Directive

In parallel, Directive 2009/30/EC revised the Fuel Quality Directive (FQD) by introducing, among other amendments, a Low Carbon Fuel Standard which requires fuel suppliers to reduce the greenhouse gas intensity of energy supplied for road transport by up to 10 % per unit of energy from fuel and energy supplied by 2020 (COM 2009b, Article 7a). If biofuels are to count towards the greenhouse gas intensity reduction obligation, they must comply with the sustainability criteria laid down in the RED (COM 2009b, Article 7b).

4.1.2.4 Subsequent Developments in EU-Level Sustainability Regulation

Following the RED with its binding sustainability criteria for biofuels and bioliquids, the Commission evaluated and subsequently rejected the option of extending sustainability requirements to solid and gaseous biomass in the electricity and heating sectors (cf. COM 2010a, b). Cited reasons were the wide variety of biomass feedstocks which impose difficulties on the implementation of a harmonised scheme, the fact that imports of these bioenergy carriers from non-EU countries had little relevance so far, and the disproportionate costs mandatory certification would impose on EU producers under these circumstances (ibid). However, member states were invited to implement national sustainability criteria on a voluntary basis, although the commission recommended that these should "in almost all respects" (COM 2010b: 8) be the same as those laid down in the RED [COM 2009a, Articles 17(1)–18(1)]. Under this approach, member states would still be obliged to count biomass not fulfilling national sustainability requirements to the RED's RES expansion targets; they could, however, exclude such biomass from receiving financial support (COM 2010a: 8). Further the Commission stated that member states' efforts would be monitored and the need for common sustainability criteria re-evaluated, as well as the need for EU actions on addressing ILUC (COM 2010b: 10).

After much deliberation on ILUC (cf. COM 2010c; DG Energy 2010a), a proposal for amending the RED and the Fuel Quality Directive was adopted in 2012 by the European Commission (COM 2012b). The proposal suggests that the use of food-based biofuels in fulfilling the RED's 10 % transport sector target should be limited to 5 % (COM 2012b: 14); at the same time, the contribution of a number of wastes and residues should be considered to be four times their energy content (cf. COM 2012b: Annex IX). On top of that, both in the RED and the FQD minimum greenhouse gas saving thresholds are increased, and ILUC estimates are to be included in reporting requirements (COM 2012b: 3).[2] After a process of negotiation and amendment (European Parliament 2013; ICCT 2013), a draft law has been agreed on by the European Parliament, stating that by 2020 first-generation biofuels from crops grown on agricultural land should account for no more than 7 % of energy consumption in the transport sector (European Parliament 2015). Moreover, member states have to adopt non-legally binding separate targets for advanced biofuels—at the same time, their contributions towards targets remain weighted at twice times their energy content, instead of four times (ibid.). Also, discussions about a proposal for binding EU-wide sustainability criteria for solid and gaseous bioenergy carriers are ongoing, with expectations that they may contain a 60 % GHG emission reduction threshold for electricity and heating sector biomass installations of above 1 MW electrical or 2.5 MW thermal capacity (Argus Media 2013).

4.1.2.5 Outlook: The EU's 2030 Framework for Climate and Energy Policies

In October 2014, the European Council adopted a framework for the EU's climate and energy policy up to 2030 (COM 2014a; European Council 2014). Most importantly, the 2030 framework includes binding member state-level targets only for GHG emission reductions; for RES share and energy efficiency, only EU-level targets are adopted. Specifically, the council endorsed a 2030 greenhouse gas reduction target of at least 40 % compared to 1990 (European Council 2014). EU-ETS sectors are to contribute emission reductions of 43 % compared to 2005, whereas non-EU-ETS sectors are to realise 30 % of emission reductions compared to 2005; this commitment is translated into binding national emission reduction targets, which are determined on the basis of member states' relative GDP per capita (ibid.). For RES, a 27 % share in the EU's energy consumption has been adopted as a binding 2030 target. However, this corresponds to the minimum share of RES that is expected to result from the GHG emission reduction target (COM 2014a: 6). For energy efficiency, only an indicative EU-level target has been endorsed by the Council, amounting to energy savings of 27 % by 2030 compared to projections (European Council 2014). By limiting targets which are binding on the member state level to GHG emission reductions, the EU Commission turns away from the approach followed with the 20-20-20 targets. This is motivated by an increased emphasis on the cost-effectiveness of GHG mitigation and market integration, reaffirming the EU-ETS as the central instrument for a common climate

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[2] With this proposal, the Commission decided against the use of modelling-based ILUC factors in the calculation of GHG balances, which had previously been debated (cf. DG Energy 2010b; Edwards et al. 2010).

policy (European Council 2014: 1f.; COM 2014a: 4f.). But also, individual member states' assertion that their energy mix should remain a matter of national competence was an important contributing factor to the decision of abolishing national RES and energy efficiency targets (Gawel et al. 2014a; European Council 2014: 5). For similar reasons, the EU Commission has also declared to abstain from setting sectoral targets for reducing the GHG intensity of fuels, such as those set out in the Fuel Quality Directive (COM 2014a: 6). This has far-reaching consequences for EU biofuel policy in particular, which up to 2020 is driven by the FQD's Low Carbon Fuel Standard as well as the RED's 10 % RES transport sector target.

4.1.3 The Role of Bioenergy in the German Energy Transition

On the German policy level, consecutive governments have supported the large-scale expansion of renewable energy use as means of GHG mitigation, improving the security of supply, and securing the long-term viability of energy supply (BMWi and BMU 2010: 3). The "Energiewende" is flanked by ambitious long-term targets—by 2050, the 2010 Energy Concept envisions a 60 % share of RES in final energy consumption, and a 80 % share of RES in final electricity consumption; for the electricity sector, long-term targets are even implemented in law (section 1 (2) EEG 2014). Moreover, the energy concept supports GHG emission reductions of 80–90 % by 2050, which would require a comprehensive decarbonisation of the energy sector (cf. Schlesinger et al. 2010: 143ff.).[3] In achieving this, renewable energies and energy efficiency improvements will need to play a decisive role, as nuclear power is to be phased-out until 2022 (BMU 2011a) and carbon capture and storage is still subject to considerable uncertainties and political debate (e.g. SRU 2009).

4.1.3.1 Bioenergy's Part in Meeting 2020 RES Expansion Targets

Perspectives on the role of bioenergy in the energy transition differ according to the time horizon adopted. For achieving the RED's 2020 RES targets, the expansion of bioenergy use in all three sectors is seen as an important means (cf. BMU and BMELV 2009a; Federal Government of Germany 2010). Specifically, the RED's 10 % transport target has been implemented in a biofuel-specific fashion: by 2020, biofuels have to achieve a net GHG reduction of road transport fuel emissions of 6 % (section 37a (4) BImSchG 2015). Earlier versions of the law included a net emission reduction target of 7 % (section 37a (3a) BImSchG 2013); this was

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[3] This long-term GHG mitigation target is also supported by 2013s new coalition agreement (Federal Government of Germany 2013: 50f.).

estimated to be equivalent to an energy content-based share of approx. 12 % (BMU and BMELV 2009a: 10). In the heating and electricity sectors, targets are technology neutral: by 2020, the share of RES in final heat consumption has to amount to 14 % (section 1 (2) EEWärmeG), while in the electricity sector, 35 % of final electricity consumption has to be met by RES (section 1 (2) EEG 2012). The EEG 2014 changed this target to a RES share in the electricity sector of 40–45 %, which is to be achieved by 2025 (section 1 (2) EEG 2014). Nonetheless, further expansion of bioenergy use in these sectors is expected to play a significant part, as illustrated by Fig. 4.2 which depicts sectoral RES expansion pathways as outlined in Germany's National Renewable Energy Action Plan (NREAP). According to these, bioenergy would in 2020 account for 23 % of the total contribution of renewable energies in the electricity sector, 79 % in the heating sector, and 89 % in the transport sector (own calculations based on ECN 2011).[4] The government's 2009 biomass action plan envisions an associated total increase in energetic biomass use by a factor of 1.65 from 792 PJ in 2007 to 1309 PJ 2020, with bioenergy accounting for 10.9 % of total final energy consumption in 2020 (BMU and BMELV 2009a: 10).

4.1.3.2 A Strategic Focus for Bioenergy?

Besides a quantitative contribution to mid-term targets, however, the strategic long-term role for bioenergy is heavily debated. Widely uncontested is the view that it is necessary to focus energetic biomass utilisation more strongly, as competition for limited sustainable biomass potentials is expected to intensify in the future (cf. Bringezu et al. 2008; BMU and BMELV 2009a; Ericson 2009; Thrän et al. 2011a). In particular, chemical and material industries are poised to emerge as major competitors for renewable resources as the bioeconomy sector takes shape, which is seen as an important strategic area of future growth by policy makers and industrial representatives alike (OECD 2009; BioÖkonomieRat 2012; BMELV 2013). From the resource base side, there is wide support for focussing energetic biomass uses on waste and residues, as well as on second and third generation non-food biomass (particularly ligno-cellulosic material and algae, respectively) (e.g. BMU and BMELV 2009a: 13). Correspondingly, the wider implementation of closed material cycle concepts is promoted, with energetic uses following material uses in cascades. However, given limited potentials of wastes and residues, which are at times subject to competing uses themselves, and uncertainties concerning resource costs and availability, it remains debated whether waste- and residue-based bioenergy could make a sizable contribution to the energy transition, and

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[4] This corresponds to an absolute increase in energetic biomass use from 14,025 GWh in 2005 to 49,457 GWh in 2020 in the electricity sector, 7261 ktoe in 2005 to 11,355 ktoe in 2020 in heating, and 1919 ktoe in 2005 to 5473 ktoe in 2020 in transport (cf. ECN 2011).

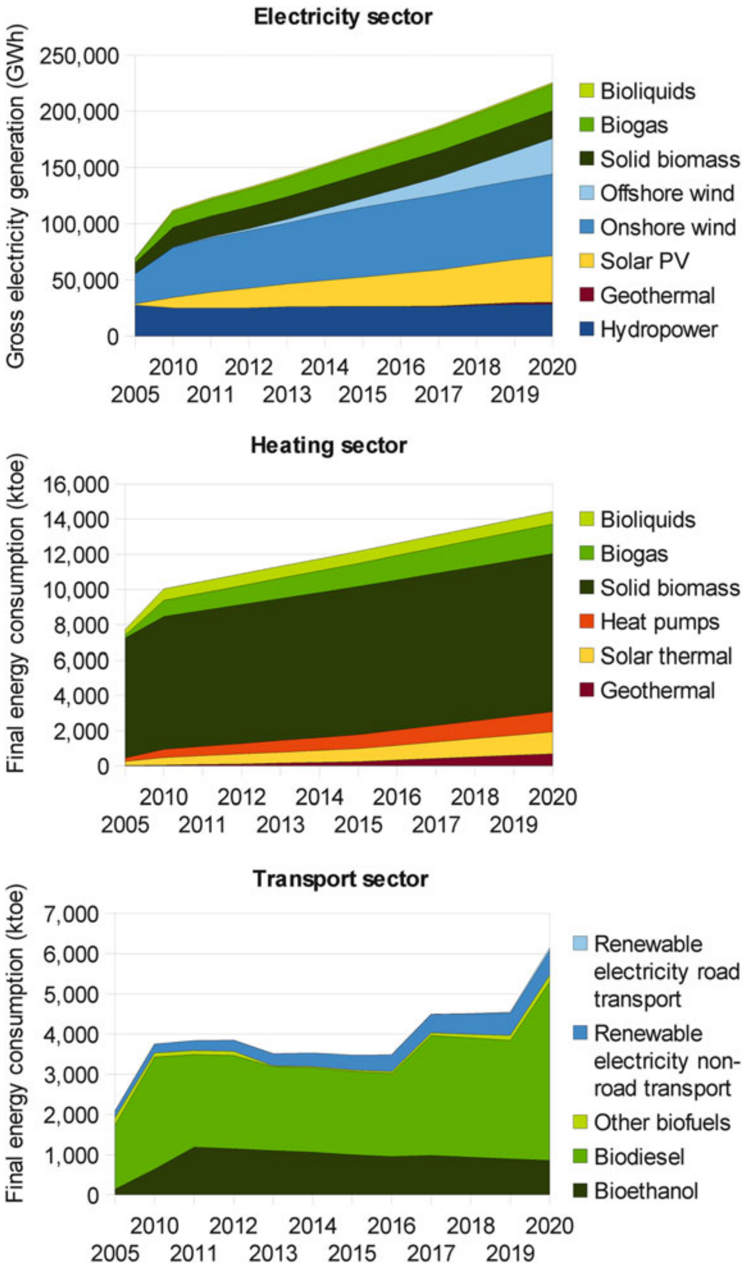

Fig. 4.2 Expected contribution of each technology to the 2020 RES expansion targets, according to the German National Renewable Energy Action Plan (based on data from ECN 2011. *Note*: conservative estimates have been used for bioethanol from wastes, residues, non-food cellulosic material, ligno-cellulosic material, and other biofuels)

whether or not there is a role for the energetic use of dedicated renewable resources beyond that of a bridging technology (WBGU 2008: 199; Thrän et al. 2011a: 136).

On the utilisation side, several strategic long-term focuses can be identified in the literature:

1. *Flexible power generation in a RES-based electricity sector and cross-sectoral integration*: In the electricity sector, bioenergy plants could make a systemically important contribution by balancing fluctuations of the intermittent RES wind and solar power, which are expected to provide the bulk of future renewable electricity production (Bofinger et al. 2010; Szarka et al. 2013). This role could be fulfilled through flexible demand-oriented feed-in, the provision of balancing power, and the production of biomethane which can be stored in the gas grid. At the same time, the use of cogenerated heat remains an important strategic focus for bioelectricity plants, which could play an important part in future heat supply concepts by feeding renewables-based heating grids (Thrän and Pfeiffer 2015: 147ff.). Moreover, upgrading biogas to biomethane provides opportunities for flexible bioenergy production and cross-sectoral integration (ibid.). Biomethane can not only act as an energy storage option, but is also characterised by a high versatility in its use. Building upon the existing natural gas infrastructure, it can be allocated flexibly to the electricity, heating and transport sectors according to demand (Bowe 2013).
2. *Combined heat-and-power generation as part of regional RES supply concepts*: Rather than focussing on integrating bioelectricity into the spot market and biomethane into national gas grids, "bioenergy village" concepts focus on the use of bioenergy to feed heat distribution networks, with cogenerated electricity as an additional product (Jenssen et al. 2014). These concepts are frequently integrated with ambitious regional RES targets, and stress the aim of rural value creation (Bohnet 2013).
3. *Biofuels in heavy load transport, shipping and aviation*: While for personal road-based transport several technological alternatives exist in the mid- to long-term, this is not yet the case for heavy load transport, shipping and aviation, which are expected to continue to rely on energy-dense, easily storable carbon-based fuels (WBGU 2008: 191; Bauen et al. 2009: 12; Kampman et al. 2010: 52). For the foreseeable future, biofuels remain the only renewable option likely to be feasible. At the same time, demand and emissions in these sectors are projected to increase, leading to a rising interest in biomass use in these applications (Bengtsson et al. 2012; Gegg et al. 2014).
4. *Integration of energetic and material biomass uses*: Finally, an increased focus on cascading biomass uses is seen as an important means for reducing competition between material and energetic uses and relieving pressure on land resources (Carus et al. 2014; Arnold et al. 2009). By using renewable resources first materially (optimally several times) and only then energetically, the efficiency of resource and land use can be increased significantly (Arnold et al. 2009: 28f.). As a result, life cycle balances of GHG and other environmental impacts tend to compare favourably to the energetic use of primary

biomass resources (Carus et al. 2014: 213ff.). However, current market and regulatory framework conditions set few incentives for expanding cascading use concepts (ibid.: 135ff.).

However, decisions about strategic focuses are surrounded by large uncertainties, concerning developments of sectoral framework conditions as well as cost developments of bioenergy technologies and substitutes. For example, using biomass for heating purposes without cogeneration is generally discouraged, because it is technically less efficient than combined heat and power production; moreover, it is assumed that it will be possible to realise drastic decreases in heat demand by energy efficiency improvements in the future (e.g. WBGU 2008: 195ff.). But in terms of current use (cf. Sect. 4.1.4.1), biomass-fuelled household applications remain a major RES option in the heating sector. The same is true for biofuels in personal road transport. A successful diffusion of major technological alternatives like electromobility and fuel cells in transport, or passive standard houses in heating depends on many factors, such as relative prices, opportunity costs and not least consumer preferences. In the heating sector in particular, where bioenergy is nowadays a cost-competitive option to fossil fuels and meets additional consumer preferences (cf. Thrän et al. 2011a: 135), bioenergy might therefore well continue to play an important role if reductions in heat demand fail to materialise. This example may serve to demonstrate problems of interactions between market conditions and politically set sectoral focuses, which may require comprehensive interventions for their implementation (see Chap. 5).

4.1.4 Current State of Bioenergy Use and Biomass Potentials

In 2012, renewable energies accounted for 12.7 % of total final energy consumption in Germany, amounting to 318,062 GWh (BMU 2013a: 12); in the electricity sector, they supplied 23.5 % of gross electricity consumption; in the heating sector, 10.2 % of final energy consumption of heat; and in the transport sector, 5.7 % of fuel consumption (ibid.). Overall, bioenergy made the most significant contribution, accounting for 8.2 % of final energy consumption and 66 % of total renewable energy supply (FNR 2013a: 3). In the electricity sector, bioenergy made up 30 % of RES' contributions (or 6.8 % of gross electricity consumption), while in the heating sector, bioenergy accounted for 91 % of the RES share (or 10.4 % of total final energy consumption of heat) (BMU 2013a: 12; FNR 2013a: 4f.). In the transport sector, RES-based motor fuel supply is exclusively made up of biofuels (BMU 2013a: 12 and 15).

With a gross inland consumption of energy from biomass and renewable wastes of 23,578 ktoe in 2013, Germany is the EU member state with the highest level of bioenergy use in absolute terms, followed by France (15,117 ktoe), Italy (13,511 ktoe), Sweden (10,946 ktoe), Finland (8747 ktoe), and Poland (7800 ktoe)

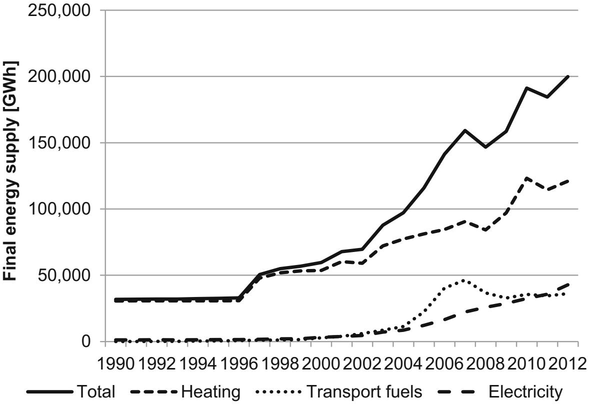

Fig. 4.3 Final energy supply from biomass in Germany, 1990–2012. Total in 2012: 200 TWh (based on data from ZSW 2013: Tables 3, 6 and 7)

(cf. Eurostat 2015). Also, with a 2.3-fold increase in gross inland consumption of bioenergy between 2004 and 2013, Germany is one of the countries which have experienced the largest expansion of bioenergy use over the last decade (ibid.).

Figure 4.3 depicts the development of final energy supply from biomass in the electricity, heating and transport sectors over time. Note that, due to different conversion efficiencies of bioenergy technologies, the shares of primary energy consumption that the electricity, heating and transport sectors account for differ, increasing the relative importance of the electricity sector (cf. Thrän and Pfeiffer 2015: 35). While the use of wood in heating has a long tradition, its deployment in the transport and electricity sectors only picked up after 2000 in response to greater political support (cf. Thornley and Cooper 2008; BMU and BMELV 2009b: 15ff.). In particular, Germany was one of the first EU member states to promote the large-scale expansion of biofuel use (Londo and Deurwaarder 2007: 293) and is now not only one of the EU members with the highest share of biofuels in transport (Eurostat 2013: 84), but also one of the largest producers of biodiesel globally (Wackerbauer and Lippelt 2011: 39; Worldwatch Institute 2014).

4.1.4.1 Dominant Technologies

In 2012, private household-scale installations running on solid biomass accounted for more than half of the final bioenergy supply in the heating sector, followed by industrial applications (see Fig. 4.4). In the transport sector, bioenergy use is dominated by biodiesel, although the deployment of bioethanol has been increasing in recent years (cf. ZSW 2013: Tab. 7). Both biodiesel and bioethanol are primarily used for the blending of mineral oil diesel and petrol, respectively (Thrän et al. 2011b: 28f.). So far, applications like aviation, shipping or rail traffic only make up very minor shares of biofuel use in the transport sector; in 2012, 98.5 % of final energy consumption from biofuels was accounted for by road transport (Diekmann et al. 2013: 10). In the electricity sector, meanwhile, the most common

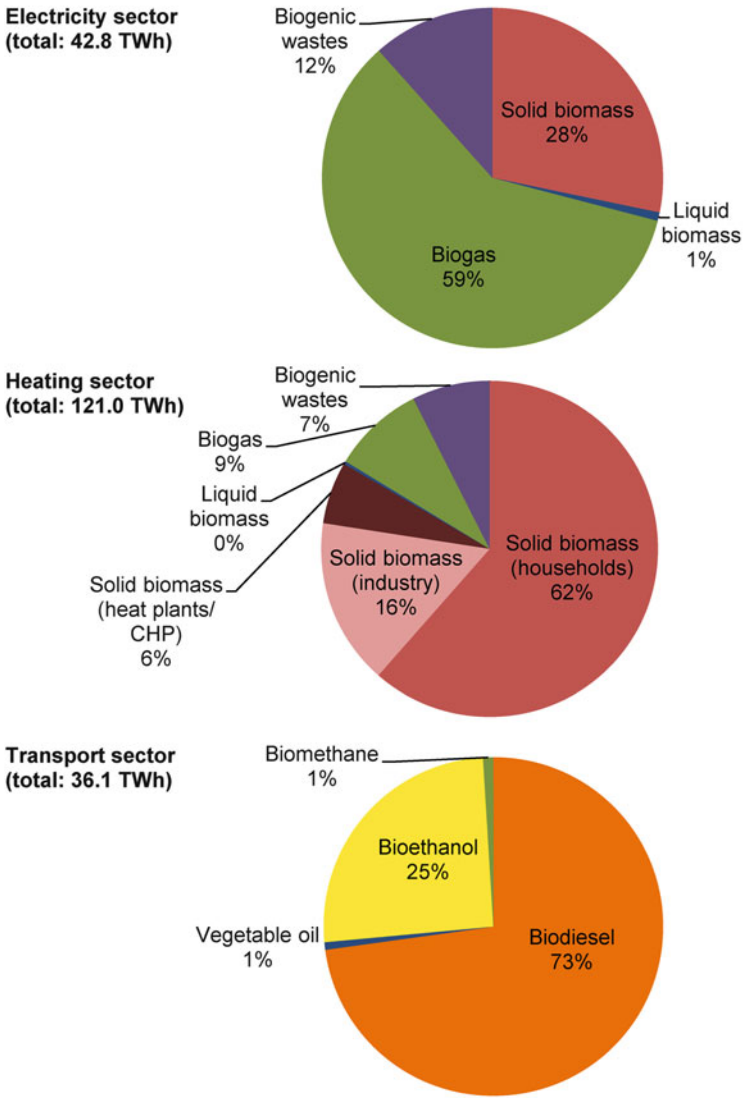

Fig. 4.4 Structure of bioenergy deployment in Germany by sector, 2012 (based on data from ZSW 2013: Tables 3, 6 and 7)

bioenergy application is the digestion or anaerobic fermentation of biomass to biogas, which primarily fuels small-scale cogeneration plants on farms, followed by the use of solid biomass in power and cogeneration plants and the combustion of biogenic waste. In recent years, particularly biogas production has seen a rapid expansion; between 2008 and 2012, the use of solid biomass in electricity production increased by 33 % and the use of waste by 6 %, but biogas-based electricity production grew by 131 % in the same period [own calculations based on ZSW

(2013: Tab. 3)]. As an alternative to direct electricity and heat production, the upgrading of biogas to biomethane and feed-in into gas grids is also growing in popularity (Thrän et al. 2011b: 14).

4.1.4.2 Dominant Feedstocks and Their Sources

In biogas production, the most widely used substrates are renewable resources, primarily maize silage, in combination with animal excrements (Thrän et al. 2011a: 15, b: 17f.; FNR 2013a: 36). In combined heat and power (CHP) plants using solid biofuels mainly woody residues are employed (Thrän et al. 2011a: 13). Household applications in the heating sector, meanwhile, mainly make use of split logs, wood pellets, other wood and wood chips (Thrän et al. 2011a: 35; AGEE-Stat 2012). In the biofuels market, finally, first generation bioethanol from cereals, sugar beet and sugar cane, as well as biodiesel from rapeseed oil continue to dominate (FNR 2012, 2014: 20). Albeit to different degrees, almost all biomass feedstocks have seen continuing trends of price increases over the last decade (Thrän et al. 2011a: 18, b: 33ff.; FNR 2013a: 12); this includes some types of wastes residues that can be accessed with relative ease, like woody residues, for which prices have risen significantly since the introduction of feed-in tariffs for woody biomass (Thrän et al. 2011a: 19).

Overall, bioenergy demand is currently primarily covered by domestically sourced wood-based solid biomass, which provided 56.6 % of biomass-based final energy supply in 2012 (ZSW 2013: Tab. 3, 6 and 7), and energy crops used in biogas and biofuel production (FNR 2013b). Energetic uses of wood and crops have grown significantly over the last 10 years, and now lay claim to large shares of both the domestic agricultural area and the domestic wood supply (see Fig. 4.5; Mantau 2012: 9). The agricultural area used for the cultivation of renewable resources has grown from 246,000 ha in 1993 to an estimated 2.4 million ha in 2013—of these, 2.1 million ha were dedicated to energy crops, whereas a comparatively small area of 0.3 million ha was used for growing crops for material uses (Peters et al. 2010: 12; FNR 2014: 8). In total, renewable resource cultivation made use of about 20 % of Germany's total agricultural area in 2013; among the cultivated crops, the largest shares were accounted for by rapeseed (871,500 ha, 746,500 ha of which were used for biofuel production) and maize for biogas production (832,000 ha) (FNR 2013b). Meanwhile, 2013 was the first year since 2008 that the area used for renewable resources did not expand further; in the material sector, the area used for industry plants has for several years remained stable at about 300,000 ha per year, since large shares of the growing demand are met by imports (ibid.).

For the forestry sector, the newest data available is for 2010; demand for energetic and material uses amounted to ca. 70 million m^3 each, with energetic uses slightly exceeding material uses for the first time (accounting for 50.6 % of total wood demand) (Mantau 2012: 9). As with energy crops, the energetic use of wood has grown considerably over the last decade. Until 2015, a further increase of energetic wood demand to up to 80 million m^3 is expected (Mantau 2012: 9). It has

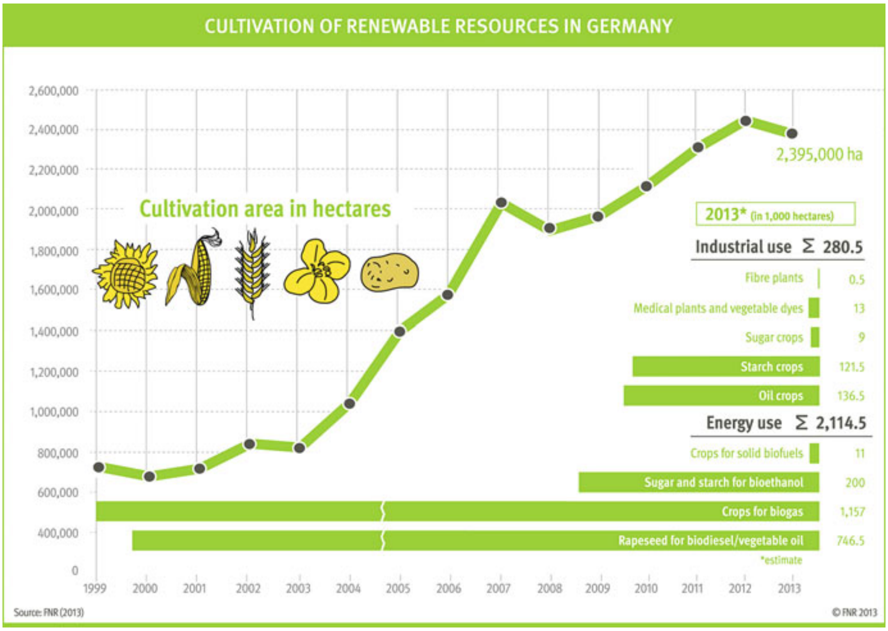

Fig. 4.5 Renewable resource cultivation for energetic and material uses in 2013 [reproduced from Fachagentur Nachwachsende Rohstoffe e.V. (FNR 2013c)]

to be noted, however, that due to the utilisation of cascades, figures about the use of wood are not directly related to forest-based wood production, and multiple uses of 1 m^3 wood for material and energetic applications are possible (Mantau 2012: 9, 12). Consequently, domestic options for meeting a growing wood demand consist of increasing wood production from existing forests, increasing the managed forest area, or increasing cascading uses (Thrän et al. 2011a: 65ff.; Mantau 2012: 9).

Trade is mainly relevant for resources that have a high energy density and high economic viability which makes transport worthwhile (Thrän et al. 2011a: 126). This is particularly the case for wood pellets, bioethanol, biodiesel, although raw materials such as vegetable oils, cereals, root crops, oleiferous fruits and sugar also have developed significant international markets (Thrän et al. 2011a: 70). Table 4.2 shows trade-streams for bioenergy carriers in Germany for the year 2010. Regarding solid biofuels, Germany was an exporter for wood pellets; of certified pellets destined for the heating market, about 90 % were consumed domestically, but pellets for power generation (which is not politically supported in Germany) were entirely exported (Thrän et al. 2011b: 42). On the other hand, Germany was a net importer for waste wood. The same was true for bioethanol, while for biodiesel, Germany both imported and exported significant amounts, with trade occurring primarily with bordering countries (Thrän et al. 2011b: 44ff.).

Table 4.2 Energetically used biomass imports and exports for Germany, 2010 (based on data from Thrän et al. 2011b: 42–46)

	Wood pellets	Waste wood	Biodiesel	Bioethanol
Export volume in 2010 (tons)	715,000	12,000	918,000	343,000
Import volume in 2010 (tons)	270,000	755,000	992,000	1,343,000, ca. 25 % of which were used as fuel
Net exports in 2010 (tons)	445,000	−743,000	−74,000	−1,000,000
Main receivers of exports from Germany	United Kingdom, Sweden, Denmark, Italy, Austria	The Netherlands	Poland, the Netherlands, Belgium, France	Poland, the Netherlands
Main sources of imports to Germany	Denmark, Russia, the Baltics, Czech republic, Austria, Belarus	The Netherlands, United Kingdom	The Netherlands (as port, main countries of origin: Argentina, Indonesia), Belgium	The Netherlands (main country of origin: United States), Belgium, France, Poland

Globally, both production and trade in liquid biofuels and solid biofuels have grown exponentially over the last 10 years (Junginger et al. 2011; Lamers et al. 2011, 2012). For biodiesel and wood pellets, global net trade accounts for a significant share of global production (see Junginger et al. 2011 for an overview). Intra-European trade plays an important role particularly for solid biofuels; while trade in these commodities has grown from 56 to 300 PJ between 2000 and 2010, intra-European trade made up two-thirds of this in 2010 (Lamers et al. 2012).

4.1.4.3 Future Perspectives for Domestic Production and Imports

Table 4.3 gives a (non-exhaustive) overview of the estimated technical potential for domestic biomass production in the medium and longer term.[5] Although increases from current levels are possible in the three main resource categories forestry, wastes, and energy crops (cf. Federal Government of Germany 2010), it is clear that the domestic potential is limited; gross inland consumption of bioenergy in 2013

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[5] While the theoretical potential describes the biophysically possible—i.e. the energy content of the total biomass in a specific region during a certain time interval—the technical potential describes that part of the theoretical potential which can be developed under the given technical, structural, environmental, administrative and legal restrictions (BMVBS 2010: 20f.).

Table 4.3 Technical potential bioenergy assessments for Germany (based on Wiesenthal et al. 2006; BMVBS 2010; Fritsche et al. 2004; Hauff et al. 2008; Nitsch 2008; FNR 2013a)

	Study	Total technical bioenergy potential (PJ/a)	Technical potential from residues and waste (PJ/a)	Technical potential from forestry (PJ/a)	Technical potential from energy crops (PJ/a)
2020	BMVBS (2010)	1500–1800	371–381	511 (incl. forestry residues)	501–860
	Nitsch (2008)	1309	520	219	570
	Hauff et al. (2008)	1091	638	176	277
	Wiesenthal et al. (2006)	1415	620	222	574
	Fritsche et al. (2004)	577–1084	539–565	153–219	37–519
2050	FNR (2013a)	1640	540	360	740

already amounted to 987 PJ (Eurostat 2015). Moreover, as less accessible resources are developed, domestic resources become more expensive, limiting economic attractiveness and competitiveness to imports (Thrän et al. 2011a: 126).

In a study on resource competition, the DBFZ estimates that even if additional wood resources can be mobilised, by 2020 domestic wood supply (estimated at 1280 PJ per year) will fall short of domestic wood demand (estimated at 1560 PJ/a) (Thrän et al. 2011a: 65ff.). If the resulting “timber gap” was to be met entirely through imports, an increase of wood imports from 4.4 million m^3 in 2007 to 35 million m^3 in 2020 would be required (Thrän et al. 2011a: 65); alternatives are substituting wood for residues or short-rotation coppice grown on agricultural land.

In the agricultural sector, the role of imports is likewise expected to increase in the future, but the extent of this depends on a variety of factors, such as the availability of transport infrastructure, technologies for compacting biomass, international laws and technical standards, sustainability regulation, and, last but not least, the development of global demand for biomass and biomass prices (Junginger et al. 2011; Lamers et al. 2011; Thrän et al. 2011a). On a global level, the amount of available biomass potential for energetic uses is highly uncertain, with estimates ranging from below 50 to 1500 EJ/a (Dornburg et al. 2010; Chum et al. 2011: 17ff.). The largest potential is estimated for energy crops, but as with assessments of German potential, the divergence in estimates across studies is also particularly high for this resource category. Results are strongly dependent on how boundary conditions are defined and what assumptions are made, for example, concerning the demand for competing uses of biomass resources, technology development, population and economic growth, and societal preferences (Chum et al. 2011: 17ff.). The potential for energy crops is, amongst other factors, dependent on a timely introduction of high-yield perennial energy grasses and dedicated bioenergy cropping systems, which could increase the productivity of bioenergy production significantly compared to conventional oil and starch energy crops (Wiesenthal et al. 2006).

In the FNR's (2013a) long-term estimate for biomass potential in 2050, bioenergy would be able to cover 23 % of total German energy demand. However, considerable political efforts are required to ensure that this potential is in fact developed sustainably. In the absence of adequate measures and safeguards, even deployment levels well below estimates for sustainable potential run the risk of increasing environmental or socio-economic pressures (Wiesenthal et al. 2006). In modelling exercises, for example, the displacement of food production by energy crops can easily be excluded by assumption. In reality, however, dealing with the consequences of increasing bioenergy demand is a complex issue, because a conceptual, global "food first" approach (cf. COM 2005; BMU and BMELV 2009a) is easily undermined by contrary price signals.

4.2 Major Instruments of German and European Bioenergy Policy

Political framework conditions relevant for bioenergy are set not only on national and European governance levels, but also on global and regional levels. International treaties and agreements such as the Kyoto Protocol under the United Nations Framework Convention on Climate Change, the Convention on Biological Diversity, or World Trade Organization (WTO) rules set important boundary conditions for policy design (Thrän et al. 2011a: 6). At the same time, policies and legal regulations on subnational state (i.e. "Bundesland") level can have significant influence on the decisions of bioenergy market actors, for example, through regulations in state-specific environmental laws or the design of rural structural support programmes.[6] Likewise, regional and municipal planning instruments impact the spatial allocation of bioenergy plants (Otto 2011; Schneider and Boenigk 2012). However, the most comprehensive drivers for bioenergy use and production can be found on the German federal and European levels, where climate policy and renewable energy targets as well as the adoption of instruments for their implementation are located. For this reason, this chapter focuses on the national and European policy levels. Table 4.4 presents an overview of instruments which have been identified as the most relevant for bioenergy policy as part of a literature and policy document assessment.

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[6] For example, the federal state-level water acts differ in the proscription of sizes for riparian buffer stripes, which impact pesticide run-off from fields and therefore the environmental impacts of bioenergy production (Bunzel et al. 2014); also, federal states have adopted widely diverging practices in providing investment support for short rotation coppice (SRC) plantations, even though these measures are financed by federal and EU structural support funds (Marx 2012).

Table 4.4 Instruments of European and German bioenergy policy (own compilation, based on Federal Government of Germany 2010; DG Environment 2012; BMU 2013b; DG Energy 2013; DG AGRI 2014a)

<table>
<tr><th rowspan="2"></th><th rowspan="2">Primary production stage</th><th colspan="3">Utilisation stage</th></tr>
<tr><th>Heating</th><th>Electricity</th><th>Transport</th></tr>
<tr><td rowspan="3">EU level</td><td rowspan="2">Common Agricultural Policy (CAP);
Environmental framework directives;
Waste Framework Directive;
Import tariffs on biofuels and agricultural commodities</td><td colspan="3">EU Renewable Energy Directive (RED):
• 20 %-target for share of renewable energy sources (RES) in total EU energy consumption 2020
• Sustainability standards for biofuels and bioliquids</td></tr>
<tr><td>Obligation to set minimum efficiency/ RES requirements for buildings (Directive on the Energy Performance of Buildings)</td><td>European Emissions Trading System (EU-ETS)</td><td>EU RED:
• 10 %-target for RES share in transport 2020
• Double counting for waste-/residue-based and second generation biofuels;
Low Carbon Fuel Standard (Fuel Quality Monitoring);
EU-ETS for aviation</td></tr>
<tr><td colspan="4">Support for research and development</td></tr>
<tr><td rowspan="3">Member state level Germany</td><td rowspan="2">Agricultural, forestry and environmental framework conditions;
Rural development policies (EU financed);
Waste and recycling regulations</td><td>Renewable Energy Heat Act:
• Legally binding 14 %-target for RES share in final energy consumption in heating 2020
• Obligation to use RES in new buildings
• Grants and loans (Market Incentive Programme);
Energy tax incentives for solid bioenergy carriers</td><td>Renewable Energy Sources Act:
• Legally binding targets for RES share in electricity consumption (40–45 % 2025, 55–60 % 2035, 80 % 2050)
• Priority grid access for RES
• Feed-in tariff/ feed-in premium differentiated by technology and feedstock;
Sustainability ordinance for bioliquids</td><td>Biofuels quota:
• Energy content-based until 2014, GHG-based from 2015
• 2020 target: Net-GHG reduction in transport through biofuels 6 %;
Energy tax incentives for biofuels (until 2015);
Sustainability ordinance for transport biofuels</td></tr>
<tr><td colspan="3">Priority access to the gas grid for biogas</td></tr>
<tr><td colspan="4">Support for research and development</td></tr>
</table>

Instruments affect either the production of biomass and bioenergy carriers or their utilisation in the electricity, heating and transport sectors. A further distinction can be made between instruments that are aimed specifically at bioenergy, such as sustainability standards and technology-specific feed-in tariffs; instruments which set general sectoral framework conditions which are relevant for bioenergy allocation decisions, but contain no bioenergy-specific provisions, such as priority grid access rules for RES in the electricity sector and general environmental regulation in the production sphere; and instruments which affect bioenergy indirectly by changing the relative prices of substitutes, such as the European Emissions Trading System (EU-ETS). Moreover, instruments can be distinguished according to whether they set market-based incentives, are command-and-control-based, or exert moral suasion (cf. Michaelis 1996).

In the case of Germany, incentives for energetic biomass utilisation are mainly utilisation-sided. With few exceptions, such as regulations concerning SRC plantations, the growing of energy feedstocks is subject to the same environmental, agricultural and forestry framework conditions as other forms of biomass production (SRU 2007: 60; Möckel 2011). The choice of conversion technologies, meanwhile, is governed through utilisation-sided instruments; only support for research and development is anchored directly in the processing stage.[7] In the following overview of the major instruments of German and European bioenergy policy, the focus shall therefore be on utilisation-sided measures, and particularly those with bioenergy-specific provisions; production-sided instruments are only briefly summarised. Apart from an outline of the instruments' design, their impact on bioenergy expansion in recent years and relative importance in the bioenergy policy mix are assessed.

4.2.1 Instruments in the Primary Production Sphere

In the production sphere, energy feedstocks produced on agricultural land within the EU are subject to the same environmental and agricultural framework conditions as other agricultural production, whereas forestry sector framework conditions apply to woody biomass harvested from forests. For the energetic use of wastes and residues, waste and recycling regulation is relevant, whereas import tariffs on bioenergy carriers and intermediate products influence the relative costs of domestic production versus imports.

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[7] For example, public funding for R&D in the bioenergy conversion stage is provided by the "Biomass for Energy" programme, which from 2011 to 2013 provided six million euros annually to optimise conversion technologies according to GHG mitigation characteristics (BMU 2011b).

4.2.1.1 EU Common Agricultural Policy

In the agricultural sector, the European Common Agricultural Policy (CAP) with its two pillars of direct payments and rural development measures sets important framework conditions for farmers' production decisions. Until 2008, energy crop production received direct support through the CAP, in that it remained admissible on land that was counted towards obligatory set-aside requirements; from 2003, an energy crop premium offered additional incentives (DG AGRI 2014a). Both measures, however, were abolished in 2008 as part of the CAP Health Check Reform, in order to reflect the international increase in bioenergy demand, among other reasons (Thrän et al. 2009: 29; DG AGRI 2014a). Now, direct payments are generally decoupled from production, leaving cultivation decisions to farmers and market signals. In order to be eligible for direct payments, farmers—including bioenergy producers—have to meet compulsory cross compliance criteria, which include statutory management requirements pertaining to the environment, food safety, animal and plant health and animal welfare [see Council Regulation (EC) No 73/2009 Art. 5 and Annex II]; also, farmers are under the obligation of keeping land in "good agricultural and environmental condition", which is operationalised as a set of standards relating to soil protection, the maintenance of soil organic matter, habitat quality, and water management (see Council Regulation (EC) No 73/2009 Art. 6 and Annex III; DG AGRI 2014b). In addition, the CAP reform 2013 introduced green direct payments which will account for 30 % of national direct payment envelopes from 2015, and which will be paid to farmers who respect agricultural practices such as the maintenance of permanent grassland, ecological focus areas and crop diversification (DG AGRI 2013: 7). However, it has been criticised that in the CAP reform negotiation process, the stringency of greening measures has been diluted, and that numerous exemptions apply (cf. Pe'er et al. 2014): farmers now need to establish "Ecological Focus Areas" on 5 % of the farmed area, instead of 7 % as initially intended, and only on farms with more than 15 ha of arable land; in some regions, member states can reduce requirements even further. Pe'er et al. (2014) argue that this area threshold exempts as much as 88 % of EU farms and 48 % of farmed area from this environmental requirement. Further, the CAP allows for the percentage of permanent grassland compared to the area of agricultural land at national or regional scales to be reduced by up to 5 %, before countermeasures have to be taken by national agencies or farmers, and crop diversification measures only require farms with more than 10 ha of arable land to cultivate at least two crops, which increases to three crops for farms >30 ha (Defra 2014; Pe'er et al. 2014).

The second pillar of the CAP, meanwhile, is dedicated to rural development programmes; eligible operations are defined by member states, but have to encompass agri-environment measures which compensate farmers who voluntarily commit to measures related to the preservation of the environment for additional costs or foregone revenue (DG AGRI 2014c). As part of rural development programmes, member states may choose to support various bioenergy related measures, such as support for decentralised biogas production, perennial energy crops, or the processing of agricultural and forest biomass for energetic uses (DG AGRI 2014a). In Germany, rural development plans are formulated and implemented regionally by the federal states, and contain for example investment subsidies for SRC plantations (Marx 2012; European Network for Rural Development 2014). In the CAP's second pillar, bioenergy-related support could in principle enter into competition with incentives for environmental conservation; on the other hand, rural development and in particular agri-environment measures can be used to foster synergies between bioenergy cultivation and environmental benefits (e.g. through crop diversification or incentives for the use of residues). However, as Steinhäußer (2012: 445) shows, currently it is economically more viable to grow energy crops with a high energy yield, such as maize, while making use of utilisation-sided support and the CAP's direct payments, rather than combining utilisation-sided support with agri-environment schemes. In this context, green direct payments could potentially be used to provide incentives for bioenergy producers to adapt practices compatible with conservation aims, particularly regarding crop diversification requirements (Steinhäußer 2012: 446). In order to deliver any significant environmental benefits, though, more stringent requirements would be needed than the reformed CAP's prescription of cultivating two or three different crops on medium or large farms, respectively (Pe'er et al. 2014).

4.2.1.2 Environmental Framework Conditions in Agriculture and Forestry

Whereas the CAP's cross compliance criteria are only mandatory in so far as they are prerequisites for receiving direct payments, all agriculture and forestry actors have to comply with environmental minimum standards laid down in the relevant environmental laws, and respect restrictions on permitted land uses in protected areas. On the European level, the Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC) set framework conditions for species and habitat conservation, which need to be implemented by member state legislation. In Germany, central environmental legislative requirements that bioenergy and other land users need to adhere to are formulated in the Federal Nature Conservation Act (BNatSchG), the Federal Soil Protection Act (BBodSchG), the Federal Water Act (WHG), the National Forest Act (BWaldG), the Fertilisers Act (DüngG) and the Fertilisers Ordinance (DÜV), the Crop Protection Act (PflSchG) and the Genetic Engineering Act (GenTG)—see SRU (2007: 62ff.) and Möckel (2014) for a detailed discussion.[8] Relevant minimum standards for agricultural actors are summarised under the term "good professional practice", which is implemented in BBodSchG, BNatSchG, DüngG, PflSchG, and GenTG. As such, it covers a range

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[8] Besides legislation at the national level, federal state-level environmental legislation is also relevant.

of practices and rules, reaching from precise threshold values (e.g. section 4 (3) DÜV for nitrogen application) to relatively abstract sustainability guidelines (e.g. section 17 (2) BBodSchG, section 5 (2) BNatsSchG) (Möckel 2014). Similarly, section 5 (3) BNatSchG prescribes that forestry activities should aim to establish nature-oriented forests and manage them sustainably without clear-cutting. Section 11 (1) BWaldG adds that forests need to be managed "ordnungsgemäß", i.e. according to relevant rules which are further specified in the forest acts of the individual federal states (cf. Ludwig et al. 2014).

4.2.1.3 The Waste Hierarchy According to Waste and Recycling Regulation

For the resource category of wastes and residues, central legal framework conditions are set by the Closed Cycle Management Act (KrWG), which on the European level is aligned with the Waste Framework Directive (2008/98/EC). The KrWG regulates the prevention, re-use and disposal of wastes, which are understood as "all materials or objects which their owner disposes of, wishes to dispose of or must dispose of" (section 3 (1) KrWG, own translation). The law seeks to promote closed cycle management, with the aim of conserving natural resources and protecting humans and the environment when generating and managing wastes (section 1 KrWG). Of particular relevance for energetic uses is the waste hierarchy established in section 6 KrWG (cf. Ludwig et al. 2014: 51ff.). According to section 6 (1) KrWG, the prevention of waste, preparation for re-use, and recycling have priority over "other re-uses", which include particularly energetic uses. Moreover, those measures should take priority that are the most suitable for protecting humans and the environment, taking into account the wastes' entire life cycle, including emissions, contributions to resource conservation, energy input and output of waste processing, and the accumulation of contaminants (section 6 (2) KrWG). Section 8 (3) KrWG specifies that an energetic use of wastes is considered equivalent to a material re-use or recycling, if the respective heating value amounts to at least 11,000 kJ per kg.

In principle, the waste hierarchy limits the scope of wastes and residues that can be used directly for energy production, because first of all material re-uses have to be explored. However, the hierarchy's application is limited through section 6 (2) sentence 4 KrWG, which states that in the choice of waste management measures, the technical feasibility, economic reasonableness and social impacts of measures need to be taken into account (Baur 2013; Ludwig et al. 2014: 81). As a consequence, it would be difficult in practice to persecute violations of the waste hierarchy.

For woody residues from industrial uses and waste wood, additionally the waste wood ordinance (Altholzverordnung, AltholzV) is relevant, which formulates specific requirements for the energetic and material re-use of waste wood (Ludwig et al. 2014: 58).

4.2.1.4 Import Tariffs on Bioenergy Carriers and Intermediate Products

Import tariffs on bioenergy carriers or intermediate products increase the costs of imports, thereby improving the competitiveness of domestic producers. In the EU, tariffs are most relevant for liquid biofuels and certain intermediate products (cf. Junginger et al. 2011; Lamers 2011:11, 13). For bioethanol imports into the EU, a tariff of 0.19 € per litre applies, although particularly for developing countries, preferential trade agreements imply reduced charges or exemptions from duties (Junginger et al. 2011: 2031). For biodiesel, an ad valorem tariff of 6.5 % applies, but higher anti-dumping tariffs are raised against imports from certain countries, in order to counter export subsidies and other measures found to provide an unfair competitive advantage to these countries' producers (cf. Lamers 2011: 11; COM 2013).

For other transport-worthy biomass, such as woody biomass or biomethane, trade streams are less regulated so far (Junginger et al. 2011: 2013). However, with Russia as a major example, some producer countries have introduced export tariffs on raw wood, in order to encourage domestic processing (BMELV 2011b: 15; Lamers et al. 2012: 3179).

4.2.2 Indirect Instruments in the Utilisation Sphere

In the utilisation sphere, the EU-ETS and energy taxes constitute indirect instruments, which can incentivise energetic biomass use if they increase the relative prices of fossil fuel substitutes to a sufficient degree. On the other hand, major instruments which support bioenergy directly are the Renewable Energy Sources Act in the electricity sector, the Renewable Energy Heat Act (EEWärmeG) and the Market Incentive Programme (Marktanreizprogramm, MAP) in the heating sector, and the biofuels quota in the transport sector (see Table 4.4). Transport biofuels and liquid biofuels, moreover, are only eligible for support if they meet sustainability requirements as laid out in the Renewable Energy Directive (see. Sect. 4.1.2.2).

4.2.2.1 The European Emissions Trading System

The European Emissions Trading System (EU-ETS) covers the CO_2 emissions of major point sources in the EU and, since 2012, aviation, as well as emissions of nitrous oxide (N_2O) and perfluorocarbons (PFCs) from selected processes (DG CLIMA 2014b).[9] Operators of combustion facilities with a thermal output of more than 20 MW, which can mainly be found in the energy sector, and energy-

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[9] Specifically, N_2O emissions from the production of nitric, adipic, glyoxal and glyoxylic acids and PFC emissions from aluminium production are included (DG CLIMA 2014b).

intensive industrial installations have to annually surrender emission allowances corresponding to the CO_2 emissions they release (DEHSt 2014a). From 2013, the auctioning of allowances has become the standard procedure. While operators of electricity plants have to bid for the entirety of their emission allowances, industrial and heating plants continue to benefit from a free allocation of certificates during a transition period; in 2013, the share of freely allocated certificates is 80 %, but will decline to 30 % by 2020 (DEHSt 2014b). Industries, for which emissions trading would represent a disadvantage in international competition, remain exempted and receive 100 % of their emission allowances for free, in order to counter risks of international carbon leakage (ibid). In aviation, aircraft operators are included if they carry out flights departing from or arriving within the European Economic Area's territory; from 2013 onward, the share of allowances which are allocated for free amounts to 82 % (DEHSt 2013).

Plants which exclusively combust biomass are exempt from the EU-ETS; if other energy carriers can in principle be used according to the plant's permit under the Federal Immission Control Act, the plant has to participate (DEHSt 2011: 18). However, according to the European Commission's decision 2007/589/EC, Annex 1 No. 11 and No. 12, emission factors of zero apply for a wide range of biomass types, so that a competitive advantage is not only generated for biomass-only plants, but incentives are also set for, for example, the co-combustion of biomass in fossil fuel-plants or the blending of biofuels with kerosine in aviation. In principle, incentives for emission reduction are even effective if allowances are allocated for free—as plant operators can sell allowances which they do not require, surrendering allowances for their own emissions bears opportunity costs.

However, in recent years carbon certificate prices have been too low and volatile to offer investment incentives for dedicated bioenergy plants (Tuerk et al. 2011). For Germany, Tuerk et al. (2011: 4) estimate that depending on biomass prices, CO_2 prices of 40–50 €/tCO_2 are required to make biomass plants competitive with coal plants. In contrast, daily closing prices on the London lead market for emission allowances fluctuated between 2.70 and 7 € in 2013 (cf. DEHSt 2014c, periodical reports third trading period). Co-combustion of biomass in coal power plants becomes competitive at lower CO_2 prices than dedicated bioenergy capacity, because investment costs for retrofitting plants are comparatively low, but even here current prices seem insufficient to incentivise any significant share of biomass use (Kangas et al. 2009: 1903).

4.2.2.2 Energy Taxes

Besides the EU-ETS, EU member states raise taxes on energy products and electricity. Binding minimum tax rates are implemented on the EU level in the Energy Taxation Directive (2003/96/EC), although in Germany, tax rates for most energy products are significantly higher than the minimum rates (cf. DG TAXUD 2013). The taxes set incentives for bioenergy use if they increase its competitiveness relative to fossil fuel substitutes. In the electricity sector, this is not the case, as under the Electricity Tax Act (StromStG) final electricity demand is taxed, with no distinction being made according to a fossil fuel or renewable provenance (cf. sections 1, 3 and 5 StromStG).[10] For heating and transport energy services, the Energy Tax Act (EnergieStG) distinguishes between energy products, although the degree to which incentives for bioenergy use are established varies between sectors.

In the heating sector, woody biomass and other renewables such as solar power, geothermal heat or wind are not taxed, while the use of biogas for heating is exempted (cf. Khazzoum et al. 2011: 84, 112). However, reduced tax rates apply for fossil fuels used in heating, so that incentives for employing RES substitutes are diminished (cf. Gawel and Purkus 2015). Moreover, for businesses in the industrial, agricultural and forestry sectors further exemption possibilities apply (sections 37, 51, 54, 55 EnergieStG), while for coal, even the standard tax rate is very low, reducing the effectiveness of incentives further (0.33 €/GJ, cf. section 2 (1) No. 9 EnergieStG).

In the transport sector, tax exemptions for biofuels used to be a strong driver for the market development (cf. FNR 2013a: 20), but have been phased out since the introduction of the biofuels quota in 2007, and lost relevance since (see section 50 EnergieStG). To ease the transition, exemptions for biomethane and biofuels which are considered particularly worthy of support remain in place until the end of 2015 (section 50 (2) EnergieStG); these are "(1) synthetic hydrocarbons or synthetic hydrocarbon mixtures obtained by the thermochemical conversion of biomass; (2) alcohols obtained by biotechnological methods for the digestion of cellulose; and (3) energy products with a bioethanol content of at least 70 % by volume" (section 50 (4) EnergieStG, own translation). Tax privileges for pure biodiesel and vegetable oils have been mostly phased out by the end of 2012 (Copenhagen Economics 2009: 258); without delimitation they only remain valid if the biofuels in question are used by agricultural and forestry businesses when carrying out agriculture- and forestry-related activities (section 57 (5) No. 2a and 2b EnergieStG, cf. Diekmann et al. 2013: 8). The shift from tax exemptions to a quota instrument was motivated by the 10 % transport sector renewables target in the EU's Renewable Energy Directive, but also by the increasing public costs of energy tax privileges—in 2012, tax revenue from biofuels amounted to 2300 million euros or 5.9 % of total energy tax revenues, and remaining privileges were reduced from 508 million euros in 2008 to 20 million euros in 2012 (Diekmann et al. 2013: 8ff.).

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[10] Electricity from RES is only exempt if it is sourced from a separate grid or power line fed exclusively from renewables (section 9 (1) No. 1 StromStG); in practice, this is only of relevance for the self-consumption of solar power (Diekmann et al. 2013: 4f.).

4.2.3 Direct Instruments of Bioenergy Support in the Electricity Sector: The Renewable Energy Sources Act

Bioelectricity pathways have been supported through the Renewable Energy Sources Act (EEG) since 2000, replacing the earlier "Stromeinspeisungsgesetz" dating back to 1991. The EEG encompasses several regulatory elements:

1. *Binding targets for the share of RES in the electricity sector*: E.g. under the EEG 2012, at least 35 % by 2020; 50 % by 2030; 65 % by 2040; and 80 % by 2050 (section 2, EEG 2012).
2. *Priority purchase and transmission rules*: Grid operators are obliged to purchase, transmit and distribute all available RES electricity, while in using the grid, RES have priority over non-renewable energy sources (section 8, EEG 2012).
3. *Priority grid connection rules*: Grid operators have to connect RES installations to their grid, immediately and as a priority (section 5, EEG 2012); if necessary, they are obliged to optimise, strengthen and expand their grids (section 9, EEG 2012).
4. *Feed-in tariffs (FIT) or feed-in premium (FIP)*: Over 20 years, a guaranteed remuneration is paid for each kWh, which differs according to technology and installation size (sections 16ff. EEG 2012). FIT rates for new installations are subject to an annual decrease, so as to set incentives for cost reductions (section 20 (2) EEG 2012). Since 2012, producers who market their electricity directly can choose to claim a sliding feed-in premium instead, which compensates for the difference between FIT rates and average market values (section 33g EEG 2012).

In the case of biomass, FIT rates do not only differ according to technology and installation size, but also according to the feedstocks employed (sections 27, 27a–c EEG 2012).[11] FIT rates and technology- and feedstock-specific bonuses changed considerably with revisions of the EEG in 2004, 2009, 2012, and 2014; the set-up of plants including installation sizes, predominant technologies and feedstocks tends to closely follow changes in political specifications (Scholwin et al. 2011; Scheftelowitz et al. 2014). Remuneration for biogas and solid bioenergy carriers is so far not bound to the fulfilment of sustainability standards, but both the EEG 2012 (section 64b EEG 2012) and the EEG 2014 (section 90 EEG 2014) contain an authorisation for the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety to issue ordinances on sustainability requirements for biomass. Bioliquids have to fulfil sustainability requirements laid down in the Biomass Electricity Sustainability Ordinance (BioSt-NachV), which implements EU sustainability requirements and is comparable in its contents to the Biofuel Sustainability Ordinance (Biokraft-NachV, see Sect. 4.2.5).

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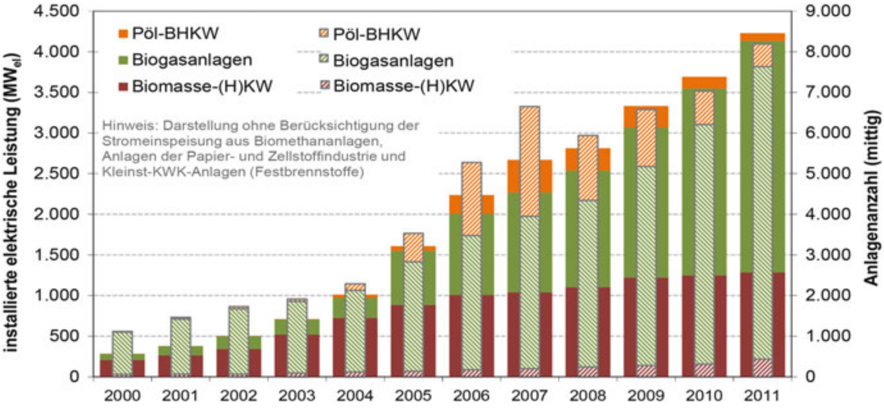
[11] What kinds of biomass are eligible for funding under the EEG is regulated in the Biomass Ordinance (BiomasseV).

4.2.3.1 Feed-in Tariffs According to the EEG from 2000 to 2011

While early bioelectricity production was focussed on solid biomass and especially on scrap wood, the EEG 2004 with its bonuses for renewable resource use, cogeneration, and innovative technologies triggered a sizable expansion in biogas production, which was predominantly based on the use of energy crops (Witt et al. 2012: 100; Delzeit et al. 2012). Responding to rising cereal and oil plant prices, the EEG 2009 increased FIT rates for biogas plants, and introduced a bonus if a 30 % minimum share of slurry was used; however, this measure failed to effectively counter the growing dependence on energy crops and maize in particular (Scholwin et al. 2011: 38f.; Delzeit et al. 2012). From 2009 to 2011 alone, ca. 3150 biogas plants with an electric capacity of 1420 MW became operational, while the expansion of solid biomass plants remained rather moderate (see Fig. 4.6; Witt et al. 2012: 103f.). The number of liquid biomass plants, meanwhile, has been dwindling since 2008, primarily due to price developments in vegetable oil markets (Witt et al. 2012: 104).

4.2.3.2 Feed-in Tariffs According to the EEG 2012

The strong expansion of biogas production in particular inspired critique, due to increasing impacts on land and resource competition, the sizable expansion of maize cultures with associated environmental impacts particularly in areas with a



DBFZ, 2012

Fig. 4.6 Development of the installed electric capacity (MW$_{el}$) and number of plants (on average) for electricity generation from biomass 2000–2011 (reproduced from Witt et al. 2012: 101). Notes: not included are electricity generation in biomethane plants, installations of paper and pulp industries and solid biomass cogeneration plants <10 kW$_{el}$. Striped bar segments from *top* to *bottom*: number of vegetable oil plants; number of biogas plants; number of solid biomass plants. Solid bar segments from top to bottom: installed electric capacity of vegetable oil plants; installed electric capacity of biogas plants; installed electric capacity of solid biomass plants high livestock farming intensity, and the high costs of support (cf. Scholwin et al. 2011; WBA 2011; Delzeit et al. 2012). With the EEG 2012, support has undergone a significant restructuring, including a general decrease of FIT rates and an abolishment of most bonuses. According to the EEG 2012, plants receive a basic tariff which decreases with size to account for economies of scale; a substance tariff which is paid according to the energy yield of different feedstocks, to reflect different provision costs and energy yields of substrates, but also different environmental characteristics; and a processing bonus which is paid when biogas is upgraded to biomethane and fed into the natural gas grid (Scheftelowitz et al. 2014: 13f.). The annual decrease of tariffs only applies to the basic tariff, which decreases by 2 % from 2013 onwards for new plants (section 20 (2) No. 5 EEG 2012). Table 4.5 gives an overview of the structure of remuneration.

Table 4.5 Feed-in tariff rates for biomass in the EEG 2012 (based on Scheftelowitz et al. 2014: 14; sections 27, 27a-27c EEG 2012)

	Tariff for					
	Biogas (excl. bio-degradable waste) and solid biomass (sec 27 EEG)				Bio-degradable waste fermentation[a] (sec 27a EEG)	Small manure installations[b] (sec 27b EEG)
Rated average annual capacity	Basic tariff	Substance tariff class I[c]	Substance tariff class II[d]	Biogas processing bonus (sec 27c and Annex I EEG)		
(kW$_{el}$)	(€ct/kWh$_{el}$)					
$\leq$75	14.3	6	8	Size of biogas production plant $\leq$700 sm^3/h: 3 $\leq$1000 sm^3/h: 2 $\leq$1400 sm^3/h: 1	16	25
$\leq$150						–
$\leq$500	12.3					
$\leq$750	11	5	8/6[e]		14	
$\leq$5000	11	4				
$\leq$20,000	6	–	–	–		

[a] Only applicable to plants fermenting specific biowastes (according to section 27a (1) EEG 2012), if the installations for the fermentation are directly linked to a final composting facility for solid fermentation residues and the composted material is recovered

[b] Special category for manure plants up to 75 kW installed capacity, cannot be combined with other tariff rates (e.g. base tariff or substance tariff)

[c] For 500–5000 kW: only 2.5 ct/kWh for electricity from bark and forest residues

[d] Only selected, environmentally beneficial substrates [according to Biomass Ordinance (BiomasseV)]

[e] 6 ct/kWh for electricity from certain types of manure over 500 kW (Annex 3 no. 3, 9, 11–15 BiomasseV)

In general, remuneration is limited to biomass plants of up to 20 MW of electric capacity, while the co-combustion of biomass in coal power plants is not eligible for funding at all. Further, given sharp price increases in vegetable oils, liquid biomass is no longer eligible for funding under the EEG 2012; the same is true for scrap wood with the exception of industrial residual wood, because all relevant potentials are considered to already be in use (Scheftelowitz et al. 2014: 13f.). Earlier bonuses for cogeneration and slurry use, meanwhile, have been replaced with binding prerequisites for support. For one, bioelectricity plants have to demonstrate that at least 60 % of the annual electricity production is from combined heat and power generation (section 27 (4) No. 1 EEG 2012); for biogas, alternatively a minimum manure use of 60 mass percent can be chosen (section 27 (4) No. 2 EEG 2012). Moreover, for biogas plants a maize cap has been established, according to which the share of maize and cereal grain kernels must not exceed 60 mass percent (section 27 (5) No. 1 EEG 2012).

Overall, the changes implemented in the EEG 2012 have significantly curtailed the expansion of biogas production. While in 2011, 1300 plants were completed, only 300 new plants became operational in 2012 and a further 200 plants in 2013 (Scheftelowitz et al. 2014: 18ff.). Meanwhile, extensions of existing plants saw an increase, but even taking these into account the increase in installed capacity remained a third below 2011 levels; installed electric capacity increased by 350 MW in 2012 and 200–250 MW in 2013, building up to a total of 7700 biogas plants with an installed electric capacity of up to 3450 MW at the end of 2013 (ibid.). As to solid biomass plants, it was mainly the market segment of small plants <1 MW which was still expanding, inspired by technological advances in the thermo-chemical gasification of wood; in total, an estimated number of 760 solid biomass plants, including cogeneration plants, with an electric capacity of ca. 1524 MW had been installed at the end of 2013 (Scheftelowitz et al. 2014: 28f.). New installations using liquid biomass for electricity generation, which are no longer eligible for FIT, were limited to insular applications; in 2012, total electric installed capacity amounted to 170 MW (Scheftelowitz et al. 2014: 31f.).

4.2.3.3 Direct Marketing According to the EEG 2012

The EEG 2012 also introduced the market premium scheme (MPS) as a sliding feed-in premium to promote participation in direct marketing and demand-oriented electricity production (BMU 2011c: 13ff.). Incentivising the latter is of particular relevance for bioelectricity, because under the FIT, it is most profitable for plants to maximize full load hours and produce base load power independent of electricity prices and demand (Rohrig et al. 2011: 3). In this way, the advantage of storability and flexible applicability that bioenergy has over intermittent RES like wind and solar power is left unutilised.

Under the EEG 2012, plant operators can choose between feed-in tariffs (FIT) and MPS on a monthly basis, except for large biogas plants with an installed electric capacity of over 750 kW, which are no longer eligible for the FIT from the start of

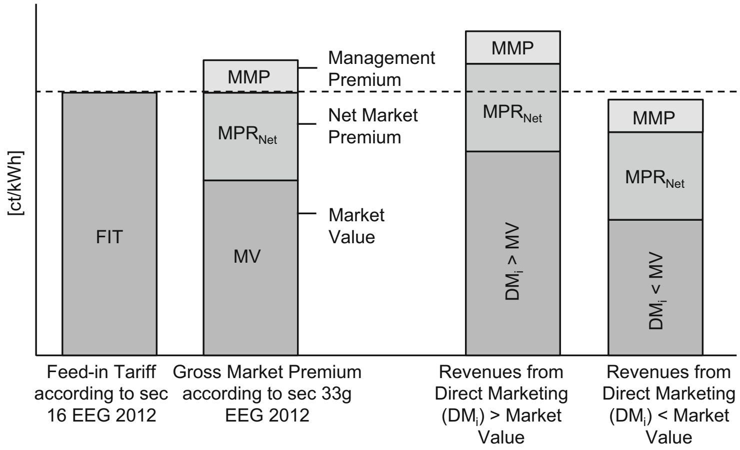


Fig. 4.7 Design of the market premium scheme (reproduced from Gawel and Purkus 2013: 600; based on Annex 4, no. 1 EEG 2012; Lehnert 2012; Wustlich and Müller 2011)

2014 but can participate in the MPS (sections 27 (3), 27a (2), 27c (3) EEG 2012). The market premium covers the difference between the FIT a plant would be entitled to and the average market value of the electricity generated (see Fig. 4.7). Moreover, producers receive a management premium intended to cover additional costs resulting from their direct participation in the market, which for dispatchable RES amounts to 0.30 ct/kWh in 2012, decreasing down to 0.225 ct/kWh from 2015 (Annex 4 no. 2.1 et seqq. EEG 2012). By selling electricity when demand—and therefore the market price—is high, producers can earn revenues above the average market values used in calculating the market premium, thereby improving their income relative to the FIT. In this way, the market premium offers incentives for demand-oriented electricity production (Gawel and Purkus 2013; Klobasa et al. 2013). Moreover, biogas plants participating in the scheme can take advantage of a flexibility premium, because incentives set by the MPS alone are considered too low to encourage necessary investments in flexible plant designs (Rohrig et al. 2011: 7; Scheftelowitz et al. 2014: 129).[12] Hence, the capacity-oriented premium is intended to compensate for investment costs in additional storage and production capacities required for a more flexible electricity generation (section 33i and Annex 5, No. 2.3 EEG 2012). Further market-based revenues can be generated by participation in balancing markets (Reeg et al. 2013: 3; Scheftelowitz et al. 2014: 144), which are open to plants in direct marketing, but not the FIT (section 16 (3) EEG 2012). Minimum heat or manure requirements as laid down in section 27 (4) EEG 2012 do not apply to plants in the MPS (section 33h EEG 2012).

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[12] Additional income through demand-oriented feed-in is defined by the average peak-offpeak-spread on electricity markets, which amounted to 1.94 ct/kWh between 2007 and 2010 (Rohrig et al. 2011: 17).

Since its introduction, participation in the scheme by biomass plants has seen a steady increase, from 933 MW installed capacity in January 2012 to 3450 MW in April 2014 (cf. 50Hertz et al. 2014); this was equivalent to about 65 % of total installed bioelectricity capacity (Holzhammer and Stelzer 2014). A slight majority of plants participating in direct marketing used biogas and biomethane (ca. 56 %), the remainder was largely made up of solid biomass plants (ibid.). Other forms of direct marketing have become largely irrelevant for bioelectricity producers (cf. 50Hertz et al. 2014); apart from direct marketing without remuneration particularly the "green electricity privilege" lost in relevance, which allows electricity suppliers which sell certain shares of RES as part of their portfolio a reduction in the EEG surcharge, i.e. the surcharge suppliers pass on to their customers to finance the EEG feed-in tariffs.

In assessing the effectiveness of the MPS in incentivising demand-oriented production, a central question is whether bioelectricity plants in the MPS actually change their production behaviour and switch from a mere maximisation of full-load hours to demand-oriented feed-in (Gawel and Purkus 2013: 604). An indicator for this is the use of the flexibility premium by biogas plants to finance prerequisite investments. After a slow start, which has been attributed to the complexity of compensation rules and investments (Welteke-Fabricius and Filzek 2012; Klobasa et al. 2013: 22), participation has picked up in 2013 and 2014—by March 2014, 344 plants with an installed electric capacity of ca. 195 MW received the flexibility premium (Holzhammer and Stelzer 2014). Based on this, it is estimated that 10 % of biogas and biomethane capacity in direct marketing had switched their production behaviour to flexible, demand-oriented feed-in. The share of plants participating in balancing markets was somewhat higher, amounting to 24 % or 820 MW of total electric biomass capacity (ibid). Concordantly, Reeg et al. (2013: 255) find that participation in balancing markets can provide much higher economic incentives for participating in direct marketing then the MPS and market price bonuses of demand-oriented feed-in.

4.2.3.4 The Role of Biomass in the EEG 2014

In August 2014, a new revision of the EEG was adopted, which contains drastic reductions in the support for bioelectricity (cf. Table 4.6). Substrate tariffs from the EEG 2012 are cancelled entirely, as is the bonus for gas processing (cf. Thrän et al. 2014). In effect, a new 150 kW biogas or solid biomass plant faces a reduction in tariff rates from 20.3 ct/kWh in the EEG 2012 (using a substrate from substrate tariff class I) to 13.66 ct/kWh based on the EEG 2014, not taking potential capacity-oriented income through the flexibility premium into account (cf. Tables 4.5 and 4.6). Moreover, a 100 MW cap is introduced on the annual expansion of electric

Table 4.6 Tariff rates for biomass according to the EEG 2014 (based on sections 44–46 EEG 2014)

	Tariff for		
Rated average annual capacity	Biogas (excl. bio-degradable waste) and solid biomass (sec 44 EEG 2014)	Bio-degradable waste fermentation[a] (sec 45 EEG 2014)	Small manure installations[b] (sec 46 EEG 2014)
(kW$_{el}$)	(€ct/kWh$_{el}$)		
≤75	13.66	15.26	23.73
≤150			–
≤500	11.78		
≤750		13.38	
≤5000	10.55		
≤20,000	5.85		

[a] Only applicable to plants fermenting specific biowastes with an average minimum share of 90 mass percent; moreover, the installations for the fermentation must be directly linked to a final composting facility for solid fermentation residues and the composted material must be recovered (section 45 (2) EEG 2014)

[b] Special category for manure plants up to 75 kW installed capacity and a minimum slurry share of 80 mass percent (section 46 EEG 2014)

biomass capacity (section 3 (4) EEG 2014); if the cap is exceeded, remuneration for new plants is decreased further (section 28 EEG 2014).[13]

Apart from tariff rates, changes also apply to marketing arrangements and the flexibility premium. From 2015, direct marketing is obligatory for all new RES plants with an installed capacity above 500 kW; this is expanded to all new plants >100 kW from 2016 (section 37 EEG 2014). At the same time, the green electricity privilege is abolished, so that the sliding feed-in premium of the MPS becomes the standard remuneration for RES. The feed-in tariff scheme remains in place for small-scale plants which do not fall under the direct marketing obligation; larger plants have the option of falling back on it in exceptional circumstances, for example, if a direct marketing company becomes insolvent, but in this case FIT rates are reduced by 20 % so that a lengthy use of this option would be economically unattractive (section 38 EEG 2014). From 2017 at the latest, the EEG 2014 foresees a change from centrally administered tariff rates to a tendering scheme, where the level of remuneration would be determined by competitive bidding (section 2 (5) EEG 2014).[14]

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[13] From 2016, reference prices are reduced by 0.5 % every three months (section 28 (2) EEG 2014); if the “breathing cap” of 100 MW is exceeded, this dynamic decrease is accelerated to 1.27 % (section 28 (3) EEG 2014). The 100 MW cap relates to the gross expansion of bioenergy capacity, taking not only new plants, but also extensions of existing plants into account.

[14] As a concession to planning security, plants that become operational after 2017 continue to be eligible for remuneration according to FIT or feed-in premium for a transitional period (section 102 EEG 2014).

In the meantime, the separate management premium in the MPS is cancelled, although additional costs of direct marketing are reflected in standard tariff rates (BMWi 2014: 8). According to section 37 (3) EEG 2014, the reference price for dispatchable plants such as biomass plants in direct marketing is 0.2 ct/kWh higher than for plants in the FIT; for wind and photovoltaics (PV), the difference is 0.4 ct/kWh. Nevertheless, even taking this differentiation into account, standard tariffs decrease compared to the EEG 2012. The annual flexibility premium for existing biogas plants remains 130 €/kW of additional, flexibly available electric capacity, as long as certain prerequisites are met (section 54 and Annex 3 EEG 2014). New plants receive an annual flexibility bonus of 40 €/kW of electric capacity installed, as long as their total electric capacity is above 100 kW (section 53 EEG 2014); this bonus is paid on total electric capacity, and is supposed to compensate not only for additional investment costs, but also for recurring additional costs of direct marketing (EEG Gesetzentwurf der Bundesregierung 2014: 224). Simultaneously, for biogas plants above 100 kW, funding under the FIT or MPS is limited to that part of annual electricity production which corresponds to a power rating of 50 % of the installed electric capacity (section 47 (1) EEG 2014). Electricity beyond this limit will receive no funding under the MPS, or the average market value if marketed by transmission system operators under the FIT. The intention behind this regulation is that only biogas plants with flexible electricity generation should be incentivised in the future, which, rather than running in base load mode, concentrate electricity feed-in on hours of high demand (EEG Gesetzentwurf der Bundesregierung 2014: 215). Moreover, in order to increase incentives for voluntary curtailment in times of negative electricity prices, reference prices in the EEG 2014 are reduced to zero when the value of the hourly contracts on the EPEX Spot exchange is negative in at least six consecutive hours (section 24 EEG 2014); this regulation applies only to plants >500 kW which are commissioned after 1 January 2016.

The overall intention of the revisions is to move the focus of bioelectricity production away from renewable resources to waste and residues, which, after the cuts, are expected to be the only economically feasible feedstock option (BMWi 2014: 11f.). Moreover, for biogas plants, the intent is that only plants producing in a demand-oriented manner should be supported (EEG Gesetzentwurf der Bundesregierung 2014: 215). Accordingly, the EEG 2012s requirements on the maximum share of maize and minimum shares of heat and slurry use are abolished (cf. section 47 (2) EEG 2014 and p. 215 EEG Gesetzentwurf der Bundesregierung 2014), assuming that concepts based on renewable resources and non-economic heat use will no longer be profitable under the new tariff regime.

The proposed changes have, however, triggered strong criticism by bioenergy practitioners and researchers alike (cf. Thrän and Nelles 2014; Fachverband Biogas 2014). Thrän et al. (2014b) conclude that new tariff rates are too low to allow for an economically feasible exploitation of waste and residue potentials, especially since feasible concepts often rely on a mixed use of waste, residues and energy crops. As a result, bioelectricity expansion is expected to grind to a halt, and technological developments, particularly in new, promising pathways such as biomethane production, are expected to be cut short.

4.2.4 Direct Instruments of Bioenergy Support in the Heating Sector: The Renewable Energy Heat Act and the Market Incentive Programme

Central instruments for the promotion of bioenergy and other RES in the heating sector are the Market Incentive Programme (Marktanreizprogramm, MAP) and the Renewable Energy Heat Act (Erneuerbare-Energien-Wärmegesetz, EEWärmeG). Of secondary importance is the Energy Saving Ordinance (EnEV), which implements the EU Directive on the Energy Performance of Buildings (2010/31/EU). The EnEV sets requirements for the technical primary energy efficiency of buildings, which can partially also be fulfilled by using RES (section 5 EnEV 2009).

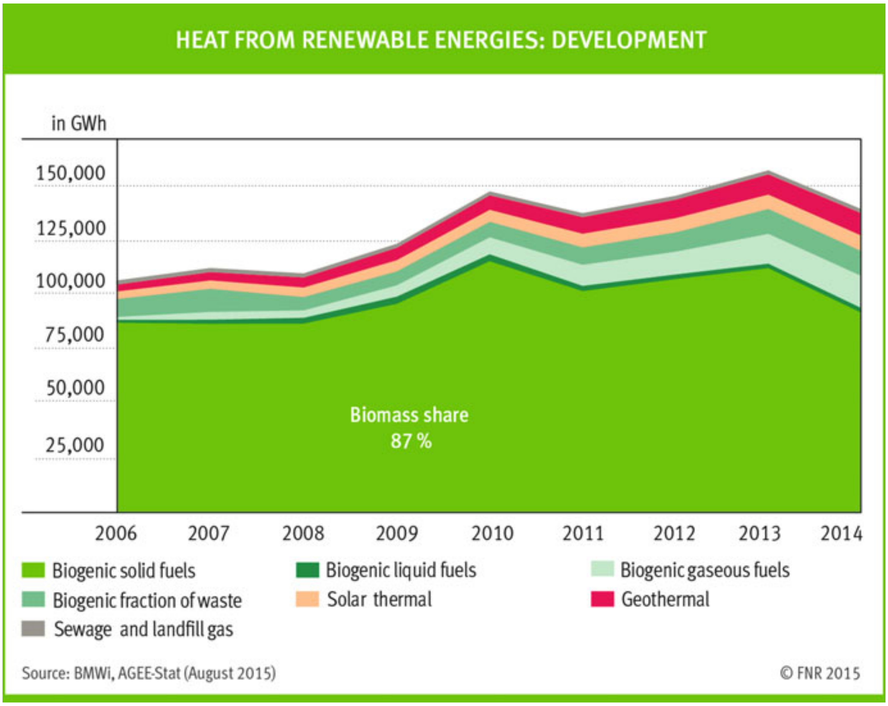
4.2.4.1 The Market Incentive Programme (MAP)

Since 2000, the MAP offers investment support and low interest loans for investments in RES heating installations. It is split into two sections—investment grants for small solar thermal plants, biomass plants below 100 kW installed capacity, and heat pumps, which are handled by the Federal Office of Economics and Export Control (BAFA), and low interest loans and loan repayment support primarily for larger plants, heating grids and heat storage facilities, managed by the KfW (Kreditanstalt für Wiederaufbau) (Langniß et al. 2012: 1). The programme is financed by revenues from the auctioning of emission allowances within the EU Emissions Trading System, as well as energy tax revenues (Schlegelmilch 2014: 211). In 2012, support offered through the MAP amounted to 300 million euros, triggering investments of 1.33 billion euros (BMUB 2014). Table 4.7 gives an overview of the measures supported.

In 2011, the MAP provided incentives for a quarter of the total market for renewable heat, and is seen as an important incentive for investments in renewable heat technologies. It complements the renewables obligation in the EEWärmeG, in that only measures are eligible for support which do not count towards fulfilling the obligation (section 15 (1) EEWärmeG). Particularly in the case of biomass, demand

Table 4.7 Measures supported through the MAP in 2012 (based on BMUB 2014)

	BAFA investment grants	KfW low interest loans and repayment support
Supported measures 2012	74,779 measures	2724 loans
Support volume 2012	144 million euros	131 million euros
Structure of support	Solar thermal (50 %), Biomass (41 %), Heat pumps (7 %)	Heating grids (67 %), Large-scale biomass (21 %), Heat storage (7 %), Large-scale solar thermal (3 %)



Source: BMWi, AGEE-Stat (August 2015) © FNR 2015

Fig. 4.8 Development of RES heat supply 2006–2014 [reproduced from Fachagentur Nachwachsende Rohstoffe e.V. (FNR 2015)]

for technology-specific support has been high (Langniß et al. 2012: 4f.). However, the programme's dependency on public budgets is seen as a central problem for the planning security of investors (Langniß et al. 2012: 6f.); not only is the amount of available funding negotiated anew each year, budgetary shortages can also lead to funding cuts during the year, as happened in 2010 when a temporary suspension of support contributed to a substantial decline in demand for renewable heat installations (Langniß et al. 2011: 10) (cf. Fig. 4.8).

4.2.4.2 The Renewable Energy Heat Act (EEWärmeG)

The EEWärmeG, which was implemented in 2009, prescribes a 14 % minimum RES share in heating by 2020 (section 1 (2) EEWärmeG); this target is instrumentally supported through the MAP's funding (section 13 EEWärmeG) as well as through a renewables obligation for new buildings and public buildings if fundamental renovations are undertaken (section 3 EEWärmeG).[15] Mandatory minimum

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[15] Moreover, section 3 (4) no. 2 EEWärmeG determines that federal states are allowed to impose a renewables obligation also on the existing building stock.

Table 4.8 Minimum RES shares according to the EEWärmeG (based on sections 5 and 5a EEWärmeG)

RES technology	Solar (%)	Biogas (%)	Biomass solid/liquid (%)	Geothermal/ ambient heat (%)
Minimum share in new buildings	15	30	50	50
Minimum share in public buildings in case of fundamental renovations	15	25	15	15

RES shares vary depending on the technology used (see Table 4.8); combinations of technologies are possible, as well as the use of compensation measures such as energy efficiency improvements or the use of waste heat or heat from cogeneration plants (section 7 EEWärmeG). The instrument's design is essentially open to all forms of technology, as actors decide how they will fulfil their obligation depending on their building's context and the costs of different RES technologies and compensation measures. In particular, biomass installations have proven to be a popular option, having contributed at least 90 % to RES heat supply in the years 2009–2012 (BMU 2013a: 22), dropping only slightly to a share of 87 % in 2014 (see Fig. 4.8).

The renewables obligation's focus on new buildings and public renovations, however, limits the instrument's sphere of influence; in the case of residential buildings, it is estimated that less than 1 % of the building stock are affected each year (Thrän et al. 2009: 95). Accordingly, the lack of incentives for RES investments in the building stock is seen as a major challenge for further RES expansion in the heating sector, which has to be addressed in a revision of the EEWärmeG (Hofmann et al. 2013: 329ff.). Among the options being discussed are an extension of the renewables obligation to the building stock, increases in the energy tax for fossil heating fuels, and the introduction of a bonus or quota model for companies which market heating fuels or installations, an analogue to the transport sector's biofuel quota (Bürger et al. 2013: 52; Hofmann et al. 2013: 334ff.).

4.2.5 *Direct Instruments of Bioenergy Support in the Transport Sector: The Biofuel Quota*

In 2007, tax exemptions for biofuels were superseded as the primary biofuel support instrument by the biofuel quota, which has been implemented in the Federal Immission Control Act (section 37a BImSchG 2015). The biofuel quota requires suppliers of mineral oil to account for an increasing minimal share of biofuels in the amount of petrol and diesel they put on the market each year (see Table 4.9; Naumann et al. 2014: 2ff.). As such, the biofuel quota is intended to implement the EU Renewable Energy Directive's 10 % target for RES in the transport sector and the EU Fuel Quality Directive's Low Carbon Fuel Standard (see Sect. 4.1.2).

Table 4.9 Biofuel quota requirements 2007–2020 (based on section 37a BImSchG 2015)

In %	2007	2008	2009	2010–2014	2015	2017	2020
Total quota	–	–	5.25	6.25	3.5	4	6
Petrol fuels	1.2	2	2.8	2.8	–	–	–
Diesel fuels	4.4	4.4	4.4	4.4	–	–	–
Quota system	Share in the energy content of transport fuels brought into circulation				Reduction in GHG emissions of transport fuels brought into circulation		

Note: On 1 January 2015, the revised BImSchG 2015 entered into force. In previous versions of the law, quota requirements demanded a 3 % reduction in GHG emissions from 2015, 4.5 % from 2017 and 7 % from 2020 (section 37a (3a) BImSchG 2013)

From 2007 to 2014, the quota refers to the share in the energy content of transport fuels brought into circulation, and is divided into subquotas for petrol and diesel fuels (section 37a (3) BImSchG 2015). From 2015, the quota requires minimum reductions in the GHG emissions of transport fuels brought into circulation which are to be achieved through the use of biofuels, with no further distinction between petrol and diesel fuels (section 37a (4) BImSchG 2015). If suppliers fail to comply with the biofuel quota, they are charged with a fee according to section 37c (2) BImSchG 2015, amounting to 19 €/GJ for suppliers of diesel fuels and 43 €/GJ for suppliers of petrol fuels. Obligated parties can arrange for their obligations to be fulfilled by third parties (section 37a (6) BImSchG 2015), allowing for a trade in biofuel energy quantities (until 2014) or biofuel-induced emission reductions (from 2015), respectively (Peiffer 2013). The Quota can be fulfilled by blending small shares of biofuels with mineral oil-based fuels—to this end, in 2010 the permissible maximum amount of bioethanol in petrol fuels was increased from 5 to 10 % (marketed as “E10”), while diesel fuels may contain up to 7 % biodiesel (10. BImSchV section 13 (1) nos. 2 and 3). But also, higher blends (e.g. “E85”) or pure biofuels (mainly biodiesel and vegetable oils) can be used, as can biomethane (section 37b BImSchG 2015).

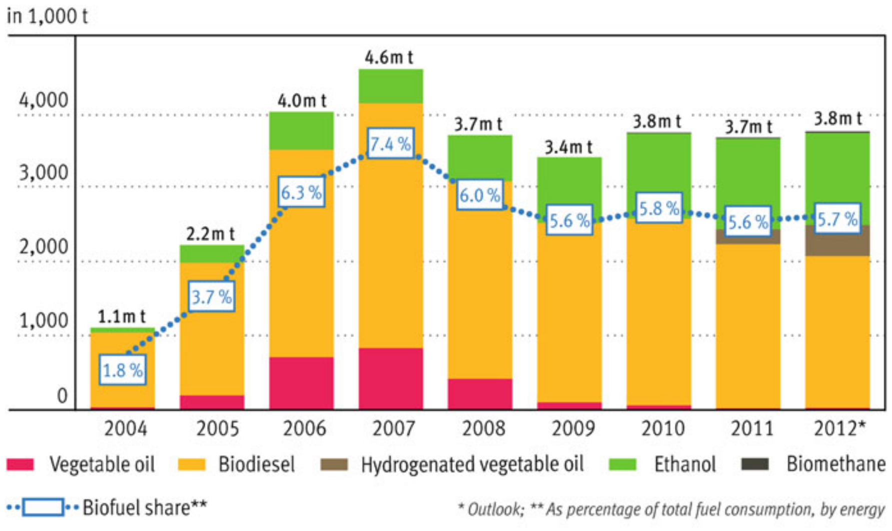
In order to count against the quota, liquid and gaseous biofuels in transport have to fulfil minimum sustainability requirements according to the Biofuel Sustainability Ordinance (Biokraft-NachV), which implements the EU RED’s demands (see Sect. 4.1.2.2). Table 4.10 gives an overview of the requirements; compliance has to be verified by obtaining certification from accredited institutions for the entire value chain (sections 14ff. Biokraft-NachV).

From 2007 to 2013, the biofuel quota has been exceeded each year, with surplus quantities being bankable to the next year (cf. Zoll 2014). Overall, however, the energetic share of biofuels in total transport fuel consumption has fallen from 7.2 % in 2007 to 5.2 % in 2013 (Naumann et al. 2014: 57). In particular, biofuel consumption has declined strongly between 2007 and 2008, stagnating at about 3.8 million t/a since (cf. Fig. 4.9). Apart from the gradual phasing-out of tax exemptions for biofuels (see Sect. 4.2.2.2), a reason for this can be found in a change of the biofuel quota which was adopted in 2008, reducing the required minimum biofuel share for 2009 and introducing the switch to a GHG-based system beyond 2015

Table 4.10 Mandatory sustainability requirements for liquid and gaseous biofuels (based on sections 4–8 Biokraft-NachV)

Conservation of natural habitats (sec 4–6 Biokraft-NachV)	Biomass used in the production of biofuels may not originate from • Biodiversity-rich areas (forested areas with primary forests or other natural forested areas; areas dedicated to conservation purposes; grassland with high biodiversity) • Areas which are rich in above- or below-ground carbon (wetlands or continuously forested areas) • Peat lands.
Sustainable agricultural production (sec 7 Biokraft-NachV)	Energy crop cultivation within the EU has to follow cross compliance requirements and maintain a good agricultural and environmental condition.
GHG mitigation potential (sec 8 Biokraft-NachV)	Biofuels need to have a GHG mitigation potential of at least 35 % compared to the fossil fuel reference; from 2017, this increases to at least 50 %, from 2018 to at least 60 %. GHG reduction potentials have to be calculated using actual measured values, following the methodology laid out in Annex I Biokraft-NachV. For the calculation, producers may also use standard values as defined in Annex II Biokraft-NachV.

Note: For bioliquids in the electricity sector, the Bioelectricity Sustainability Ordinance (BioSt-NachV) formulates identical requirements



Source: BAFA, BMF, FNR (August 2013) © FNR 2013

Fig. 4.9 Development of biofuel consumption 2004–2012 [reproduced from Fachagentur Nachwachsende Rohstoffe e.V. (FNR 2014: 20)]

(Naumann et al. 2014: 3ff.); further changes in GHG reduction requirements were implemented in the BImSchG 2015 (see Table 4.9). Also, the introduction of the E10 petrol blend was met with poor public acceptance and concerns about technical compatibility, which kept demand at much lower levels than initially expected (e.g. Scherer 2012). Further decreases in the planning security for investors result from continued uncertainties about future changes in European and national biofuel policy (see Sect. 4.1.2.4; cf. Majer and Naumann 2013). Besides a reduction in total consumption, the shift from tax exemptions to a quota obligation has also changed the structure of biofuel use. In particular, the use of pure vegetable oil and pure biodiesel has lost in relevance, mediated by increases in global vegetable oil prices and reduction of tax exemptions for unblended biofuels (Naumann et al. 2014: 56f.). At the same time, the blending of diesel or petrol with biodiesel and bioethanol has increased (ibid.).

4.3 Instruments of German Bioenergy Policy: Empirical Economic Analysis

The analysis of German bioenergy policy shows a large distance to recommendations by neoclassical economists, which envision bioenergy policy to be integrated into a cost-effective GHG mitigation strategy (see Sect. 3.1.4). Instead, the actual policy mix employed reflects the complexity of the allocative and regulative problems involved in bioenergy policy making, given the range of relevant market failures and policy aims. German bioenergy policy encompasses a mix of instruments directed at governing framework conditions in the primary biomass production sphere, R&D support for conversion technologies, indirect instruments in the utilisation sphere which increase the costs of fossil fuel substitutes and direct utilisation-sided instruments which offer subsidies or command-and-control impulses for bioenergy use.

From a neoclassical perspective, it would be ideal if all market failures in the primary production sphere were addressed by first-best instruments, which would allow for a focus on the choice of indirect utilisation-sided instruments to govern allocation decisions about the use of bioenergy and other GHG mitigation options (see Sect. 3.1.3). But the analysis of German bioenergy policy shows that instruments that have actually been implemented fall significantly short of addressing market failures comprehensively. This applies to indirect utilisation-sided instruments like the EU-ETS and energy taxes (cf. Lehmann and Gawel 2013; Gawel et al. 2014b; Helm 2010; Gawel and Purkus 2015), but also to instruments in the primary production sphere, for example, with regard to the insufficient internalisation of environmental costs and benefits in the CAP (cf. Pe’er et al. 2014), insufficient incentives for waste avoidance and re-use in the waste hierarchy (cf. Ludwig et al. 2014: 81) or long-standing implementation deficits of environmental law and “good professional practice” rules (cf. Möckel

2014; Lübbe-Wolff 1996). In explaining these shortcomings, constraints such as transaction costs, information problems, institutional path dependencies and political feasibility constraints, which have been discussed as part of the new institutional economics perspective (see Sect. 3.5), play an important role.

The use of separate targets for RES and direct support instruments in the utilisation sphere can be understood as policy makers' attempt to address these constraints, overcome technological and institutional lock-in situations, and address multiple policy aims (Lehmann and Gawel 2013; Matthes 2010; Kemfert and Diekmann 2009; Grubler et al. 2012). From an NIE perspective, the German bioenergy policy mix therefore performs better than its reputation from neoclassical analyses would lead to believe. However, the choice and design of direct support instruments is subject to diverse sources of government failure as well. In some cases, the reform of indirect instruments and framework conditions may yield more cost-effective and sustainable contributions to policy aims than direct instruments, but may be infeasible at least in the short- to mid-term. Using a policy mix with direct instruments may be able to loosen these constraints and allow for more comprehensive reforms over time, or it may even increase welfare compared to a single instrument solution, for example, when combining an emissions trading scheme with RES subsidies to internalise learning spillovers (see Lehmann 2012, 2013; Bennear and Stavins 2007 for overviews). In other cases, however, direct instruments may be part of symbolic policy efforts aimed at demonstrating environmental activism to voters, while transferring rents from diffuse interests with a low degree of organisation to well-organised interest groups (cf. Sect. 3.5.5.1). To establish whether direct support instruments fulfil the requirements of a rational bioenergy policy that takes institutional constraints into account, a detailed assessment of instrument choice and design is required.

Nonetheless, several general characteristics of direct support instruments in German bioenergy policy can be identified based on the preceding overview. For instance, direct instruments represent hybrids between market-based and hierarchical governance structures, but tend to lean more heavily towards the hierarchical side of the spectrum—with the exception of the EEWärmeG which offers obligated parties a comparatively wide choice of compliance options, instruments are designed in a highly technology-specific manner. In this way, policy makers have a high degree of control over choices between GHG mitigation options (e.g. RES use vs. energy efficiency improvements), RES technologies and even different bioelectricity, biofuel or bio-heat technologies. As the theory of economic order highlights, this situation can prove problematic given the high information requirements imposed on policy makers and the various risks of government failure, which would result in large-scale distortions of allocation decisions (see Sect. 3.4). For example, the strong degree of technology differentiation leaves significant scope for lobbying efforts. Whether disadvantages of comparatively hierarchical instruments can be balanced by advantages when analysed from an NIE perspective will be discussed in Sects. 5.3 and 5.4.

Another characteristic can be found in the strong sectoral fragmentation of direct deployment support—different instrument types are used in different sectors (encompassing quotas, FIT and FIP schemes, subsidies and command-and-control instruments), with little coordination between them. This is particularly problematic because until recently, bioenergy expansion was driven forward in all three energy sectors (cf. BMU and BMELV 2009a: 11). But even with 2014's cuts in bioelectricity support (see Sect. 4.2.3.4), the lack of coordination between sectoral instruments remains a problem—for example, both the EEG 2014s bioelectricity support regime and the new GHG-based biofuels quota place the focus on waste and residues-based pathways, and are likely to fan competition for these resources. Still, there is no alignment of sectoral instruments with common criteria, such as GHG mitigation costs, learning curve potential or security of supply contributions (see Sect. 4.4.1). Rather, instrument design appears to reflect a mixture of all three dimensions as well as contributions to further aims, including distributive ones such as rural value creation. The emphasis between aims changes between sectors, but also over time (cf. Londo and Deurwaarder 2007).

Shifts in political priorities, meanwhile, are reflected in changes in instrument design, as the examples of the EEG and the biofuel quota demonstrate. Such shifts can be triggered by changes in political majorities, relative bargaining strengths of interest groups, or perceived voter preferences; they can also reflect new scientific information. In all cases, however, significant policy changes have negative impacts on planning security. This applies to rapid changes, such as those enacted in the EEG 2014 revision, as well as to ongoing EU-level discussions about how to address ILUC in biofuel support, which increase investor uncertainty. As this example demonstrates, policy changes need not always be initiated by the national governance level, but may arise from EU-level decisions, in which case additional dynamics of transnational decision making need to be considered. Biofuel policy in particular has been shaped significantly by EU-level decisions, due to the RED's 10 % target for the share of RES in transport and the FQD's Low Carbon Fuel Standard (see Sect. 4.1.2). In the electricity sector, the EU Commission's new state aid guidelines (COM 2014b) which contain a strong preference for the market integration of renewables and competitive bidding schemes will have a strong impact on future national policy design. In the years to come, the European Council's decision to abandon separate RES targets for 2030 and abstain from sectoral GHG emission reduction targets is likely to prove significant for national bioenergy policy design—in particular, it removes European regulative drivers for biofuel support beyond 2020.

Meanwhile, even if important impulses for bioenergy policy come from EU regulations, instrument design and (to some degree) choices are left to member states—as such, the main drivers for bioenergy expansion in Germany can be clearly found on the national policy level. In combination with EU-level import tariffs for biofuels, instruments so far tend to favour domestic bioenergy pathways (cf. WBA 2007: 176). From a multi-level governance perspective, the distribution of responsibilities between national, regional and local governance bodies is also of interest—environmental impacts such as eutrophication and acidification, landscape externalities and impacts on biomass resource flows are local or regional in their scale, whereas major incentives and remuneration rules are defined in national-level instruments. Interactions between federal state-level environmental laws, state-level and municipal planning tools and national support instruments are therefore another relevant dimension for a more detailed policy assessment, which is however not the focus of this work.

4.4 Assessment of German Bioenergy Policy: Mains Strands of Critique

In contrast to the overview of critique by neoclassical economists in Sect. 3.1.4, this section provides an overview of the broad strands of critique that dominate the wider public debate. The EEG, the EEWärmeG in combination with the MAP, and the biofuel quota have proven very effective in promoting the expansion of bioenergy use in recent years (see Sect. 4.2). However, following neoclassical points of critique, the lack of efficiency in support design is a major point of contention. Beyond that, the insufficiency of sustainability regulation is a second important strand of critique. Major arguments are briefly outlined below.

4.4.1 Cost-Effectiveness in Contributing to GHG Mitigation and RES Expansion Targets

First of all, it is criticised that bioenergy policy fails to contribute to GHG mitigation in a cost-effective manner (e.g. Henke and Klepper 2006; Isermeyer and Zimmer 2006; SRU 2007: 88ff.; WBA 2007: i; Frondel and Peters 2007; Kopmann et al. 2009; Hermeling and Wölfing 2011: 46). Both across energy sectors and within individual sectors, support is not systematically focussed on pathways which realise large GHG mitigation potentials at low costs. For example, biofuels constitute a comparatively expensive GHG mitigation option among biomass uses, with estimated GHG mitigation costs ranging between 113 €/tCO_2-eq. for biomethane from biowastes and 456 €/tCO_2-eq. for bioethanol from wheat (Naumann et al. 2014: 76). Even for the longer term, no significant reductions in GHG mitigation costs are expected—even if the change to a GHG-based biofuel quota incentivises search processes for options with low GHG mitigation costs, such as wastes, residues and rapeseed biodiesel, the limited availability of these biomass resources is foreseen to bring about an equalisation of future biofuels GHG mitigation costs at a level of 250–400 €/tCO_2-eq. (ibid.). But also within the electricity sector, it is criticised that bioenergy pathways are supported which have comparatively high GHG mitigation costs, whereas pathways with comparatively low mitigation costs, such as co-combustion, are not supported (dena 2011;

Ehrig and Behrendt 2013).[16] Moreover, in the electricity sector bioenergy pathways constitute comparatively expensive options for achieving RES expansion targets compared to other RES options (WBA 2011: if.). For example, in the EEG 2012, biomass plants were able to achieve the second highest FIT rates after geothermal power plants (cf. sections 23–33 EEG 2012).

From an economic efficiency perspective, it is seen as particularly problematic that current bioenergy policy fails to set a uniform price signal across sectors, which would allow for an optimisation of biomass use (WBA 2007: 175ff.; Kopmann et al. 2009). The current instrument mix is seen to promote a quantitative expansion in all three energy sectors, with little coordination between sectoral support measures (SRU 2007: 88; Kopmann et al. 2009). But this approach not only increases competition for biomass resources between pathways and prices of bioenergy carriers, thereby negatively impacting competitiveness of bioenergy with fossil fuels and other RES; it also introduces distortions into the competition between energetic and material uses, as well as food and feed uses (WBA 2007: 177; Kopmann et al. 2009; Meyer et al. 2010: 203ff.; BioÖkonomieRat 2012: 6).

Optimisation of biomass use and improved coordination of policy instruments, meanwhile, are impeded by the fact that different bioenergy policy instruments reflect different political priorities (Henke and Klepper 2006; Isermeyer and Zimmer 2006). Import tariffs on biofuels, for example, favour the aim of domestic value creation, but increase the costs of bioenergy expansion. In the case of the biofuel quota, which sets strong signals for bioenergy pathways with comparatively high GHG mitigation costs (e.g. Sterner and Fritsche 2011) the focus seems to be on security of supply considerations (Berndes and Hansson 2007). In particular, critics remark that the support strategy is not optimised towards GHG mitigation as the primary policy aim (Isermeyer and Zimmer 2006; Henke and Klepper 2006; SRU 2007: 92; WBA 2007: 175; Kopmann et al. 2009).

Finally, while the cited points of critique focus on bioenergy policy design in particular, neoclassical theory-based critique is often more far-reaching, questioning the rationale for any kind of RES support on top of a technology-neutral internalisation of GHG externalities (see Sect. 3.1.4). Here, the argument is that the adoption of RES targets and support instruments is sufficient to prevent the cost-effective choice of GHG mitigation options, without considering the specific challenges of bioenergy policy (e.g. Frondel et al. 2010; Frondel and Schmidt 2006; Weimann 2008: 118f., 2009; Sinn 2008: 161ff).

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[16] For comparisons of estimates of GHG mitigation costs of different bioenergy pathways, see e.g. WBA (2007: 153ff.), Leible et al. (2009), Sterner and Fritsche (2011), Hennig and Gawor (2012) and Rehl and Müller (2013); due to differences in methodologies and assumptions, estimates vary significantly across studies.

4.4.2 Dynamic Efficiency and Incentives for Innovation

Besides cost-effectiveness in a static sense, it is also relevant whether instruments incentivise innovations and cost-reductions over time. For bioenergy pathways, a major problem for dynamic efficiency is the high importance of resource costs in overall costs; as cost decreases in the sourcing of substrates are not expected, the potential for cost reductions over time is limited (Bofinger et al. 2010: 2; Thrän et al. 2011c: 42; Naumann et al. 2014: 76). Moreover, the technologies which have largely contributed to bioenergy expansion so far are fairly established, like heating and cogeneration based on solid bioenergy carriers, electricity and cogeneration using energy-crop- and slurry-based biogas, and energy-crop-based biodiesel and bioethanol biofuel pathways. As these technologies have already progressed down their respective learning curves, there is only limited scope for further cost-reductions (WBA 2007: 174f.; Thrän et al. 2011c: 42ff.). In the electricity sector, the implementation of additional technical and environmental requirements is likely to further increase costs, as is the adaptation of plant design and feed-in patterns to demand-oriented production (Thrän et al. 2011c: 44ff.; Rohrig et al. 2011: 13).

At the same time, other bioenergy technologies which have not been widely deployed so far still have high innovation potential (cf. Nitsch et al. 2004: 38ff.; Thrän et al. 2011c: 42ff.). For example, thermo-chemical gasification plants for solid biomass are mainly at the pilot and demonstration stage, and considerable technological advances still have to be made before reaching marketability (Thrän et al. 2011c: 42ff.). Also, second generation biofuel processes (e.g. BtL, Bio-SNG) are expected to reach marketability only after 2020 (Thrän et al. 2011a: 31; Fiorese et al. 2013), and come with their own set of open questions regarding feasibility, costs, and environmental advantageousness (Meyer et al. 2010: 220f.). Biorefineries offering options for the integration of energetic and material biomass uses are also still at an early stage of development (Oertel 2007: 12; Cherubini 2010).

4.4.3 Effectiveness of Sustainability Safeguards

Sustainability provisions are seen to be insufficient along four dimensions: first, existing environmental framework conditions are seen to be inadequate to cope with additional land use pressures introduced through bioenergy support instruments. Secondly, it is criticised that driver instruments do not take sustainability restrictions into account to a sufficient degree. Thirdly, where it exists, the effectiveness of mandatory sustainability certification is called into question. Lastly, incentives for low competition resources which minimise adverse environmental and social impacts, such as waste and residues, are considered to be insufficient.

4.4.3.1 Inadequacy of Environmental Framework Conditions

In German and EU bioenergy policy, the challenge of safeguarding sustainable biomass production is predominantly framed as one of securing the sustainability of imports, whereas production within the EU, which adheres to good agricultural and forestry practices and cross compliance requirements, is considered as sustainable per definition (BMU and BMELV 2009a: 16; COM 2010b: 3f.). However, the adequacy of good agricultural and forestry practices to ensure the sustainability of bioenergy can be challenged on several grounds.

For one, it is debatable whether the state of agriculture within the EU can be described as sustainable, and whether the existing framework of CAP and good agricultural practice is sufficient in ensuring that a good agricultural and environmental condition is maintained (Hirschfeld et al. 2008; Oppermann et al. 2009, 2012). Given the increasing pressures for agricultural intensification, it is deemed necessary to improve the binding character, operationalisation and implementation of minimum standards (SRU 2007: 60). For example, the minimum control rate for adherence to cross compliance obligations amounts to only 1 % (EC No 1122/2009, Art. 64), while non-compliance simply results in reductions in or loss of support payments (EC No 1122/2009, Art. 71–72). Moreover, with cuts in direct support payments in the CAP 2014 reform and increasing agricultural commodity prices, incentives for not claiming direct support under the CAP at all may become stronger, which would lead to producers being released from cross compliance obligations (Steinhäußer 2012: 446).

Meanwhile, agri-environment schemes offer in principle incentives for enhancing the environmental impacts of agriculture and for exploring synergies between bioenergy production and conservation; however, compared to incentives for energy crop production (e.g. area-based CAP direct support combined with EEG feed-in tariffs), their profitability is relatively low (Steinhäußer 2012: 445). Moreover, on a more general level, agri-environment schemes are criticised for a lack in ecological effectiveness, economic efficiency and social acceptance (see Müller 2009: 4f. for an overview; Oppermann 2012).

4.4.3.2 Lack of Sustainability Safeguards in Bioenergy Support Instruments

Accordingly, the fact that so far only limited attention has been paid to implementing sustainability safeguards in instruments which drive bioenergy demand has been criticised (SRU 2007: 60ff.; WBGU 2008: 318ff.). As of 2015, compliance with sustainability standards is only a prerequisite for support in the case of biofuels and bioliquids. However, the importance of international trade is also increasing for solid biomass (Heinimö and Junginger 2009; Hewitt 2011), while the import of biomethane via gas pipelines may gain relevance in the future (Nollmann 2012). As the risks of—direct and indirect—negative environmental and social impacts are not limited to liquid biofuels (e.g. Wunder et al. 2012), an extension of binding sustainability criteria to solid biomass and biogas in the electricity and heating sectors is being demanded (Fehrenbach 2012; Fritsche 2012: 1) At the same time, however, the extent of the effectiveness of sustainability certification is called into question (see Sect. 4.4.3.3).

As an alternative or complementary measure, investment and production decisions can be steered more directly towards sustainable outcomes, for example, via the adjustment of feed-in tariffs according to feedstock-specific environmental impacts and the introduction of environmental requirements as prerequisites for support (see e.g. Pietsch 2013). First steps in the latter direction were made in the EEG 2012 with the establishment of two substance classes and a cap on the use of maize (cf. Steinhäußer 2012). However, in assessing sustainability impacts, it has to be taken into account that the use of crops with lower energy output per area also increases the land requirements of biogas production (Delzeit et al. 2012). Moreover, it is criticised that current instruments neglect the spatial dimension of environmental and socio-economic impacts of bioenergy, for example, regional increases in tenure prices or negative environmental impacts of high regional densities of maize cultivation (Scholwin et al. 2011: 121; WBA 2011: 11).

4.4.3.3 Limited Effectiveness of Sustainability Certification

In evaluating the experiences with mandatory biofuel sustainability standards to date, studies caution against overestimating the effectiveness of certification schemes in safeguarding against adverse environmental and social impacts (German and Schoneveld 2012; Schlamann et al. 2013). For one, broader environmental issues of biomass production, like impacts on water, soil and agricultural biodiversity, remain outside the reach of mandatory sustainability requirements; the same applies to social sustainability criteria (Fritsche et al. 2010; van Dam et al. 2010). The extent to which they are addressed in certification schemes varies considerably between initiatives, as do monitoring and verification mechanisms (Mohr and Bausch 2013; Schlamann et al. 2013). Voluntary certification schemes which can be used to prove compliance with the requirements of the EU RED and the sustainability ordinances generally encompass a wider set of criteria, with some schemes also incorporating social sustainability concerns (Scarlat and Dallemand 2011; German and Schoneveld 2012). However, incentives for choosing schemes with stringent requirements may be low, given the absence of significant market price premiums for sustainability certification (Pacini et al. 2013) and the obligation of EU member states to accept all approved voluntary schemes, even if their requirements are less stringent than envisioned in national legislation (German and Schoneveld 2012). Indeed, particularly for social criteria, which some certification schemes do not consider at all, a “race to the bottom” may result (German and Schoneveld 2012; Kaphengst et al. 2012).

On the other hand, more comprehensive standards raise transaction costs, but can still fail to ensure sustainable production due to leakage effects (van Dam et al. 2010; Van Stappen et al. 2011). In fact, “overloaded” standards might even increase the risk of leakage, because incentives arise to reroute trade streams to regions with less stringent import regulations. Also, certification with high transaction costs could discourage the participation of smallholders and producers in low-income countries (Beall 2012; Pacini et al. 2013). Even with existing standards, the lack of significant price premiums for certified biofuels in combination with high domestic demand in traditional biofuel export countries appears to have caused the participation of developing countries in European biofuel markets to decrease (Pacini et al. 2013).[17]

Moreover, dealing with the impacts of bioenergy demand on global food security and ILUC constitutes a major problem. Resulting from macroeconomic price effects on agricultural commodity markets, these issues are beyond the scope of certification, and remain the subject of lively debates among EU policy makers, stakeholders and research communities (Gawel and Ludwig 2011; Van Stappen et al. 2011; Di Lucia et al. 2012; Fritsche et al. 2012; Council of the European Union 2013). Moreover, even if ILUC is left aside, the accuracy of the RED's methodology for calculating GHG mitigation values is criticised (e.g. Soimakallio and Koponen 2011; Van Stappen et al. 2011). Open issues in the calculation of emission factors, for example, are the definition of system boundaries and assumptions about nitrous oxide emissions and carbon stock changes, both of which are highly dependent on local conditions (Van Stappen et al. 2011: 4828f.). Another critical issue is the assumption of "carbon neutrality" of biomass combustion. The EU RED and the German sustainability ordinances set the emissions of using biofuels and bioliquids to zero (cf. Annex 1, No 13 Biokraft-NachV; Annex 1, No 13 BioSt-NachV), because they equal the amount of carbon sequestered in the plants during their growth. However, this approach neglects that plants would have continued to absorb carbon had they not been harvested (Haberl et al. 2012). Also, when assessing bioenergy's contribution to GHG mitigation targets, "carbon neutrality" rests on the assumption that land use emissions would be accounted for in the land use sector as part of GHG emission accounting under the Kyoto protocol, which is very often not the case (ClientEarth 2012; Haberl et al. 2012).

Overall, when leakage effects are taken into account, it seems impossible to guarantee that the EU demand for energy feedstocks is met sustainably, without addressing the framework conditions of agricultural production in general (Frank et al. 2013). For increasing the effectiveness of sustainability certification, an extension to a wider scope of agricultural commodities and participation by a greater number of countries is deemed necessary (Gallagher 2008: 11; WBGU 2008: 320; Scarlat and Dallemand 2011; Fritsche 2012: 19; Frank et al. 2013).

4.4.3.4 Insufficient Incentives for Low-Competition Pathways

The use of wastes and residues as well as of non-food biomass cultivated on marginal or degraded land is seen as an important option to minimise adverse

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[17] In 2011, 70.16 % of all biomass certified according to Biokraft-NachV and BioSt-NachV originated from Germany, 12.44 % from other European states and 6.17 % from the USA (BLE 2012: 35).

environmental and social impacts of bioenergy use (BMU and BMELV 2009a; COM 2009a, Article 85). However, so far the focus of German bioenergy expansion is on high competition resources such as first generation energy crops, leading to the criticism that incentives for developing potentials of low competition resources are insufficient (Meyer et al. 2010: 206ff.; Jering et al. 2012: 68ff.).

How to incentivise the use of low competition resources and the deployment of appropriate, innovative conversion technologies remains a major challenge. Apart from the early stage of development of second generation conversion processes which are required to access a larger variety of substrates, there are often reasons why the "untapped" fraction of wood and waste potential has not yet been developed; its use is inhibited by technical, logistic and economic barriers (Thrän et al. 2011a: 134). For example, while straw is estimated to have significant unused potential, an analysis of conversion pathways shows significantly higher costs than for reference plants using "conventional" biomass resources (Zeller et al. 2011: 47ff.). As conversion concepts are not commercially applied yet, cost estimates are merely indicative (ibid.: 52), adding to uncertainties about the economic viability of developing this potential.

Moreover, there is a risk that incentives for using wastes and residues create competition for waste streams—the double counting of biofuels from used cooking oil, for example, has resulted in a significant increase in demand and trade of this waste product, and its price (Majer and Naumann 2013: 15). The promotion of "low competition" resources may therefore result in new forms of competition, the diversion of waste streams from established recycling pathways and even incentives for "waste production" (Majer and Naumann 2013: 14ff.).

Likewise, there are significant uncertainties concerning the availability or even definition of marginal or "surplus land", for which also competing uses may exist (Dauber et al. 2012). Moreover, even if SRC and other lignocellulosic feedstock can in principle be grown on marginal land, producers are still likely to favour productive land due to its higher profitability and yields (Lange 2011; Scarlat and Dallemand 2011: 1643); in effect, cultivation systems on productive land would be likely to outcompete more costly production on marginal land (Bryngelsson and Lindgren 2013).

Overall, it therefore seems likely that, for the foreseeable future, bioenergy use—and its expansion—will continue to depend crucially on the availability of agricultural areas, and yield increases (Thrän et al. 2011a: 134). Substituting energy crops and timber for low-competition resources may result in trade-offs with viability, if the costs of accessing and preparing these resources are high.

4.5 Bioenergy Policy Advice from Interdisciplinary Expert Panels: Points of Departure

Naturally, the existing literature does not only criticise the current policy approach, it also formulates recommendations for bioenergy policy. While a comprehensive review is beyond the scope of this work, this chapter outlines central recommendations by interdisciplinary expert panels, to provide a basis of comparison for the economic theory-based policy recommendations developed in Chap. 5. Further insights, particularly those regarding more detailed instrument recommendations, are incorporated into the analysis conducted in Chap. 5. However, only few studies develop recommendations that address a broad range of allocative challenges of bioenergy across all three energy sectors simultaneously. Among these, interdisciplinary reports by the Scientific Advisory Board on Agricultural Policy (WBA 2007), the German Advisory Council on the Environment (SRU 2007) and the German Advisory Council on Global Change (WBGU 2008) are among the most prominent and widely cited examples. The following section compiles the recommendations these reports come to regarding the three main categories of allocative problems identified in Sect. 2.2.1.4, namely the steering of biomass flows and technology choices; the setting of incentives for dynamic efficiency and innovation; and the steering of location choices and sourcing decisions. While cost-effectiveness, dynamic efficiency and sustainability are criteria that apply to all three categories, recommendations pertaining to sustainability are discussed separately here, because, frequently, specific instruments are put forward to address this criterion. To start with, suggestions regarding the hierarchy of policy aims are presented.

4.5.1 Prioritisation of Policy Aims

WBA, SRU and WBGU view positive external benefits with regard to climate change mitigation as the most relevant market failure to provide a rationale for bioenergy support. Consequently, the three reports unanimously argue for a prioritisation of climate change mitigation as a bioenergy policy aim (WBA 2007: 175ff.; SRU 2007: 80ff.; WBGU 2008: 274). The WBA, in particular, elaborates that contributions to further aims such as security of energy supply and employment creation (both rural and otherwise) should be seen as welcome side effects, but due to their limited scale they should not be treated as a priority (WBA 2007: 183ff.). Moreover, given uncertainties about the net effects of bioenergy use on rural employment, positive employment effects should rather be sought for in technology development and export (ibid.: 187ff.).

Taking a global perspective, the WBGU considers the elimination of fuel poverty another primary policy aim, deriving a distributive reason for bioenergy support especially in developing countries (WBGU 2008: 274).

4.5.2 Steering Biomass Flows and Technology Choices

All three reports consider climate externalities as the key rationale for intervening in biomass flows and supporting energetic uses. While recommendations place the focus of interventions on behalf of energetic biomass uses at the utilisation stage, they all stress that framework conditions and support instruments should be designed in such a way that allocation decisions in bioenergy value chains are directed towards low-competition resources (mainly wastes and residues), cascading uses and the co-production of energy-carriers with material and/or food and feed products (WBA 2007: 219f.; SRU 2007: 101; WBGU 2008: 326). While the WBA explicitly discourages further expansion of energy crop production on farmland (WBA 2007: ii), the WBGU acknowledges a role for energy crop production if the potential for climate change mitigation is particularly high (WBGU 2008: 199f.), preferably on marginal land (ibid.: 210).

In accordance with their hierarchy of policy aims, WBA, SRU and WBGU advise an alignment of bioenergy support with the external climate benefits of pathways, to overcome the sectoral segmentation of support instruments (WBA 2007: 177ff.; SRU 2007: 88ff.; WBGU 2008: 325); more specifically, GHG mitigation potential per area and GHG mitigation costs are put forward as criteria (WBA 2007: 220; SRU 2007: 80; WBGU 2008: 195). The WBGU cites energy efficiency and the availability of alternative technologies as further criteria (WBGU 2008: 195).

For the long term, SRU and WBA agree with neoclassical policy recommendations and suggest that bioenergy policy be integrated into a stringent international climate policy framework that allows for market price-finding in the context of a cross-sectoral emissions trading system (WBA 2007: 177ff.; SRU 2007: 97f.).[18] In the shorter term, suggestions focus on improving the coordination between existing, direct support instruments (see Table 4.11): the WBA, for example, suggests limiting support to bioenergy pathways with GHG mitigation costs below 50 €/ tCO_2-eq (WBA 2007: i); while the WBGU recommends tying support to a minimum GHG emission reduction requirement of 60 t CO_2eq/TJ of raw biomass (WBGU 2008: 325). The SRU, on the other hand, charges policy makers with the task of identifying the most promising bioenergy pathways with regard to GHG mitigation potential and costs, and also economic potential and environmental impacts (SRU 2007: 93ff.). Conversely, both SRU and WBGU stress that sectoral quantity targets and quotas creating an inflexible demand in certain sectors should be avoided (SRU 2007: 89; WBGU 2008: 327).

Following from the support strategies suggested, WBA, SRU and WBGU recommend that bioenergy support be strategically focused on heat and electricity production, particularly cogeneration, instead of biofuels (WBA 2007: 192ff.; SRU 2007: 103; WBGU 2008: 326f.).[19]

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[18] Rather than the current emissions-based EU-ETS, the SRU recommends for the long-term perspective a shift towards an upstream system accounting for emissions at primary trade level (ibid.: 97f.). As a second-best solution, the SRU suggests the use of pricing policies (i.e. carbon taxes) to simulate such primary trade level emissions trading (ibid.: 98).

[19] Once RES come to dominate electricity supply, the WBGU envisions a role for bioenergy in providing balancing power, thereby contributing to the reliability of electricity supply (WBGU 2008: 217).

Table 4.11 Short-term recommendations for sectoral support design according to interdisciplinary expert panels (based on WBA 2007: 193ff; SRU 2007: 99f.; WBGU 2008: 326f.)

	WBA (2007)	SRU (2007)	WBGU (2008)
Electricity	Abolish preference for small plants in EEG feed-in tariff; Reduce feed-in tariffs for biogas to make heat use necessary for economically profitable operation	Realign FIT rates with contributions to GHG mitigation; Review restriction of EEG funding to small-scale, biomass-only plants	Focus on substitution of coal, cogeneration, efficient gas and steam turbines (including co-combustion), and biomethane pathways; Range of viable instruments: feed-in tariffs, direct subsidies, CO_2 emissions taxes, reformed EU-ETS (free allocation of emission allowances should be phased out)
Heating	Promote bioenergy competitiveness by increasing energy taxes on fossil fuels; Second best: increase investment support and incentives for cogeneration	Extend funding in the form of a GHG mitigation-based market incentive, financed by levies on fossil fuel use; Prioritise substitution of coal and heating oil; Promote greater use of bioenergy in district heating and industrial process heating	Support bioenergy use in heating on an interim basis only, as cogeneration and heat pumps are more promising in the long term; Instruments: regulatory obligations, investment grants and low interest loans
Transport	Discontinue support, as biofuel pathways do not meet GHG mitigation efficiency criterion; No broad deployment support for second generation biofuels without an integrated overall concept	Freeze biofuel quota at current level; Refocus existing support for second generation biofuels according to their GHG mitigation contribution	Discontinue support for biofuels, promote electric mobility; Instruments: infrastructural support, indirect instruments (eg fuel taxes)

4.5.3 Setting Incentives for Dynamic Efficiency and Innovation

All three reports acknowledge that knowledge and learning spillovers in the market entry phase of technologies can provide a rationale for interventions in innovation processes and technology choices (WBA 2007: 174; SRU 2007: 93; WBGU 2008: 278). The reports disagree, however, in how far this rationale justifies technology-specific bioenergy support.

The WBA states that direct support should be limited to situations where markets are small and uncertainty about relative advantages of alternative technologies is high; bioenergy is found to have mostly moved beyond this stage (WBA 2007: 174). Instead of supporting the dissemination of standard technologies, the WBA recommends combining indirect instruments (e.g. emissions taxes, emissions trading) with increases in support for R&D, focussing in particular on pathways and conversion technologies that are expected to be of high international relevance in the future (WBA 2007: 192).

The SRU, on the other hand, suggests that bioenergy policy should continue to assist the market entry of a broad range of technologies, and foresees an active role for policy makers in identifying promising pathways during this market entry phase; more specifically, they should attempt to identify the most promising ones based on estimates of learning curve effects and life-cycle analysis (SRU 2007: 93).

For the long term, WBA and SRU both express a preference for support that is open to all forms of technology, and recommend that the state should focus on setting an adequate climate policy framework and leave technology choices up to market actors; here, incentives for low carbon technology choices and innovation would result from indirect instruments increasing the price of carbon emissions and fossil fuel use (WBA 2007: 177; SRU 2007: 97f.). The WBGU, on the other hand, stresses that not only knowledge and learning spillovers, but also other market failures provide a rationale for complementing indirect instruments with further, targeted support measures (WBGU 2008: 278).

4.5.4 Steering Location Choices and Sourcing Decisions

Neither WBA, nor WBGU nor SRU see a case for interventions in the international division of labour that would benefit domestic production. Instead, they agree that in order to allow for a global optimisation of energy crop and food production, agricultural markets should be opened for trade, necessitating a significant reduction of tariffs (WBA 2007: 176ff. and 200ff.; SRU 2007: 83f., WBGU 2008: 321). The WBA in particular stresses that bioenergy support should focus on the utilisation stage, while production of bioenergy carriers should take place where production costs and GHG emission reduction costs are lowest (WBA 2007: 176). In order to remove artificial competitive advantages for domestic producers, the WBA recommends not only the removal of trade barriers, but also a revision of political preferences for bioenergy pathways that use biomass with a low transport worthiness (ibid.: 176f.).

At the same time, the reports point out the need to prevent the export of externalities along with biomass imports, stressing that an import strategy must take the risks of negative environmental and social impacts in export countries and indirect land-use effects into account (WBA 2007: 182; SRU 2007: 83). The WBGU in particular emphasises that all bioenergy imports (not only politically supported ones) must comply with minimum sustainability standards, otherwise they are seen as problematic (WBGU 2008: 318ff.).

Besides certification (see Sect. 4.5.5), bilateral agreements which offer preferential market access for export countries and strategic partnerships involving technology and knowledge transfer are considered important instruments for promoting compliance with sustainability criteria and securing reliable import sources

(WBGU 2008: 319; WBA 2007: 184f.). In addition, the WBA calls for an internalisation of the negative external effects of international transport in energy prices (WBA 2007: 202).

4.5.5 Governance of Sustainability

SRU (2007) and WBGU (2008) in particular attempt an operationalisation of comprehensive sustainability requirements; both are based on guard rail concepts, which require policy makers to intervene or adapt bioenergy support when biomass production violates certain environmental and social standards.

The SRU develops comprehensive "guard rails" and standards for a sustainable, environmentally sound and socially acceptable production of biomass, which are based on the concept of strong sustainability (SRU 2007: 59ff.). The WBGU also uses a guard rail concept, wherein "guard rails" are understood as quantitatively defined, non-tolerable damage limits (WBGU 2008: 27). Guard rails are defined for climate protection, biosphere conservation and soil protection as dimensions of ecological sustainability; as dimensions of socioeconomic sustainability, guard rails relating to the secure access to sufficient food, secure access to modern energy services, and the avoidance of health risks through energy use are put forward (WBGU 2008: 27ff.). These damage limits are supplemented by qualitative requirements where necessary (e.g. land management rules), in order to reflect context- and location-specific conditions which may prevent the formulation of generalised guard rails (ibid.: 29 and 31f.). Both guard rails and these additional requirements are condensed into a proposal of minimum standards for sustainable bioenergy production (WBGU 2008: 319).

Regarding the implementation of requirements, both SRU and WBGU envision a more comprehensive design and stricter implementation of sustainability regulation than is currently the case. The SRU stresses that a sustainable biomass strategy must encompass a legislative framework at national, EU and international levels that ensures an environmentally sound cultivation of energy crops (SRU 2007: 104). In general, the SRU supports the principle that the same standards should apply for renewable raw materials and food and feed production (ibid.: 102). However, the expansion of energy crops is found to justify increasing efforts towards making agriculture more environmentally compatible (ibid.): in particular, the SRU calls for a consequent implementation and advancement of existing environmental best practice and cross compliance standards (ibid.). On top of that, bioenergy support should be made conditional upon the observance of "guard rails" and binding, certified standards at national and international level, the latter preferably as part of an international agreement between import and export countries (ibid.: 103). In order to allow for the development and establishment of standards that are "sufficiently ambitious" (ibid.: 62) in countering sustainability risks, the SRU suggests that a slowing down of bioenergy expansion may be advisable in order to allow research on sustainability impacts to catch up (ibid.).

Meanwhile, the SRU recommends that production systems that have positive side effects on conservation aims in particular should be specifically promoted, for example, in the context of agri-environment schemes (ibid.: 105).

The WBGU places a stronger focus on the formulation of binding, bioenergy-specific sustainability criteria, although in the long term an integration with global strategies and instruments for sustainable land use is seen as desirable [with incentives for sustainable land use resulting, for example, from international compensation payments for biodiversity conservation (WBGU 2008: 323), and an inclusion of GHG emissions from Land Use, Land-Use Change and Forestry (LULUCF) in a post-Kyoto regime (ibid.: 316f.)]. Until a global strategy for sustainable land use is established, however, the WBGU recommends that marketing bioenergy carriers in the EU should be conditional upon compliance with a minimum standard (WBGU 2008: 318). In the short term, introducing a unilateral standard is considered feasible, complemented by support for developing and transition countries for its implementation (ibid.: 319); in the long term, an international consensus should be pursued, along with an extension to all biomass categories (ibid.: 319f.). Direct political support, on the other hand, should be limited to bioenergy pathways with positive side effects on sustainability aims (e.g. biodiversity conservation, soil conservation, or reduction of energy poverty) and especially high contributions to GHG mitigation (ibid.: 318). As a precondition for energy crop production, an analysis of regional soil and water availability and the establishment of regional strategies for sustainable soil and water management is recommended (ibid.: 324).

The WBA, on the other hand, takes a sceptical stance towards the effectiveness of sustainability standards and certification in preventing environmental and social risks. To counter direct environmental impacts of bioenergy use and the consequences of increasing agricultural intensification on the national level, the WBA recommends adjustments in relevant legal framework conditions and in bioenergy support design (WBA 2007: 180f.). At the same time, the relevance of indirect effects and the limited reach of national and European-level sustainability regulation is emphasised (ibid.: 181f.). The report points out that, although import certification can increase awareness of sustainability risks, it remains ineffective against global macroeconomic incentives for land use changes and intensification resulting from increasing price levels on agricultural commodity markets. In countering these incentives, only a global climate change mitigation strategy which included the land use sector would be effective (ibid.: 182). Given that the realisation chances of such a system are exceedingly low in the foreseeable future, the WBA recommends placing the focus of political support on RES that do not increase competition for agricultural land, and bioenergy pathways using wastes and residues (ibid.).

4.6 Summary and Implications for a New Institutional Economics Approach to Bioenergy Policy Advice

The following section summarises the chapter's findings and assesses the potential role that an NIE-based analysis can play in the development of bioenergy policy advice for Germany.

4.6.1 Aims and Strategic Context of European and German Bioenergy Policy

Political framework conditions relevant for bioenergy are set on national and European as well as on global and regional governance levels. The most important drivers for bioenergy use and production, meanwhile, are set on European and national levels, where national RES and climate policy targets are defined and supported by implementation measures. These policy levels are therefore in the focus of the chapter. Both in Germany and on EU-level, the rationale for bioenergy support is derived from the aims of climate change mitigation, security of energy supply, and the creation and protection of rural employment and value creation. However, bioenergy expansion affects diverse policy areas, so that the system of relevant policy aims has to be spanned wider, encompassing aims from policy areas such as energy policy, agricultural policy, environmental policy, macroeconomic and industrial policy, development policy, and trade policy. Between aims, both conflicts and synergies can occur; in this context it is important to observe that the political prioritisation between aims changes over time. Also, the contribution of bioenergy to individual aims is subject to continuous reassessment.

In setting the framework conditions for German bioenergy policy, European climate, energy and agricultural policies play a vital part. In particular, the EU's 20-20-20 targets and the Renewable Energy Directive (RED) with its binding RES expansion targets for 2020 have influenced national target setting and instrument choice. In principle, RED targets for the share of RES in final energy consumption are technology neutral, and do not necessarily imply an expansion of bioenergy. For the 10 % transport sector target for RES, however, the major contribution is expected to come from biofuels. Moreover, the RED proves important by laying out sustainability requirements for biofuels and bioliquids, which have to be implemented in national law. At present, debates on the handling of ILUC in EU-level legislation continue, with major implications for the future design of member states' biofuel policies.

On the national level, the RED's requirements have been translated to RES expansion targets in the electricity, heating and transport sectors, complemented by ambitious national long-term targets for the electricity sector. For achieving the RED's 2020 targets, the expansion of bioenergy use in all three sectors is seen as an important means, but the strategic long-term role for bioenergy is heavily debated, as it is considered necessary to focus energetic biomass utilisation more strongly given increasing competition for land and biomass resources. From the resource-base side, a focus on waste and residues, second and third generation non-food biomass, and closed material cycle concepts is widely promoted; however, given limits to potentials and open questions relating to costs, there is also discussion whether there is an ongoing role for the energetic use of dedicated renewable resources.

On the utilisation side, strategic long-term focuses which are supported in the literature are flexible power generation in a RES-based electricity sector, the cross-sectoral utilisation of biomethane, combined heat-and-power generation as part of regional RES supply concepts, and the use of biofuels in heavy load transport, shipping and aviation. However, decisions about strategic focuses are surrounded by large uncertainties, concerning developments of sectoral framework conditions as well as cost developments of bioenergy technologies and substitutes; also, a comparison with the current state of dominant resources and uses shows that proposed focuses are still removed from the status quo. This highlights the challenges of centrally selecting specific pathways for a strategic alignment of support.

4.6.2 Major National and EU-Level Policy Instruments

Overall, incentives for energetic biomass utilisation are mainly utilisation-sided in German bioenergy policy; utilisation-sided instruments do not only encourage the deployment of bioenergy, but also influence the choice of conversion technologies in the processing stage and feedstock choices. In the production sphere, energy feedstocks and woody biomass are mostly subject to the same environmental, agricultural and forestry regulations as other forms of biomass production. On the European level, the Common Agricultural Policy with its cross compliance criteria and support for agri-environment measures is of particular relevance; on the national level, all agriculture and forestry actors have to comply with environmental minimum standards laid down in the relevant environmental laws. For the energetic use of wastes and residues, waste and recycling regulation sets relevant framework conditions. Moreover, import tariffs on bioenergy carriers and intermediate products influence the competitiveness of domestic production and imports.

In the utilisation sphere, a mix of direct and indirect instruments influences bioenergy use. The European Emissions Trading System (EU-ETS) and energy taxes constitute indirect instruments, which can incentivise energetic biomass use if they increase the relative prices of fossil fuel substitutes to a sufficient degree. However, carbon prices in the EU-ETS have been too low and volatile in recent years to offer investment incentives for dedicated bioenergy plants. The relevance of German energy taxes for bioenergy use is likewise limited. The Electricity Tax Act taxes final electricity demand with no distinction between fossil fuels or renewable energies; in the heating sector, the Energy Tax Act does not apply to woody biomass and exempts biogas use, but reduced tax rates for fossil fuels used in heating and far-reaching exemptions for businesses diminish incentives for employing bioenergy. In the transport sector, exemptions for biofuels used to be a relevant driver of market developments, but have been largely phased out since 2007.

On the other hand, major instruments which support bioenergy directly are the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) in the electricity sector, the Renewable Energy Heat Act (Erneuerbare-Energien-Wärmegesetz, EEWärmeG) and the Market Incentive Programme (Marktanreizprogramm, MAP) in the heating sector, and the biofuels quota in the transport sector. Moreover, transport biofuels and liquid biofuels are only eligible for support if they meet sustainability requirements as laid out in the Renewable Energy Directive.

With its binding targets for the share of RES in the electricity sector, priority purchase and transmission rules, priority grid connection rules and technology-specific feed-in tariffs the EEG has proven very effective in promoting bioenergy expansion. Design parameters such as FIT rates for bioenergy and technology- and feedstock-specific bonuses changed considerably with consecutive revisions of the EEG, and had a strong influence on the set-up of plants including installation sizes, predominant technologies and feedstocks. In the EEG 2012, a general decrease of FIT rates and an abolishment of most bonuses curtailed the expansion of biogas in particular. Also, the EEG 2012 introduced a sliding feed-in premium (FIP) to promote participation in direct marketing and demand-oriented electricity production; while more than half of total installed bioelectricity capacity now participates in the FIP scheme, ensuring that actual production shifts from base load to demand-oriented feed-in remains challenging. Further changes have been implemented with the EEG 2014, which abolishes feedstock-specific tariff classes and significantly reduces overall remuneration for bioenergy. Also, direct marketing is gradually made mandatory for all but small-scale plants. While the declared aim is that only waste- and residues-based concepts should remain profitable, critics argue that new tariff rates are too low to allow for an economically feasible exploitation of remaining waste and residue potentials.

In the heating sector, the MAP offers investment support and low interest loans for investments in RES heating installations. While it is seen as an important incentive for investments in renewable heat technologies, the programme's dependency on public budgets is considered a central problem for the planning security of investors. At the same time, the EEWärmeG implements a renewables obligation for new buildings and public buildings if fundamental renovations are undertaken. While the instrument's design is essentially open to all forms of technology, the expansion of biomass use has contributed significantly to increases in RES use in the heating sector. A major challenge for the further development of the instrument remains the setting of incentives for RES investments in the building stock.

In the transport sector, the biofuel quota has replaced tax exemptions as the primary biofuel support instrument. While up to 2014, the quota refers to a minimum biofuel share in the energy content of transport fuels brought into circulation, from 2015 minimum reductions in the GHG emissions of transport fuels need to be achieved through biofuel use. In order to count against the quota, liquid and gaseous biofuels in transport have to fulfil minimum sustainability requirements which implement the EU RED's demands. While from 2007 to 2012, the quota has been exceeded each year, the total energetic share of biofuels in total transport fuel consumption has fallen since its introduction; one reason for this can be found in uncertainties about future changes in European and national biofuel policy, which decrease planning security for investors.

4.6.3 Lack of Cost-Effectiveness, Dynamic Efficiency and Sustainability: Criticisms of German Bioenergy Policy

While the EEG, the EEWärmeG in combination with the MAP, and the biofuel quota have proven very effective in promoting the expansion of bioenergy use in recent years, the main strands of critique relate to a lack of efficiency in the design of support schemes and the insufficiency of sustainability regulation.

One point of criticism is that instruments fail to focus support on pathways which realise large GHG mitigation potentials at low costs, resulting in a lack of cost-effectiveness in contributing to GHG mitigation. An economically efficient bioenergy policy would set a uniform price signal across sectors, to allow for an optimisation of biomass use; current sectoral instruments, on the other hand, are regarded to be poorly coordinated, promoting a quantitative expansion of energetic biomass use which increases and distorts competition for biomass resources. A reason for this is seen in the lack of a clear hierarchy of policy aims pursued with bioenergy support, and in particular a failure to prioritise GHG mitigation.

Besides cost-effectiveness in a static sense, the performance of bioenergy policy instruments in setting incentives for cost-reductions over time and innovation (dynamic efficiency) is also found to be wanting. Technologies which have largely contributed to bioenergy expansion so far are fairly established, with limited potential for further learning curve effects; at the same time, resource costs have a high share in overall costs, so that, given increasing resource costs trends, the potential for cost reductions over time is limited.

Finally, sustainability provisions are seen to be insufficient along four dimensions: First, existing environmental framework conditions are seen to be inadequate to cope with additional land use pressures introduced through bioenergy support instruments. A second point of criticism is that driver instruments do not take sustainability restrictions into account to a sufficient degree. Thirdly, where it exists, the effectiveness of mandatory sustainability certification is called into question. Lastly, incentives for low competition resources which minimise adverse environmental and social impacts, such as waste and residues, are considered to be insufficient.

4.6.4 Points of Departure in Bioenergy Policy Advice

Evaluating interdisciplinary recommendations from three expert panels (WBA, SRU and WBGU), advice concerning the categories of allocative challenges identified in Chap. 2 can be summarised as follows.

4.6.4.1 Steering Biomass Flows and Technology Choices

All three reports consider climate externalities as the key rationale for intervening in biomass flows and supporting energetic uses, and argue for a prioritisation of climate change mitigation as a bioenergy policy aim. The expert panels agree that framework conditions and support instruments should be designed in such a way that allocation decisions in bioenergy value chains are directed towards low-competition resources, such as wastes and residues, but it remains contested whether energy crops can play a—limited—ongoing role.

In order to overcome the sectoral segmentation of support instruments, the panels advise an alignment of sectoral bioenergy support with the external climate benefits of pathways; for this, the WBA suggests limiting support to pathways below a certain level of GHG mitigation costs, while the WBGU proposes minimum GHG emission reduction requirements. The SRU, on the other hand, foresees a more active role for policy makers in identifying the most promising bioenergy pathways with regard to GHG mitigation potential and costs, and further economic and environmental criteria. Regarding the long term, SRU and WBA agree with neoclassical policy recommendations and suggest that bioenergy policy be integrated into a stringent international climate policy framework with emissions trading.

4.6.4.2 Setting Incentives for Dynamic Efficiency and Innovation

While all three reports acknowledge that knowledge and learning spillovers in the market entry phase of technologies can provide a rationale for interventions in innovation processes and technology choices they disagree in how far this rationale justifies technology-specific bioenergy support today. In particular, WBA and SRU express a preference for support that is open to all forms of technology in the long term, while the WBGU stresses that besides knowledge and learning spillovers, other market failures provide a rationale for complementing indirect instruments with further, targeted support measures beyond the market entry phase.

4.6.4.3 Steering Location Choices and Sourcing Decisions

Neither of the expert panels sees a case for interventions in the international division of labour that would benefit domestic production. Instead, they agree that in order to allow for a global optimisation of energy crop and food production, agricultural markets should be opened for trade, necessitating a significant reduction of tariffs.

4.6.4.4 Safeguarding Sustainability

SRU and WBGU in particular attempt an operationalisation of comprehensive sustainability requirements; both are based on guard rail concepts, which require policy makers to intervene or adapt bioenergy support when biomass production violates certain environmental and social standards.

Moreover, both expert panels envision a more comprehensive design and stricter implementation of sustainability regulations than is currently the case; specifically, they argue for more comprehensive concepts of certified sustainability standards for bioenergy, and an adaptation of legislative framework conditions at national, EU and international levels to improve the general sustainability of land use.

The WBA, meanwhile, is sceptical about the effectiveness of sustainability standards and certification in preventing environmental and social risks, and recommends adjustments in relevant legal framework conditions and in bioenergy support design to counter direct and indirect environmental impacts of bioenergy use. Moreover, to avoid indirect land use changes, the WBA argues for a focus of political support on RES with lower land requirements, and bioenergy pathways using wastes and residues.

4.6.5 Outlook: A Role for NIE-Based Bioenergy Policy Advice

When comparing the main strands of critique of German bioenergy policy to the normative demands on bioenergy allocation and policy as formulated in Sect. 2.1.3, it emerges that there is significant scope for improvement regarding the system of policy aims, the alignment of aims and measures and the choice of allocation mechanisms and instruments. While recent changes to German bioenergy policy, such as the EEG reform, address some aspects of the critique, they also raise new problems. In principle, a consistent, conceptual reform of bioenergy policy would be required, which takes into account the cross-sectoral policy mix in its entirety as well as its effects along the whole length of the bioenergy value chain.

Attempts at developing recommendations for such a reform have been made by interdisciplinary expert panels, such as WBA (2007), SRU (2007) and WBGU

(2008). In brief, they all recommend a gradual stepping away from direct, sector-specific bioenergy support reflecting a number of aims towards a cross-sectorally aligned bioenergy policy which is clearly focussed on GHG mitigation benefits. Long-term recommendations of the SRU and WBA reflect implications of neoclassical theory (see Sect. 3.1). However, taking constraints such as transaction costs and political feasibility into account, it is unclear whether "optimal" long-term recommendations, such as a cross-sectoral emissions trading system or a global sustainable land use policy, will ever emerge. Short-term recommendations show greater variety; however, central unanimous recommendations such as a clear focussing of bioenergy support on pathways with high GHG potential and low GHG mitigation costs have not been implemented to date.

In developing bioenergy policy advice further, theoretical implications from NIE can make useful contributions both with regard to short-term and long-term policy recommendations. Based on a consistent theoretical framework, an NIE approach to bioenergy policy advice makes it possible to develop explicitly what implications deviations from the neoclassical model, which have proven to be extremely relevant in the bioenergy context (see Chaps. 2 and 3), have for actual policy making; these deviations encompass interactions between multiple market failures and policy aims, uncertainty and transaction costs, path dependencies, and political feasibility constraints which emerge from political rationality. A theoretical approach has moreover the advantage that it can show transparently what assumptions recommendations are based on, and under which conditions recommendations change.

While NIE-based policy advice can attempt to draw a consistent picture of what institutional solutions may prove advantageous under certain conditions, it needs to be stressed that the comparison will be one between flawed alternatives; this results from the second-best characteristics of the bioenergy policy design problem with its multiple constraints on first-best solutions, the various trade-offs in the alignment of transactions with governance structures, and the embeddedness of bioenergy policy measures and technologies in a highly path-dependent techno-institutional complex. What can be done is to show in a structural manner which alternatives are more economically rational than others, and more likely to result in a sustainable outcome over time; based on this, recommendations for the further development of the German bioenergy policy mix can be derived. What NIE-based policy advice will not produce are optimal solutions, be they short-term or long-term. As Hayek already pointed out in 1945, the dynamics of knowledge generation and coordination show the limits of the neoclassical equilibrium perspective, which corresponds with first-best policy recommendations that are expected to result in a welfare-optimal allocation. Rather than striving to identify and bring about optimal solutions in the long-term, the NIE perspective emphasises the development of institutions as a dynamic, path-dependent trial-and-error process that continues to adapt to external shocks, new information, and internal pressures. With this, the focus of attention shifts to institutions' ability to adapt to unforeseen developments, avoid lock-ins, support learning and allow for trial-and-error processes which generate new knowledge, i.e. their adaptive efficiency (see Sect. 3.5.4.4).

Moreover, the analysis in Chap. 3 has shown that NIE insights need to be combined with insights from other theoretical approaches to cover the relevant facets of bioenergy policy making. As discussed above, even in the long term it may not be possible to simultaneously address all relevant market failures in a first-best manner (including market failures in the energy sector, technology markets and the land use sector). Like NIE, the theory of second-best implies that in that case, not only short-term but also long-term recommendations are likely to deviate from the neoclassical ideal. Reasons for this are not only technical and behavioural constraints on first-best solutions, but also the continued relevance of distributive aims next to efficiency-oriented aims directed at ameliorating market failures. When designing second- (or third-) best policy interventions, information economics insights on ignorance and findings of the theory of economic order warn of the risks of government failure when adopting measures with hierarchical elements (such as technology-specific support for certain GHG mitigation options). While NIE offers a more differentiated approach which also considers the benefits of interventions with hierarchical elements, it is worthwhile to take limitations of centralised decision making into account when weighing advantages and disadvantages of different governance options. Ecological economics insights, meanwhile, prove particularly relevant when there is uncertainty about the sustainability of market outcomes and policy interventions.

Chapter 5 will discuss theoretical implications for a coherent, economically rational bioenergy concept, and apply insights to a more detailed analysis not of optimal, but feasible instrumental alternatives for direct bioenergy support in the electricity sector.

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Chapter 5
Towards a Rational Bioenergy Policy Concept

The overview of the allocative challenges of bioenergy use (see Chap. 2) and the policy mix adopted in Germany (see Chap. 4) has shown the complexity of the governance problem facing bioenergy policy makers. Not only does bioenergy policy span different sectors, governance levels and policy areas, policy decisions also have to be taken in an environment of constantly changing market conditions, and evolving scientific knowledge about the costs and benefits of different bioenergy pathways. In this context, a coherent policy concept that serves as a guideline for policy decisions can be of great value. If short-term developments are allowed to dictate policy responses, the risk is high that conflicts between policy aims, side effects of interventions on other societal aims, and interactions with instruments already in place will be neglected (Berg and Cassel 1992: 189). A likely result would be a progression of discretionary interventions, reacting to problems as they became apparent, but unable to address their underlying causes (ibid.).

This chapter aims to develop recommendations for a German bioenergy concept which rationally handles constraints imposed by uncertainty and political feasibility, striving for efficiency and sustainability even while acknowledging that optimal "first best" solutions are out of reach (see Sect. 2.1.3). First, elements of a bioenergy policy concept are defined (Sect. 5.1). Then, as laid out in Sect. 3.7.7, the analytical framework provided by new institutional economics will be used to develop recommendations for the different elements of a rational bioenergy policy concept (Sects. 5.2–5.4). NIE approaches are used as the theoretical basis of the analysis, because Chap. 3 has led to the result that they yield the most useful insights for tackling the allocative and regulative challenges of bioenergy policy, while also providing distinct analytical tools for generating concrete policy recommendations. This NIE-based analysis is complemented by insights from the theory of second-best, information economics, the theory of economic order, and ecological economics. Also, each section discusses which aspects of neoclassical economics-based policy recommendations can be adopted to formulate a rational bioenergy policy concept, and where the insights of NIE and the other theoretical approaches discussed in Chap. 3 make deviations necessary.

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5.1 Elements of a Bioenergy Policy Concept

As a first step towards formulating a “bioenergy policy concept”, it is necessary to clarify what elements it should entail. Here, a definition from the theory of economic policy shall be adapted. In accordance with the demand that economic policy should be rational, a concept can be defined as a system of consistent aims, allocative principles, and instruments for influencing economic processes (Berg and Cassel 1992: 189; Streit 2005: 294; Welfens 2013: 653). Allocative principles describe where on the spectrum between markets and hierarchies interventions on behalf of policy aims should be balanced, and determine the choice of suitable instrument types. As such, the elements of a policy concept mirror the requirements for a rational bioenergy policy defined in Sect. 2.1.3, pertaining to a rational setting of the system of policy aims, the alignment of aims and measures, and the rational choice of allocation mechanisms and instruments for the implementation of aims.

Meanwhile, a concept does not attempt to prescribe detailed policy responses for specific, predefined situations. Rather, its task is to provide “clarity about ultimate aims, essential means and fundamental rules of conduct” (Berg and Cassel 1992: 189, own translation). By doing so, it can act as a reference system for individual policy decisions, allowing for coherent policy making in contexts characterised by complex means-end relations such as bioenergy policy (cf. Berg and Cassel 1992: 189; Streit 2005: 294f.). In the following, the elements of a concept are defined more closely, along with the requirements they need to fulfil in order to combine to a coherent whole.

5.1.1 System of Policy Aims

In Sect. 2.1.3 several criteria have been defined (see Table 2.1) which a system of policy aims should meet to comply with the requirements of a rational policy concept (Jakubowski et al. 1997: 48ff.; Gawel 1999: 244ff.; Welfens 2013: 655ff.). To sum up, a system of aims for a particular policy context should: (i) be sufficiently complete, i.e. reflect all relevant societal aims; (ii) be consistent, i.e. if conflicts between aims arise, a prioritisation is necessary to maintain consistency; (iii) allow for aims to be operationalised and for indicators to be defined which measure progress towards achieving those aims; (iv) be controllable by a responsible agency and politically and economically feasible (formal requirements). Moreover, the setting of aims should (v) reflect trade-offs in the use of scarce resources and balance costs and benefits, and (vi) be undertaken in a process which is transparent and acceptable to the public (economic requirements).

Among these requirements, the establishment of a complete and consistent system of policy aims is of particular importance, as argued in Sect. 2.3.1. Any instrument employed to achieve a specific aim not only influences that aim, but also other societal aims; in principle, aims can be conflicting, synergetic, or neutral (or, in extreme cases, identical or mutually exclusive) (Luckenbach 2000: 355ff.). To take interactions into account, a concept has to encompass a system of policy aims that includes all relevant aims for which side effects can be expected (Pütz 1979: 80). Moreover, if conflicts between aims appear, it is necessary to undertake a prioritisation; otherwise, conflicts between aims are transferred from the level of aim setting to the level of instrument choice, where they severely inhibit the alignment of aims with measures. As a result, defining a consistent hierarchy of relevant policy aims is a prerequisite for a rational design of bioenergy policy (cf. Sect. 2.3.1).

Once a system of policy aims is defined, aims can be compared to the status quo, leading to an identification of those aims whose achievement requires government intervention (Luckenbach 2000: 360). As a legitimation for interventions, two basic rationales can be distinguished (see Sect. 2.3.1). For one, the achievement of aims can be prevented by market failures, leading policy makers to intervene to improve the efficiency of market processes (Luckenbach 2000: 135). For another thing, policy makers may wish to improve the distributive outcome of market processes (Luckenbach 2000: 173). However, distributive interventions may impact the efficiency of market processes (Luckenbach 2000: 188f.), making a weighing of both rationales and a careful design of interventions necessary. In any case, government interventions are associated with costs (in terms of direct costs, transaction costs, and negative side effects on other aims in the system of policy aims), which need to be taken into account when assessing the desirability of intervening in market processes. Therefore, an assessment is needed to determine what market failures or deviations from distributive aims are deemed relevant enough to justify intervention.

5.1.2 Allocative Principles Between Market and Hierarchy

Once a system of policy aims has been defined, and a need for intervention in market processes identified, the question arises as to what allocation mechanism should be chosen to implement aims (cf. Pütz 1979: 33). Here, the definition of allocative principles shall be adopted from transaction cost economics. As discussed in Sect. 3.5.2.3, policy interventions predominantly take the form of hybrid governance structures between markets and hierarchy (cf. Williamson 1996: 104). While the detailed balance between the two governance modes is determined on the level of instrument design, policy makers first have to decide whether they intervene in market processes indirectly by changing framework conditions or relative prices, leaving allocative responses to market actors, or whether they take a more direct role in steering allocation decisions. Alternative allocative principles would therefore be the use of governance structures close to markets, where incentive intensity is high and market actors adapt autonomously to disturbances using time- and space-dependent knowledge; and the use of comparatively hierarchical governance structures, which combine investment safeguards with coordinated responses to disturbances, relying to a greater degree on centrally available knowledge (see Sect. 3.5.2.3).

In principle, policy makers have to choose an allocative principle with regard to each of the major allocative challenges of bioenergy use, i.e. the steering of biomass flows and technology choices, the setting of incentives for dynamic efficiency and innovation, and the steering of location choices and sourcing decisions. Given the disparate characteristics of allocative challenges and relevant market failures, different allocative principles may be appropriate for different challenges.

5.1.3 Instruments

Finally, a concept should state what instruments are considered essential for achieving the aims; these instruments should be consistent with the system of aims, i.e. they should in principle be suitable for bringing about the desired aim (Berg and Cassel 1992: 208; Streit 2005: 307). Moreover, they need to be compatible with the adopted allocative principle (Streit 2005: 294). Instrument types can be categorised as command-and-control instruments, which determine what alternatives are permissible in economic actors' decision processes, thereby directly affecting their behaviour; incentive instruments, which steer behaviour by influencing the costs and benefits of alternatives; and moral suasion instruments, which change the information available to actors and may also attempt to change their preferences (Michaelis 1996: 26). Moral suasion instruments and indirect incentive instruments which change relative prices are compatible with the allocative principle of using governance structures close to the market mechanism, whereas direct incentive instruments which administer prices or quantities or command-and-control instruments which prescribe or proscribe certain activities represent more hierarchical governance structures.

In the bioenergy context, voluntary sustainability certification is an example of a moral suasion instrument, which signals sustainability characteristics of biomass products to consumers; here, consumers decide freely whether or not to buy bioenergy products on grounds of the information given. GHG emissions taxes or tradable permits are indirect incentive instruments; while they devaluate high emission options, market actors remain free to choose their reaction and face high incentive intensity to reduce the costs of the solutions they adopt. Examples of direct incentive instruments are feed-in tariffs, which offer fixed prices for predefined technologies, and the biofuel quota, which establishes an obligation to market a certain share of biofuels. These instruments offer investment safeguards relating to prices or demanded quantities, respectively, but require centralised knowledge about technological alternatives and their costs. Environmental minimum standards which require certain forms of behaviour represent hierarchical command-and-control instruments. The transition from market-oriented to hierarchical interventions, meanwhile, can be of a gradual nature.

When choosing between instrumental alternatives that appear to be consistent both with policy aims and allocative principles, a comprehensive cost-benefit analysis (CBA) including the potential side effects on other societal aims would provide an ideal basis for decision making (Streit 2005: 313; Welfens 2013: 660). However, insufficient causal knowledge about an instrument's effect on a certain aim under specific conditions, the complexity of side effects, and problems of weighing trade-offs between different aims all severely limit the accuracy of CBA-based rankings (Berg and Cassel 1992: 208f.). Here, the focus will therefore be on theoretical insights regarding the performance of instrument types and certain design choices against efficiency and sustainability requirements when addressing the allocative problems of bioenergy, while taking into account implications of uncertainty and political feasibility constraints. As pointed out in Sect. 2.1.3, uncertainty about the benefits and costs of alternatives directs particular attention to the dynamic properties of instrument choices, namely whether they can set incentives for innovations which improve the efficiency and sustainability of allocative outcomes over time, and initiate structural changes compatible with the achievement of policy aims (cf. also Sect. 3.4.1).

While the role of a policy concept is not the determination of a detailed instrument design (Pütz 1979: 225), several central characteristics can be identified, which under uncertainty have major implications for an instrument's consistency with aims and allocative principles and its performance against efficiency and sustainability criteria. These are, in particular, the choice between price and quantity instruments, an instrument's mechanism for differentiating between technologies and feedstocks, and arrangements for policy adjustments (Purkus et al. 2015). Theoretical implications for these three elements of instrument design will be analysed in Sect. 5.4, alongside findings regarding the choice between general instrument types.

5.2 Elements of an NIE-Based Bioenergy Policy Concept: Defining a System of Policy Aims

This section, as well as the following ones, aims to apply the theoretical insights developed in Chap. 3 to the case of German bioenergy policy. To do this, the same general approach is used for analysing the system of policy aims (Sect. 5.2), the choice of allocative principle (Sect. 5.3), and instrument choice and design (Sect. 5.4). Each section first discusses insights from NIE for the respective element of the concept, complemented by other relevant implications derived from the theories examined in Chap. 3. As part of this, recommendations based on the NIE analytical framework are contrasted with bioenergy policy recommendations of neoclassical economists (see Sect. 3.1.4). These theoretical insights are then applied to an assessment of German bioenergy policy. Thirdly, recommendations are derived.

5.2.1 Prerequisites for an Economically Rational System of Policy Aims: Theoretical Insights

As discussed in Sect. 5.1.1, an economically rational system of policy aims should fulfil the requirements of completeness, consistency, operationalisation and measurability, controllability and feasibility; moreover, it should balance costs and benefits of pursuing aims and be defined in a transparent and publicly acceptable process (see also Table 2.1 in Sect. 2.1.3). NIE and other theories examined in Chap. 3 yield further insights regarding these criteria; in particular, these pertain to the completeness of the system of policy aims and the process in which trade-offs are balanced, the establishment of a consistent hierarchy of policy aims, and the operationalisation of aims.

5.2.1.1 Completeness and Consistency of Policy Aims, and the Balancing of Trade-offs

With regard to the completeness of the system of policy aims, second-best theory emphasises the importance of considering all relevant societal aims and their interactions when formulating a policy concept. The neoclassical approach's focus on GHG mitigation as the most relevant market failure in formulating a bioenergy concept is made possible by the assumption that all other market failures affecting bioenergy allocation are addressed by other first-best policies; at the same time, aims which are not based on the efficiency rationale, such as distributive aims, are neglected (see Sect. 3.1). As such, negative side effects of bioenergy policy on other aims can be excluded from the analysis. Second-best theory, however, calls this assumption into question. Instead, as discussed in Sect. 3.2.1, there are a number of reasons why market or policy failures may prove unresolvable, giving rise to constraints which have to be taken into account in policy making. Consequently, a bioenergy concept needs to consider the entire system of relevant policy aims, encompassing both efficiency-oriented aims which strive to address market failures and improve the welfare outcome of market processes, as well as aims based on other rationales such as distributive justice, which reflect societal preferences as revealed in the democratic process (see Sect. 2.3.1). If a policy intervention in pursuit of one aim leads to an increase in bioenergy use, the intervention might exacerbate unresolved market failures. On the other hand, synergistic effects are also possible, if addressing one market failure ameliorates another. Given the many uncertainties involved in bioenergy policy, the extent and exact shape that interactions between multiple aims and market failures will take is often also uncertain or assessable only with hindsight. Ecological economics suggest that in evaluating trade-offs the precautionary principle should be applied if non-reversible negative side effects of an intervention on other societal aims are a possibility (see Sect. 3.6.1).

To be able to resolve trade-offs, however, establishing a hierarchy between conflicting aims is a prerequisite. This applies to the three aims commonly adopted in political discourse to justify bioenergy support—GHG mitigation, security of energy supply, and rural value creation—which clearly contain potential for conflict (see Sect. 2.3.1). But also, if side effects on other aims occur, a hierarchy between aims of bioenergy support and these other societal aims needs to be defined. In the absence of a clear hierarchy of aims, market actors face uncertainty about which priority aim to align investments with, and which binding side constraints to consider. For example, investments undertaken in response to a perceived priority of security of supply may be devalued if the priority shifts to GHG mitigation. Conversely, asset specific investments whose profitability depends on a bioenergy policy aligned with GHG mitigation will only be undertaken if credible commitment for this prioritisation exists (cf. Sect. 3.5.2.5).

However, public choice theory shines a light on problems that both the establishment of a clear hierarchy of policy aims and the constitution of a transparent deliberative process for balancing trade-offs have to face (see Sect. 3.5.5). For politicians, it is rational to leave the hierarchy of policy aims unclear, so different aims can be stressed when addressing different constituents, and play down conflicts between aims (see Sect. 3.5.5.3). At the same time, the actual prioritisation of aims as expressed in interventions will be a reflection of the relative bargaining strength of different constituencies, and of policy makers' attempts to maximise political support (see Sect. 3.5.5.1). Given that the aim of rural value creation possesses a strong and comparatively homogeneous political lobby, whereas GHG mitigation and security of energy supply reflect public goods with diffuse benefits, it was argued in Sect. 3.5.5.3 that rural value creation is likely to play a strong role among the three main aims of bioenergy support. Ministerial bureaucracies, meanwhile, are likely to emphasise the policy aims they are primarily responsible for, when it comes to influencing policy design and implementation.

Nonetheless, despite these challenges, establishing a prioritisation between policy aims is a key requirement for the formulation of a rational bioenergy concept—without it, no economic assessment of the effectiveness and cost-effectiveness of measures' contributions to policy aims is possible (see Sect. 3.7.7).

5.2.1.2 Operationalisation and Measurability of Aims

Furthermore, for meeting the economic rationality requirement that aims should be operationalised and measurable, the definition of targets and indicators for target achievement is required. Targets can serve to define the content, scale, spatial and temporal reach of aims (cf. Jakubowski et al. 1997: 48ff.), and allow for an objective evaluation of the effectiveness of policy measures. However, setting adequate targets is complicated by the constitutive lack of knowledge that policy makers face (see Sect. 3.4.1). Given that targets are formulated under uncertainty as the outcome of a political process, it bears discussion whether their use is always appropriate—this is highlighted, for instance, by the demerit goods approach which focuses on incentives for structural changes, rather than on the achievement of targets (cf. Sect. 3.4.1). On the other hand, reliable long-term targets can make an important contribution towards establishing credible policy commitment (see Sect. 3.5.2.5). This seems particularly important in the context of GHG mitigation and RES expansion, because both require asset specific investments whose profitability depends on stable political framework conditions. However, in order to avoid lock-ins, it seems important to set targets on a level that is sufficiently technology open as to accommodate changes in framework conditions or new insights regarding side effects on other aims (see Sect. 3.5.4.4). Meanwhile, the operationalisation of aims through measurable targets may not only be hindered by uncertainty, but also by political rationality considerations—when attempting to maximise political support, the ability to accurately measure the success or failure of policy measures may not be a desirable characteristic of a system of policy aims. Furthermore, as part of symbolic policy endeavours (see Sect. 3.5.5.3), launching ineffective policies to support aims which are neither controllable nor feasible may be a viable strategy to garner political support.

5.2.2 Application to German Bioenergy Policy

With economic rationality requirements outlined and potential problems discussed, this section examines the performance of the German bioenergy policy's system of aims against the criteria stipulated above.

5.2.2.1 Completeness and Consistency of Policy Aims, and the Balancing of Trade-offs

In terms of completeness, the German system of bioenergy policy aims started rather narrow, emphasising synergies between GHG mitigation, security of energy supply and rural development (cf. COM 2005), and broadened over time, as conflicts between these aims and with further aims became prominent in the public discourse (cf. BMU and BMELV 2009). Rather than transparently discussing trade-offs, however, the political focus remains on supposedly synergistic options, like wastes and residues, even though potentials are likely to be limited, and new trade-offs arise (Thrän et al. 2011a; Giuntoli et al. 2014).

The continued search for options which are supposedly free from trade-offs is mirrored in the lack of a clear hierarchy between aims, which would be required to maintain consistency. Despite unanimous expert advice to adopt a clear prioritisation of GHG mitigation (cf. Sect. 4.5.1), the hierarchy between the three main aims of bioenergy support, i.e. GHG mitigation, security of energy supply, and rural development, has never been unequivocally established. Frequent shifts in stated hierarchies can be observed also in the case of further aims (see Table 4.1, Sect. 4.1.1). A prime example of this is the 2014 EEG reform, in which politicians (cf. BMWi 2014a), but also many researchers emphasised the economic viability of energy supply and the affordability of energy prices for consumers as the main drivers for political changes (see Schuffelen and Kunz 2014 for an overview). While in many other aspects, adopted changes can be regarded as primarily symbolic when it comes to effective cost reductions (Gawel and Lehmann 2014), bioelectricity support was the subject of significant cuts.

The public choice-based hypothesis, that rural development or rather value creation would play a dominant role in the hierarchy of policy aims (see Sect. 3.5.5.3), seems to apply particularly to the earlier stages of German bioenergy policy development: from its beginnings, German bioenergy policy has been focussed on pathways based on domestically produced energy crops, as well as, in the electricity sector, small-scale on-farm plants (see Sect. 4.1.4). Recently, though, both biofuel and bioelectricity policies have shifted the intended focus of bioenergy use to waste and residues. In the case of biofuel policy, this was done by adopting a GHG-based quota which favours resources with low GHG mitigation costs. Bioelectricity policy's cuts in reference prices, meanwhile, favour low-cost resources in general, the assumption being that these will also be beneficial in GHG mitigation terms (cf. Sect. 4.2.3.4). Nonetheless, these changes do not disprove the applicability of public choice findings—rather, they could be interpreted as a shift of political bargaining strength in favour of an advocacy coalition between public interest groups critical of energy crop-based bioenergy production for environmental and socio-economic reasons, and consumer interest groups and industrial interest groups concerned about EEG surcharge developments. Particularly in the case of biofuel policy, EU-level developments also have a major impact on decisions (cf. Sect. 4.1.2.4). At the same time, given high price levels for agricultural commodities in Germany (cf. Hemmerlin et al. 2013), agricultural interest groups may have had fewer incentives to engage on behalf of bioenergy as a source of rural value creation.

Overall, it remains unclear whether recent developments point towards a future prioritisation of GHG mitigation in bioenergy policy. Following the 2013 federal elections, responsibility for energy-related issues has been transferred from the environmental ministry (BMU, from 2014 BMUB) to the ministry for economic affairs (BMWi)—given that this step divides ministerial responsibilities for climate and energy policy, this may lead instead to a prioritisation of energy cost aspects and industrial policy-related aims. What is clear, however, is that repeated changes in political priorities have increased policy uncertainty for investors—this is particularly evident in the bioelectricity and biofuel sectors (cf. Sects. 4.2.3 and 4.2.5).

5.2.2.2 Operationalisation and Measurability of Aims

As far as the use of targets is concerned, different bioenergy policy aims have been operationalised to varying degrees. Security of energy supply and rural development are not equipped with specific targets, whereas for GHG emission reduction and RES expansion, quantified targets have been adopted. This is in line with the

NIE-based argument that targets are particularly relevant for these aims, because their achievement depends on highly asset specific investments with long amortisation periods. In the absence of quantified targets, contributions towards security of energy supply and rural development are less measurable, but given the multifaceted nature of these aims a qualitative assessment whether structural changes have been initiated may be more appropriate. Moreover, combining a GHG mitigation target with a separate RES expansion target can be seen as a reflection of the security of energy supply aim (Lehmann and Gawel 2013).

Whether GHG mitigation and RES expansion targets succeed in reducing policy uncertainty for market actors depends on their political credibility. Only for RES use in the electricity sector legally binding long-term targets have been established (see Fig. 4.1 in Sect. 4.1.2.1). For the transport and heating sectors, legally binding targets only extend to 2020; national level GHG mitigation targets extend to 2050 but are non-binding (cf. Rodi et al. 2011: 42ff.), whereas on the EU-level, emission reduction pathways extend to 2030 (see Sect. 4.1.2.5). In the absence of binding long-term targets, policy uncertainty increases for market actors undertaking long-term investment decisions.

In the transport sector, EU-level debates concerning adjustments of the 2020 target and the German change from an energy content-based to a GHG mitigation-based target have further increased policy uncertainty (cf. Majer and Naumann 2013). This highlights an important problem of technology-specific targets—if implemented without adjustments, planning security for investors is high but adaptability to new insights is low, risking a lock-in into an inefficient development pathway. If this is to be avoided, adjustments are necessary, which in turn reduce planning security.[1]

5.2.3 Recommendations

Following the structure adopted above, recommendations can be derived regarding the completeness and consistency of policy aims and the balancing of trade-offs, as well as the use of targets for operationalising aims.

5.2.3.1 Completeness and Consistency of Policy Aims, and the Balancing of Trade-offs

Over time, the German bioenergy policy's system of aims has developed to become more comprehensive, encompassing more and more aims as it went along. However, the recent focus on supporting waste and residues as options which are

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[1] While the EU-RED's transport sector target is in principle technology-neutral, the absence of feasible RES alternatives makes it implicitly a biofuel-specific target (see 4.1.2.2).

expected to avoid conflicts between aims may prove too narrow: not only are resources limited, giving rise to conflicts between competing uses, but also new trade-offs may arise. Rather, a bioenergy concept needs to acknowledge that there will always be trade-offs. While synergistic "win-win" options exist and should be exploited, it is unlikely that they will suffice to solve the challenges of the energy transition—after all, not only bioenergy, but also the expansion of other RES and their land use requirements, including grid expansions in the electricity sector, give rise to conflicts between different societal aims (Mengel et al. 2010; Beckmann et al. 2013). Likewise, the costs of bioenergy use need to be weighed against the costs of fossil fuel-based substitutes. As a result, rather than focussing on supposedly conflict-free options, an open discussion is necessary when the benefits of bioenergy use can justify associated costs, and what constitutes an acceptable trade-off between policy aims and what not. However, this weighing of trade-offs requires that a hierarchy of policy aims is defined, and also an operationalisation of what constitutes sustainable bioenergy use and what doesn't. While there is no simple answer to this question, the analysis undertaken in preceding chapters suggests several promising approaches that can contribute to this process:

1. Adopting inclusive consultation processes with broad stakeholder participation when it comes to the adoption of a new bioenergy concept or the reform of bioenergy policy instruments in the electricity, heating and transport sectors (see Sect. 3.6.2). Such processes can help to reduce uncertainties about the impacts of policy measures as perceptions of different stakeholder groups are taken into account. However, public choice theory warns against transferring decision making authority to stakeholder processes, because this would increase risks that policies are captured by rent-seeking interest groups. Also, a balance needs to be found between stakeholder consultation and transaction cost concerns.
2. A transparent discussion of trade-offs may also be assisted by a clear assignment of political responsibilities to ministerial agencies, which will act as advocates for the aims in their sphere of influence (cf. Sect. 3.5.5.2). Table 4.1 in Sect. 4.1.1 demonstrates that relevant aims of bioenergy policy touch the responsibilities of various federal ministries: most notably, the ministry of economics, the environmental ministry, the ministry of food and agriculture and the ministry for economic cooperation and development. As such, bioenergy policy should be treated as a cross-sectional task, in which all relevant ministries are included in decision making processes. This not only serves to institutionalise the process of balancing various aims and trade-offs; it also establishes a measure of control over regulatory capture by interest groups (SRU 2013: 140). In this respect, the recent assignment of energy transition responsibilities to a single ministry, the ministry of economics, constitutes a development in the wrong direction.
3. Once an understanding of what constitutes unacceptable costs of bioenergy use has been established, the definition of binding and transparent guard rails can help to safeguard the sustainability of developments while providing long-term planning security for market actors (cf. Sect. 4.5.5, SRU 2007: 59ff.). For internationally traded bioenergy carriers like biofuels or wood pellets,

> sustainability certification, despite its shortcomings, remains the primary option for implementing guard rails (cf. Sect. 4.4.3.3, SRU 2007: 70ff.). For domestically produced bioenergy carriers, guard rails can also be implemented in existing environmental and forestry law, with the advantage that stipulations need not be bioenergy-specific. For biogas plants, where biomass supply concepts tend to be regional, a spatially explicit implementation of guard rails would be sensible: for example, support for energy-crop-based bioelectricity production from new plants could be limited to areas where energy crops (or specific monocultures, such as maize) did not exceed a certain share of the agricultural area (cf. DBFZ 2013). If the regional energy crop cultivation area approached this limit, project planners' remuneration would no longer be guaranteed, providing them with incentives to either develop alternative feedstocks (such as categories of wastes and residues which would be more costly to exploit than energy crops), choose a different site for the plant or abandon the project. In principle, spatially explicit guard rails could also be implemented in sustainability certification, for example by linking certification to regional land use patterns. However, this would not only increase transaction costs of certification, it would also reduce the planning security for biomass producers.

Which priority aim should guide an intervention on behalf of bioenergy must in the end also emerge from the political and deliberative process. However, NIE reinforces the importance of making this prioritisation explicit. If it remains unclear, policy uncertainty for market actors remains high, leading to a reduced willingness to undertake asset specific investments if shifts in political priorities are expected. The next section discusses what prioritisation can be recommended from an economic perspective.

5.2.3.2 Prioritisation of Policy Aims

Realistically, main candidates for a priority aim are GHG mitigation, security of energy supply, and rural development, which are commonly put forward as the three main aims of bioenergy support in German and European bioenergy policy (e.g. COM 2005; BMU and BMELV 2009; see Sect. 4.1.1). From a neoclassical perspective, technological development and the protection of the environment are further relevant aims which are based on the efficiency rationale and would therefore justify government interventions (cf. Sect. 2.3.1, Table 2.4). However, with regard to the alignment of bioenergy policy, these would make poor priority aims. Knowledge and learning externalities arise from a large range of economic activities, making a justification necessary why addressing them in the case of bioenergy and other RES technologies should have a priority. In the RES context, the argument is that knowledge and learning spillovers should be addressed because they hinder the provision of the public good GHG mitigation at lower costs in the future (see Sect. 3.2.2). As such, these spillovers only gain their specific relevance in interaction with the GHG mitigation aim. For environmental protection beyond

GHG mitigation, meanwhile, bioenergy policy does not seem to be a suitable method of choice. Depending on allocation decisions in value chains, there is a potential for positive environmental externalities, but increases in pressures on land use can likewise give rise to a range of negative environmental externalities. Environmental externalities beyond GHG mitigation need to be taken into account in bioenergy design as negative and positive side effects, but contributions are too ambiguous to make their correction a suitable priority aim for bioenergy policy.

As far as rural value creation is concerned, this study shares the assessment of neoclassical economic policy advice, that bioenergy policy is unsuited for making a major contribution to this aim (see Sect. 3.1.4; Isermeyer and Zimmer 2006; WBA 2007: 183ff.; Hermeling and Wölfing 2011: 82; Henke and Klepper 2006). Structural problems of the agricultural sector, such as a lack of international competitiveness, would not be addressed—rather, policy incentives for bioenergy use as a means of rural value creation would distort allocation decisions in the biomass production sphere as well as in the utilisation sphere. For pursuing the aim of increasing rural value creation and employment, production-independent income transfers such as those implemented within the EU's CAP would be a more efficient solution than increasing the demand for certain commodities—after all, this insight inspired the decoupling of support from production decisions in past CAP reforms (DG AGRI 2009). From a dynamic perspective, bioenergy policy can in principle support a diversification of income, education and skills, enhancing the flexibility of agricultural production factors to adapt to changes in market conditions (see Sect. 2.2.3.6). However, skills and expertise are built up in a specific area only, whose profitability depends on the continuation of policy incentives. Consequently, for facilitating adjustment processes, measures aimed at diversifying skills more broadly seem preferable, including skills that allow for a higher factor mobility between the agricultural sector and other sectors (besides the energy sector) (cf. Henrichsmeyer and Witzke 1994: 353f.). Lastly, net rural employment effects are limited by displacement effects on other forms of agricultural production and associated jobs (Isermeyer and Zimmer 2006; Berndes and Hansson 2007; Nusser et al. 2007).

The use of security of energy supply as a priority aim does not prove promising either, even though positive externalities associated with increases in the security of energy supply could provide a rationale for intervening in market processes on efficiency grounds. However, as neoclassical policy advisors rightly point out, the potential contribution of bioenergy to a secure energy supply is rather small and uncertain (Henke and Klepper 2006: 11; Isermeyer and Zimmer 2006: 11f.). Besides the importance of land use restrictions and impacts of large-scale bioenergy use on competing biomass uses, the fact that biofuel prices are coupled to mineral oil prices proves problematic for security of supply contributions: in the transport sector, rising oil prices increase the demand for biofuels as substitutes, thereby driving up their prices in turn (FAO 2008: 23ff.; Hermeling and Wölfing 2011: 46). Also, agricultural and oil markets are coupled through agricultural input prices (FAO 2008: 23). Therefore, biofuels—particularly those based on energy crops—can make only a limited contribution to reducing price volatility in the transport fuel market. Furthermore, neoclassical arguments for an international division of labour hold—an import diversification strategy which increased imports of bioenergy carriers and RES electricity from a variety of supplier countries would indeed be a more cost-effective means of increasing security of supply than a focus on domestic self-sufficiency (cf. Isermeyer and Zimmer 2006: 10ff.; WBA 2007: 184).

The case for adopting GHG mitigation as a priority aim for bioenergy policy is much stronger. Negative externalities associated with GHG emissions of fossil fuel combustion significantly disadvantage low carbon options, such as bioenergy, if left unaddressed (see Sect. 2.2.3.1). On the other hand, bioenergy could make a significant contribution to reducing emissions—however, given the heterogeneous GHG balances of bioenergy pathways, this will only be the case if policy measures are strictly aligned with GHG mitigation. Therefore, this study shares the viewpoint adopted in economic and interdisciplinary policy advice alike, that GHG mitigation should act as a priority aim (cf. WBA 2007: 175ff.; SRU 2007: 80ff.; WBGU 2008: 274; Kopmann et al. 2009). Unlike with neoclassical policy advice, however, this prioritisation does not mean that interactions with other policy aims can be neglected in developing recommendations for policy design.

Nevertheless, it can be argued that a prioritisation of GHG mitigation holds the greatest potential for synergies between the three major aims of German bioenergy policy: expanding the use of bioenergy pathways with beneficial GHG balances does not adversely affect rural development or security of energy supply; rather, positive contributions are possible (cf. WBA 2007: 183ff.; SRU 2007: 80). If, on the other hand, policy measures were aligned with the aims of rural development or security of energy supply, there would be no guarantee that pathways supported by an intervention would contribute to GHG mitigation (see Sect. 2.3.1). On the contrary, they could be associated with negative GHG externalities of their own. In the public debate at least, a consensus seems to exist that in order to be eligible for support, bioenergy should deliver measurable GHG reductions; however, to move beyond the symbolic, a priority for GHG mitigation must also be consequently reflected in the design of interventions. At the same time, mechanisms need to be established to ensure that GHG mitigation measures conform to normative sustainability requirements, by keeping negative environmental externalities in check and meeting requirements of distributive justice.

5.2.3.3 Operationalisation and Measurability of Aims

The use of quantified targets appears particularly useful for aims which require highly asset specific investments for their achievement. This is particularly the case for GHG mitigation and RES expansion (as a lower level aim). For rural development creation and security of energy supply, the definition of adequate targets covering all facets of these aims would be challenging, given uncertainty about future developments in markets and societal framework conditions (see Reeg et al. 2015 for a discussion of the problems of defining security of energy supply in the electricity sector, and the various options that could contribute to it). In evaluating progress towards these aims, a focus on whether or not desirable structural changes have been initiated appears more appropriate. For this, appropriate indicators and monitoring processes need to be defined.

For RES expansion and GHG mitigation, targets have been established as part of German and European energy and climate policies. In order to serve not only as a framework for measuring aim achievement, but to provide reliable long-term guidance for market actors, targets need to meet two requirements: first, they need to be formulated at a level which is sufficiently technology neutral to allow for decentralised search processes for solutions under changing framework conditions. Second, targets need to be backed by credible political commitment, allowing for reliable expectations that appropriate measures will be undertaken to bring about the targets' realisation.

In the electricity sector, a number of feasible technological RES alternatives are available. As a result, the combination of binding RES targets and EU-ETS emission reduction pathways represents a sensible balance between maintaining flexibility in how targets are met, and providing the planning security required for undertaking asset specific electricity generation investments with long planning horizons which moreover necessitate adjustments of the electricity system's infrastructure. In the transport sector, the current biofuel-specific target lacks technology neutrality, and consequently requires frequent adjustments which lead to policy uncertainty. This problem would also apply to a broader sectoral RES target, because to date, not many feasible alternatives for meeting the target exist.[2] In this case, a sectoral GHG emission reduction target might prove more appropriate, because it would allow for greater flexibility in choices between RES use, energy efficiency improvements and absolute reductions in energy use, for example, in the context of alternative mobility concepts. In the heating sector, a sectoral GHG emission reduction target also shows advantages compared to a sectoral RES target. Even though a range of RES alternatives exist, efficiency improvements, for example, through thermal insulation are considered key for reducing GHG emissions in the heating sector, as they could bring about significant reductions in future heat demand (e.g. WBGU 2008: 195ff.; Blazejczak et al. 2014: 49ff.). Reductions in energy demand need to be accompanied by RES expansion to cover residual heat demand, but separate RES targets fail to reflect the diversity of the building stock, which determines the relative advantages of energy efficiency measures, RES-based heat production or the use of district heating. Separate targets for RES, energy efficiency and combined heat and power production would impose high information requirements on policy makers, with considerable potential for steering errors.[3]

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[2] In the longer term, electromobility may make a sizable contribution, but in this case, its GHG mitigation potential and even its classification as an RES technology depend on the source of electricity used, and therefore on the achievement of RES targets in the electricity sector.

[3] The Combined Heat and Power Law (Kraft-Wärme-Kopplungsgesetz, KWKG) sets targets for an increase in the share of electricity from CHP (section 1 (1) KWKG), complementing RES and energy efficiency targets (see 4.1.1).

Furthermore, in order to succeed in providing planning security for investments with high asset specificity, targets need to be underpinned by credible political commitment. Establishing such a commitment is anything but straightforward—implementing binding long-term targets in law, for instance, is in itself not sufficient, as has been shown for the case of the UK's ambitious 80 % GHG reduction target for 2050 (Helm 2010; Lockwood 2013). Rather, targets need to be nested in a wider process of institutional change (see Sect. 3.5.4.3). In particular, to guard against a reversal of policies, it is deemed crucial that constituencies are created which have vested interests in the implementation of targets (Patashnik 2008: 31; Lockwood 2013). In achieving this, instrument choice and design can play an important role; for example, the EEG has successfully incentivised organisations to undertake investments in capital but also skills and knowledge specific to the energy transition policy regime, creating a vocal "advocacy coalition" (Jacobsson and Lauber 2006; Lehmann et al. 2012: 344). Also, installing public organisations to act as "guardians" of targets can add to credible commitment, although the effectiveness of this approach is influenced strongly by whether or not organisations have access to instruments which control a target's achievement (Helm et al. 2003; Helm 2010).

5.3 Elements of an NIE-Based Bioenergy Policy Concept: Choice of an Allocative Principle

This section first develops theoretical insights regarding the choice of an allocative principle between markets and hierarchies, before reconstructing what allocative principles have so far been used in German bioenergy policy. Based on an evaluation of the latter against theoretical findings, recommendations are formulated.

5.3.1 Choice of Allocative Principles Between Markets and Hierarchies: Theoretical Insights

Neoclassical theory generates clear recommendations concerning the choice of allocative principle (see Sect. 3.1): as a correction of a market failure, government interventions should aim at reconstituting the functionality of the price mechanism. For GHG externalities under perfect information, this would be done by internalising the external costs of GHG emissions, so that the private costs of activities which cause the emissions equal their social costs. Alternatively, if the optimal abatement level is unknown, policy makers would set a mitigation target and choose an instrument so that it can be efficiently achieved. This implies not only the use of the most cost-effective GHG mitigation options, but also an equalisation of marginal abatement costs across all emitters. Importantly, the choice of mitigation options should be left to the market mechanism; following the principle of profit maximisation, economic actors would then adopt the most cost-effective options. In searching for these options, they would make use of dispersed, time- and space-dependent knowledge, allowing for a greater scope for experimentation and trial-and-error processes than would be the case with more hierarchical interventions (see Sect. 3.4.1). Accordingly, in the case of market-based interventions, the restored price mechanism not only fulfils the task of coordinating allocation decisions, it also coordinates the generation of new knowledge. Indirect incentive instruments are the instrument type most consistent with this allocative principle. At the same time it is assumed that further market failures are taken care of by other first-best instruments.

In comparison, the NIE perspective displays two major differences which affect the choice of allocative principles. Firstly, even if GHG mitigation is accepted as the priority aim for interventions on behalf of bioenergy, interactions with other policy aims and unresolved market failures have to be considered because they affect the allocative performance and feasibility of first-best interventions. Secondly, once knowledge and learning externalities, information problems, transaction costs, and path dependencies are taken into account, interventions with hierarchical elements which influence allocation decisions more directly can under some circumstances be more efficient than market-based ones. Importantly, the NIE perspective encompasses a continuum of governance options, with markets and hierarchies as extremes of the spectrum. As a result, the choice of allocative principle is not one between markets and hierarchies as such, but one between a steering approach which is closer to the market end of the spectrum, and a steering approach in which hierarchical elements outbalance market elements. In the following, the term “hierarchical intervention” is used to describe an intervention which leans towards the hierarchical side of the continuum of governance options; whereas a “market-based” or “market oriented intervention” is one which is closer to the market end of the spectrum in comparison. Thus, market-based interventions can still have hierarchical elements, and vice versa; the exact balance is determined in instrument choice and design (see Sect. 5.4).

For determining an adequate allocative principle, three questions need to be discussed: firstly, whether there is a rationale for directly intervening in the choice of GHG mitigation options; secondly, if so, whether this rationale applies to the case of bioenergy; and thirdly, whether further interventions are required in allocation decisions elsewhere in the bioenergy value chain, in order to address effects on other societal aims and interactions between market failures.

5.3.1.1 Is There a Rationale for Hierarchical Interventions in the Choice of GHG Mitigation Options?

As outlined in Sect. 3.2.2, the combined presence of GHG externalities and knowledge and learning spillovers distorts technology decisions, leading to a suboptimal allocative outcome if only GHG externalities are addressed. Specifically, technology-neutral interventions close to markets would cause market actors to choose the mitigation options with the lowest costs, but investments in innovative low carbon technologies would remain lower than socially optimal, increasing future GHG mitigation costs. While as a first-best solution for internalising knowledge and learning externalities, public R&D support is frequently recommended (Frondel et al. 2010; Hermeling and Wölfing 2011: 84), spillovers which promote dynamic cost reductions of innovative technologies also occur in the diffusion phase (Grubb and Ulph 2002; Lehmann 2012). From a second-best perspective which accounts for dynamic efficiency considerations, policies which ensure that a broad portfolio of technologies moves down the learning curve are called for (cf. Sect. 3.2.2). Compared to a first-best solution, in which only mitigation options with the highest static cost efficiency are implemented, increasing technological diversity not only reduces the costs of RES production in the long term, it also helps to avoid lock-ins and improves the resilience of the technological system against disturbances (van den Bergh 2007: 45ff.).

In order to promote technological diversity, a differentiation of policy incentives by technologies is required; simply increasing technology-neutral emissions tax rates or emission targets to improve the profitability of innovative technologies would not be an efficient solution, because technologies differ in their innovative potential and market actors would still have incentives to choose mitigation options which minimise costs in the short term (Grubb and Ulph 2002; Menanteau et al. 2003; Lehmann 2012). This implies that a more hierarchical approach to the governance of choices between GHG mitigation options is appropriate, i.e. the use of hybrid governance structures with hierarchical elements (cf. Sect. 3.5.2.3).

Increasing technological diversity, meanwhile, is not the only rationale for hierarchical interventions. If investments in GHG mitigation technologies are costly and irreversible, and at the same time dependent on the continued existence of political incentives, then investors will require reliable safeguards (cf. Helm et al. 2003). Both with direct and indirect interventions, market actors face the problem of a potential political hold-up, i.e. policy makers may be tempted to renegotiate the terms of regulatory contracts, once investments have been undertaken (see Sect. 3.5.2.2). This problem needs to be addressed through establishing credible political commitment, and an institutional environment that supports investor security (Langniß 2002: 6; Finon and Perez 2007: 88).

However, with interventions close to markets, such as a first-best emissions trading scheme, investors bear not only uncertainties relating to future changes in political framework conditions, but also uncertainties about present and future income streams, which are determined by supply and demand in emission allowance markets, and the GHG balance of potential bioenergy investments, which may change depending on advances in scientific knowledge. As a result, investors would only adopt GHG mitigation options with a high asset specificity, if they were confident that future emission allowance prices would be high enough to recover investments, and that advances in scientific knowledge would not devalue their investments. In the EU-ETS, emission prices have proven to be very volatile (cf. Koch et al. 2014); furthermore, future price developments depend directly on the future ambitiousness of climate change policy, where credible commitment is exceedingly difficult to establish (Helm et al. 2003). Under these circumstances, forming stable expectations about future GHG allowance prices is extremely difficult. Moreover, given persistent uncertainties about GHG balances and the dynamics of leakage effects, the assessment of certain bioenergy pathways may change over time. If this affects the amount of emission allowances a producer is entitled to, it can have significant impacts on income streams. Without sufficient safeguards, investments in GHG mitigation would be dominated by options with short pay-off periods (e.g. some energy efficiency measures), or investments which could be redeployed to other uses (e.g. the conversion of fossil fuel power plants). As a result, technology choices would be distorted; particularly high capital investments in asset-specific technologies which had not fully moved down their learning curve yet, such as renewable energies, would be disadvantaged.

A further source of distortion in choices between GHG mitigation options are technological and institutional path dependencies, which in the case of the energy sector are reinforced by market power on the side of incumbents with sunk investments in fossil fuel-based production capacities (see Sects. 2.2.3.4 and 3.5.4.2). The theory of institutional change highlights that overcoming the lock-in into a fossil fuel-oriented techno-institutional complex is likely to require concerted efforts, including the use of direct interventions in technology choices to create advocacy coalitions and political momentum (see Sect. 3.5.4.3; Lehmann et al. 2012).

Therefore, in the case of asset-specific GHG mitigation investments with knowledge and learning spillovers, there is a rationale for adopting hierarchical interventions. These would need to provide safeguards relating to the political credibility of incentives, income streams, and also the assessment of GHG benefits of bioenergy pathways. However, hierarchical interventions require central choices about what technologies are considered promising enough to warrant hierarchical support; these have considerably higher information requirements than indirect interventions close to markets, and face the problem of the constitutive lack of knowledge of central decision making (see Sect. 3.3.2; Hayek 1945). Consequently, hierarchical interventions should only be employed where strong investment safeguards are required, whereas transactions with low asset-specificity are better governed by interventions closer to markets. For GHG mitigation, this argues for a combination of allocative principles in governing investment decisions—for example, investments in renewable electricity plants, which in the absence of political support would not be competitive in the next best application, are highly asset-specific, arguing for hierarchical interventions, whereas investments in efficiency improvements in fossil fuels power plants, for instance, with low asset specificity could be incentivised by instruments close to markets, such as an emissions trading scheme.

5.3.1.2 Is There a Rationale for a Hierarchical Intervention on Behalf of Bioenergy as a GHG Mitigation Option?[4]

While the arguments so far establish the case for hierarchical interventions in the choice of GHG mitigation options, it still needs to be discussed whether a need for direct interventions on behalf of bioenergy technologies can be inferred from them, and if so, at which stage of the value chain they should be undertaken. In the case of bioenergy, investments in dedicated biomass combustion and bioenergy-specific conversion facilities are highly asset-specific, and would not be undertaken in the absence of safeguards. Particularly for biofuel production facilities and dedicated bioelectricity plants, income streams are highly dependent on the continued existence of policy incentives; investments in biomass-based heating applications are less asset specific, because they are closer to commercial competitiveness (cf. Sects. 4.1.4 and 4.2.3). If asset-specific bioenergy facilities in the electricity and transport sectors are to play a part in GHG mitigation and the transformation towards a low carbon energy system, hierarchical interventions providing them with safeguards are necessary. This, however, raises the question to what degree a GHG mitigation strategy requires investments in dedicated bioelectricity plants and biofuel refineries, or whether investments with lower asset specificity, like co-combustion and conversion of fossil fuel power plants or, for example, efficiency improving measures in the transport sector, would suffice.

Potential arguments for direct interventions on behalf of asset-specific bioenergy investments would be the presence of knowledge and learning spillovers, and path dependencies. Both in biofuel and bioelectricity production, knowledge and learning spillovers differ significantly between technologies, and cost reductions due to learning curve effects are often limited due to the importance of biomass costs in the overall cost structure (see Sect. 4.4.2). Biofuels are unlikely to contribute to overcoming path dependencies in the energy system, because they show good compatibility with fossil fuel infrastructures and demand patterns (see Sect. 2.2.3.6). As a result, there is a case for focussing hierarchical interventions aimed at supporting biofuels on technologies where asset specificity and the expectation of significant knowledge and learning spillovers combine, making them desirable candidates for inclusion in a future low carbon technology portfolio in the transport sector. In particular, this is the case for second generation biofuels, whereas first generation biofuels have reached a comparatively high level of technological maturity (cf. Eggert and Greaker 2013; Carriquiry et al. 2011; Sims et al. 2010). Also, the use of biofuels in aviation is associated with high innovative potential and significant scope for learning curve effects (Gegg et al. 2014; Köhler et al. 2014).

In the electricity sector, major technologies such as biogas and solid biofuel-based combined heat and power (CHP) production have reached a comparatively high level of technological maturity, even though there is still potential for incremental innovation (Thrän et al. 2011b: 42ff.; Gross 2004). However, the fact that

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[4] Parts of this section have been published in abridged form in Purkus et al. (2015).

path dependencies exist provides arguments for direct interventions on behalf of dedicated bioelectricity plants. For one, competition with conventional energy technologies is not only distorted by persistently low levels of emission allowance prices, but also by economies of scale and past learning effects which conventional energy technologies can benefit from (Lehmann and Gawel 2013). Moreover, current market framework conditions set only limited incentives for the provision of flexible capacities, even though their systemic importance is growing as shares of volatile RES increase (Rohrig et al. 2011; BMWi 2014b; Arnold et al. 2015). Flexible dedicated bioelectricity plants can play a complementary part in an electricity system based on large shares of volatile RES by generating external security of supply benefits; so can the upgrading of biogas to biomethane which can be used in gas power plants (Bofinger et al. 2010). On the other hand, the use of biomass in coal power plants would be less compatible with an RES-based electricity system, because of their comparatively low flexibility potential (Mayer et al. 2013). As part of initiating a path of transition towards a RES-based electricity system, hierarchical interventions on behalf of dedicated biomass capacity and other renewables-based flexibility options with high asset specificity can therefore be justified, even in cases when learning and knowledge spillovers might not be significant. Here, deployment support can be viewed as a means of reflecting the option value of bioenergy as a low carbon dispatchable RES in the future electricity system—deployment support allows for a further development of bioenergy technologies as part of a portfolio of RES technologies, until the path of transition is so advanced that market framework conditions and indirect instruments provide sufficient incentives and planning security for investing in low carbon flexibility options.

Meanwhile, investments lower down in bioenergy value chains, such as in the primary production sphere and intermediate processing stages (e.g. vegetable oil production facilities) tend to have much lower asset specificity. Here, producers have a range of possible buyers from different material, energetic or food sectors to choose from, and can adapt allocation decisions comparatively easily to changes in market and political framework conditions.[5] Conversely, bioenergy producers in the utilisation sphere are not necessarily dependent on individual biomass producers, but can adapt sourcing decisions, or else implement private investments safeguards (e.g. long-term biomass supply contracts). Hence, the need for specific public investment safeguards is lower than in the case of investments in dedicated bioenergy combustion or conversion plants.

Meanwhile, utilisation-sided safeguards propagate down the value chain—primary biomass producers, for instance, will be more inclined to undertake investments in energy crop production or enhanced wood harvesting when demand for resources is viewed as secure, particularly if required investments are sizeable. On

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[5] An exception are perennial feedstocks such as SRC, where sizable upfront investments are required and land is tied up for several years; at the same time, the scope of applications is as of yet narrowly defined.

the other hand, policy makers need to acknowledge that by setting incentives for certain biomass uses, they impact allocation decisions in the primary production sphere and therefore resource availability for actors in processing and utilisation spheres. This problem, however, would not be solved by intervening in biomass production decisions, for example by directly supporting energy crop cultivation. Rather, a careful coordination of utilisation-sided interventions is required.

Overall, it therefore seems most advantageous to focus hierarchical interventions concerning the use of bioenergy as a GHG mitigation option on the utilisation sphere. Not only is asset specificity of transactions highest here; also, the overall performance of bioenergy pathways in terms of costs, GHG balances and side effects on other societal aims is determined in the utilisation sphere, in comparison to reference fuels which bioenergy replaces. Moreover, utilisation-sided incentives—and to some degree, also safeguards—are passed down the value chain, allowing for adjustment reactions of market actors in the conversion and primary production spheres, where investments are less asset-specific and benefits of using market processes to coordinate dispersed knowledge outweigh the benefits of hierarchical interventions.

Nonetheless, the question remains whether in the case of bioenergy allocation decisions, side effects on other aims than GHG mitigation require further hierarchical interventions, either in the utilisation sphere or further down the value chain—this will be the focus of the next section. Also, the choice of a hierarchical allocative principle for the use of bioenergy as a GHG mitigation option leaves open just how hierarchical interventions in the utilisation sphere should be. To find a balance between incentive intensity and investment safeguards, it is necessary to carefully weigh the benefits of different hybrid options, taking the specifics of relevant transactions into account. This is the task of instrument choice and design, which will be discussed under Sect. 5.4.

5.3.1.3 Do Interactions Between Multiple Policy Aims and Market Failures Merit Further Interventions Specifically in Bioenergy Value Chains?

If an intervention on behalf of GHG mitigation and bioenergy specifically aggravates other market failures and negatively impacts other societal aims, there are in principle three options that policy makers can adopt.

First, they can attempt to ameliorate persistent market failures by policy measures which are aimed at all relevant sectoral allocation decisions, not just bioenergy. While it is unrealistic to assume that all other market failures can be solved by first-best solutions, it is necessary to examine whether it is possible to at least loosen relevant constraints which have prevented a more comprehensive addressing of market failures in the past (cf. Sect. 3.2.1). For example, support for bioenergy on behalf of GHG mitigation and other aims increases pressures on the environment, thereby highlighting shortcomings of existing environmental regulations in the agriculture or forestry sectors (SRU 2007: 60). Changes in circumstances could potentially generate enough political momentum to make a comprehensive reform of environmental policy framework conditions possible, for example, through a greening of agricultural subsidies or a tightening of environmental minimum standards (see Sect. 4.2.1) From a public choice perspective, this could be the case if pressure from public interest groups towards environmental reforms were to combine with an increased willingness to accept reforms on the part of primary producer interest groups, which value the continued existence of a policy-induced increase in biomass demand. Adopted interventions need not be first-best measures; indeed, for safeguarding potentially critical levels of environmental quality, hierarchical interventions employing proscriptions or prescriptions may be more effective and cost-efficient than indirect, outcome-oriented measures, once transaction costs, sustainability constraints and risk attitudes of biomass producers are taken into account (cf. Sects. 3.5.2 and 3.5.3.2). Rather, the crucial point is that interventions apply not only to bioenergy value chains, but also to other biomass uses; in this way, allocation decisions between energetic and non-energetic biomass uses are not distorted.

If comprehensive reforms of policy framework conditions are not possible at least in the short term, two options remain. For one, policy makers can adjust the utilisation-sided, GHG mitigation-oriented intervention to take adverse interactions with other aims and market failures into account. For example, the offer of strong investment safeguards could be limited to certain technologies and feedstocks which were assessed as not likely to have significant negative impacts on other policy aims; constraining support to waste and residues would be consistent with this approach. Another possibility would be the introduction of binding minimum sustainability standards as a prerequisite for support, as has been done in biofuel policy.

On the other hand, policy makers can undertake further hierarchical interventions in allocation decisions in the bioenergy value chain, to correct for side effects of the original intervention. One example of this are import tariffs on biomass and bioenergy carriers, which influence location and sourcing decisions; in principle, also the adoption of bioenergy-specific environmental regulations would be possible.

The theory of economic order is especially critical if an intervention in market processes leads to further corrective ones; since all interactions between market failures and policy aims are almost impossible to foresee, corrective interventions might require even more interventions to address their side effects, a situation which might lead to an intervention spiral (see Sect. 3.4.1). Particularly for downstream allocation decisions in value chains which affect transactions with low asset specificity, direct bioenergy-specific interventions should be avoided, because, here, the advantages of using time- and space-dependent knowledge are likely to outweigh the benefits of hierarchical interventions. Furthermore, the more bioenergy-specific interventions to address interactions with other market failures and policy aims are, the greater the risk of displacement effects. For example, if the conversion of extensively managed grassland was prohibited for energy crop production only, farmers could produce energy crops on existing crop land and convert grassland for the production of non-energy crops—a classic case of indirect land use change (cf. Searchinger 2009). As adverse side effects of other biomass uses come into the political focus, for example, increases in primary biomass production for bioeconomy value chains, further specific interventions would become necessary. Compared to a reform of general regulatory framework conditions which apply to all biomass applications, case-by-case interventions would eventually result in a complex, high transaction cost system.

Under these conditions, taking interactions with other market failures and aims into account in utilisation-sided, GHG-oriented interventions seems like the more promising solution, if general, non-bioenergy-specific reforms of framework conditions are not feasible in the short term. Under incomplete knowledge about side effects, a gradual implementation of interventions on behalf of bioenergy seems recommendable, differentiating between pathways according to the associated risks and uncertainties (cf. Sects. 3.5.4.3 and 3.6); as learning takes place, interventions can be adjusted to better reflect relevant interactions, although trade-offs between adjustability and investment safeguards once again require careful balancing. How side effects can be taken into account in utilisation-sided interventions, meanwhile, is an issue of instrument design (see Sect. 5.4).

5.3.2 Application to German Bioenergy Policy

German bioenergy policy is characterised by a combination of indirect, market-based and direct, hierarchical interventions. Allocative principles, which have been adopted for dealing with the various allocative problems of bioenergy use, can be inferred from the instruments employed (see Sect. 4.2).

For steering biomass flows and technology choices, the EU-ETS and energy taxes represent a combination of indirect interventions close to markets, which increase the degree to which environmental externalities are reflected in energy prices (Sect. 4.2.2). While the EU-ETS leaves technology and abatement decisions to market actors, the German energy tax is not aligned with either carbon emissions or energy output of energy products; rather, a differentiation of tax rates by energy product and application introduces hierarchical elements into what would in principle be a market-based instrument (Gawel and Purkus 2015). At the same time, the German energy and climate policy mix sports direct interventions to support bioenergy use in the electricity, heating and transport sectors (EEG FIT and market premium scheme, EEWärmeG and MAP, and the biofuel quota, see Sects. 4.2.3–4.2.5). The EEG's technology-specific price incentives and the quantitative biofuel quota represent particularly pronounced instances of a central steering of technology decisions, strongly influencing biomass flows to different applications. In the heating sector, RES shares required by the EEWärmeG differ between RES technologies, as do MAP support rates, thereby influencing technology choices. Overall, however, the comparative costs of different RES technologies, energy efficiency compensation measures, and building-specific requirements can be expected to have a greater influence on allocation decisions (see Sect. 4.2.4.2). This implies a more market-oriented allocative principle than bioenergy-specific remuneration or quantitative requirements in EEG and biofuel quota, respectively.

In the primary production sphere, biomass flows and technology choices are primarily steered through indirect interventions, such as the setting of environmental framework conditions and the waste framework hierarchy (see Sect. 4.2.1). With the exception of designated areas of high conservation value, where restrictions to potential land uses apply, production choices are left to market actors; agri-environment programmes, which support a range of specific measures, are somewhat more hierarchical, but the incentive impact on bioenergy remains relatively small when compared to utilisation-sided incentives (see Sect. 4.2.1.1). Also, subsidies for SRC plantations in some federal states represent hierarchical interventions.

With regard to incentives for dynamic efficiency and innovation, indirect instruments like the EU-ETS and energy taxes lead to investments in innovations which are likely to generate savings in the foreseeable future for individual investors. Aside from R&D support, this is accompanied by direct interventions in the electricity, heating and transport sectors, which support the diffusion of selected technologies.

As for the steering of location and sourcing decisions, there are few explicit hierarchical interventions. Decisions about the location of plants are left to market actors, within the framework conditions set by environmental law and planning law. Also, bioenergy producers are in principle free to choose between domestic feedstocks and imports. However, in older versions of the EEG, sourcing decisions are influenced implicitly by the differentiation of remuneration by feedstock and technology, which somewhat favoured small-scale, decentralised biogas pathways with domestically sourced feedstocks of low transport worthiness (WBA 2007: 176f.). In the EEG 2014, no distinction is made between gaseous and solid biomass with better transportability characteristics, although high reference prices for small-scale slurry and biowaste digestion plants remain (Sect. 4.2.3.4). Also, the continuing focus on small- to mid-scale, decentralised plants and the exclusion of co-combustion from EEG support has an impact on sourcing decisions, because building up international value chains is associated with transaction costs which, due to economies of scale, large-scale bioenergy producers with a demand for considerable amounts of biomass may be more willing to incur than smaller actors.

With biofuels, distinct sub-quotas for petrol fuels and diesel fuels influence sourcing decisions, given that Germany is one of the largest producers of biodiesel globally (see Sects. 4.1.4 and 4.2.5). From 2015, however, this distinction is abolished with the change towards a GHG-based quota. At the same time, import tariffs on biofuels and intermediate products continue to be a direct intervention in sourcing decisions (Sect. 4.2.1.4); on the one hand, they distort allocation decisions in favour of domestic production, while also influencing the choice of trading partners depending on the existence of bilateral trade agreements.

Overall, major direct interventions are centred on the utilisation sphere, and target, with the exception of biofuel import tariffs, primarily the governance of biomass flows, technology choices and innovation incentives, rather than location and sourcing decisions. From a neoclassical perspective, but also a theory of economic order perspective, the prevalence of hierarchical interventions would have to be assessed as highly problematic. Not only do direct policy instruments prevent an alignment of energy technology decisions with GHG mitigation costs (see Sect. 3.1.4); technology-specific policy design also requires a fair amount of steering knowledge on the side of policy makers. Given the constitutive lack of knowledge these operate under, technology-specific, direct RES support may result in high cost of errors and an inefficient restriction of market actors' search processes (see Sect. 3.4.1; Hayek 1945; Hayek 1945/2005). However, the NIE and second-best viewpoints differ, in that hierarchical interventions may be appropriate if they reflect the presence of knowledge spillovers and dynamic efficiency considerations, the need for safeguards in case of asset specific investments, and the need to overcome path dependencies. Nonetheless, the NIE perspective also stresses that in case of downstream allocation decisions with low asset specificity market-based interventions should be adopted, because here the benefits of a decentralised coordination of knowledge and search processes are likely to outweigh the benefits of the higher planning security that a central steering of allocation decisions can offer. Likewise, as discussed under Sect. 5.3.1.3, effects of interacting market failures are best addressed through non-bioenergy-specific interventions or, if not possible, taken into account in utilisation-sided interventions. These, in turn, should in their design reflect the hierarchy of policy aims; solving conflicts between aims through additional direct bioenergy-specific interventions on an ad hoc-basis would not be recommendable, because this might well lead to an intervention spiral.

On the basis of these theoretical recommendations, the following sections assess the performance of the allocative principles that can be inferred from German bioenergy policy. This is done separately for the three primary allocative challenges, i.e. the steering of biomass flows and technology choices, the setting of incentives for dynamic efficiency and innovation, and the steering of location and sourcing decisions.

5.3.2.1 Assessment of Hierarchical Interventions in Biomass Flows and Technology Choices

Over the past years, EEG and biofuel quota have both offered sufficient safeguards for market actors to undertake highly asset specific investments in biofuel refineries and dedicated bioelectricity plants (see Sect. 4.1.4). With the biofuel quota, policy uncertainty concerning future EU regulation on biofuels and the implementation of the GHG-based quota have somewhat counteracted the effectiveness of safeguards, leading to a stagnation of biofuel expansion (see Sect. 4.2.5). In the absence of path dependencies that might justify direct interventions on behalf of biofuels, the failure of the energy content-based biofuels quota to differentiate between technologies according to learning curve effects has to be viewed critically; indeed, so far the quota has mainly succeeded in promoting the diffusion of first generation biofuels (cf. Sect. 4.1.4), where the scope for further learning-induced cost reductions is likely to be limited (Eggert and Greaker 2013).

While it remains to be seen whether the GHG-based biofuel quota will perform better in stimulating the use of innovative biofuel technologies with superior GHG balances, one major weakness is that, by focussing on biofuels, the intervention fails to promote a portfolio of GHG mitigation options in the transport sector; this is problematic, because the degree to which biofuels can substitute for mineral oil is clearly limited by sustainable biomass potentials. At the same time, although specific emissions of CO_2 and other harmful emissions per transportation unit have decreased significantly between 1995 and 2010, in personal transport reductions have been partly compensated by an increase in traffic, while in the case of freight transportation, absolute emissions have even increased (UBA 2013). This highlights the need for more broadly defined interventions, which increase incentives for absolute reductions in energy use and shifts in the modal split towards more energy and climate efficient modes of transport (Bracher et al. 2014: 13ff.).

As discussed in Sect. 5.3.1.2, hierarchical interventions on behalf of dedicated bioelectricity plants can be justified if they contribute towards overcoming path dependencies. In this respect, the EEG's approach of offering technology-specific reference prices with low risks for investors performs well, as does the EEG 2012 and 2014s attempts to increase incentives for demand-oriented feed-in and plant layout (at least in the case of biogas plants) (Sect. 4.2.3.3). On the other hand, significant cuts in funding value and the introduction of the annual 100 MW cap, after which an accelerated decrease of reference prices applies (Sect. 4.2.3.4), have increased policy uncertainty and reduced the reliability of investment safeguards (see also Sect. 5.4.2). In the heating sector, the allocative principle embodied by EEWärmeG and MAP, which prescribe certain shares of RES or the adoption of energy efficiency measures and offer cost-based investment support while leaving specific technology choices to market actors, appears well aligned with the lower asset specificity of heating sector investments.

Meanwhile, besides providing rationales for hierarchical interventions in some cases, NIE-based insights suggest that downstream allocation decisions with lower asset specificity should be governed by more market-based allocative principles. In German bioenergy policy, this is mostly the case—direct interventions are mainly centred on the utilisation sphere, and leave incentives to propagate further down the value chain. Allocation decisions by producers of intermediate products and primary biomass resources are not directly intervened with, although of course the profitability of different outlets is influenced by utilisation-sided incentives. Primary producers wishing to supply biomass to publicly supported biofuel value chains need to comply with sustainability criteria, but this still constitutes an utilisation-sided instrument: producers are free to decide whether to incur the additional costs involved in catering to this market, and, in case they fail criteria, are still able to sell to other markets unless private contract restrictions apply. The energy crop premium, on the other hand, was an example of a more direct intervention that was not tied to the utilisation side. Given the low asset specificity of accordant investments, and the limited applicability of learning curve and path dependency arguments, NIE-based rationales for a direct intervention in primary producers' allocation decisions do not apply. Consequently, the premium's abolishment can be considered as the right step. In the case of subsidies for SRC plantations in some federal states, it could be argued that as a perennial crop with comparatively high investment costs, cultivating SRC is associated with higher asset specificity than other energy crops; however, given the multiplicity of competing land uses, it seems doubtable whether public safeguards for specific cropping decisions can be an efficient solution in the long term. Potentially, reliable utilisation-sided safeguards for bioenergy producers might generate sufficient incentives for them to enter into long-term contracts with SRC primary producers and provide safeguards in private contracts. Nonetheless, learning curve effects associated with SRC cultivation might provide a justification for diffusion support on a limited scale (cf. de Wit et al. 2013).

The third question to be discussed is whether interactions between market failures and detrimental effects on societal aims other than GHG mitigation are addressed through general non-bioenergy-specific measures or, if that is not feasible, adjustments of utilisation-sided instruments, rather than "repaired" by additional bioenergy-specific interventions. With regard to non-bioenergy-specific measures, the recommendation that existing environmental policy and agricultural policy framework conditions should be adjusted to offer more effective protection of environmental public goods has been put forward for several years now (e.g. SRU 2007: 63ff.; Möckel 2014; SRU 2015). With land use pressures increasing, not only an adjustment of environmental standards and practices, but also an improved enforcement of existing regulation is necessary to reduce the extent of market failures—examples are the good professional practice rules in German environmental law, which in many cases lack legal instruments that would allow for effective monitoring or enforcement of compliance (Möckel 2014: 15). Although bioenergy expansion may have brought an increased awareness to land use policy deficits, comprehensive reforms are faced with significant political opposition and transaction costs. An example of this is the 2014 reform of the EU CAP, which aimed to improve the environmental balance of agricultural production in the EU (see Sect. 4.2.1.1); after 3 years of negotiations, however, "greening" requirements have become diluted enough to make their environmental effectiveness questionable (Pe'er et al. 2014). Another production-sided, indirect instrument with scope for improvement is the waste and recycling regulation, which addresses external costs of waste disposal and extraction of raw materials both, with the aim of moving closer towards a circular flow economy which conserves natural resources (section 1 KrWG, cf. Sect. 4.2.1.3). If the costs of biogenic waste disposal were increased or the enforcement of the waste hierarchy improved, for instance, incentives for using wastes and residues energetically or in material applications would grow—as such, adjustments of the waste and recycling regulation could be a useful addition or even alternative to a targeted support of waste and residues in direct bioenergy support instruments (Baur 2013).

Meanwhile, the CAP's agri-environment scheme makes it possible for federal states to offer cost-based compensation for some forms of bioenergy production, which could be interpreted as a bioenergy-specific direct intervention in downstream allocation decisions; however, at the same time, a large variety of other activities that generate environmental benefits are also supported, thus limiting distortions in allocation decisions. Theoretically, output-oriented payments for ecosystem services would embody an allocative principle closer to markets and could increase efficiency through avoiding distortions between measures (e.g. Robert and Stenger 2013; Sattler and Matzdorf 2013). However, the principal-agent approach shows that risk-averse actors are likely to respond better to support which is tied to the implementation of measures than to results, and that monitoring costs of a result-based scheme would be high (see Sect. 3.5.3.2). In this regard, offering support for bioenergy-related measures that verifiably contribute to environmental improvements seems justifiable from a second-best perspective.

Rather than undertaking bioenergy-specific "corrective" interventions when steering biomass flows and technology choices, German bioenergy policy primarily utilises adjustments in utilisation-sided instruments to address interactions between multiple policy aims and market failures. Compared to corrective interventions which entail the risk of descending into intervention spirals, this is positive. Utilisation-sided adjustments are adapted to changing framework conditions and information in an ongoing trial-and-error process; the introduction of a cap on maize use in the EEG 2012 and its subsequent replacement by FIT cuts, or the change towards a GHG-based biofuel quota are two examples of this. What is problematic is that learning is not implemented in a gradual way; potential side effects and market failure interactions have not been taken into account from the outset, but adjustments follow only after a high demand for certain bioenergy uses was triggered. As a result, subsequent adjustments have led to decreases in planning security for market actors, particularly if changes affect existing investments, as is the case with the new biofuel quota. Under the EEG, changes affect only new plants, but while this implies higher planning security it negatively affects the reversibility of policy decisions (see also Sect. 5.4.2).

5.3.2.2 Assessment of Hierarchical Interventions in Innovation Efforts

As discussed in Sect. 5.3.1.1, hierarchical interventions which help to bring a portfolio of technologies down the learning curve and speed up innovation can be justified if knowledge and learning spillovers are present. This argument is widely used in favour of direct support for renewable energy technologies (e.g. Kemfert and Diekmann 2009; Lehmann 2013). With bioenergy, however, the existence of numerous technology-feedstock combinations with different degrees of innovativeness, environmental and cost characteristics establishes an important difference when compared to other RES. It is particularly relevant under dynamic efficiency aspects that the diffusion of first generation technologies which are comparatively established and low-cost does not necessarily transfer to more innovative, but also more expensive second generation pathways (Berndes et al. 2010; Eggert and Greaker 2013). In making a choice about whether to offer specific support to these more expensive pathways, policy makers have to assess the future need for these options compared to first generation technologies and other RES.

The biofuel quota attempts to address this problem through double counting of second generation and waste-based pathways; moreover, EU-level discussions on limiting the contribution of first generation biofuels to the 10 % transport sector RES target could effectively act as sub-quotas for second generation biofuels (see Sect. 4.1.2.4). However, so far the high costs of these pathways and the many uncertainties involved (regarding e.g. logistics, future policy changes, or learning curve potentials) have prevented a sizable deployment (see Sect. 4.4.2). In the electricity sector, the EEG 2012 attempted to incentivise the use of lignocellulosic feedstocks such as straw for anaerobic digestion through the allocation of a higher substrate tariff class (Appendix 3 BiomasseV 2012), but the EEG 2014 disincentivises the use of comparatively expensive pathways.

In principle, policy makers could promote second generation pathways by offering stronger specific safeguards to selected technology-feedstock combinations; however, the uncertainties that market actors have to deal with are shared by policy makers, and are joined by uncertainties about the impacts of a growing demand for second generation feedstock resources and even the need for comparatively expensive bioenergy options in future energy systems. In the electricity sector, for example, a range of alternative options could balance fluctuations in volatile RES production, such as (non-biomass based) power to gas, storage systems, or demand side management (cf. Leprich et al. 2012). Taking these uncertainties into account, it would be preferable to design instruments so that bioenergy could compete with these options on a fair basis; here, offering strong safeguards for comparatively expensive options whose competitiveness with other flexibility options is uncertain would distort allocation decisions and could lead to inefficiencies in the provision of demand-oriented electricity feed-in and balancing power. In the biofuel sector, on the other hand, several applications exist where mineral oil would be difficult to substitute by anything apart from biofuels (see Sect. 4.1.3.2). To improve GHG balances and reduce the costs of such biofuels, specific safeguards for second generation biofuels seem warranted, although it would be advisable to align them with their innovative and GHG mitigation potential.

Regarding the governance of innovation efforts downstream in bioenergy value chains, German bioenergy policy once again complies quite well with NIE-based requirements. Direct interventions in technology choices which affect incentives for dynamic cost reductions centre on the utilisation sphere; from there, actors pass pressure to reduce costs down the value chain, either in order to reduce their costs of compliance with quantitative measures such as the biofuel quota or the renewable heating obligation, or to increase the difference between price-based support and actual costs, as in the case of FIT or market premium scheme. For supporting innovation downstream, mainly R&D support is used, which through its internalisation of knowledge externalities is reasonably close to the market-based allocative principle (even though in practice, the direction of technological progress can still be steered by the selection of projects for R&D funding).

For addressing interactions between market failures and multiple policy aims, dynamic incentives would become effective if pressure increased over time to take relevant side effects on other policy aims into account. In the case of environmental and agricultural policy framework conditions, there is no institutionalised tightening of requirements over time, but they are subject to revisions and renegotiations. Hence, dynamic incentives for improving environmental balances would only become effective if a further "greening" of agricultural policy or a tightening of environmental standards or their stricter enforcement were expected. In the absence of reliable dynamic incentives in general framework conditions, the effectiveness of utilisation-sided dynamic incentives for increasing the overall sustainability of bioenergy pathways becomes crucial. However, there is only one institutionalised dynamic incentive which addresses this aspect, namely GHG requirements in sustainability standards for biofuels and liquid bioenergy carriers, which increase in stringency over time. Further environmental minimum requirements remain static, whereas social sustainability requirements are so far only incorporated voluntarily (Sect. 4.4.3.3). In the heating and electricity sectors, dynamic incentives for improving sustainability balances exist primarily on a less formalised level, that is, in the knowledge that future acceptance of direct bioenergy support hinges at least in part on pathways' sustainability performance.

5.3.2.3 Assessment of Hierarchical Interventions in Location Choices and Sourcing Decisions

Utilisation-sided, national level bioenergy policy instruments are largely location-independent, although the introduction of stronger spatial elements has been discussed; proposals to link EEG support to regional maize shares are an example of this (DBFZ 2013). In general, location-independent support instruments have the advantage of creating higher planning security for investors, who can align location decisions with their dispersed knowledge, individual circumstances and the availability of adequate feedstock supply. Given that knowledge and learning spillover effects do not apply to location decisions to a significant degree, path dependencies and interactions with other market failures are left as rationales for direct interventions.

While distorting investment decisions, favouring decentralised dedicated bioenergy plants over co-combustion in fossil fuel plants can make a contribution towards overcoming path dependencies in the electricity system; employing biomass in coal power plants can deliver GHG reductions, but particularly lignite coal power plants lack in flexibility and therefore perform poorly when it comes to compatibility with an electricity system with high shares of volatile RES (Mayer et al. 2013; Götz et al. 2014). A major rationale for intervening in location choices and sourcing decisions, meanwhile, can be found in interactions with environmental externalities which are not fully addressed either in Germany or in export countries; also interventions in location and sourcing decisions may be called for to ensure that social sustainability requirements are met in bioenergy production.

Moreover, the policy aim of rural value creation can be a relevant motivation for interventions; this is, for example, likely to play a significant role in import tariffs on biofuels (cf. Sect. 4.5.4). As a distributive aim, however, rural value support could be more efficiently addressed through measures other than bioenergy support, and should not act as the priority aim of interventions (see Sect. 5.2.3.2).

The question remains as to how far interventions succeed in addressing market and policy failures regarding environmental and social sustainability. Focussing support on domestically sourced pathways reduces potential adverse impacts of large-scale imports, but does not prevent indirect land use changes; therefore, it does not constitute an effective strategy from a sustainability point of view. Likewise, import tariffs on biofuels and intermediate products which increase the costs of imports benefit domestic producers, but are not directly related to the environmental performance of the imported product and its value chain. In principle, tariff cuts could be used to negotiate improvements in land use governance with export countries (Di Lucia 2010); however, the successful implementation of such schemes depends on expectations about whether future EU demand for bioenergy offers a lasting outlet for exports. Also, competition between exporters would intensify the more countries entered in bilateral agreements, reducing the attractiveness of negotiated tariff cuts. As a result, it seems doubtful whether bilateral biofuel tariff reductions alone would be sufficient to trigger significant and lasting improvements in land use governance. Despite all the shortcomings of sustainability certification (see Sect. 4.4.3.3)—and in particular of unilaterally adopted, bioenergy-specific standards—they still seem a more accurate way of distinguishing between imports based on sustainability characteristics than either tariffs or a focus on domestic production, unless, in the latter case, ILUC effects can be reliably excluded (e.g. through production on degraded land or the use of waste and residues).

5.3.3 Recommendations

Overall, the choice of mixed hierarchical and more market-based allocative principles that can be observed in the German bioenergy concept, as reconstructed from the instruments employed, does perform quite well when evaluated against the theoretical insights discussed in Sect. 5.3.1. Unlike the neoclassical approach to policy analysis, the NIE concept sees a case for hierarchical interventions both in the choice of GHG mitigation options and on behalf of bioenergy pathways, if investments are asset specific, generate knowledge and learning externalities, or are inhibited by path dependencies. The presence of stronger investment safeguards for bioenergy applications in electricity and transport sectors than in the heating sector conforms to theoretical recommendations. Also, from an NIE viewpoint, it is favourable that hierarchical interventions in bioenergy value chains focus on the utilisation sphere rather than on interventions in downstream allocation decisions.

However, scope for improvements in the choice of allocative principles exists in several respects. In the electricity sector, direct interventions supporting flexible bioelectricity options can be justified given the interactions between GHG and security of supply externalities, asset specificity and path dependencies. In the case of biofuels, however, the combination of asset specificity and technological spillovers form a central rationale for hierarchical interventions. As a result, it would be recommendable to differentiate more strongly between biofuel pathways depending not only on their GHG balances, but also on the learning and knowledge externalities they generate. Also, biofuel policies need to be accompanied by stronger efforts on behalf of further GHG mitigation and energy efficiency measures in the transport sector, using both market-based and hierarchical allocative principles depending on the characteristics of the options in question. In general, indirect instruments such as the EU-ETS and energy taxes could, if reformed, play a stronger role in governing GHG mitigation and energy production decisions, acting as complements to direct instruments. In the case of bioenergy, market-based instruments would need to be complemented with a mechanism for differentiating between pathways, such as sustainability certification; current practices in the EU-ETS, which account for bioenergy as carbon neutral, fail to take different GHG balances into account (see Sect. 4.2.2.1).

As to dynamic incentives, both market-based and direct German bioenergy policy interventions set incentives for cost reductions, but incentives for sustainability improvements over time that go beyond moral suasion exist only in the case of GHG mitigation requirements for biofuels and other energetically used bioliquids. Determining how dynamic sustainability incentives could be implemented remains challenging and will be discussed further in Sect. 5.4.

Furthermore, with regard to the treatment of interacting market failures and potentially adverse impacts on other societal aims, there is clear scope for improvement. Quite some potential remains for non-bioenergy-specific interventions that could ameliorate market failures, mitigate adverse impacts on policy aims or even benefit the generation of synergies. This applies particularly to the institutional framework conditions for primary biomass production and land use; here, improvements could consist of an adjustment and more stringent enforcement of good professional practice and cross compliance rules in agriculture and a further greening of agricultural subsidies under the CAP. Moreover, improvements in waste and recycling regulation could increase the profitability of developing a greater share of technically available waste potential for energetic uses.

In the second-best case that interacting market failures and policy aims are taken into account through adjustments to utilisation-sided instruments, a more gradual, learning-oriented approach to direct interventions on behalf of bioenergy would be desirable; if instruments trigger a large-scale demand for certain pathways and are adjusted afterwards in consecutive trial-and-error processes, high transaction costs and policy uncertainty will result. It is to be hoped that experiences with bioenergy policy will inform future interventions on behalf of the more broadly defined bioeconomy, and inspire a more cautious approach. To implement sustainability constraints, it can be worth exploring spatially explicit elements in utilisation-sided interventions. Meanwhile, tariffs on biofuels and intermediate products as a downstream, bioenergy-specific measure are rather ineffective when it comes to differentiating between pathways according to sustainability characteristics, and tend to cater rather to the motivation of supporting domestic rural value creation. Given the hierarchy of policy aims argued for in Sect. 5.2.3, the distortionary impact of import tariffs makes their abolishment advisable. Instead, despite their many shortcomings, sustainability certification coupled to utilisation-sided interventions still seems a more promising approach to the governance of imports than an emphasis on domestic biomass production would be. Moreover, sustainability standards allow in principle for the implementation of environmental and social requirements which increase in stringency over time, thus improving dynamic sustainability incentives.

Finally, the use of various hierarchical interventions gives rise to increased coordination requirements—whereas market-based interventions which internalise various externalities in different energy sectors could make use of the price mechanism to coordinate resource allocation, the cross-sectoral coordination of hierarchical interventions increases knowledge requirements on policy makers significantly.

5.4 Elements of an NIE-Based Bioenergy Policy Concept: Instrument Choice and Design for the Case of German Bioelectricity Policy

The development of NIE-based instrument recommendations is a much more complex undertaking than the identification of first-best instruments in neoclassical theory. Focussing on GHG mitigation as the sole relevant policy aim, instrument recommendations by neoclassical economists are clear (see Sect. 3.1.4): These envision the phase-out of direct, technology-specific support instruments in the heating, transport and electricity sectors, focussing instead on the implementation of technology-neutral emissions taxes or tradable permit schemes as cost-effective, dynamically efficient and effective instrument choices for implementing a given GHG mitigation target. A first-best version of an emissions trading scheme would show considerable differences to the EU-ETS—an efficient allocation of mitigation efforts would require an extension of the scheme to all emitting sectors, including not only the electricity sector but also the heating, transport and land use sectors. Moreover, given the global character of GHG externalities, a global system would have to be established. In such a system, different bioenergy pathways would compete with a wide range of alternative abatement options on the basis of GHG mitigation costs. Downstream allocation decisions (e.g. concerning substrates, conversion methods, or location decisions), would be left to market forces; only bioenergy pathways with overall GHG mitigation costs below the equilibrium emissions allowance price would be realised.

The limits of this approach have been discussed in Sect. 3.1.5. For developing NIE-based instrument recommendations, a much closer alignment with the existing institutional context is necessary—basically, a comprehensive analysis of the bioenergy policy mix would have to consider all relevant instruments discussed in Chap. 4, developing recommendations for their further development and improved coordination, with the aim of improving overall efficiency and sustainability. Recommendations for allocative principles as developed in Sect. 5.3 provide guidance as to how interventions should be balanced within the spectrum between markets and hierarchies. However, the actual performance of policies is determined on the level of detailed instrument choice and design—a finding which is emphasised by institutional analyses of RES policies (Finon and Perez 2007; Ragwitz et al. 2007; del Río 2012; IEA 2008). The design of policy interventions determines the exact balance between, for instance, high-powered market incentives and reliable investment safeguards, autonomous and cooperative adaptation, or adaptive efficiency and cost-effectiveness of aim achievement. This makes adequate policy responses highly context dependent and transaction specific. While the inclusion of transaction costs, uncertainty, political rationality considerations, path dependencies, interacting market failures and multiple policy aims increases the realism of policy advice compared to the neoclassical approach, the ability to produce clear cut and generalizable recommendations is diminished. Instead, the NIE approach highlights the importance of trade-offs in policy design.

Given the broad range of direct and indirect instruments that play a role in German bioenergy policy, it is necessary to select a focus when discussing instrument choice and design. Chapter 4 has identified direct interventions in the utilisation sphere as the most relevant for bioenergy expansion in Germany; moreover, as discussed in Sect. 5.3, the design of utilisation-sided interventions plays an integral part in taking side effects and interactions between market failures into account. As argued in Sect. 5.3, direct instruments should be combined in a policy mix with indirect, market-based instruments which set incentives for GHG mitigation options with low asset specificity; moreover, attempts should be made to find non-bioenergy specific solutions to ameliorate further market failures which occur further down the value chain, in order to address utilisation-sided interventions' side effects on relevant societal aims. While the policy mix context has to be taken into account, a detailed discussion of adjustment needs of other instruments in the mix, such as the EU-ETS or the CAP's agricultural subsidies, is beyond the scope of this work.

Likewise, a focus is required when analysing direct support instruments more closely, because these need to be tailored to the specific characteristics of bioenergy transactions in the electricity, heating and transport sectors. In order to demonstrate the applicability of the developed analytical framework to recommendations for instrument choice and design, the analysis is undertaken exemplarily for direct bioenergy support in the electricity sector. That is, with relation to Table 4.4, only the instrumental implementation of the Renewable Energy Sources Act (EEG) is analysed, which in Sect. 4.2 has been identified as the main driver for bioelectricity use. Bioelectricity policy has been chosen as an example because here, instrument choice and design are currently undergoing major revisions, lending the topic high political relevance.

In the transport sector, the GHG-based quota takes effect from 2015, and to develop recommendations for a further development of biofuel policy, it seems sensible to take experiences from its implementation into account. Moreover, given the policy uncertainty that investors already face in the light of the ILUC debate and EU policy developments, further significant changes in instrument choice and design seem unlikely in the near future. Quota schemes have a high path dependency in general, because the profitability of existing investments depends on the ongoing existence of the scheme and central design parameters (Kopp et al. 2013: 23). Under political feasibility aspects, a complete change away from the quota therefore seems unlikely at least in the short- to mid-term, although a freezing of the quota trajectory at the 2020 level and a combination with other instruments would constitute a feasible option. Based on the arguments put forward in Sect. 5.3.2.1, these additional instruments should not be biofuel-specific, but should incentivise the uptake of alternative technologies for low carbon transport, such as electromobility, and, importantly, absolute reductions in energy use and shifts in the modal split towards climate efficient transport modes.

In the heating sector, the problem of direct instrument design is again a very different one, because here bioenergy can already be competitive with fossil fuel alternatives. Despite this, particularly the use of woody biomass in small-scale heating applications in the household sector constitutes a comparatively inefficient use of biomass resources in terms of GHG potential or energy conversion efficiency, and a further expansion would intensify resource competition with CHP and also material applications. As a result, the question in direct instrument choice and design in the heating sector is primarily how to incentivise more capital-intensive RES technologies, the use of district heating (including district heating from biomass CHP) and energy efficiency improvements. Incentives for biomass CHP will be discussed in the context of instrument design in the electricity sector; the other named aspects are also very relevant, but go beyond the scope of this work.

The following section discusses theoretical implications for bioelectricity policy instrument choice and design; these do not apply exclusively to the electricity sector, but could also be transferred to the heating and transport sectors. Findings will then be applied to an assessment of bioelectricity support in the German feed-in tariff (FIT) and market premium scheme (MPS), followed by a discussion of feasible alternatives. Lastly, recommendations are derived.

5.4.1 *Implementing Bioelectricity Policy Interventions Under Uncertainty: Theoretical Insights*[6]

Even once the decision for a direct intervention in allocation decisions has been made, the choice and design of instruments determines the exact balance

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[6] An abridged version of this section has been used in Purkus et al. (2015).

between hierarchical and more market-oriented elements. For deriving theoretical recommendations regarding this balance, transaction cost and contract economics, the theory of institutional change, and the price vs. quantity literature seem particularly fruitful; where appropriate, findings of other theoretical approaches discussed in Chap. 3 are taken into account. In the following, theoretical implications are discussed for three major elements of instrument choice and design: the choice between price, quantity and hybrid instruments, the design of a mechanism for differentiating between technologies and feedstocks, and the design of an adjustment mechanism. Each of these elements has major implications for how the allocative problems of steering biomass flows and technology choices and the setting of incentives for innovation are handled. Location choices and sourcing decisions, meanwhile, can be influenced through technology differentiation by introducing location-specific requirements, or can be left to other instruments. As argued in Sect. 5.3.3, an adjustment of non-bioenergy-specific instruments, such as a strengthening of environmental regulations in the land use sector, would be the preferable option. However, in the following it shall be assumed that in the short term, such adjustments may not prove feasible; therefore, when discussing technology differentiation mechanisms, the impacts of design choices on location and sourcing decisions need to be taken into account.

5.4.1.1 Choice Between Price and Quantity Instruments

When designing direct instruments for bioelectricity support, policy makers have to make decisions under uncertainty about the level and slope of both the aggregated marginal cost (MC) curve of bioelectricity production, including private and external costs, and the aggregated marginal benefit (MB) function, including various external benefits (see Fig. 5.1). External benefits encompass GHG mitigation benefits, but also security of supply benefits, or contributions towards an improvement in environmental quality in the primary production sphere; external costs arise primarily if GHG emissions increase in comparison to fossil fuel reference systems, for example, because of land use changes, and from other environmental externalities of primary biomass production.

As discussed in Sect. 3.1.2, Weitzman's (1974) findings emphasise the importance of cost uncertainty for the efficiency of instrument choices, whereas errors in assessing the MB curve's position result in the same social costs for both instrument types, as long as cost uncertainty and benefit uncertainty are not correlated. Under uncertainty about the MC function, quantity instruments in RES support assure that a given target is reached, but the costs of doing so remain uncertain; market actors exploit the cheapest RES options first, but then move on to successively more expensive options. Price instruments offer a higher degree of cost control; the most expensive technology employed will be the one which is just about profitable under a given price incentive. However, meetings targets will require repeated

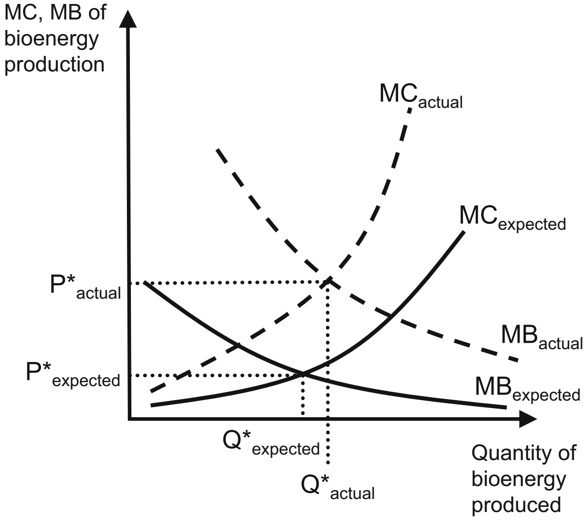

Fig. 5.1 Simultaneous uncertainty about the marginal cost and benefit curves of bioelectricity production (reproduced from Purkus et al. 2015: 67, based on Hepburn 2006: 232. *Note*: P*: optimal price; Q*: optimal quantity; MC: marginal costs; MB: marginal benefits)

adjustments of incentives, which can increase policy uncertainty for RES investors (Menanteau et al. 2003: 804).

As Weitzman (1974) showed, the advantages of adopting price or quantity instruments under uncertainty depend on the relative slopes of MC and MB curves. If the MC curve is comparatively steep, price instruments will achieve a better welfare result; whereas if the MC curve's slope is comparatively gentle, a quantity instrument would be the favoured solution. In the latter case, a price instrument could lead to large errors in target achievement: an overestimation of the MC curve would result in much higher levels of bioelectricity expansion than expected (Menanteau et al. 2003: 802f.). This would increase total support costs, and could also lead to higher-than-expected external costs, if these rise with the quantity of bioelectricity produced. If the MC curve is underestimated, bioelectricity use would be much lower than expected and RES targets might be missed. A quantity instrument that implements a given target and misjudges the position of the MC curve is associated with lower costs of errors, because of the MC curve's comparative gentleness. With a comparatively steep slope of the MC curve, however, a price instrument performs better than a quantity instrument in minimising the social costs of errors—if the MC curve is underestimated here, a quantity instrument would lead to much higher costs of target implementation than expected, whereas a price incentive that deviates from the optimum would elicit only weak responses in terms of bioelectricity produced.

However, estimating the relative slopes of the MC and MB curves of bioelectricity production is not straightforward. As for the MB curve, the presence of multiple benefits besides GHG mitigation complicates the assessment. The MC curve's slope, meanwhile, depends on whether the scale of bioelectricity expansion aimed for is significant compared to the available resources. The MC curve may be relatively flat for low levels of bioelectricity use relying on the use of low competition feedstocks, but it is likely to grow steeper for higher levels of implementation, if competition for feedstock and land increases (cf. Thrän et al. 2010; Thrän et al. 2011a). Therefore, the relative advantages of price and quantity instruments may change depending on the scale of energetic biomass use. Moreover, with bioenergy, it seems reasonable to assume a non-zero correlation between cost and benefit uncertainties, in which case benefit uncertainty affects price versus quantity recommendations (see Sect. 3.1.2; Stavins 1996). However, depending on the bioelectricity pathway in question, correlation may be negative or positive. For example, the use of lignocellulosic feedstocks grown on marginal land can provide beneficial GHG balances and environmental co-benefits, but can also increase production costs (Liu et al. 2011), whereas the use of low competition wastes likewise allows for high GHG savings, but at low costs. Given that it is not feasible to estimate relative slopes and correlation effects for all bioelectricity pathways and implement separate instruments, the problem of heterogeneous pathways needs to be addressed through selection mechanisms as part of technology differentiation.

Meanwhile, as Menanteau et al. (2003) and Finon and Perez (2007) show, dynamic efficiency considerations and investors' attitude towards price risks also influence the respective advantages of price and quantity instruments. Quantity instruments perform better in exerting pressure to reduce costs, because producers compete on a price basis; whereas price instruments allow producers a higher surplus that can be invested in R&D, thereby speeding up innovation (Menanteau et al. 2003: 808). Moreover, with a quantity instrument, risk-averse investors will require price premiums to compensate for price volatility, increasing the costs of achieving targets (Menanteau et al. 2003: 806; Finon and Perez 2007: 90). On the other hand, information asymmetries pose more of a challenge for price instruments. When attempting to set prices which correspond to certain levels of RES deployment, policy makers rely on cost information from RES producers; if these behave opportunistically, adverse selection problems can arise (see Sect. 3.5.3.1). In quantity instruments, on the other hand, prices are determined competitively.

Faced with these trade-offs between price and quantity instruments and uncertainties that extend to the relative slopes of MC and MB curves, policy makers often opt for hybrid instruments with both price and quantity elements in practice (Hepburn 2006: 230). A price ceiling in a quantity instrument limits bioelectricity expansion if it turned out to be more expensive than expected. A quantity constraint in a price instrument, on the other hand, guards against lower-than-expected production costs, which would lead to higher levels of bioelectricity use than envisioned. However, if the MB curve of bioelectricity use was steeper than expected, the quantity constraint could lead to errors on the side of caution if set too low. Whether hybrid combinations increase or decrease efficiency in the case of bioelectricity with its multiple market failures and uncertainties is discussed further below (Sects. 5.4.2.1 and 5.4.3).

5.4.1.2 Different Types of Price and Quantity Instruments

Among price and quantity instruments, different types can be distinguished, which in themselves have important implications for where exactly instruments are located on the spectrum between market- and hierarchy-based governance structures, and for policy outcomes. These implications will be discussed in more detail in Sects. 5.4.2 and 5.4.3, using as examples instrument types that have already been implemented in German bioelectricity policy or that are discussed as alternatives for its further development. Here, a broad overview of RES policy instrument types and central characteristics shall be given. In distinguishing between different types of price and quantity instruments, an important question is what variables act as parameters of action, i.e. variables which can be fixed by policy makers or market actors, and what variables are parameters of expectation, which means that they cannot be determined ex ante (Hansen 1958/2014: 69).

In general, feed-in tariffs (FIT) as price instruments are associated with the highest planning security for market actors, because policy makers guarantee fixed remuneration rates. Usually, these are combined with a purchase guarantee for renewable electricity, resulting in low price and volume risks (Mitchell et al. 2006; Klessmann et al. 2008).[7] As a result, fixed FIT schemes have proven very successful in stimulating RES deployment (Mitchell et al. 2006; Ragwitz et al. 2007; Klein et al. 2010); moreover, they tend to result in low risk premiums and lower support costs of reaching RES targets than other instrument types (Mitchell et al. 2006; Ragwitz et al. 2007; Steinhilber et al. 2011; Resch et al. 2009). However, unless combined with quantity constraints, policy makers have little control about the quantity of RES expansion and associated support costs (Menanteau et al. 2003).

Sliding or fixed feed-in premiums (FIP) represent different types of price instruments. Sliding premiums balance out the difference between administered reference prices and average market prices, whereas fixed feed-in premiums provide RES producers with a set bonus on top of the market price (Kitzing et al. 2012). With a sliding FIP, average total remuneration is still determined by policy makers, resulting in low long-term price risks for market actors. With a fixed FIP, total remuneration depends on electricity price developments, increasing price risks by a significant degree (Gawel and Purkus 2013; Klessmann et al. 2008). In both models, market actors also face higher volume risks, because feed-in will cease to be profitable when prices on the electricity spot market are lower than the difference between marginal electricity generation costs and expected feed-in premium (Gawel and Purkus 2013; Andor et al. 2010). Particularly for bioelectricity plants with positive marginal electricity generation costs this sets signals for voluntary curtailment in hours with low or even negative electricity prices. Volume risks are lower with a capacity premium as another type of price instrument—here, a fixed premium is paid on the electric capacity installed, not on the amount of electricity

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[7] Price risks arise from imperfect knowledge about price developments in the electricity market, volume risks from imperfect information about the volumes of electricity that can be sold.

produced (Andor et al. 2012). With all premium types, whether RES expansion targets are met or not remains a parameter of expectation for policy makers; the higher the influence of electricity prices on total remuneration, the higher the risks of missing or exceeding targets, because they affect the strength of incentives for RES expansion.

Turning to quantity instruments, a renewable quota in combination with a tradable green certificate scheme represents a governance structure which, compared to other RES support instruments, is relatively close to the market side of the spectrum. Here, policy makers set the quota's quantity target as their parameter of action. Prices for "green" renewable energy certificates emerge from the interaction between certificate demand and competition among RES producers, who also act as producers of green certificates. Market actors therefore face two types of price risks: those regarding electricity price developments when selling electricity in the spot market, and those concerning green certificate price developments (Finon and Perez 2007). Also, they face volume risks, given that production is not profitable if marginal costs exceed the sum of electricity prices and green certificate prices. In practice, the high risks associated with quota schemes tend to result in high risk premiums which increase the support costs per kWh of RES electricity generated and low levels of RES expansion (Finon and Perez 2007; Diekmann et al. 2012). In principle, low levels of RES investments should increase green certificate prices, and therefore investment incentives—however, to control RES expansion costs and improve political feasibility, quotas are usually combined with buy-out prices, which can result in targets being missed (Haas et al. 2011; Finon and Perez 2007).

Competitive bidding schemes, finally, represent another type of quantity instrument. Here, the action parameter for policy makers is again the quantity that is tendered; when making bids, market actors get to decide on the price they wish to ask for a given quantity of RES electricity or capacity. Electricity price risks and volume risks associated with participation in electricity markets depend on the type of remuneration that is tendered—this can in principle be a fixed FIT, or a form of feed-in or capacity premium (Fürstenwerth et al. 2014: 13f.). However, a major risk that market actors face is that of not succeeding in the competitive bidding process, when participation is associated with upfront costs. Also, there are price risks arising from the fact that remuneration may turn out to be insufficient to allow profitable operation—compared to other RES support instrument types, this risk is higher for competitive bidding schemes, because RES project developers have an incentive to understate costs to beat competitors in the bidding process (Fürstenwerth et al. 2014: 17). As a result, low project realisation rates have been a major problem of implemented competitive bidding schemes for RES (Menanteau et al. 2003; Finon and Perez 2007; del Río and Linares 2014). Similarly to quotas, this limits the accuracy with which policy makers can steer RES expansion. Moreover, if there is insufficient competition for tendered quantities, problems can arise with respect to collusion and the placement of strategically high bids (Kopp et al. 2013: 42ff.; Fürstenwerth et al. 2014: 9ff.).

5.4.1.3 Differentiation Between Technologies and Feedstocks

As discussed in Sect. 5.3.1.1, knowledge and learning spillovers and path dependencies provide a rationale for differentiating RES support by technologies. However, bioelectricity policy makers also have to deal with the question as to what degree of differentiation would be sensible *within* the bioelectricity technology group, given the heterogeneity of private cost characteristics and differences in external costs and benefits.[8]

Private costs of bioelectricity producers encompass investment costs, costs of capital and variable costs (del Río and Cerdá 2014: 365). In particular, feedstock costs as a variable cost component play an important role in determining the electricity generation costs of bioelectricity technologies. For plants using solid bioenergy carriers, feedstock costs tend to make up more than 30 % of total electricity generation costs (Thrän et al. 2011b: 49). For biogas plants, the share of feedstock costs varies strongly with installation size and the mix of feedstocks used, but shares of 40–60 % of total electricity generation costs are common (ibid.: 59). For both plant types, feedstock price developments therefore have a significant impact on profitability.

While learning curve effects tend to lower investment costs as the accumulated installed capacity increases, feedstock costs tend to rise—first, bioelectricity producers exploit low cost resources, but as installed capacity and the amount of bioelectricity generation grows, they have to move on to consecutively more expensive biomass resources. The availability of different feedstock types can be characterised by biomass supply curves (see Fig. 5.2). Exploitation of different types of wastes, residues, energy crops, wood etc. for energetic uses starts once a certain minimum price is paid for these resources. Higher prices for biomass resources unlock more expensive contingents of biomass resource potentials (e.g. residues with higher collection and preparation costs, energy crops on marginal land). As resource potentials are being depleted, the supply curve grows more inelastic and even a sharp rise in the price for biomass resources will result only in a small increase in the quantity of biomass supplied (Hoogwijk et al. 2009: 36; Newes et al. 2012: 47f.; Ruth et al. 2013: 14ff.). Concerning future bioelectricity generation cost developments, increases in feedstock costs are expected to dominate cost reductions through learning curve effects (cf. Thrän et al. 2011b: 41ff). This is because the potential of low cost resources has largely been exploited (ibid.; BMWi 2015), while the technological maturity of major bioelectricity technologies such as biogas and solid biofuel-based CHP production is comparatively advanced, so that the scope for further learning curve effects beyond incremental innovations is limited (Thrän et al. 2011b: 42ff.).

When steering technology and feedstock choices, policy makers are faced with the question of whether to differentiate remuneration levels so as to reflect different

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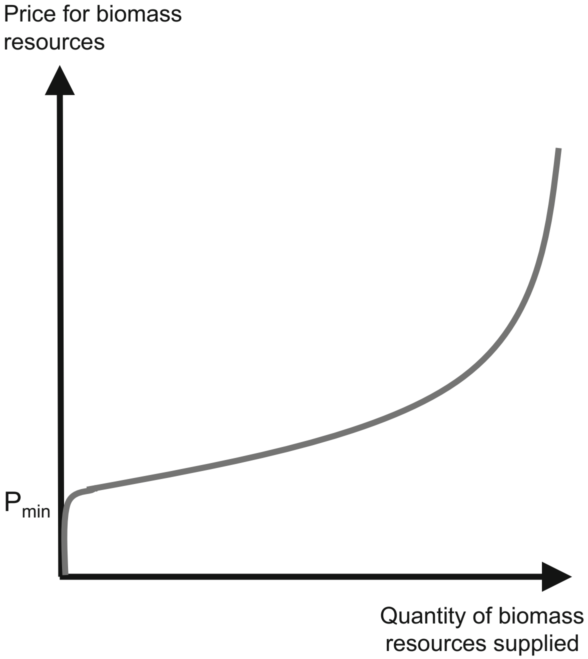
[8] For technologies at a very early stage of development, R&D support may prove more appropriate than diffusion support.

Fig. 5.2 Stylized biomass supply curve (based on Hoogwijk et al. 2009: 36; Newes et al. 2012: 47f.; Ruth et al. 2013: 14ff.)



costs of bioelectricity technologies and feedstocks, or whether to offer a uniform remuneration level (see Fig. 5.3). In the latter case, bioelectricity generation costs are minimised overall, resulting in a bioelectricity support that is cost-effective form a static perspective (cf. Jägemann 2014; Green and Yatchew 2012).[9] With a uniform remuneration level, bioelectricity investors would have strong incentives to search for technology-feedstock combinations that minimise the sum of investment costs, capital costs and variable costs, in order to maximise profits. As a result, there would be strong competition for low cost resources. Optimally, remuneration would equal the marginal costs of the last unit of electricity generation needed to fulfil quantitative targets (del Río and Cerdá 2014: 365)—these can in principle be bioenergy-specific targets with a uniform remuneration level for the bioelectricity technology group, or overall RES targets. In the latter case, the remuneration level would be set at the marginal costs of the last unit of RES electricity generation required for target fulfilment, independent of technology. In a quantity instrument such as a quota or competitive bidding scheme, the cost-effective remuneration level would be determined through competition. In a price instrument, estimation by policy makers is required. Given information asymmetries between producers and policy makers, the remuneration level would emerge from a political negotiation process and likely lie above or below the cost-effective level.

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[9] Similarly, a uniform remuneration level not only for all bioelectricity technologies but for all RES technologies minimises overall private costs of RES generation in a static perspective.

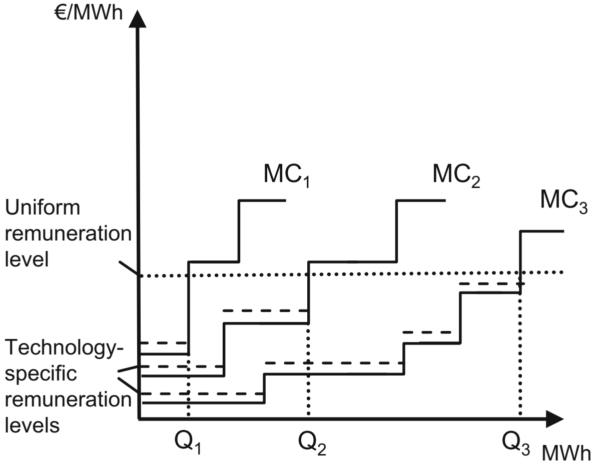

Fig. 5.3 Uniform and technology-specific remuneration levels (based on del Río and Cerdá 2014: 367. *Note*: MC_1, MC_2 and MC_3 represent marginal cost curves of different bioelectricity technologies, e.g. solid biomass-based CHP, biogas and biomethane production and combustion (MC curves are illustrative and exemplary only). Feedstock costs increase with the quantity of bioelectricity production, causing the stepped shape of MC curves. The sum of Q_1, Q_2 and Q_3 is assumed to equal the target level of total bioelectricity production Q*)

However, even if bioelectricity generation costs are minimised, a uniform remuneration level does not necessarily minimise policy support costs (del Río and Cerdá 2014). In EU member states, these are usually borne by electricity consumers and represent an important decision making variable for policy makers (ibid.: 365). With a uniform remuneration level, producers using low cost technologies and low cost feedstocks achieve high profits. Technology-specific remuneration levels based on technology costs can be used to limit these, and transfer rents from producers to electricity consumers (ibid.: 366). Here, policy makers would set cost-based remuneration levels not only separately for each RES technology, but also for different technology-feedstock combinations within the bioelectricity technology group. In a competitive bidding scheme, technology differentiation can be introduced by undertaking separate tenders for different technologies, whereas in quotas with green certificate trading, it is possible to introduce technology-specific sub-quotas or vary the amount of green certificates allocated to technology-feedstock combinations (ibid.: 367f.; Ragwitz et al. 2007: 53f. and 137ff.). In a price instrument, policy makers would optimally set remuneration levels just above marginal generation costs of different technology-feedstock combinations, to still allow sufficient profits to incentivise investments (del Río and Cerdá 2014: 366f.). The quantity of all technologies supported in this manner should add up to overall bioelectricity targets. In practice, however, problems involved with estimating marginal costs are compounded compared to a uniform price approach. In the negotiation of remuneration levels, producers are likely to achieve information rents (see Sect. 3.5.3.1). If remuneration levels for individual technology-feedstock combinations come to lie above the marginal costs of the last unit of bioelectricity generation required to meet targets, then static cost-effectiveness is not achieved.

From a dynamic perspective, of course, policy makers may wish to offer higher remuneration levels for technologies with large learning curve potentials, even if they would not be part of a cost-effective RES mix from a static perspective. This is more easily achieved with technology-specific remuneration levels (del Río and Bleda 2012; Midttun and Gautesen 2007). If a uniform remuneration level was set high enough to encourage innovative but costly technologies, profits for producers using low cost technologies would increase, and there would be few incentives to actually implement more expensive technologies with low profits. Moreover, technology- and feedstock-specific remuneration levels allow policy makers a higher degree of control over resource competition. Low remuneration levels for low cost wastes and residues would limit bioelectricity producers' ability to pay for these resources, limiting the distorting effect of bioelectricity support on resource competition with non-energetic uses, such as recycling or other material uses. On the other hand, information problems of setting remuneration levels become aggravated the greater the detail of technology differentiation, alongside an increase in transaction costs of negotiating, administering and adjusting the scheme. Also, a careful design of differentiation is required to maintain incentives for cost-effective technology and feedstock choices within remuneration classes (del Río and Cerdá 2014: 368). Identifying the right degree of technology differentiation is therefore a challenging undertaking, and requires the balancing of several trade-offs.

At the same time, bioelectricity technologies do not only differ in their private cost characteristics, but also with regard to external costs and benefits. Using a uniform remuneration level for all bioelectricity options without any further selection mechanism does not seem promising; this would incentivise the use of low-cost technology-feedstock combinations, but disregard differences in external costs and benefits. Basic options for differentiation would be:

(a) A uniform support level with minimum sustainability criteria: here, all technology-feedstock combinations would be eligible for support, as long as they prove compliance with minimum criteria regarding external costs and benefits.
(b) Reflection of external costs and benefits in technology- and feedstock-specific support levels and eligibility requirements: here, policy makers would choose which technology-feedstock combinations they want to see in the market not only according to private cost characteristics, but also according to an assessment of their external cost and benefits. Additionally, policy makers may define specific requirements that technology-feedstock combinations must meet in order to be eligible for support.

In evaluating the respective advantages of alternatives, transaction cost and contract economics can offer useful insights. In case of a uniform support level with no further differentiation beyond sustainability requirements, technology choices are made by market actors, which can use dispersed and context-dependent information in developing solutions (cf. Hayek 1945; Williamson 1999).

Independent of whether the support level is fixed centrally or determined competitively, bioelectricity investors would have a high incentive intensity to reduce production costs and costs of compliance with sustainability criteria, in order to maximise profits. However, there would be few incentives to provide external benefits exceeding minimum requirements. In case of technology-specific support levels, greater information requirements apply to policy makers, which have to decide on which support level to grant to which technologies, taking into account not only static and dynamic cost characteristics but also external benefits. As decisions apply to all eligible bioelectricity projects, costs of errors are large; on the other hand, transaction costs are likely to be lower than under sustainability certification (COM 2010: 24ff.). The more detailed prescriptions made by policy makers become, the lower is the incentive intensity for market actors to engage in search processes.

Different forms of technology differentiation have implications for the type and level of uncertainties that market actors and policy makers face, as does the choice between quantity and price instruments (see Fig. 5.4). If remuneration is determined by markets (such as in quotas or bidding schemes), and producers have to prove compliance with sustainability criteria taking into account the most recent scientific knowledge, a large share of cost- and benefit-related uncertainties is borne by market actors. If policy makers select specific bioelectricity pathways for which cost-based support is provided, and credibly assure that support for existing plants will not be affected by changes in framework conditions or advances in scientific knowledge, the brunt of uncertainties is borne by the state. While this lowers incentive intensity for bioelectricity producers to engage in decentralised search processes, planning security for investments is significantly higher; this is

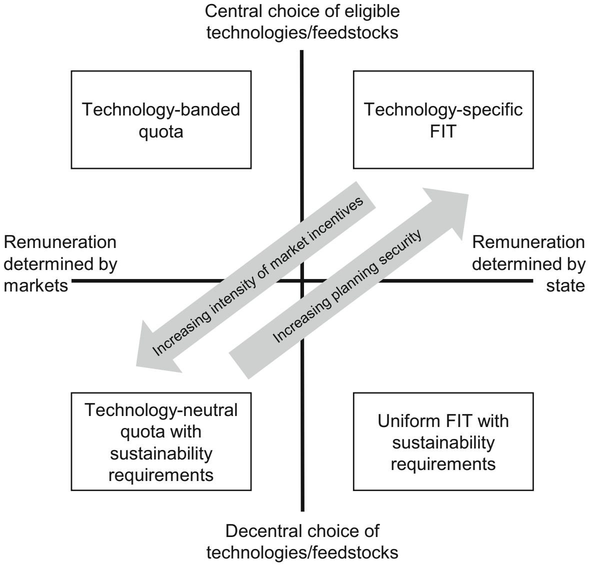

Fig. 5.4 Alternative options for differentiating between bioelectricity technologies and feedstocks (reproduced from Purkus et al. 2015: 69. *Note*: FIT and quota schemes are used as illustrative examples)

particularly important for transactions with a high degree of asset specificity, such as investments in dedicated biomass plants, whose profitability depends on the ongoing existence of policy incentives. Without sufficient investment safeguards, asset-specific investments would require high price premiums to be realised, or not be undertaken at all (Williamson 1985: 52ff.; Finon and Perez 2007: 81).

Of course, plant profitability is also determined by feedstock cost developments; even with cost-based support, associated uncertainties are borne by bioelectricity producers. However, in designing support and setting remuneration levels for new plants, policy makers can take resource availability into account, and reduce or even discontinue support for feedstocks whose energetic potentials are close to being exhausted (cf. Sect. 4.2.3.2). With a uniform support level, competition for comparatively low cost resources would increase with the expansion of installed bioelectricity capacities, leading to rising resource costs for existing plants.

Overall, it seems sensible to share uncertainties in the regulatory contract, in order to balance incentive intensity and investment safeguards. The theory of risk allocation offers insights regarding who should bear which uncertainties (Irwin et al. 1997: 8ff.; Beckers and Miksch 2002: 10f.). As discussed in Sect. 3.3.4, market actors have an advantage in dealing with static private cost uncertainties, but the state with its system perspective and democratic decision making processes is better equipped to balance multiple externalities and account for cross-sectoral interactions of policy and market incentives. Regarding the allocation of uncertainties about dynamic cost developments, external costs, GHG mitigation benefits and security of supply benefits, market actors and the state were both shown to have better control over some aspects of the issues but not over others (see Table 3.1). Sections 5.4.2 and 5.4.3 take a closer look at how these uncertainties are to be allocated in the case of German bioelectricity support.

5.4.1.4 Policy Adjustment

Policy analyses which are based on transaction costs and contract economics stress the importance of long-term commitment and credibility to enable an effective governance of transactions (see Sect. 3.5.2.5). A certain incompleteness in regulatory contracts, which allows for flexibility, is part of ensuring this credibility, making adequate adjustment mechanisms a prerequisite for robust regulations (Williamson 1985: 56ff.; Finon and Perez 2007: 88f.). Likewise, the theory of institutional change highlights the importance of being able to correct errors and to adapt to unforeseen circumstances (see Sect. 3.5.4.4). In order to meet the requirements of adaptive efficiency, adjustment mechanisms should ensure the potential reversibility of policy impacts, in order to avoid a lock-in into inefficient pathways of economic development. Adjustment mechanisms can take the form of periodical revisions of regulatory contracts, based on an assessment of policy impacts; alternatively, they can be implemented as ex ante rules, where a specified policy change takes effect when a certain condition is met (e.g. remuneration rates are reduced once a certain amount of bioelectricity capacity has been installed). Moreover, policy measures should ensure openness to experimentation; the more actors' choices and innovation opportunities are constrained, the higher the risk of incurring a lock-in (North 1990: 80ff.).

However, policy adjustments can lead to policy uncertainty, especially if they are discretionary in nature; for balancing flexibility and planning security, transparent provisions for renegotiation and adaptation and ex ante flexibility rules have been recommended (Dixit 1996: 62ff.). A related question is who should bear the costs of policy adjustments. Literature suggests that for adjustments associated with changes in political priorities, costs should be borne by the state, because otherwise policy uncertainty for investors would be too high (cf. Irwin et al. 1997: 11; Hepburn 2006: 234). For adjustments responding to new scientific knowledge, for example, regarding GHG balances, it appears important that the planning security of plants already in operation is not compromised (Hepburn 2006: 233f.). For example, research suggests that for bioelectricity supply chains based on forest residues, methane emissions during the storage of feedstocks may diminish the potential for GHG mitigation (cf. Röder et al. 2015). Emissions can be reduced through technical drying, but this requires additional investments. Policy adjustments would need to find a compromise between improving the GHG balance of existing plants and imposing additional costs on plant operators, so as not to inhibit future investments. In some situations, offering compensation for the costs of additional investments can be an option. Lastly, given that adjustments may affect the current and future allocation of property rights, political transaction costs of renegotiating regulatory contracts can be significant (Krutilla and Krause 2011: 273ff.); these too need to be taken into account when designing adjustment mechanisms.

5.4.2 Application to the Case of German Bioelectricity Policy: Assessment of the EEG's Feed-in Tariff and Market Premium Schemes

In the following, the current approach of German bioelectricity policy to controlling the social costs of errors, technology differentiation, and policy adjustment is analysed. Given the close interlinkages between adjustment problems and the choice of instrument type and technology differentiation mechanism, respectively, policy adjustment is discussed jointly with the other two categories. As part of the analysis, the revised EEG 2014s approach is compared to solutions adopted in former versions of the law, followed by a discussion whether it represents a promising approach for bioelectricity support. Moreover, open problems are identified, which form the basis for the discussion of alternatives in Sect. 5.4.3.

5.4.2.1 Prices Versus Quantities Versus Hybrids: The Social Costs of Errors in the EEG's Feed-in Tariff and Market Premium Schemes

The choice between price, quantity and hybrid instruments affects the social costs of erroneous judgements about the private costs of bioelectricity expansion, the external costs associated with it, and the external benefits arising from bioelectricity's contribution to RES targets (see Sect. 5.4.1.1). In the price-based FIT and market premium schemes alike, policy makers set reference prices, and market actors invest in bioelectricity expansion accordingly. First, the problem of setting reference prices is discussed, followed by an assessment of the "breathing cap" that has been implemented in the EEG 2014 reform (see Sect. 4.2.3.4), effectively transforming FIT and MPS into hybrid instruments.

The Problem of Setting Reference Prices

Both FIT and MPS offer a high degree of control over the private costs of the most expensive technology-feedstock combination that is still incentivised under the scheme and high planning security for market actors. Planning security is slightly higher in the FIT than the MPS, because in the latter, actual earnings for the sale of bioelectricity might deviate from the average market value which is the basis for the calculation of the market premium (see Sect. 4.2.3.3); as a result, total revenue may be either higher or lower than EEG reference prices. Also, whereas in the FIT, bioelectricity is bought independently of spot market prices, the MPS incentivises voluntary curtailment in times of low or negative electricity prices, reducing the number of annual full load hours. On the other hand, producers can earn additional income by participating in balancing markets (cf. Purkus et al. 2014: 12). Overall, the degree of planning security in profitability calculations therefore remains high.

However, policy makers have to deal with the central problem of price instruments: that there is uncertainty about the true marginal costs of producers. Rather, reference prices emerge from a political negotiation process, in which politicians interact with various stakeholder interests; this process is characterised by information asymmetries, particularly between bioelectricity producers and politicians (see Sect. 3.5.3.1), but also uncertainties, for example, relating to environmental external costs or different external benefits which interest groups can exploit. As a result, reference prices are likely to be set at a level above or below the true marginal costs, and offer no direct control of the level of bioelectricity expansion and associated social costs of errors in terms of support costs and external costs. In the case of support costs, costs of errors are borne by electricity consumers who finance the EEG's RES support via the EEG surcharge (unless privileges apply according to sections 63ff. EEG 2014).[10] For individual consumers, costs of errors are comparatively small—Neuhoff et al. (2013: 45) estimate that in 2013, the share

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[10] In 2013, bioelectricity production received a remuneration sum of 4.06 billion euros under the FIT scheme, amounting to 29.65 % of total FIT payments, and 2.10 billion euros or 35.27 % of the payments under the market premium scheme (including flexibility premium payments) (50Hertz et al. 2014). In terms of electricity produced, bioenergy was responsible for 19,551,739 MWh or

of electricity expenditures in total consumer spending amounted to 2.5 % for an average household, of which 0.5 % points are made up by the EEG surcharge.[11] While the EEG surcharge performs well in terms of risk diversification (cf. Leprich et al. 2013: 44), it has nonetheless emerged as an important variable in political discussions about the costs of RES support (e.g. BMWi 2014a). Besides support costs, the level of expansion is also an important steering variable for controlling the external costs of bioelectricity production, given the limited potential of low cost wastes and residues. With an increasing demand for energy crops, incentives for agricultural intensification and conversion of grasslands grow stronger, with associated environmental impacts and landscape externalities.

In order to adjust reference prices in the FIT or MPS to new information, policy makers have three general options, which are discussed in turn: they can undertake a comprehensive revision of the EEG, adopt amendments of a more limited scope to adjust remuneration rules for specific technologies, or implement ex ante flexibility rules, such as the "breathing cap" that was implemented in the EEG 2014 reform.

Law amendments are required to implement changes in technology differentiation, adjustments of remuneration levels and the rate at which remuneration decreases for new plants; also, as part of revisions, general changes in instrument type and design can be implemented, such as the introduction of the market premium in 2012. Comprehensive revision processes can be lengthy and are associated with considerable political transaction costs, as they involve votes in the national parliament (Bundestag) and the Federal Council (Bundesrat), which adds regional interests to the negotiation process. Moreover, the process is not only accompanied by a scientific monitoring and evaluation of alternatives but also by intensive lobbying activities (cf. Sühlsen and Hisschemöller 2014). The EEG 2014 introduced sharp cuts to the remuneration of bioelectricity, a step that was not only criticised by bioelectricity industry associations (BEE 2014; Biogasrat 2014; Fachverband Biogas 2014), but also deviated from recommendations by scientific advisors, who assessed prior cuts and changes which had been implemented in the EEG 2012 as quite effective (Scheftelowitz et al. 2014: 3; Thrän et al. 2014). It remains to be seen whether the criticism that the EEG 2014s reference prices are too low to allow for any significant expansion or even replacement of old plants, while not adequately reflecting the external benefits of bioelectricity use will lead to a reassessment of bioelectricity support in future revisions.

The fact is that in recent years the frequency of revisions, which after the EEG's introduction in 2000 were undertaken in 2004, 2009, 2012 and 2014, has increased. In between revisions, more limited amendments have been adopted, frequently to adjust remuneration for solar installations to dynamic market developments (see Clearingstelle EEG 2014 for an overview). In general, amendments affect only new

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34.96 % of the total amount of electricity remunerated under the FIT, and 16,644,366 MWh or 25.36 % of the total amount of electricity remunerated under the market premium scheme (ibid.).

[11] However, the EEG surcharge's share in consumer spending depends on income, and tends to be higher for low income households (Bardt and Niehues 2013: 215; Neuhoff et al. 2013: 46 f.)

plants, to guarantee a high level of planning security for investors; these rely on the political assurance that their installation will receive remuneration according to the version of the EEG under which it went into operation for a period of 20 years (see Sect. 4.2.3). Changes applying to existing plants would counteract the protection of investments, with lasting impacts on political credibility. At the same time, reversibility of policy decisions is low. Nonetheless, in specific instances, amendments have implemented changes which also applied to existing plants. This was the case with the "PV Novelle 2012", adopted on 17 August 2012, which through several measures reduced remuneration for solar installations and entered into force retroactively several months before its official adoption; the management premium ordinance (MaPrV, adopted on 2 November 2012), which decreased management premium rates for plants in the market premium scheme from 2013; and the EEG 2014s decision to charge the use of self-produced electricity with a fraction of the EEG surcharge (section 61 EEG 2014). The political transaction costs and impacts on political credibility of these adjustments differ greatly: In the case of the MaPrV, for instance, there was clear evidence for an overcompensation of additional direct marketing costs in the EEG 2012 (cf. Rostankowski et al. 2012), and the act was passed with little political resistance. The introduction of EEG surcharge payments for the consumption of self-produced electricity, on the other hand, has sparked a contentious political debate, and may even be brought before the German constitutional law court (Brahms and Maslaton 2014).

From Price to Hybrid Instrument: Impacts of the Breathing Cap

Compared to revisions and amendments, ex ante flexibility rules provide a low transaction cost option of adjusting policy instruments. The EEG's dynamic decrease of remuneration rates has been implemented to reflect cost reductions achieved through technological progress and learning effects; however, as with reference prices, adequate degression rates need to be estimated and negotiated, and can be either too high, slowing down RES expansion, or too low, resulting in windfall profits for investors. To address this and increase control over expansion levels and support costs, the EEG 2014 introduced a breathing cap for bioelectricity and other RES.[12] As a quantity constraint on the gross growth of installed bioelectricity capacity, the cap guards against the case that bioelectricity production costs may be lower than expected, leading to higher levels of bioelectricity use than deemed desirable. Once the cap is exceeded, the accelerated decrease of remuneration rates kicks in, allowing for a further expansion of bioelectricity capacity until reference prices equal actual marginal costs; at this point, further expansion would no longer be profitable (see Fig. 5.5). Besides support costs, this quantity constraint offers a certain degree of control over external costs, if these increase with the extent of bioelectricity expansion.

However, setting an adequate level for the breathing cap and adequate rules for the accelerated decrease of remuneration can be challenging—on the one hand, the

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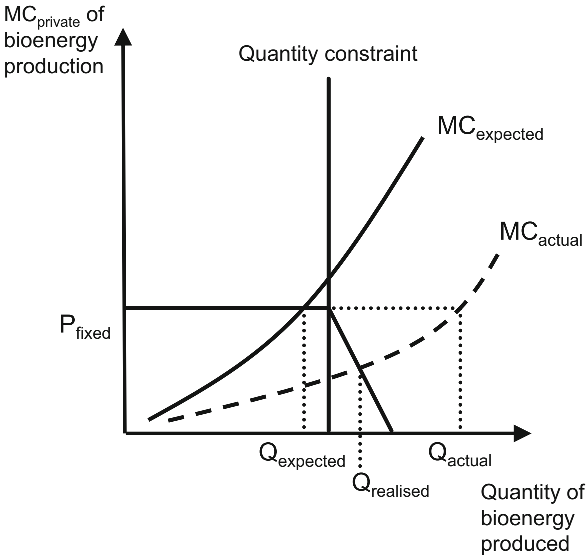
[12] For PV, a breathing cap had already been implemented in the "PV Novelle 2012".

Fig. 5.5 Effects of the "breathing cap" in FIT and market premium scheme under cost uncertainty (reproduced from Purkus et al. 2015: 72, based on Menanteau et al. 2003)



cap needs to be stringent enough to be effective, but if set too low, the quantity constraint could lead to errors on the side of caution, especially if the MB curve of bioelectricity use was steeper than expected. In the case of the EEG 2014, it is likely that the constraint is set too low to allow for an effective steering of dynamic developments (Thrän et al. 2014). Moreover, frequent adjustments of degression rates impose high uncertainty on investors about the level of remuneration they will actually receive when plants become operational; this is the case for the EEG 2014, where from 2016 reference prices decrease every 3 month (section 28 (2 and 3) EEG 2014). In terms of planning security, the quantity constraint can therefore partially negate the advantages of a price-based over a quantity instrument. Lastly, a quantity constraint on the national level does not provide an accurate steering mechanism for external costs, if they depend on the spatial context—in particular, it does not prevent the formation of regional "hot spots" (cf. Scheftelowitz et al. 2014: 2).

In sum, the FIT and MPS' strengths lie in the high level of control over private costs, and the high planning security offered by the schemes' cost-oriented support in combination with a low reversibility of policy decisions for existing plants. This not only forms the basis for the instruments' effectiveness in incentivising RES investments, it also results in low risk premiums (cf. Sect. 5.4.1.1). However, the question of what level of bioelectricity production costs can be considered adequate in the context of energy transition aims is one of political negotiation, and politically determined reference prices offer only limited control of the expansion level and associated total support costs and external costs. This problem can be partially remediated by introducing a breathing cap as a hybrid element, but setting caps which balance an effective steering of bioelectricity expansion with planning security for project developers remains challenging. Like errors in setting reference prices, errors in setting caps require transaction-cost intensive revision processes, where the very non-reversibility of policy decisions for existing plants results in low adaptive efficiency.

5.4.2.2 Technology Differentiation: Allocation of Uncertainty, Incentive Intensity and Planning Security in the EEG's Feed-in Tariff and Market Premium Schemes

In the EEG's support of bioelectricity, four dimensions of technology differentiation can be identified: namely, there is a differentiation according to installation sizes, conversion technologies and feedstocks, GHG balances and other environmental impacts, and security of supply benefits. In the following, the various mechanisms employed to differentiate between bioelectricity technologies are discussed in turn, followed by a discussion of the implications for the allocation of uncertainties and the balance between incentive intensity and planning security.

Differentiation According to Installation Sizes

The differentiation according to installation sizes reflects the trade-off between policy makers' aim of promoting participation by diverse actors in the energy transition, and cost-effectiveness (see Tables 4.5 and 4.6 in Sect. 4.2.3). Also, the aim of promoting rural value creation plays a role. Nonetheless, while larger installations can benefit from economies of scale, promoting a market structure with numerous small-scale installations can also have advantages from a dynamic perspective; this is because deploying many different units with different design choices and adjustments to specific feedstocks and operation modes allows for a greater scope for experimentation, and an acceleration of technological learning (Grubler et al. 2012: 1707f.). Meanwhile, given that large plants with high biomass demand exert a strong influence on local and regional biomass flows, smaller plants may also have benefits when it comes to limiting the EEG's distortionary impacts on competition for biomass resources. Also, particularly in the case of biogas plants, minimising transport distances for feedstocks is of concern for the overall energetic and environmental performance where feedstocks with a low energy yield such as slurry are concerned (Bacenetti et al. 2013). These arguments may support a certain differentiation of remuneration according to installation sizes, but a balance needs to be found to efficiency concerns.

Since the EEG 2009, the differentiation of basic tariff rates follows four steps.[13] In the EEG 2014, tariffs for biogas and solid biomass plants range from 13.66 €ct/kWh for plants $\leq$150 kW$_{el}$ rated average annual capacity to 5.85 €ct/kWh for plants $\leq$20 MW$_{el}$ (see Table 4.6). In the EEG 2012, basic tariffs were slightly higher (14.3 €ct/kWh for plants $\leq$150 kw$_{el}$ and 6 €ct/kWh for plants $\leq$20 MW$_{el}$, see Table 4.5).

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[13] For the EEG 2009 and EEG 2012, these are: $\leq$150 kW$_{el}$, $\leq$500 kW$_{el}$, $\leq$5 MW$_{el}$, $\leq$20 MW$_{el}$ of rated average annual capacity. In the EEG 2014, the demarcation was changed to $\leq$150 kW$_{el}$, $\leq$750 kW$_{el}$, $\leq$5 MW$_{el}$, $\leq$20 MW$_{el}$ (see Tables 4.5 and 4.6).

However, substrate tariff classes introduced an additional degree of differentiation; for example, for a plant using feedstocks falling under substrate tariff class I (e.g. maize or cereal grains), the remuneration span widens to 20.3 €ct/KWh for plants $\leq$150 kW_{el} to 6 €ct/kWh for plants $\leq$20 MW_{el}. Under the EEG 2009, various bonuses were also differentiated by installation size (Thrän et al. 2011b: 10f.). In past reform processes, high remuneration levels for small-scale, energy crop-based biogas plants with high GHG mitigation costs and low competitiveness to other RES technologies proved a particular point of contention (WBA 2007: 198f.; WBA 2011: 8f.). The EEG 2014 still favours small-scale plants, but with the abolishment of bonuses and substrate tariff classes only concepts based on low cost resources will remain competitive. At the same time, the limited remaining availability of these resource types implies that also more cost-effective mid-scale bioelectricity plants are unlikely to be realised under the new support conditions (Thrän and Nelles 2014; BMWi 2015).[14] Compared to the EEG 2014s overall cut in remuneration levels, reducing the remuneration structure's emphasis on small-scale plants and promoting the use of economies of scale appears as a preferential option for increasing cost-effectiveness of support while still enabling the realisation of mid-scale new plants and ongoing incremental innovations.

Differentiation According to Conversion Technologies and Feedstocks

In its approach, the EEG follows a cost-based technology differentiation (see Sect. 5.4.1.3)—remuneration levels are set so that bioelectricity producers can recover investment costs, capital costs and feedstock costs and achieve a profit high enough to incentivise investments (Thrän et al. 2011b: 90ff.). While the same logic applies to the support of other RES in the electricity sector, the importance of feedstock costs in bioelectricity generation costs poses specific challenges for bioelectricity support design. By supporting RES diffusion, the EEG seeks to reduce costs of RES electricity generation over time. Producers have an incentive to reduce costs to maximise profits; new plants can benefit from learning curve effects, and cost reductions are passed on to consumers through the annual degression of remuneration levels and EEG revision processes. In the case of bioelectricity technologies, however, feedstock costs follow biomass supply curves, i.e. they increase with demand (see Fig. 5.2). As the energetic use of biomass resources expands, cost reductions through innovation therefore become compensated by increasing feedstock costs (Thrän et al. 2011b: 41ff.).

With its substrate tariff classes, the EEG 2012 was explicitly designed to take the growing dominance of feedstock costs over learning curve effects into account (Thrän et al. 2011b: 90ff.; Scheftelowitz et al. 2014: 127f.). Here, basic tariffs are offered independent of the technology used; these are combined with remuneration according to substrate tariff class I if feedstocks with significant costs are used (such as maize and other energy crops, cf. Annex 2 BiomasseV 2012). An even higher

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[14] In particular, this applies to plants between 150 kW_{el} and 5 MW_{el}. Plants above 5 MW_{el} were not able to benefit from the EEG 2012s substrate tariff classes I and II or the biogas processing bonus, so that the EEG 2014 resulted only in a small reduction in remuneration (cf. Tables 4.5 and 4.6).

remuneration is available for feedstocks where comparatively high costs combine with environmental co-benefits or low degrees of resource competition (Thrän et al. 2011b: 92). Examples are waste and residues whose potentials have not been explored yet due to high collection and processing costs, like straw or material from landscape maintenance, or perennial energy crops and SRC with co-benefits for agricultural biodiversity but high capital requirements (Annex 3 BiomasseV 2012). Also, separate cost-based remuneration categories apply to bio-degradable waste fermentation and small slurry installations. When it comes to electricity generation costs, the latter are particularly costly, but they provide the added benefit of preventing methane emissions from slurry (WBA 2011: 9).

The EEG 2012s split between technology-independent basic remuneration and feedstock-specific remuneration represents a move away from the approach followed in EEG 2004 and EEG 2009, where specific innovative conversion technologies were supported through bonuses (section 8 (4) EEG 2004; section 27 (4) No. 1 and Annex I EEG 2009). Also, instead of offering cost-based support for a range of feedstocks, EEGs 2004 and 2009 offered bonuses for the use of plants or plant components from agriculture, forestry or landscape maintenance ("NawaRo-Bonus", i.e. renewable resource bonus) and slurry (section 8 (2) EEG 2004; section 27 (4) No. 2 EEG 2009). The EEG 2012, meanwhile, retained only the bonus for upgrading biogas to natural gas quality (section 27c and Annex I EEG 2012). While bonuses can be used to incentivise deployment of a range of different bioelectricity technologies and speed up associated technological progress, they represent a rather hierarchical approach to steering technology choices, with associated shortcoming. Bioelectricity investors optimise plants according to the bonuses offered, rather than choosing the most cost-effective solutions. However, it is uncertain whether the incentivised innovative technologies will live up to expectations, and costs of errors are high; if the bonus exceeds the costs of implementing the process in question, plant operators have an incentive to do so, and in general continue to receive the bonus for their 20 years of guaranteed remuneration. Not only does this result in a low reversibility of policy decisions, but also plant investors and operators have little incentive to engage in search processes for alternative solutions. An adjustment of central steering impulses, meanwhile, requires an amendment of the EEG.

Compared to its predecessors, the EEG 2012 equips producers with higher incentives to search for cost-effective solutions when making technology and feedstock choices. Producers can combine feedstocks from different substrate classes and change their feedstock mix depending on price developments, although technical constraints apply for existing plants. If prices for wastes and residues in substrate tariff class 0 become too high to allow for profitable bioelectricity production, producers can move on to more costly feedstocks in substrate tariff classes I and II; however, within these classes, they have incentives to minimise costs. This includes technological innovations which facilitate the use of hitherto little used resource potentials, for example, innovative conversion processes for lignocellulosic residues (e.g. Friedrich and Wufka 2012). On the one hand, the option of receiving cost-based support for resources with comparatively high costs allows bioelectricity generation to expand even as feedstock prices increase; on the other hand, it limits competition for resources in the lower cost segment, which is important for the ongoing profitability of existing plants (Thrän et al. 2011b: 93; Scheftelowitz et al. 2014: 127f.).[15] However, this form of technology differentiation requires a close monitoring of feedstock cost developments as well as of the range of relevant feedstocks, and regular adjustments to new developments. Given the interplay between feedstock cost developments and learning curve effects, "automatic" adjustments like the annual degression of remuneration rates for new plants may not reflect cost developments appropriately. However, giving up on degression rules would reduce incentives for cost reductions over time, and prevent potential savings from being passed on to the consumers who finance the EEG surcharge. An alternative option for an "automatic" adjustment would be tying substrate tariffs to feedstock price indexes; however, this would amplify resource competition, particularly since new plants might be equipped with a higher ability to pay for resources than existing ones (Thrän et al. 2011b: 92). Also, incentives for searching for less costly feedstock would be lost, making this option not a promising one. At the same time, if adjustments are not automated but require changes to the law this will be associated with costly negotiation and decision making processes.

The EEG 2014, meanwhile, has abolished not only the remaining biogas processing bonus, but also substrate tariff classes. Besides separate remuneration categories for bio-degradable waste fermentation and small slurry plants, only slightly reduced basic tariffs remain (see Table 4.6). As such, it does not represent a system change from the cost-based support of earlier EEGs—rather, it expresses policy makers' decision that only low cost resources (i.e. those formerly allocated to substrate tariff class 0) should be used in bioelectricity production (BMWi 2014a: 11f.; EEG Gesetzentwurf der Bundesregierung 2014: 213f.). Effectively, technology-feedstock combinations with higher electricity generation costs are removed from the portfolio of RES technologies whose expansion is deemed necessary for meeting RES targets. While consistent with cost-effectiveness considerations, this neglects the insight that further bioelectricity expansion goes hand in hand with increasing feedstock costs (cf. Sect. 5.4.1.3). Indeed, the remaining available potential for low cost resources that would allow profitable plant concepts under the EEG 2014 are estimated to be insignificant (Thrän et al. 2014; BMWi 2015). As discussed in Sect. 5.3.1.2, however, bioelectricity could play an important part in facilitating the transition to an electricity system with high shares of intermittent RES, by virtue of being a dispatchable RES technology. But so far, price premiums for flexible feed-in in spot markets are low, whereas income from balancing markets is volatile (BMWi 2014b; Arnold et al. 2015). In order not to cut short further technological developments through incremental innovations, the "option value" of bioelectricity in a future, RES-based electricity system can

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[15] Competition is further limited through the exclusion of certain feedstocks such as scrap wood from remuneration (cf. 4.2.3.2).

therefore justify continued support for bioelectricity technologies even if electricity generation costs are above those of intermittent RES of comparable technological maturity.

Differentiation According to GHG Benefits and Environmental Impacts
The EEG employs two major mechanisms to steer GHG benefits and other environmental impacts. Firstly, cost-based remuneration is offered for technology-feedstock combinations which are comparatively costly, but have favourable environmental characteristics. Examples are separate cost-based remuneration categories for bio-degradable waste fermentation and small slurry installations, but also the EEG 2012s substrate tariff class II (see Sect. 4.2.3.2). Earlier versions of the EEG used bonuses to improve environmental balances—for example, the EEG 2009s formaldehyde bonus, which incentivised the meeting of certain emission standards (section 27 (5) EEG 2009), or the slurry bonus in EEG 2004 and 2009. Secondly, requirements can be implemented as prerequisites for funding.[16] The latter approach has been adopted by the EEG 2012 in particular. Here, a 60 % cap on the share of maize and cereal grain kernels in biogas installations' substrate mix was included to support crop diversification. Moreover, to improve GHG balances, at least 60 % of the annual electricity production in bioelectricity installations had to be from combined heat and power generation; alternatively, biogas plants could opt to meet a 60 % minimum slurry share instead (Thrän et al. 2011b: 91, 93f.).[17] However, these requirements did not apply to plants participating in direct marketing, and in the EEG 2014 with its obligatory marketing for all but small-scale plants, they were abolished altogether alongside the maize and cereal grain cap (see Sects. 4.2.3.3 and 4.2.3.4). Another prerequisite aimed at improving GHG balances of biogas plants is a technical requirement included in both EEG 2012 (section 6 (4) EEG 2012) and EEG 2014 (section 9 (5) EEG 2014), that digestate storage facilities must be gas proof, and biogas installations must use an additional gas utilisation device to prevent the escape of gas.

As with innovation incentives, up to the EEG 2012 a hierarchical approach was adopted to steer the provision of GHG benefits and environmental impacts. In terms of dynamic incentives for improvements and adaptive efficiency, this approach shares the problems of "innovative technology bonuses": beyond meeting the specified requirements, producers have little incentive to improve the environmental performance of their plants once operational, and errors in the design of requirements affect a large number of plants. The low reversibility of policy decisions is best exemplified by the bonus for the use of energy crops introduced in the EEG 2004 (see Sect. 4.2.3.1), which triggered the shift of bioelectricity production towards high yield energy crops which has been criticised since

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[16] Moreover, bioliquids have to adhere to sustainability requirements according to the biomass electricity sustainability ordinance (BioSt-NachV); however, since plants using bioliquids have been excluded from funding since the EEG 2012, this differentiation mechanism is neglected here.

[17] In earlier versions of the EEG, cogeneration with associated GHG benefits was incentivised with a CHP bonus (section 27 (4) No. 3 EEG 2009; section 8 (3) EEG 2004).

(e.g. WBA 2011; Delzeit et al. 2011). Once again, incentives for crop diversification that are based on learning and new scientific knowledge only apply to new plants and extensions. With the substrate tariff classes, trade-offs between cost-effectiveness and the aim of incentivising the use of low competition feedstocks with improved environmental balances arise; also, the allocation of feedstocks to tariff classes requires periodic reviews. The EEG 2014, meanwhile, abandons incentives for higher cost-resources alongside with requirements for minimum heat or slurry use.[18] This is based on the assumption that under reduced reference prices, only the use of wastes and residues with beneficial GHG balances and low environmental costs will be profitable (EEG Gesetzentwurf der Bundesregierung 2014: 213f.). However, it is uncertain whether this will be so, given that many low-cost wastes and residue potentials are already in use (Thrän et al. 2014).

Meanwhile, section 64b EEG 2012 and section 90 EEG 2014 authorise the environmental, economic and agricultural ministries to jointly issue an ordinance on the introduction of sustainability criteria for solid and gaseous bioenergy carriers, if such a step is deemed necessary to safeguard sustainability or comply with EU requirements. These could, in principle, also be applied to existing plants, although it is not clear yet if and when requirements would be introduced and what exactly they would encompass. Whether sustainability certification or hierarchically set requirements or cost-based support for environmentally beneficial but high-cost feedstocks seem more advantageous in differentiating between bioelectricity pathways according to environmental costs and benefits is discussed in Sect. 5.4.3.3.

Differentiation According to Security of Supply Benefits

The introduction of the market premium scheme and flexibility premium in the EEG 2012 has established an additional differentiation between bioelectricity pathways according to production behaviour and the form of marketing. In the FIT, remuneration is independent from electricity price signals, thus incentivising a base load production profile and a maximisation of annual full load hours. The market premium scheme, on the other hand, aims to offer incentives for a stronger demand-orientation of bioelectricity production, in order to increase associated security of supply benefits.

Unlike in the FIT, producers' overall revenue in the MPS is dependent on feed-in behaviour, even though exposure to price risks remains low (see Sect. 4.2.3.3). Plant operators have effective incentives to curtail production during hours with low or negative electricity prices, as soon as prices fall below the difference between marginal costs and expected market premium payments (Gawel and Purkus 2013: 603f.; Klobasa et al. 2013: 7f.). In principle, the MPS also sets incentives for positive load shifts, because producers who expand production when electricity prices are high can maximise the difference between revenues

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[18] Technical requirements for the minimisation of emissions leakage are retained, but these could in principle also be implemented as a requirement for the approval of installations according to emissions law (i.e. the BImSchG).

and operating costs; markedly, if they achieve direct marketing revenues which are above the average market value used for calculating the market premium, they can earn more than the reference prices specified in the EEG. Currently, however, these incentives are not very effective, because peak-off-peak spreads on the spot market are too low to offset the revenues foregone by running on less than full capacity (cf. Rohrig et al. 2011: 17f.). While the capacity-oriented flexibility premium is only available for biogas plants, additional income opportunities in balancing markets offer further incentives for flexible plant concepts both for directly marketed biogas and solid biomass plants (Purkus et al. 2014: 12). Currently, mainly the provision of negative rather than positive balancing power is profitable (Krautz 2013; Holzhammer and Stelzer 2014).

Compared to the FIT scheme, the MPS increases incentive intensity to individually optimise plant concepts according to plants' specific flexibilisation potentials and heat use opportunities; in doing so, plant operators can take advantage of specialised skills and knowledge of direct marketing intermediaries (cf. Wassermann et al. 2012). The EEG 2014 has made direct marketing obligatory for all new plants with the exception of small-scale installations. However, the MPS also offers incentives for existing plants to increase the provision of security of supply benefits and improve marketing efficiency, by offering higher income opportunities than under the FIT. Besides balancing market revenues, the management premium also contributes to direct marketing business models (Purkus et al. 2014: 12).

Given that under the MPS, marketing is organised in a decentralised fashion and requirements such as minimum heat or slurry use are waived, the instrument's approach is somewhat more market-based than the feed-in tariff's. However, by limiting the annual amount of electricity from biogas plants which is entitled to FIT or premium payments to a power rating of 50 % of the installed electric capacity (section 47 (1) EEG 2014), a new element is introduced which reduces the flexibility of marketing concepts; in effect, the rule favours flexible plant concepts with positive load shifts. However, in combination with the cut in reference prices, the rule decreases the profitability of new biogas plants even further. Moreover, given that GHG mitigation was identified as the most sensible choice for a priority aim in bioenergy policy, the shift away from CHP incentives and requirements is not advantageous.

5.4.2.3 Implications of Changes Implemented in the EEG 2012 and 2014

With subsequent versions of the EEG, bioelectricity support has developed to show a stronger emphasis on cost-effectiveness considerations, accompanied by a reduction of hierarchical steering elements. With the bonus structure of the EEG 2004 and EEG 2009, policy makers enacted a strong influence on technology and feedstock choices—this has not proven to be a promising approach, given that the risk of steering errors and costly lock-ins is high. Also, the possibility of combining different bonuses increases the complexity of remuneration and results in remuneration levels that can lie well above actual marginal costs of producers (cf. Thrän et al. 2011b: 90ff.; Scheftelowitz et al. 2014: 80). At the same time, this reduces control over the expansion of capacities, as exemplified by the stark increase in energy crop-based biogas plants between 2004 and 2011 (cf. Fig. 4.6).

In the EEG 2012, the independence of basic tariff rates from technologies reflects the technological maturity of major bioelectricity technologies. Alongside the abolishment of the bonus structure, attainable remuneration levels were decreased, and control over expansion levels enhanced.[19] The differentiation according to installation sizes and substrates is still associated with high information requirements for policy makers and necessitates regular adjustments, but within remuneration classes, producers have incentives for cost-effective technology and feedstock choices. Substrate tariff classes purposefully set incentives for exploring resource potentials with higher costs, following the development of biomass supply costs. By classifying feedstocks into different remuneration categories, policy makers direct producers' search processes. In this way, they take on uncertainties about the future cost-competitiveness of bioelectricity pathways compared to other low carbon options for balancing fluctuations of intermittent RES, and environmental impacts of supported feedstocks. Producers bear uncertainties about feedstock cost developments, but these are limited by policy makers' attempt to align substrate tariff classes and eligible resource types for new plants with biomass supply curves and the degree of competition for feedstocks.

Meanwhile, the EEG 2012s introduction of the optional MPS sets incentives for providing security of supply benefits through plant flexibilisation. This is achieved by offering additional income opportunities; price uncertainties remain with the state. Also, policy makers bear uncertainties about whether eligibility requirements directed at improving the environmental balance of bioelectricity production will have the intended effects. Adjustability of requirements and reference prices to new information is low, due to the EEG's guarantee that remuneration will continue according to the version of the law a plant became operational under even if the assessment of technologies or feedstocks changes. Overall, the fact that a large share of relevant uncertainties is borne by policy makers has resulted in a high degree of planning security, and has proven very successful in incentivising asset specific investments in past years. On the downside, information requirements for policy makers are high, leading to frequent adjustments of reference prices and eligibility requirements. While this does not impact planning security of existing

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[19] In 2012, 300 new biogas plants became operational, compared to 1300 in 2011 (Scheftelowitz et al. 2014: 18). Assuming a continuation of the EEG 2012s conditions, new biomass plants (incl. biogas, biomethane and solid biomass plants) were expected to account for an annual increase of about 90–150 MW_{el} in installed capacity from 2014 onwards (ibid.: 47). However, in 2012 and 2013 a significant additional increase in installed capacity originated with an extension of existing plants, which could benefit from older versions of the EEG; this has reduced the effectiveness of the EEG 2012s steering of bioenergy expansion, but can be addressed through a more precise definition of the terms plant and start-up date (Scheftelowitz et al. 2014: 122 ff.).

plants, it can increase policy uncertainty for future investors and technology developers.

In comparison, the EEG 2014 increases the share of uncertainties borne by bioelectricity investors. By making direct marketing obligatory, the option to fall back into the FIT scheme is removed.[20] Overall price uncertainty remains low, because the market premium is adjusted to average monthly market values, but producers have no longer the option of changing back into the FIT scheme in months where a high occurrence of hours with negative electricity prices is expected, when production would be voluntarily curtailed.[21] For biogas plants, limiting remuneration to the annual electricity production corresponding to a power rating of 50 % of the installed electric capacity increases the importance of achieving high prices for electricity and heat sales for plant profitability. Also, the breathing caps' accelerated degression of reference prices increases uncertainty for investors. In principle, these measures increase the incentive intensity to minimise investment and feedstock costs and develop marketing concepts which maximise the value of electricity and heat production. At the same time, however, the abolishment of substrate tariff classes means that investors would rely on low cost feedstocks whose potential is already largely exploited. As a result, plants can achieve profitability only under extremely favourable conditions, significantly increasing investment risks. This implies that the EEG 2014s measures will most likely not result in a more cost-effective bioelectricity expansion, but a stop of expansion.

As far as environmental benefits are concerned, the focus on low cost waste and residues avoids negative impacts associated with agricultural energy crop production, but chances of environmental co-benefits of more costly feedstocks are also foregone, as well as GHG mitigation contributions of new plants if expansion comes to a halt. Moreover, innovative activities with regard to the exploration of little used resource potential are cut short (cf. Thrän and Nelles 2014). It remains to be seen whether, in a future electricity system, the dispatchable character of bioelectricity technologies will justify the associated costs when competing with alternative (but to date also costly) flexibility options such as storage systems. However, past experience with stop-and-go patterns of RES support shows that, once interrupted, continuing the development cycle of technologies at a later date will increase overall costs, because knowledge and infrastructures for research, manufacturing and learning-by-doing are lost (Grubler et al. 2012: 1683f. and 1687).

Consequently, the EEG 2014s approach cannot be assessed as promising when it comes to finding a balance between incentive intensity and planning security, while effectively promoting GHG and security of supply benefits and avoiding adverse environmental impacts. In case of the EEG 2012, high information requirements for policy makers and the low adaptive efficiency of policy decisions remain

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[20] A temporary fall back remains possible, e.g. if direct marketing intermediaries exit the market; but in this case, reference prices are reduced by 20 % (section 38 EEG 2014).

[21] The flexibility premium, however, is dependent on participation in the MPS, so the option of monthly changes between schemes is primarily attractive for plants that do not receive it.

problematic. Also, designing an instrument that sets incentives for cost reductions over time but also reflects the rising cost trend of feedstocks remains challenging. Moreover, further developments of bioelectricity support face the question of how to differentiate effectively according to GHG and other environmental benefits, and set incentives for environmental improvements over time. Likewise, effective incentives are required for the provision of security of supply benefits, both for new and existing plants. The next section analyses the performance of alternative instrumental options for meeting these challenges.

5.4.3 Application to the Case of German Bioelectricity Policy: Comparative Assessment of Instrumental Alternatives

In this section, an assessment is undertaken of whether relevant alternatives can be expected to perform better in terms of efficiency, effectiveness and sustainability when compared to the status quo (see Sect. 5.4.2); this approach builds on the central insight of transaction cost economics, that in the presence of uncertainty and transaction costs a comparison of flawed alternatives is more appropriate than attempts to identify a supposedly optimal solution (see Sect. 3.7.5.1). Recommendations are derived in Sect. 5.4.4.

5.4.3.1 Selection of Feasible Alternatives: Taking Stock

Even after the EEG reform in 2014, discussions about the future instrumental implementation of RES support in the electricity sector are anything but settled. The EEG 2014 encompasses a decision to transition to competitive bidding schemes and a competitive determination of remuneration levels from 2017 at the latest (section 2 (5) EEG 2014), but details of the design and scope of such a scheme are still being discussed. The debate continues not only concerning design elements of the bidding process itself, but also regarding the form of remuneration that will be tendered (e.g. Kopp et al. 2013; Fürstenwerth et al. 2014; Öko-Institut 2014). In principle, project developers could make bids concerning the reference prices in a sliding market premium scheme, the level of a fixed feed-in premium per kWh, or the level of a fixed capacity premium per kW.[22]

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[22] Yet another option would be a feed-in premium which would be paid, not for a certain period, but for a fixed contingent of electricity produced (SRU 2013: 94 ff.). In this case, producers would have to recover costs in a smaller number of full load hours than is the case with a feed-in premium without a contingent, and would therefore require a higher premium; if the size of the contingent is sufficiently limited, this option is structurally similar to a capacity premium (Kopp et al. 2013: 29; Bode 2014: 155; EEX and EPEX Spot 2014: 6). Therefore, it is not discussed separately in the following sections.

From 2015, a pilot scheme will be implemented for ground-mounted solar installations (section 55 EEG 2014): Here, participants will bid for the sliding premium's reference prices in a "pay-as-bid" auction, where successful bidders receive remuneration according to the prices they have offered; in later rounds, a "uniform pricing" approach will be adopted, where all successful bidders will receive remuneration according to the highest bid which is still accepted (BMWi 2014c: 31). The purpose of the pilot scheme is to test different auction designs and generate learning effects both on the side of market and state actors; however, it is understood that market conditions in other segments of the RES market may differ considerably from ground-mounted PV, so that the transferability of the experience gained is limited (BMWi 2014d: 2; Fürstenwerth et al. 2014: 29). For that reason, it has been proposed that auction designs may have to differ between RES technologies (Leprich et al. 2013: 1f.; Fürstenwerth et al. 2014: 5).

Potentially, it may also turn out that a competitive bidding scheme is not an appropriate instrument for all RES technologies (ibid.). For instance, although the EU Commission's guidelines on state aid demand that, from 2017, aid should be granted in a competitive bidding process, this requirement does not apply if "(a) Member States demonstrate that only one or a very limited number of projects or sites could be eligible; or (b) Member States demonstrate that a competitive bidding process would lead to higher support levels (for example to avoid strategic bidding); or (c) Member States demonstrate that a competitive bidding process would result in low project realisation rates (avoid underbidding)" (COM 2014a: 26). Moreover, the guidelines do not require a bidding process for installations of less than 1 MW electric capacity (for wind: up to 6 MW), and allow the bidding process to be limited to certain technologies "where a process open to all generators would lead to a suboptimal result which cannot be addressed in the process design" (COM 2014a: 26). As a result, for some segments of the RES markets, a continuation of administered remuneration rates may yet prove to be the more efficient solution. However, while the guidelines name policy-related distortions on biomass resource markets as a rationale for excluding bioelectricity generators from bidding schemes, they also state that "no other operating aid may be granted to new installations generating electricity from biomass if excluded from the bidding process" (COM 2014a: 26, footnote 67).

On the other hand, some instrument choices can be regarded as ruled out in the current state of political and academic discussions about the EEG's future development. There is widespread agreement that feed-in tariffs where remuneration is independent from electricity price signals are not the way forward, except for small plants and as a fall-back option in exceptional cases (Schuffelen and Kunz 2014: 2f.). For intermittent RES like wind and PV, the benefits of direct marketing compared to central marketing organised, for example, by transmission systems operators are somewhat contested, but for bioelectricity and other dispatchable RES, direct marketing emerges as the preferential option (Leprich et al. 2013: 63ff.; Jacobs et al. 2014: 13; Purkus et al. 2014: 14). This is because, in contrast to intermittent RES, dispatchable RES have a higher capacity to react to electricity price signals, and marketing concepts that are tailored to individual plants' flexibility and heat use potential are likely to increase marketing efficiency compared to a central organisation of marketing. Furthermore, at least in the short- to mid-term, the majority of studies argue for a support scheme which is not technology-neutral but differentiates remuneration according to RES technology, to reflect technologies' various stages along learning curves and the benefits of developing a broad portfolio of technologies (Schuffelen and Kunz 2014: 9). As an instrument which performs best in a technology-neutral context, propositions of a quota scheme in combination with green certificate trading (e.g. Frondel et al. 2013; Monopolkommission 2013) have been politically sidelined by the decision for a competitive bidding process as a quantity-based instrument.

As alternatives for bioelectricity support, the following price and quantity instruments have therefore been identified as the most relevant ones for the subsequent analysis: a sliding feed-in premium, either administered as in the current market premium scheme or tendered as part of a competitive bidding scheme; a fixed feed-in premium, likewise either set administratively or tendered; and an administered or tendered fixed capacity premium, which would constitute a further development of the current flexibility premium. In the case of competitive bidding schemes, not all relevant design choices can be discussed, as associated problems are manifold and not specific to bioelectricity policy (for comprehensive assessments see e.g. Fürstenwerth et al. 2014; Hauser et al. 2014a; Klessmann et al. 2014); rather, selected elements which appear particularly relevant in the bioelectricity context are highlighted.

Meanwhile, in any of the options named, different approaches to technology differentiation within the bioelectricity technology group can be implemented. For example, a competitive bidding scheme could adopt a hierarchical approach to technology differentiation and invite separate tenders for different feedstock-technology-combinations; alternatively, technology and feedstock choices could be constrained through prequalification requirements that project developers have to meet in order to participate in tenders. If a more market-based approach is adopted and the instrument does not differentiate between bioelectricity pathways, a discussion is necessary about whether it should be combined with minimum sustainability standards and certification. Furthermore, regarding the adjustment of policies, it is of interest whether specific combinations of price, quantity and hybrid instruments and mechanisms for technology differentiation perform better or worse in striking a balance between adaptive efficiency and planning security.

5.4.3.2 Prices Versus Quantities Versus Hybrids: Assessment of Instrumental Alternatives

The first question to be discussed in the assessment of alternatives is whether they perform better than the current sliding FIP scheme in limiting social costs of errors regarding private costs, external costs, and external benefits. Three dimensions are relevant: firstly, whether a switch to an administered fixed FIP or capacity premium could be beneficial; secondly, how administered price instruments compare to a competitive bidding process; and thirdly, whether a competitive bidding scheme offering a sliding FIP, a fixed FIP or a capacity premium would be more advantageous.

Administered Sliding FIP Versus Fixed FIP Versus Capacity Premium

The main rationale for switching from a sliding FIP to a fixed FIP or a capacity premium is the higher importance of price signals for producers, which is argued to lead to a more efficient dispatch of RES capacities (e.g. Löschel et al. 2013: 12). However, of the three instrument options, the capacity premium is the only one that does not distort price signals on electricity spot markets (cf. Kopp et al. 2013: 28ff.). As is the case with the sliding FIP, plant operators receiving a fixed FIP per kWh still have an incentive to produce electricity when prices are below their MC or even negative, as long as total remuneration, including the fixed premium, is positive. At the same time, producers not only face uncertainties concerning the development of spot market prices, but also quantity-related uncertainties regarding the number of hours they can profitably feed in electricity. With a capacity premium, premium payments are independent of production, reducing volume risks; total revenues nonetheless depend strongly on market price developments. In both schemes, market actors are therefore likely to include significant risk premiums in their calculations; consequently, either comparatively high premiums will be required to incentivise the same level of expansion as under a sliding FIP, resulting in higher support costs, or investments will be lower (Leprich et al. 2013: 43f.; Öko-Institut 2014: 58).

Furthermore, a sliding FIP offers the highest degree of control over private costs, because with a fixed FIP or a capacity premium, the sum of premium payments and expectations about electricity prices and other income streams (e.g. from balancing markets or heat use) determines what technologies will be profitable. In the case of an administered fixed feed-in or a capacity premium, this increases the information requirements for policy makers, who have to make estimates about both technology costs and income streams when determining premium levels (Kopp et al. 2013: 21). Depending on market price developments, total remuneration is more likely to either lie above or below actual costs than with a sliding FIP which adjusts automatically according to average spot market prices; the first case would result in windfall profits and potentially higher levels of investment than intended, whereas the second case could lead to expansion targets being missed. As a result, frequent adjustments of premium levels would be necessary. Alternatively, fixed premiums could be adjusted through price floors and price caps. With a fixed FIP, producers would in this case receive a guaranteed floor price, when spot market prices for electricity fall below it, whereas with high prices, premium payments would be cut to ensure that a certain level of total remuneration would not be exceeded (Klessmann et al. 2008: 3656). In the case of a capacity premium, producers could be obliged to make payments once market prices exceed a certain level, which would be set off against their capacity premium payments (Öko-Institut 2014: 5). In both cases, however, the complexity of schemes and transaction costs of their administration would increase. Moreover, in case of a cap-and-floor

FIP, market price signals for an efficient dispatch would be further distorted, whereas with a capacity premium, an electricity price-based balancing mechanism would reduce planning security for investors.

Additionally, fixed premiums share the sliding FIP's problem that expansion cannot be steered accurately through price-based support, resulting in little control over the external costs associated with expansion levels. Breathing caps as a hybrid element, meanwhile, function best in combination with the sliding FIP, which unlike fixed premium options controls total remuneration. With regard to the steering of external benefits, it is sometimes suggested that a fixed FIP or a capacity premium could work as a Pigou subsidy that compensates for the provision of external benefits, to avoid the problems of centrally assessing technologys' costs (Löschel et al. 2013: 12). However, the assessment of external benefits is associated with its own range of uncertainties, so that the setting of a benefit-oriented premium would in the end also need to be solved in a political negotiation process with all its potential shortfalls. In a setting of administered prices, the sliding FIP in combination with a breathing cap therefore remains a more promising option than a fixed FIP or a capacity premium for limiting the social costs of errors.

Administered Prices Versus Competitive Bidding

In transitioning from a price instrument to a quantity-oriented competitive bidding scheme, the biggest advantage is the competitive determination of remuneration and associated potential increases in the cost-effectiveness of support: rather than having policy makers set reference prices under asymmetric information, bidding schemes make use of market processes to reveal how high private costs would need to be in order to achieve a certain target (Kopp et al. 2013: 3ff.; BMWi 2014d: 1; Frontier Economics 2014: 1f.). If bidding schemes are to differentiate between RES technologies, however, this requires the setting of technology-specific expansion targets, an analogue to the expansion corridors used in the design of breathing caps. As a result, expansion targets would become the focus of political negotiation processes including lobbying efforts, rather than remuneration levels.

Whether the competitive determination of remuneration succeeds in making RES support more cost-effective depends on various factors, which need to be taken into account in the design of tenders (Kopp et al. 2013: 42ff.; Fürstenwerth et al. 2014: 9ff.): As an important prerequisite, competitive bidding processes require conditions of scarcity; the quantities offered in bids must exceed the tendered quantity, to ensure sufficient competition. Also, the rules of the bidding process must be designed so as to ensure competitive bidding and to effectively guard against strategic bidding behaviour such as underbidding or collusion. Given differences in the market characteristics of different RES technologies, for example, regarding the diversity and number of project developers, investment volumes and planning time required, different tender designs may be appropriate for different RES technologies. At the same time, the rules must remain transparent and be readily understandable to market actors, and the transaction costs of tenders must not be so high as to negate potential cost-effectiveness improvements.

Moreover, competitive bidding schemes' focus on the achievement of targets can potentially increase support costs compared to a price instrument (Öko-Institut 2014: 89). To increase control over total costs, budget restrictions can be introduced; alternatively, it would also be possible to tender budgets for certain technologies, rather than quantities (Kopp et al. 2013: 37f.). On the other hand, despite being a quantity instrument, competitive bidding schemes do not automatically guarantee that targets will be achieved, because it is reasonable to assume that a certain share of projects will fail to be realised when in the process of project implementation it becomes clear that the actual costs deviate from the expected costs reflected in the bid. To safeguard against this, it is advisable to combine tenders with prequalification requirements, for example, regarding the existence of planning permission, securities which are forfeit if projects are not implemented in a timely fashion, or penalties which apply under the same circumstances (Kopp et al. 2013: 48). The more stringent these safeguards are, however, the higher the costs and risks of participating in tenders, which will then be reflected in the bids and increase support costs (Öko-Institut 2014: 93f.). Furthermore, higher risks and requirements increase participation barriers for small market actors, whose continued participation in the energy transition is not only deemed necessary for acceptance reasons, but also increases competition in the electricity market (Leprich et al. 2013: 48).

As a result, even though a competitive bidding scheme in principle guarantees that no more expansion takes place in a technology group than the quantity tendered, targets may still be missed; conversely, in order to achieve a certain level of expansion, the tendered quantity would need to be higher than the target, to take estimated failure rates into account (Kopp et al. 2013: 46). Overall, the control of expansion levels is therefore only slightly more precise than in the case of breathing caps, which allow the expansion of low cost pathways once predetermined quantities are exceeded. Lastly, to avoid regional hot spots of bioelectricity expansion with high external costs, tenders could be regionalised, but in principle the introduction of regional quantitative constraints would also be possible with administered price instruments (Scheftelowitz et al. 2014: 6). In the case of a competitive bidding scheme, regionalisation would have negative impacts on the liquidity of tenders, and strategic bidding and market power problems may ensue (Öko-Institut 2014: 92).

Competitive Bidding for a Sliding FIP, a Fixed FIP or a Capacity Premium? When comparing a competitively tendered sliding FIP to an administered one, market actors face higher risks before their project becomes operational; if bids are successful, subsequent cost and price risks are comparable in both schemes.[23]

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[23] An exception would be competitive bidding schemes where, after a successful bid, remuneration is not paid over a plant's estimated depreciation period, but only for a considerably shorter period. Here, existing plants would have to continue to compete in tenders, providing high incentive intensity to reduce costs. However, planning security would be very low, on a level comparable to quota schemes with green certificate trading. To facilitate comparability, it is assumed here that remuneration periods will continue to be aligned with depreciation periods in a competitive bidding scheme.

However, the potential costs of unsuccessful bids or penalty payments in the case of project failures would be reflected in higher risk premiums, which would need to be balanced by savings in support costs due to a competitive determination of remuneration. In order to ensure that support costs in a competitive bidding scheme remain below the administered FIP, bids for "full costs", i.e. reference prices which include the sliding market premium, could be accompanied by technology-specific price caps based on cost estimates or current FIP reference prices (Kopp et al. 2013: 3). Like with the breathing cap in the case of an administered feed-in premium, this would turn the competitive bidding scheme into a hybrid instrument, where policy makers try to influence both price and quantity variables (cf. Sect. 5.4.1.2). Moreover, the form of the bidding process influences comparative support costs. A uniform pricing approach, where all bidders receive reference prices according to the last successful bid, results in windfall profits for low cost producers; a pay-as-bid tender avoids this problem, but incentives for strategic bidding are high (Öko-Institut 2014: 93).

With a tendered fixed FIP or capacity premium, the crucial difference to administered variants is that market actors instead of the state have to build expectations about different income streams over the plant's lifetime, and deal with associated uncertainties. However, with the transition of the electricity system and potential future adjustments in the market design, not only the state but also market actors face difficulties in forming reliable expectations (Bode 2014: 140). For bioelectricity producers, price uncertainties are compounded, because they have to deal not only with uncertainties regarding income streams, but also regarding resource cost developments, which add to the risk of project failure. The higher the cost- and revenue-sided uncertainties, the higher the remuneration asked for in bids will be. Here, a tendered sliding FIP has the advantage that at least uncertainties about spot-market price developments are reduced; when bidding for a fixed FIP or capacity premium, risk-averse producers are likely to assume very low spot market prices and ask for a premium that would cover a high share of full costs. Unless there is strong competition among bidders and the bidding design effectively prevents strategic bidding, high windfall profits might result in this case, increasing support costs.

Comparing a tendered capacity premium and a fixed FIP, the former has the advantage that it breaks the connection between remuneration and actual feed-in, thereby reducing volume risks and offering higher planning security (Öko-Institut 2014: 7). Moreover, being independent from electricity production, it allows for a stronger focus on non-spot market revenue streams, for example, in balancing markets or through heat sales. By diversifying revenue streams (cf. Hauser et al. 2014b: 81), producers would in principle have the opportunity to maximise the market value of bioelectricity, and use price signals to determine where the use of scarce biomass resources would be most efficient. In such a situation, a competitive determination of remuneration may offer improvements compared to the administered alternative because information asymmetries can be overcome; in making bids, actors could use time- and space-dependent knowledge about how much remuneration is needed in addition to diverse spot market and non-spot market income streams to cover full costs. An important prerequisite, however, would be a tender design that gives actors incentives to truthfully reveal information. The high importance of the “price discovery” function of tenders in the case of a capacity premium could argue for the use of dynamic bidding processes such as the descending clock auction, where information is revealed between auction steps and bidders and auctioneer both can make adjustments depending on participants’ bidding behaviour (Cramton and Kerr 2002: 7f.; Öko-Institut 2014: 92). However, a dynamic process with several bidding rounds would increase transaction costs compared to a single bid process.

Combining quantity-oriented bidding schemes with a capacity premium offers the additional advantage that policy makers can retain more control over total support costs, which in the case of a feed-in premium depend on actual production (Kopp et al. 2013: 29). However, there are also some shortcomings. For one, in order to maximise premium payments, investors may choose to optimise plant concepts with regard to capacity rather than availability (ibid.: 30). Moreover, even though a capacity premium sets incentives for efficient bioelectricity production, in that feed-in is only incentivised when electricity prices exceed marginal costs, this may result in a suboptimally low share of bioelectricity in the electricity mix (Leprich et al. 2013: 63f.). This is because spot market prices do not fully express the external costs of fossil fuel plants; if bioelectricity plant operators aligned their feed-in decisions exclusively with spot market prices and marginal costs, coal power plants would precede bioelectricity plants in the merit order. In this case, bioelectricity would not have a feed-in priority anymore, and would only run when electricity prices were comparatively high, feedstock costs were very low, heat revenues high, or if they were successful in offering positive balancing power (ibid.). To prevent this, Leprich et al. (2013: 64) suggest supplementing a capacity premium with a fixed feed-in premium which would place bioelectricity left of coal power plants in the merit order. However, independent of whether premiums were administered or competitively determined, this would increase the complexity of setting remuneration levels, and increase potential risks of over- or undersupport. A more comprehensive solution would consist of increasing fossil fuel plants’ marginal costs through emissions pricing, which would require a reform of the EU-ETS. This would also reduce distortions between coal and gas power plants and other low carbon options, but political feasibility problems arise at least in the short term. In the longer run, meanwhile, increasing shares of volatile RES with MC close to zero would increase the efficiency benefits of a capacity premium that does not distort price signals.

5.4.3.3 Technology Differentiation: Assessment of Instrumental Alternatives

Both in administered price instruments and competitive bidding schemes, different mechanisms can be implemented in order to differentiate between technologies and feedstocks. Reference prices and premium payments can be differentiated according to the technologies and feedstocks used; policy makers can set requirements which need to be met as a precondition for support; or minimum sustainability standards can be introduced in combination with a certification scheme. The following section discusses these options, and whether their feasibility and performance is influenced by the choice between a price instrument and a competitive bidding scheme.

Moreover, for external security of supply benefits, the choice between a sliding FIP, a fixed FIP or a capacity premium has a repercussion; as discussed in Sect. 5.4.3.2, the capacity premium sets the highest incentives for an efficient dispatch of plants because it does not distort electricity market price signals. As implications of different premium types on the allocation of price uncertainties have already been discussed in the previous section, the focus here shall be on the differentiation according to installation sizes, costs, GHG benefits and other environmental impacts. Lastly, what implications it would have to allow existing plants to participate in the bidding scheme, compared to a scheme that is limited to new plants, is assessed.

Differentiation According to Installation Sizes

First of all, it can be stated that implementing a differentiation according to installation sizes presents challenges within competitive bidding schemes. Separate tenders for different size classes would increase the transaction costs of the scheme and decrease competition for tendered quantities; also, policy makers would have to define quantity targets for different size classes, which could easily lead to inefficient production structures. When competing in tenders, however, larger plants which can use economies of scale have a competitive advantage over smaller ones. A more pronounced focus on larger plants can potentially reduce bioelectricity generation costs, but on the downside, they might have a greater distortionary impact on regional biomass flows (see Sect. 5.4.2.2). Also, to increase the GHG benefits of bioelectricity production, installation sizes should be aligned with regional heat sinks (Thrän et al. 2011b: 91). A potential solution to account for different installation sizes in competitive bidding schemes would be the introduction of separate price caps for different size classes (cf. Hölder 2015).[24] However, without separate quantity targets, smaller plants would only be successful if the tendered quantity could not be provided by larger-scale plants at the specified price cap. This increases the participation risks of smaller plants, due to upfront costs incurred in the preparation of the bid and in meeting potential prequalification requirements, such as obtaining legal planning permission (Fürstenwerth et al. 2014: 21f.). Also, the information requirements for policy makers, who have to specify several price caps, are high. Finally, it would be possible to continue to support small-scale projects through an FIT rather than a tendering scheme, although with this solution, trade-offs with cost-effectiveness result.

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[24] Hölder (2015) discusses price caps as a means of differentiating between different technologies and plant types (e.g. depreciated plants and new plants). In principle, an extension to different size classes would be possible.

Differentiation According to Technology and Feedstock Costs

A differentiation according to technology and feedstock costs can be implemented in administered price instruments with comparatively low transaction costs, but exhibits problems in terms of the high information requirements for policy makers, high adjustment costs and the lack of reversibility of incentives for existing plants, as discussed in Sect. 5.4.2.2. An interesting question would therefore be whether the information discovery function of competitive bidding schemes could offer advantages in differentiating between technologies according to different relevant characteristics.

Establishing a hierarchical differentiation between technologies in competitive bidding schemes meets with similar difficulties to those encountered with differentiation according to installation sizes. In principle, it would be possible to establish separate tenders for separate technology-feedstock combinations (e.g. for biogas plants, plants using solid biofuels and biodegradable waste plants). However, this would significantly increase information requirements for policy makers, who would need to set detailed technology-specific targets. At the same time, ensuring sufficient competition for tendered quantities would become more difficult the more specific the design of tenders became. Moreover, such a differentiation would run counter to the purpose of competitive bidding, which is to identify the most cost-effective solutions.

Given the relatively mature nature of many bioelectricity options and the uncertainty about learning curve potentials of innovative options (e.g. wood gasification), increasing the incentive intensity to select bioelectricity options with low costs promises advantages compared to instrument options with administered prices. In principle, competitive bidding schemes leave it to market actors to assess the resource supply situation and make estimates of the remuneration required to implement projects. A low availability of low cost feedstocks would therefore be reflected in bids, which would reveal the costs of implementing a targeted quantity. This implies that when moving along biomass supply curves, the remuneration from tenders that producers receive may increase with time—but compared to the current EEG's use of planned degression and revisions, the interplay between cost reductions from learning curve effects and cost increases from feedstock prices would be reflected in bids, and would not need to be assessed hierarchically.

In practice, however, problems arise when it comes to differentiating between high cost and low cost producers. Theoretically, in a pay-as-bid auction, market actors would reveal the costs of different technology-feedstock combinations, and their remuneration would be differentiated accordingly. However, remaining flexible in the light of changing feedstock prices poses problems. Under the EEG 2012s sliding FIP of FIT, actors can change between feedstocks and receive cost-oriented remuneration accordingly. With competitive bids whose calculation is based on a specific feedstock, on the other hand, the plant's continued profitability would be endangered if expectations about dynamic feedstock cost developments were to prove false. At the same time, actors who made a successful bid based on high cost resources would have an incentive to switch to low cost ones afterwards to maximise profits, outcompeting plants which receive remuneration based on lower bids in the process. Alternatively, plants could be required to use a range of feedstocks specified in the bid, but monitoring may be costly given incentives for cheating, and the lack of flexibility to adjust to changing feedstock costs would be problematic. The same problems would arise if separate price caps were used to differentiate between feedstock classes.

A uniform pricing approach, on the other hand, would set all successful bidders on a fair competitive footing. However, due to the heterogeneity of cost structures of bioelectricity producers, this may result in high windfall profits for low cost plants. As discussed in Sect. 5.4.1.3, the result may be cost-effective (if collusion and strategic bidding can be kept in check), but it does not minimise the support costs borne by consumers. Moreover, new bioelectricity projects would compete for low cost resources not only amongst themselves, but also with existing plants, which would endanger the continued profitability of the latter. To counter the higher ability to pay of new plants supported under the competitive bidding scheme, it would be possible to offer existing plants the option of receiving the same uniform price that results from auctions—however, this would be particularly attractive for producers who receive comparatively low FIT or administered FIP rates, and would increase support costs. The problem of competition with existing plants also arises in pay-as-bid auctions, if it cannot be effectively prevented that producers with high successful bids enter the market for low costs wastes and residues.

Meanwhile, prices arrived at in a competitive bidding scheme would not normally reflect differences in environmental benefits—options with comparatively high costs but environmental co-benefits, such as some of the feedstocks supported under the EEG 2012s substrate tariff class II, would only be adopted once potentials of lower cost resources were depleted. In principle, competitive bidding schemes could be designed so as to allow for competition not only on the basis of prices, but also on the basis of benefits. On the one hand, this would be an interesting option to increase incentive intensity for improving the environmental balance of bioelectricity production. On the other hand, it would be associated with a host of practical problems. The calculation of GHG mitigation benefits, for instance, depends crucially on the LCA methodology, system boundaries and the various assumptions used; at the same time, it would be insufficient to regard GHG benefits in isolation, as other environmental impacts such as eutrophication and acidification also play a role in assessing the sustainability of different pathways (cf. Thrän et al. 2011b: 75f.; Hennig and Gawor 2012; Lansche and Müller 2012; Bacenetti et al. 2013). Besides the verification of bids, the monitoring of value chains during the plant's operation would increase transaction costs significantly. Moreover, there is not always a positive correlation between environmental benefits and costs, as the example of low cost resources among wastes and residues shows. Aligning remuneration with benefits alone would therefore result in windfall profits for low cost options, which might increase support costs.

Finally, for small-scale slurry biogas plants whose main benefits derive from slurry treatment (WBA 2011: 9), it seems sensible to continue support using an administered FIT. Given high GHG mitigation potentials, a limited scope for cost reductions (Scheftelowitz et al. 2014: 132) and the secondary nature of GHG benefits from electricity production, making these plants compete in bidding processes with associated transaction costs and risks for project developers does not appear to be a sensible option.[25]

Differentiation Through Eligibility Requirements

Setting requirements as a precondition for support represents a hierarchical approach which can be adopted in competitive bidding schemes as well as in administered price instruments. For example, it seems straightforward that the EEG's definition of the types of biomass which are eligible for remuneration in the BiomasseV should also be extended to competitive bidding processes. But the implementation of more far-reaching requirements, such as a cap on energy crops or minimum heat or slurry use requirements, is also possible.

Requirements which are easy to monitor and clearly improve external benefits or reduce external costs represent low transaction cost measures for improving the sustainability of bioelectricity production. Examples are rules proscribing covered digestate storage tanks, and other plant design features or operational proceedings which have been shown to reduce methane leakage (Liebetrau et al. 2010; Lansche and Müller 2012). Likewise, rather than allowing all technology-feedstock combinations to compete in tenders and try to differentiate by prices or sustainability standards, transaction costs can be reduced and planning security for project developers improved by excluding feedstocks ex ante where the resource competition situation is known to be problematic and high costs meet comparatively low GHG mitigation potentials (cf. Hennig and Gawor 2012); this was done with liquid biomass in the EEG 2012.

For the implementation of more far-reaching requirements, where uncertainty about their costs and benefits is higher and their monitoring more complicated, competitive bidding schemes prove in principle to be more learning-friendly than administered price instruments (cf. Kopp et al. 2013: 3ff.). The reason for this is that prerequisites could be changed from tender to tender, to incorporate new information as learning takes place. As a result, erroneous decisions would affect a lower number of plants than in the case of the legal requirements of the EEG, which affect all plants that go into operation between revisions. Also, if tenders are held regionally, there is the possibility that the eligibility requirements could be adapted to regional characteristics; for instance, areas with a high share of maize production in the arable area could limit participation to plants using wastes and residues. Moreover, compared to administered instrument options, competitive bidding processes have the advantage that the costs of compliance with requirements are revealed. For example, combining a tender with an ambitious cap on the use of energy crops would reveal the costs of using alternative feedstocks. Under the EEG 2014, with its reduced reference prices, expansion might come to a halt if prices are set too low. On the other hand, prices revealed in competitive bidding schemes

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[25] At the same time, it would be more efficient to provide indirect incentives for small-scale slurry biogas plants by increasing the costs of GHG emissions in the agricultural sector.

might prove too high to be acceptable for policy makers; for reasons of cost control, the combination with a price cap for bids or the use of dynamic auction processes therefore seems recommendable (see Sect. 5.4.3.2). On the basis of the information revealed in bids, price caps, tendered quantities and eligibility requirements could be adjusted in future rounds of tenders.

While this approach retains high planning security for operational plants, frequent changes in requirements would still increase policy uncertainty for project and technology developers. Incentive intensity to improve the environmental balance and GHG benefits might prove slightly higher than in administered instrument options with less frequent revisions of requirements, because opportunities for tightening standards would occur more often, and investors who anticipate new requirements and work out low cost modes of compliance would have a competitive advantage in the bidding process. Moreover, by developing more environmentally friendly production processes, technology developers could try to establish benchmarks based on their products. At the same time, frequent adjustments to eligibility requirements could incentivise strategic bidding: if market actors expected that a requirement might be dropped if too few bids were made, bids would be postponed to future tenders.

Lastly, as with the differentiation by prices, incentives for reducing external and private costs and increasing the provision of external benefits would remain limited to new plants. In order to make existing plants comply voluntarily with new eligibility requirements, financial incentives would be necessary.

Differentiation Through Minimum Sustainability Standards

Sustainability certification schemes have so far primarily been applied in contexts where imports of biomass from non-EU countries play a major role, for example, in the case of biofuels and liquid biomass, or solid bioenergy carriers when used in large-scale co-combustion, as is the case in the UK (cf. COM 2014b; Purkus et al. 2015). Since, in Germany, bioelectricity production in large-scale plants (>20 MW) or co-combustion in coal-power plants is not promoted by direct support instruments, it is reasonable to assume that small- to mid-scale options with predominantly regional supply chains will continue to play the predominant role at least in the short- to mid-term. However, a successful reform of the EU-ETS and increasing GHG emissions prices could make co-combustion with an associated large-scale demand for biomass more viable, and the urgency of introducing sustainability certification on solid and gaseous biomass would increase. For this section, the focus shall however be on introducing sustainability standards and certification for plants supported under the EEG.

Because of the ordinances contained in the EEG 2012 and 2014, sustainability certification would be one of the few regulatory options available for improving the environmental balance not only of new plants but also of at least a subset of existing plants, without increasing support costs through the provision of additional financial incentives.[26] For those plants that would be subject to sustainability standards

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[26] However, the majority of currently operational bioelectricity plants are receiving remuneration based on earlier versions of the EEG. Extending sustainability standards to these plants may be associated with high political costs and legal difficulties.

and certification, the allocation of uncertainties about GHG benefits and those environmental costs reflected in the standards would shift from the state to bioelectricity producers, who would have to ensure that supply chains meet minimum sustainability requirements. Examples of measures which reduce uncertainties for market actors are adjustment periods in which only reporting but not compliance with standards is required, and a tightening of requirements over time which allows for a gradual improvement of supply chains; these measures were employed in the UK sustainability standards for bioelectricity generation from solid and gaseous biomass which entered into force in 2014 (cf. DECC 2013; Ofgem 2014).

In combination with a uniform administered FIP or a competitive bidding scheme which does not differentiate within the bioelectricity technology group, sustainability standards and certification represent a market-based alternative to hierarchical eligibility requirements or price differentiation when it comes to safeguarding minimum environmental benefits. By setting clear framework conditions and leaving detailed technological and resource decisions to producers, they provide a higher incentive intensity to search for decentralised solutions to meet sustainability standards than more hierarchical options. If standards are designed to increase in stringency over time, dynamic incentives for improving the environmental balance of bioelectricity production would also be set. However, these incentives would only apply to the external benefits and costs reflected in the standards. Also, transaction costs of sustainability certification are significantly higher than the more hierarchical approaches to technology differentiation. Long-term planning security for project developers, meanwhile, could be higher than with hierarchical approaches where the eligibility requirements of technology- and feedstock-specific reference prices change with revisions or rounds of tenders; this depends, however, on whether the state could credibly assure that the content of sustainability standards would not change beyond a predefined dynamic tightening. In the case of the UK, for example, the government has assured that until 2027 no unilateral changes will be undertaken regarding GHG mitigation requirements, including the GHG accounting methodology and the trajectory for emission reductions (DECC 2013: 16). While this increases planning security for market actors, the reversibility of policy decisions in light of new scientific discoveries and learning is reduced (cf. Purkus et al. 2015).

For GHG mitigation requirements, standards which set an upper level for plants' total GHG emissions would be more appropriate that those proscribing a certain level of GHG mitigation. With an increasing share of RES in the German electricity mix, the amount of mitigated emissions from fossil fuel technologies would otherwise decrease over time. In any case, GHG accounting for bioelectricity plants remains associated with significant uncertainties. In order to ensure comparability between bioelectricity producers, the state has to provide a standard methodology. For the balance between adaptive efficiency and the provision of investment safeguards, it is of central importance how the process for implementing changes to criteria and methodology is designed. The UK system, for example, precludes "unilateral changes", but it is as yet unclear how a non-unilateral adjustment process will look like in practice, and how high associated political transaction costs would be.

For the use of wastes and residues with low environmental impacts and GHG emissions, certification requirements could be relaxed or waived to reduce transaction costs.[27] For bioelectricity concepts based on other feedstocks, however, it needs to be discussed whether the higher incentive intensity of sustainability certification justifies the additional transaction costs compared to hierarchical technology differentiation options.

In determining GHG balances of bioelectricity pathways, a limited number of major influencing factors stand out. Of major importance is the type of feedstocks used (Thrän et al. 2011b: 72ff.; Hennig and Gawor 2012; Lansche and Müller 2012; Bacenetti et al. 2013). Apart from waste and residues, the use of woody biomass is associated with very low GHG emissions, because no fertiliser inputs are required (except in the case of SRC). Conversely, the use of energy crops causes higher emissions, even if grown on existing agricultural lands and neglecting ILUC effects. GHG emissions can be reduced by a co-digestion of energy crops and slurry, because of avoided methane emissions from liquid manure storage; given the low energy yield of slurry, however, this effect is very small for slurry shares below 35 % on a mass basis (Lansche and Müller 2012: 316). Still, in most cases biogas pathways using energy crops perform better than electricity production from liquid biofuels such as palm oil or rapeseed oil (Hennig and Gawor 2012: 134).

Compared to emissions from the cultivation and feedstock preparation phase, emissions related to conversion processes and transportation are much smaller for most pathways (ibid.). Exceptions are biogas processing installations which feed biomethane into the gas grid, where higher methane emissions occur during the conditioning phase, palm oil installations with higher transport emissions and biodegradable waste where transportation tends to cause the highest GHG emissions along the value chain (Thrän et al. 2011b: 72; Hennig and Gawor 2012: 134). In biogas plants, open digestate storage tanks and an incomplete combustion of fuels in the cogeneration unit can be major emission sources (Liebetrau et al. 2010). Credits from the use of cogenerated heat, on the other hand, add significantly to the GHG savings potential (Thrän et al. 2011b: 73f.; Lansche and Müller 2012: 316; Bacenetti et al. 2013: 548). Differences in installation sizes, meanwhile, are found to have a relatively small impact (Thrän et al. 2011b: 72). As to acidification and eutrophication potential, differences between similar plant types are also low—again, the type of feedstock used has the largest influence on performance. Here, energy crops perform worst, primarily due to emissions from agricultural processes (Thrän et al. 2011b: 75; Lansche and Müller 2012: 317).

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[27] In the UK sustainability standards for bioelectricity, for example, fuels falling in the waste category are largely exempt from reporting requirements regarding land criteria, the timber standard or GHG criteria; for processing residues, producers need to report only on emissions associated with collection processes, and non-woody residues are also exempt from reporting on the performance against land criteria or the timber standard (Ofgem 2014: 16).

Overall, it emerges that major influencing factors for GHG emissions and also eutrophication and acidification are relatively clear—at the same time, the calculation of plant-specific LCA balances remains associated with high uncertainties, being dependent on modelling and calculation methodologies and diverse assumptions (Hennig and Gawor 2012: 137). This would argue for the use of hierarchical requirements over sustainability standards, for example, regarding the use of gas-tight digestate storage tanks, minimum heat use requirements, or caps on the use of energy crops (as was implemented in the EEG 2012). These would have the advantage of being more easily monitored than GHG balances in certification. Moreover, biogas plants in particular are often operated by farmers "on the side", with limited capacity to optimise value chains according to GHG aspects and engage in decentralised search processes for better options. This limits the benefits of sustainability standards' higher incentive intensity.[28] As such, it can be more efficient to develop recommendations for plant design and value chain optimisation by centrally funded research, and implement "best practice" findings in hierarchical requirements. In this case, the state would continue to bear GHG- and other sustainability-related uncertainties, and continuous monitoring would be necessary to determine whether requirements yield the expected outcomes, followed by adjustments if needed. With minimum heat use requirements, for example, it has been found that cogenerated heat does not always replace an existing demand for fossil fuels, which is a prerequisite for actual GHG mitigation taking place (Scheftelowitz et al. 2014). Alternatively, if remuneration was designed so that heat revenues were a vital necessity for the profitability of plant concepts, incentive intensity to align new plants with existing heat demand could be increased (see Sect. 5.4.4).

Also, it needs to be taken into account that many major influencing factors are related to elements of plant design—due to, for example, a limited range of feedstocks which can be combined with a specific conversion technology, or limited heat use sinks in a plant's vicinity. As a result, the scope for implementing major changes in GHG balances of existing plants is somewhat limited. Meanwhile, sustainability standards could cover a greater scope of criteria than would be feasible for hierarchical requirements. However, given the associated transaction costs, this seems particularly merited when there is limited control over more general legal framework conditions, as is the case with transnational value chains.

Treatment of Existing Plants in a Competitive Bidding Scheme

With a change of the remuneration system from administered to competitively determined prices, it has to be decided if and in what form existing plants are allowed to participate in the scheme. Basically, there a four different options: (i) participation can be restricted to new plants only; (ii) besides new plants, extensions of existing plants can be allowed to participate; (iii) not only extensions,

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[28] This role could be filled by intermediate actors, comparable to direct marketing intermediaries—this would, however, further increase the transaction costs of the scheme.

but all existing plants can participate if they undergo a major overhaul; (iv) existing plants can participate when they reach the end of their remuneration period.

In general, the 20-year remuneration period offered under the EEG allows RES plants' to be fully written off. For RES with low variable costs like wind or solar power, it remains profitable to continue producing electricity after this period (unless major investments are required to maintain serviceability). For bioelectricity plants with their significant share of feedstock costs in electricity generation costs, the situation is different—for many plants now in operation, the revenue from electricity and heat sales alone is expected to be insufficient to cover variable costs, which would lead to plants being retired once remuneration claims expire (Arnold et al. 2015: 6). With a limited expansion of new plants, this would effectively lead to a reduction in installed bioelectricity capacity from 2020 (ibid.). This leads to a discussion of whether plants at the end of their remuneration period should be able to participate in tenders (Hölder 2015).

On the one hand, allowing depreciated plants to participate in tenders would reduce average bioelectricity generation costs and remuneration levels and increase competition in the bidding processes. The same would apply to the participation of partly depreciated existing plants. At the same time, however, competition between plants with different degrees of depreciation would distort the price discovery function of competitive bidding schemes, and would likely result in price levels that are too low to allow any significant number of new projects to be realised. Allowing old plants to continue to operate would stabilise the amount of bioelectricity capacity installed, but new plants would be required for further expansion. Also, if successful bids were mainly made by existing plants, innovation would stall; moreover, old plants may exhibit a lower conversion efficiency of biomass, fewer flexibility opportunities and less advantageous environmental balances than new ones.

In comparison, it seems more promising to tie participation of existing plants to a technical overhaul and replacement investments, which update plants to state-of-the-art technical and environmental performance characteristics, and allow for demand-oriented electricity production. Additional investment needs would somewhat reduce but not resolve distortions in the competition with new plants. However, the implementation of technology updates would support demand for innovative solutions, allowing technological development to proceed through incremental innovations and process optimisation. Also, if participation in the bidding scheme was tied to the fulfilment of enhanced environmental requirements, this option would set incentives for environmental improvements of existing plants. The same is true for flexibilisation and the optimisation of cogenerated heat use, if they are effectively incentivised through the competitive bidding scheme's remuneration design. However, existing plants would only adopt the bidding scheme and undertake associated investments if (a) the alternative was shutting down due to a lack of profitability; or (b) a higher remuneration was expected than in the current FIT or MPS. The latter motivation might be particularly relevant for plants based on low cost waste and residues, which particularly under a uniform pricing approach might be able to increase remuneration levels. This would however increase support costs. A lack of profitability, meanwhile, cannot only occur at the end of the remuneration period, but can also be caused by feedstock cost developments. In the second case, opening up tenders for existing plants may be an option for preventing them from being crowded out of the market by new plants with a higher ability to pay for resources. Nonetheless, an important prerequisite would be access to capital for implementing required improvements.

Furthermore, independent of whether plants are subject to major overhauls or not, letting them compete with new plants for tendered quantities implies that expansion corridors for bioelectricity may well be missed. In terms of contributions to net growth of installed capacity, including plant extensions in bidding schemes performs better. Extensions can be a more cost-effective way than new plants to provide additional capacity (Hölder 2015). Certainly, making extensions compete with new plants would result in more cost-effective solutions than supporting them under the original plant's version of the EEG, and in a more precise steering of bioelectricity expansion. However, in order to realise benefits from incremental innovation, demand-oriented feed-in and improvements in environmental balances, the same requirements should apply to extensions as to new plants.

The last option would be to restrict the competitive bidding scheme to new plants. Here, the scheme's price discovery function would not be distorted by different degrees of depreciation of investments. However, given comparatively small expansion targets, the market may end up being quite narrow, with only a limited number of projects competing in the tender. By admitting extensions and possibly also overhauled plants, competition for tendered quantities can be increased and risks of collusion limited (Hölder 2015).

5.4.4 Recommendations

Summing up, a major problem of the current FIT/FIP approach relates to the setting of reference prices in the presence of asymmetric information, in combination with high transaction costs of adjustments and a low reversibility of erroneous decisions. Also, dealing with increasing cost trends due to feedstock price developments remains a challenge. Control of the level of bioelectricity expansion and total support costs is improved through the breathing cap, but solving the trade-off between the accuracy of the cap's steering impact (which is improved by frequent adjustments of degression rates to expansion levels) and planning security for investors remains problematic. Also, a breathing cap on national capacity installed is not effective in preventing regional "hot spots".

The instruments' limited adaptive efficiency proves also problematic for a hierarchical steering of technology and feedstock decisions with high information requirements for policy makers; at the same time, hierarchical mechanisms for technology differentiation result in low incentive intensity for improving private and external cost and benefit balances. While the EEG 2014, with its turning away from substrate tariff classes, technology bonuses and eligibility requirements and focus on direct marketing, sets stronger incentives for private cost decreases and security of supply benefits, policy makers have less control regarding GHG benefits and other environmental impacts. Also, the mismatch between increasing feedstock costs and reduced remuneration levels strongly restricts further expansion and technology development, and means that the changes implemented in the EEG 2014 will only be relevant for a small number of plants. In the following, recommendations are derived for handling the social cost of errors in the choice between price and quantity instruments, and the different dimensions of technology differentiation. Lastly, requirements for the cross-sectoral coordination of bioenergy policy instruments are discussed.

5.4.4.1 Choice Between Price Instruments, Quantity Instruments and Hybrids

Among price instruments, the sliding FIP in combination with a breathing cap performs better than a fixed FIP or a capacity premium in limiting the social costs of errors. With the latter two options, the problem of setting reference prices administratively is compounded by uncertainty about electricity price developments, and risk premiums increase support costs. Also, even if combined with a breathing cap, steering of expansion levels is less accurate, because compared to a sliding FIP the instruments control a smaller share of total remuneration.

Introducing a competitive bidding process to determine reference prices may increase the cost-effectiveness of reaching targets, but whether this will be the case depends on a careful design of the bidding process and characteristics of RES markets. If, in the case of bioelectricity, sufficient competition for tendered quantities could be ensured, a well designed competitive bidding process could help to reveal the costs of implementing an expansion corridor, whereas in the administered sliding FIP, reference prices which are set too low could bring a halt to investments in new plants and domestic technology development. To retain control of support costs and the private costs of bioelectricity production in a competitive bidding scheme, the use of a dynamic, multi-round tender design such as a descending clock auction appears advantageous. If a more detailed assessment reveals that transaction costs of a dynamic tender process are prohibitively high, and sealed-bid tenders are adopted, introducing price caps on bids appears advisable, particularly during the learning phase with the new instrument. These could be set at the level of EEG 2012 reference prices, for example. As with the breathing cap, hybridisation can thus prove to be a useful instrument for controlling the costs of errors. Meanwhile, the need to adjust tendered quantities to expected failure rates means that steering expansion levels and associated external costs is not necessarily more precise than under the administered sliding FIP with a breathing cap. Overall, there does not appear to be an unequivocal answer to whether a tendered sliding FIP reduces the costs of errors compared to an administered one with a breathing cap; increases in cost-effectiveness are not self-evident, particularly once transaction costs are taken into account.

In choosing between a sliding FIP, a fixed FIP and a capacity premium as the form of remuneration in a tender, the fixed FIP performs worst. Here, producers face considerable price risks which would be reflected in bids, and at the same time, price signals remain distorted. A capacity premium sets more effective signals for efficient dispatch by being independent of generated electricity quantities. In combination with a competitive bidding scheme, a capacity premium is likely to perform better than its administered variant: this is because market actors have greater control over diverse income streams and cost uncertainties than policy makers, making a competitive bidding process a useful instrument for discovering price information. To avoid full cost-oriented bids for capacity premiums, however, framework conditions in different markets that bioelectricity plant operators can participate and earn revenues in will have to be adjusted, to ensure that RES options can compete fairly with fossil fuel technologies (e.g. in balancing markets, or heat markets). But even if this were the case, price risks would remain higher than with a tendered sliding FIP—the security of supply benefits of a more efficient dispatch therefore need to be weighed against the higher costs of achieving targets. One way to deal with this trade-off would be to first combine a competitive bidding scheme with a sliding FIP with comparatively high planning security, to generate learning effects. This could be followed by a transition to a tendered capacity premium once uncertainties surrounding electricity price developments have been reduced, which would entail a reform of electricity market framework conditions according to energy transition requirements (cf. Kopp et al. 2013: 3).

Regarding costs of errors, it can be concluded that neither an administered fixed FIP nor an administered capacity premium seem promising. The choice between an administered sliding FIP, a tendered sliding FIP and a tendered capacity premium, on the other hand, requires a careful weighing of trade-offs. Whether these three options show comparative advantages when it comes to questions of technology differentiation is discussed in the following.

5.4.4.2 Implementation of Technology Differentiation

Compared to administered FIT and FIP schemes, competitive bidding schemes lower information requirements for policy makers, help to identify the most cost-effective solutions among bioelectricity technologies with a comparatively high technological maturity, and have a higher adaptive efficiency because eligibility requirements and remuneration levels can change between tenders. On the other hand, handling heterogeneous cost structures and also differences in external costs and benefits of different technology-feedstock combinations is challenging within a competitive bidding scheme.[29] A uniform price approach sets incentives for cost-

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[29] Differences in external costs and benefits even apply to plants using waste and residues—for example, the extraction of woody residues can negatively impact biodiversity (Giuntoli et al. 2014), while the fermentation of bio-degradable waste is associated with additional benefits of waste disposal.

effective technology and feedstock choices while setting new plants on a fair competitive footing when competing for biomass resources. However, compared to a cost-based differentiation within the bioelectricity technology group this approach results in higher support costs (see Sect. 5.4.1.3). Also, new plants are likely to end up with a higher ability to pay for low cost resources, and competition for feedstocks with existing plants may endanger the profitability of the latter. With a pay-as-bid scheme, to some degree a self-selection into different remuneration classes takes place, but where low cost bids are concerned, the "curse of the winner" may occur (cf. Fürstenwerth et al. 2014: 17)—if feedstock costs or project development costs are higher than expected, investments may never manifest, causing expansion targets to be missed. Also, successful projects with high bids can still compete for low cost resources.

To address this problem, it is possible to introduce price caps which differentiate between technology-feedstock combinations, but this increases significantly the complexity and information requirements of bidding schemes. In principle, the use of differentiated price caps would result in a similar remuneration structure to the one adopted in the EEG 2014 or EEG 2012—with the difference that with a competitive determination of remuneration within price categories, rent would be transferred from producers whose bioelectricity generation costs are below reference prices to consumers who bear the EEG surcharge. In this way, support costs may be lowered compared to an administered price instrument, but incentives to invest in bioelectricity projects decrease. Also, bids that qualify for a category with a comparatively high price cap would still face uncertainty about whether they would be accepted, or whether the tendered quantity could be met with bids from lower categories. This could only be addressed through separate tenders for separate technology-feedstock combinations, but this does not seem promising due to the high information requirements for policy makers. As a result, there are few incentives to explore resources such as those in the EEG's substrate tariff class II, with higher costs but low competition, environmental co-benefits and innovative potential. From a static perspective, effectively excluding these resources from support may be cost-effective, but from a dynamic perspective, gathering experience with their use may prove beneficial.

Implementing a differentiation according to installation sizes in competitive bidding schemes meets with similar problems to a differentiation according to technologies and feedstocks. Effectively, competitive bidding favours larger plants which can benefit from economies of scale, although they may be associated with higher impacts on regional resource streams. However, if larger plants can generate electricity, security of supply benefits, and GHG mitigation benefits at lower costs, the necessity for a differentiation according to sizes needs to be assessed critically. Here, a clear distinction between rural value creation as a rationale and sustainability impacts is necessary. To safeguard the latter, implementing an effective differentiation mechanism according to GHG benefits, environmental impacts, and other sustainability dimensions which may be affected by plants' impact on regional resource competition seems more appropriate than targeting support at small-scale plants with higher costs. Moreover, in cases where small-scale plants can take advantage of regionally adapted feedstock supply concepts or achieve high revenues through heat sales, competition with larger plants might be possible. At the same time, to avoid extensive impacts on regional resource streams, maintaining the cap on the maximum installation size eligible for remuneration is recommendable. In combination with a regionally differentiated competitive bidding scheme, the maximum limit could be adjusted depending on resource competition conditions. However, to allow meaningful spatial governance, regions might need to be defined smaller than, for example, at federal state level; in that case, ensuring sufficient competition and liquidity of tenders would become ever more difficult. Therefore, it would prove more advantageous to undertake adjustments in regional planning and plant approval procedures.

Small-scale plants, meanwhile, could be further supported under an administered FIT or FIP, but care needs to be taken that this does not result in inefficient production structures. For small-scale slurry plants, which yield GHG mitigation benefits beyond those related to electricity production, a cost-based FIT remains the most cost-effective support option in the short term at least, because cost reduction potentials of this pathway are limited, and direct marketing and/or tendering processes would result in high transaction costs. In the long run, however, it should be investigated whether incentives can be set more efficiently through adjustments in environmental law and agricultural policy framework conditions, by increasing the costs of agricultural GHG emissions.

Overall, it can be stated that for realising expansion corridors while controlling for cost heterogenity and feedstock competition between existing and new plants, an administered sliding FIP with substrate tariff classes seems a more promising approach than a competitive bidding scheme. Moreover, it needs to be taken into account that potential increases in cost-effectiveness offered by bidding schemes depend crucially on tender design and market conditions. Comparing targets for expansion corridors and expansion under the EEG 2012 (and even more so under the EEG 2014s conditions), sufficient competition may not manifest, resulting in bids which are strategically high. Price caps which are too restrictive, on the other hand, would result in expansion targets being missed. Furthermore, any reduction in bioelectricity generation costs has to be weighed against increased transaction costs of a bidding scheme. To incentivise cost-effective technology choices and avoid steering errors, the EEG 2012s approach to maintain differentiation according to feedstocks while making remuneration largely independent of technology choices and move away from bonuses performs well.[30]

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[30] For processing biogas to biomethane, the EEG 2012 retains a bonus, which was only abolished with the EEG 2014. However, this bonus could also lead to steering errors, given that electricity generation from biomethane is associated with higher GHG emissions than biogas CHP production (Thrän et al. 2011b: 72 f.). For equivalent uses, the direct use of biogas would therefore be more beneficial. Rather than supporting biomethane production through a bonus, it would be advantageous if higher costs were compensated by higher value utilisation options, such as transport sector applications or electricity production in peak load hours. Moreover, a bonus distorts competition with other RES-based flexibility options (e.g. power to gas, storage technologies using RES electricity).

However, it remains to be questioned whether an administered FIP can remain a model for the future, given uncertainties about the long-term competitiveness of bioelectricity technologies with other low carbon flexibility options, and future feedstock cost developments which are likely to be increasingly determined not only by demand for energetic and conventional material uses, but also by the resource demand of innovative bioeconomy applications. Also, an increase in interactions between individual energetic but also energetic and material sectors will pose increasingly challenging to handle for a sector-specific, comparatively hierarchical steering instrument. Furthermore, it remains challenging to set effective incentives for existing plants to increase the provision of security of supply benefits and implement environmental improvements, without increasing support costs by offering compensation.

To address these long-term challenges, a tendered capacity premium shows promising characteristics, if combined with a diversification of income streams. However, this requires an adjustment of framework conditions in relevant markets and indirect instruments, to improve the competitiveness of bioelectricity and other low carbon options compared to fossil fuel alternatives. Examples are a reform of the EU-ETS and adjustments in electricity and balancing markets to increase flexibility incentives and ensure security of supply with increasing shares of intermittent RES (cf. BMWi 2014b). In the heating sector, bioelectricity CHP plants could be supported through the Combined Heat and Power Act (Kraft-Wärme-Kopplungsgesetz, KWKG), at the same conditions as fossil fuel CHP plants (cf. Hauser et al. 2014b: 58ff.).[31] Moreover, adjustments in waste and agricultural policy would be desirable, to increase economic incentives for using bioelectricity as a means of waste disposal (where feasible, at the end of a cascade of material and energetic uses) and provide incentives for the use of feedstocks with environmental co-benefits. Here, agri-environment schemes would be a useful channel to compensate producers using high cost resources with external benefits.

If income streams such as these were available, a tendered capacity premium could be used to remunerate bioelectricity technologies for the provision of dispatchable RES-based capacity and the associated contribution to the path transition in the electricity system. Compared to a feed-in premium, it has the advantage that allocation decisions between electricity, heat, but also transport sectors in the case of biomethane would not be distorted; at the same time, in the electricity sector incentives are set for a maximisation of sales revenues through demand-oriented feed-in and participation in balancing markets, offering both negative and positive balancing power. Also, if capacity markets were to be introduced, a capacity premium would show good compatibility, and could in the long-term even be

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[31] So far, receiving support under both EEG and KWKG is not possible. In the KWKG, the cogeneration of heat and electricity is supported through remuneration for a contingent of kWh. Combining this form of remuneration with a capacity premium according to the EEG would have the added advantage that the competitiveness of bioelectricity cogeneration plants in the electricity market's merit order would be increased compared to fossil fuel plants, without the need to provide an additional fixed FIP (cf. Sect. 5.4.3.2, Leprich et al. 2013: 63 f.).

integrated into a focused capacity market for low carbon options offering reliable electricity supply (cf. Matthes et al. 2013). Given the diverse nature of income streams, a competitive determination of the capacity premium would be necessary, to make use of dispersed information. To reflect different remuneration needs, a pay-as-bid scheme may perform better than a uniform price approach. However, to avoid full cost-oriented bids, it is not only crucial that other income opportunities are available, but also sufficient competition for tendered quantities must be ensured. This argues for an inclusion not only of new plants, but at least of extensions as well. Meanwhile, calculating plant profitability on the basis of various income streams represents a learning process for market actors and policy makers alike—under these conditions, a dynamic bidding process such as provided by descending clock auctions could provide advantages.

As far as the differentiation according to GHG benefits and environmental impacts is concerned, the analysis indicates that hierarchical requirements have advantages over sustainability standards, as long as bioelectricity supply chains are predominantly based on domestic value chains. While hierarchical requirements result in lower incentive intensity than sustainability standards, they are associated with lower transaction costs and can be effective in improving GHG and environmental balances of bioelectricity production because main influencing factors are quite clear. Requirements can be implemented in a competitive bidding scheme as well as an administered premium; in tenders, they can be more easily adjusted based on learning, resulting in a higher adaptive efficiency. Once plants become operational, reversibility is low also for tenders, but depending on the frequency with which they are undertaken errors affect a smaller number of plants than in an administered price instrument with lengthy revision processes. Meanwhile, low reversibility proves also to be a problem for sustainability standards, because planning security demands a certain stability of standards and GHG calculation methodology.

Besides technical requirements, for example, regarding covered digestate storage tanks, a central requirement that would improve the GHG and environmental balance of bioelectricity production would be a cap on the use of energy crops—this should be defined more broadly than under the EEG 2012, to incorporate not only maize and cereal grains but more generally crops grown on agricultural land using fertiliser inputs. The cap should be ambitious enough to set incentives for using slurry and other wastes and residues, and ensure that GHG emissions and environmental impacts such as eutrophication and acidification from agricultural processes is effectively limited; on the other hand, a limited share of energy crops should remain permissible to improve energy yield and cost-effectiveness of bioelectricity production. If for woody biomass, demand pressures increase further and imports gain relevance, remuneration could be limited to wood or woody residues sourced from certified forests. Such a measure could build on existing sustainable forestry certification schemes, thereby limiting transaction costs.

Secondly, effective heat use incentives are very important for beneficial GHG balances. These could be implemented through ambitious minimum heat use requirements in combination with reporting and monitoring mechanisms which ensure that cogenerated heat is used to meet heat demand formerly supplied by fossil fuels (Scheftelowitz et al. 2014: 136ff.). Alternatively, incentives for heat use could be set economically, by designing remuneration so that high heat revenues are required to ensure plants' profitability. For doing this, offering a capacity premium as part of a portfolio of income streams is an interesting possibility. However, a crucial factor would be that strong competition in tendering processes can be ensured. The smaller the degree of full costs covered by tendered capacity premiums, the higher are incentives for plants to look for further revenue streams to diversify income risks, including also income from participation in balancing markets and agri-environment measures. Besides the Combined Heat and Power Law, revenue opportunities for cogenerated heat could be further supported through the EEWärmeG's RES heat use obligation and MAP incentives for district heating grids.

Setting incentives for the provision of security of supply benefits and improvements of environmental balances of existing plants, meanwhile, remains challenging. Given limited adjustment opportunities for existing plants, the introduction of stringent sustainability criteria with high adjustment costs seems politically unfeasible. Voluntary switches to the MPS were incentivised through higher income opportunities, particularly through the management premium and participation in balancing markets. A short-term option would be to bind eligibility for the flexibility premium in the MPS to requirements that can be implemented with relative ease, for example, the installation of covered digestate storage tanks. Also, the option of extending the flexibility premium to solid biomass plants should be further investigated, in order to provide incentives for flexibility-oriented adjustments in plant design and operation (cf. Scheftelowitz et al. 2014: 142f.).

But also with a competitive bidding scheme, incentives for existing plants to increase security of supply benefits, implement cost reductions and undertake environmental improvements would be desirable. However, since the scheme entails higher risks than receiving remuneration according to old versions of the EEG, voluntary participating is likely to be limited to plants at the end of their remuneration period and those receiving low cost-based remuneration rates. On the other hand, increasing competition for feedstocks and rising resource costs could enhance the attractiveness of changing to a capacity premium, because it would decouple remuneration from production and increase viability of plant concepts focussing on positive load shifts with decreased feedstock input. However, misuse (e.g. claiming the capacity premium for old plants with high operating costs, without producing electricity) would have to be monitored. Meanwhile, direct competition of existing plants with new plants and extensions would depress prices in the bidding scheme and hamper further expansion. Possibilities for the inclusion of existing plants would be the introduction of a separate tender round, possibly with shorter remuneration periods than for new plants; as a lower transaction cost option, an administered capacity premium could be offered to existing plants, aligned in its level with results from tenders. In any case, to incentivise dynamic sustainability improvements, existing plants should be subject to the same environmental requirements as new ones and extensions. Finally, existing plants should be targeted through information and moral suasion instruments aimed at improving their environmental balance.

Even under these conditions, however, it can be stated that a move to a competitive system that does not differentiate according to feedstock costs will entail risks for the profitability of existing plants with low remuneration rates, at least those not able to upgrade and adapt to new market conditions or meet new technical and environmental standards. Even if in the long-term, the cost-effectiveness of bioelectricity generation may increase, in the short term political costs are to be expected alongside a possible increase in policy uncertainty for future investors. This problem would occur with a tendered capacity premium as well as a tendered FIP—but in the latter case, the benefits compared to an administered sliding FIP are much more unclear, as well as its compatibility with future market developments. If adopted, the focus of such a scheme should therefore be on learning processes, acting as a bridge until reforms of market framework conditions and indirect instruments have been undertaken which would allow a more market-oriented tendered capacity premium to work successfully. However, care needs to be taken not to bring technological development to a halt in the meantime, and not to cause lasting insecurity in investors through frequent policy changes.

5.4.4.3 Cross-Sectoral Coordination Requirements

In the neoclassical first-best solution, cross-sectoral allocation of biomass resources would be coordinated by a unified price for GHG mitigation, implemented through a cross-sectoral carbon tax or emissions trading system (see Sect. 3.1.4). With direct support instruments in electricity, heating and transport sectors, alternative solutions need to be found. The expert panels WBA (2007: i) and WBGU (2008: 325) recommend that sectoral instruments should be aligned with a common carbon price, excluding more expensive options from support. Given that in quantity instruments, prices are determined by the market, such an alignment could be more easily implemented through administered price instruments. However, this solution neglects that costs of RES alternatives and also fossil fuel options differ between sectors. Using a unified price as an orientation could lead to a strong expansion of biomass use in the heating sector, where it can at times already be competitive with fossil fuels and where in principle many alternative GHG mitigation measures exist, whereas in the transport sector it may be too low to incentivise biofuel use at all.

Quantity instruments, on the other hand, allow for the implementation of a certain share of bioenergy use in all three sectors, but can have strong distortionary effects. An example is the biofuel quota which has brought pathways with high GHG mitigation costs into the market. This distortionary impact is particularly relevant when a high level of demand is created, as has been the case with the quota. So far, distortions between energetic uses have mainly affected the use of agricultural areas for energy crop production, destined either for biofuel processing or biogas production, and the use of solid bioenergy carriers, either in heat or electricity (incl. CHP) production. Of course, distortions affect also resource competition between energetic and non-energetic uses. Moreover, the change from an energy content- to GHG-based biofuel quota is likely to increase transport sector demand for wastes and residues, where the ability to pay for resources may potentially be much higher than in the electricity sector or in material recycling applications.

Distortions can be limited by hybrid elements, such as buy-out prices in the biofuel quota or price limits in a competitive bidding scheme. However, if buy-out prices or limits are set too low, incentives for RES investment are strongly reduced. Also, biomass allocation is influenced by market price developments. Increasing gas prices, for example, improve the competitiveness of using biomass in domestic heating applications, even if in terms of GHG mitigation CHP options may be more advantageous.

To address trade-offs associated with hybrid elements and interactions of policy incentives with market price developments, coordination measures that go beyond a coordination of price signals are required. In the transport sector, the GHG-based quota's impacts on resource competition should be closely monitored; if significant distortions appear, an adjustment of buy-out prices may become necessary, although such a step would no doubt be opposed by biofuel market actors and might have negative impacts for the credibility of future political commitments. Instead of increasing the biofuel quota further beyond 2020, incentives for other GHG mitigation options in transport should be strengthened. Similarly, in the heating sector, existing instruments such as the EEWärmeG and the MAP should be adjusted so that the use of district heating and biomass-based CHP, other RES options and efficiency measures is incentivised more strongly, rather than domestic heat-only biomass applications. This could be implemented through an adjustment of technology-specific minimum RES shares in the EEWärmeG, and the choice of measures supported under the MAP (see Sect. 4.2.4).

Further coordination requirements pertain to the feed-in of biomethane into the gas grid. The fact that it can be supplied flexibly to heating, electricity and transport sectors, depending on demand, benefits an efficient allocation (see Sect. 4.1.3.2). On the other hand, GHG mitigation benefits change depending on what sectoral energy mix is displaced (cf. Patterson et al. 2011). Under the current EEG, remuneration of biomethane is based on its use for electricity generation (section 47 EEG 2014). If remuneration was changed to a tendered capacity premium, this requirement would be more difficult to implement. In such a case, a plant could benefit from support in the electricity sector and transport sector both, for example, if biomethane was sold as biofuel. If sufficient competition in tenders can be ensured, however, this case of "double support" need not be a problem. On the other hand, it would contribute to a diversification of income streams, and allow biomethane plants with higher costs than "conventional" biogas plants to make competitive bids.

5.5 Summary: Conceptual Recommendations for a Rational Bioenergy Policy

By applying theoretical insights developed in Chap. 3 to the case of German bioenergy policy, this chapter has developed NIE-based recommendations for a rational bioenergy policy concept and contrasted them with neoclassical recommendations. A policy concept allows for coherent policy making in governance contexts characterised by high complexity, by acting as a reference system for individual policy decisions.

5.5.1 Elements of a Bioenergy Policy Concept

Adapting a definition from the theory of economic policy, a policy concept is understood here as a system of consistent aims, allocative principles regarding how resource allocation should be steered in order to implement aims, and instruments for influencing economic allocation processes. In order to comply with the requirements for a rational bioenergy policy defined in Sect. 2.1.3, a system of policy aims should be sufficiently complete, consistent, allow for an operationalisation of aims and indicators, be controllable by a responsible agency and politically and economically feasible; moreover, the system of aims should be defined in a transparent and democratically accepted process and reflect trade-offs. Given conflicts between aims, the establishment of a complete and consistent system of policy aims with a clear hierarchy is found to be of particular importance for bioenergy policy design.

The choice of an allocative principle determines what allocation mechanism is used to implement aims. Transaction cost and contract economics offers the insight that there is a continuum of allocation mechanisms between markets and hierarchies, which represent extremities at each end of the spectrum. Allocation mechanisms which balance towards the market end provide high incentive intensity and allow market actors to adapt autonomously to disturbances using time- and space-dependent knowledge. More hierarchical modes of steering resource allocation, on the other hand, provide investment safeguards and coordinated responses to disturbances, but rely to a greater degree on centrally available knowledge. For different allocative challenges, different allocative principles may be appropriate.

Moreover, a concept should include a choice of instruments which are considered appropriate for achieving aims, and are generally in line with the chosen allocative principle. Moral suasion instruments and indirect incentive instruments which change relative prices represent governance structures close to the market mechanism, whereas direct incentive instruments which administer prices or quantities and command-and-control instruments are more hierarchical governance structures.

5.5.2 NIE-Based Recommendations for a Rational Bioenergy Concept

For developing NIE-based policy recommendations, Sects. 5.2–5.4 have discussed theoretical insights for the definition of a system of policy aims, the choice of allocative principle and instrument choice and design. Recommendations, which are based on an evaluation of German bioenergy policy against these insights, are summarised in the following.

5.5.2.1 Recommendations for the Definition of a System of Policy Aims

Compared to the neoclassical approach, second-best theory stresses that market or policy failures which are unresolvable at least in the short term need to be taken into account in policy recommendations. To achieve this, a bioenergy concept needs to consider the entire system of relevant policy aims, encompassing both efficiency-oriented and distributive aims. However, the many uncertainties involved in bioenergy policy mean that the extent and shape of interactions between multiple aims and market failures will often be assessable only with hindsight. Furthermore, uncertainties need to be considered when setting targets, which need to strike a balance between credible commitment and adjustability in the light of new information and changing framework conditions. Taking this into account, the theories examined in Chap. 3 yield important implications concerning the definition of a complete and consistent system of policy aims and the balancing of trade-offs, as well as the use of targets for operationalising aims.

Although the system of aims of German bioenergy policy has become more comprehensive over time, a transparent discussion of trade-offs and a clear prioritisation of aims is lacking. Instead, policy strategies focus on supposedly synergistic options, and policy instruments are adjusted when conflicts become major issues in the public discourse. Bioelectricity and biofuel sectors in particular have been subject to shifts in political priorities, significantly increasing policy uncertainty for investors. In order to provide the planning security necessary for incentivising asset-specific investments and, eventually, structural changes, an open discussion of trade-offs is needed, leading to a stable and credible hierarchy of policy aims and an operationalisation of what constitutes sustainable bioenergy use. Stakeholder consultation processes can contribute to this process, as can a clear assignment of political responsibilities to ministerial agencies, which can act as advocates for the aims in their sphere of influence. For this reason, bioenergy policy should remain a cross-sectional task which includes all relevant ministries in decision making processes. Moreover, once an understanding has been established what constitutes unacceptable costs of bioenergy use, the definition of binding and transparent guard rails can help to safeguard the sustainability of developments while providing long-term planning security for market actors.

Which priority aim should guide an intervention on behalf of bioenergy must in the end also emerge from the political and deliberative process. From an economic perspective, neoclassical arguments for aligning bioenergy policy with GHG mitigation rather than rural development or security of energy supply hold even if the political importance of other aims is taken into account, because such a prioritisation holds the greatest potential for synergies between the three aims. Meanwhile, public choice theory highlights the challenges involved in establishing credible commitment for a hierarchy of policy aims or implementing a transparent deliberative process for balancing trade-offs. For realising a rational bioenergy policy, these challenges will need to be overcome.

For the operationalisation of aims, the use of quantified targets appears particularly useful for aims which require highly asset specific investments for their achievement. In particular, this is the case for GHG mitigation, and for RES expansion as a lower level aim. For rural development creation and security of energy supply, the definition of adequate targets covering all relevant facets would be challenging, suggesting that a focus on whether or not desirable structural changes have been initiated appears more appropriate.

In order to provide reliable long-term guidance for market actors, targets need to be formulated at a level which is sufficiently technology neutral to allow for decentralised search processes for solutions under changing framework conditions. If this is not the case, frequent adjustments are required, which increase policy uncertainty. In the electricity sector, where a number of feasible technological RES alternatives are available, the current combination of binding RES targets and EU-ETS emission reduction pathways represents a sensible balance between maintaining flexibility in how targets are met, and providing investment safeguards. In the transport sector, where biofuels are the primary RES option to date, a sectoral GHG emission reduction target might prove more appropriate than a RES target, because it would allow for greater flexibility in choices between RES use, energy efficiency improvements and absolute reductions in energy use. In the heating sector, a sectoral GHG emission reduction target also promises to be favourable compared to a sectoral RES target. The latter fails to reflect the diversity of the building stock, which determines the relative advantages of energy efficiency measures, RES-based heat production or the use of district heating, and the significant role that efficiency improvements are expected to play in reducing future heat demand.

Moreover, targets need to be backed by credible political commitment. For this, implementing long-term targets in law is in itself not sufficient; rather, policy makers have to initiate a process of institutional change that supports the realisation of targets. To guard against a reversal of policies, this process needs to create constituencies with vested interests in the implementation of targets. At the same time, institutional changes should adhere to requirements of adaptive efficiency. To avoid new inefficient lock-ins, a gradual implementation of policies which allows scope for learning processes is recommendable. Also, if non-reversible negative side effects of an intervention on other societal aims are a possibility, the precautionary principle should be applied when setting binding targets.

5.5.2.2 Recommendations for the Choice of Allocative Principles

In comparison to a neoclassical approach, the NIE perspective displays two major differences when it comes to the choice of allocative principle. Firstly, interactions between GHG mitigation and other policy aims and unresolved market failures have to be taken into account when formulating policy recommendations. Secondly, the choice of allocative principle is not viewed as a choice between markets on the one side, and hierarchies with a central steering of allocation decisions on the other; rather, there is a continuum of governance options to choose from. As a simplification, a distinction can be made between a steering approach which is closer to the market end of the spectrum (defined as "market-based intervention" in the following), and a steering approach in which hierarchical elements outbalance market elements (defined as "hierarchical intervention" in the following). Under some circumstances, such hierarchical interventions can be more efficient than interventions which are balanced towards the market end of the spectrum.

Rationale for Hierarchical Interventions in the Choice of GHG Mitigation and RES Options

Technology choices in the energy sector are not only distorted by GHG externalities, but also by knowledge and learning externalities and path dependencies. Under these circumstances, hierarchical interventions in technology choices are found to be necessary, in order to promote technological diversity, reduce the long-term costs of GHG mitigation and overcome the institutional and technological lock-in. Technology-neutral market-based interventions, on the other hand, would only promote the adoption of those GHG mitigation options which are the most cost-effective from a static perspective, given existing institutional framework conditions. Furthermore, investments which are costly and irreversible and whose profitability depends on the continued existence of policy incentives will only be undertaken in the presence of reliable safeguards. For GHG mitigation options which require highly asset specific investments, hierarchical interventions with high investment safeguards and coordinated adaptation responses entail lower transaction costs than market-based interventions, even though the latter result in higher incentive intensity to search for low cost options and impose fewer information requirements on policy makers.

These arguments provide a rationale for hierarchical interventions on behalf of asset specific RES investments, for instance. Investments with low asset specificity, on the other hand, are more efficiently governed by market-based interventions. Therefore, from an NIE perspective, combining indirect interventions close to markets such as the EU-ETS and direct hierarchical ones such as RES support schemes performs quite well.

Rationale for Hierarchical Interventions on Behalf of Bioenergy as a GHG Mitigation Option

In assessing German bioenergy policy, however, the question needs to be answered whether this rationale can be extended to hierarchical interventions on behalf of bioenergy. Here, high asset specificity applies especially to investments in biofuel production facilities and dedicated bioelectricity plants, which would not be able to compete in the absence of state interventions. Hierarchical interventions on behalf of these bioenergy options can be called for, if allocation decisions are distorted by knowledge and learning spillovers or path dependencies.

Compared to wind, solar and hydropower, dedicated bioelectricity is a comparatively expensive RES option. A technology-neutral RES support instrument would therefore lead to only very low levels of bioelectricity expansion. Learning spillovers, which can justify cost-based support for innovative RES, are limited in the case of bioelectricity—major technologies have reached a comparatively high level of technological maturity. Potentials for incremental innovation remain, but the potential for cost reductions is limited because of the large impact of biomass costs on electricity generation costs. However, a rationale for technology-specific bioelectricity can be inferred from interactions between security of supply externalities and path dependencies. As a dispatchable RES option, bioelectricity technologies can make higher contributions to security of supply than intermittent RES. At the same time, the current electricity market remains dominated by fossil fuel capacities with sunk investment costs, resulting in market price signals which do no incentivise investments in low carbon options for balancing fluctuations in the supply of intermittent RES. Deployment support for flexible bioelectricity plants can therefore be justified if it allows for a further development of bioenergy technologies as part of a portfolio of RES technologies, until the path transition is so far progressed that market framework conditions and indirect instruments provide sufficient incentives and planning security for investing in low carbon flexibility options. Path dependency considerations furthermore support the exclusion of biomass co-combustion in coal power plants from direct support instruments. At the same time, indirect instruments such as the EU-ETS and energy taxes should be reformed to play a stronger role in governing GHG mitigation and energy sector investment decisions with lower asset specificity, to act as complements to direct instruments.

Biofuels, on the other hand, show not only strong differences in GHG balances, but also in learning and knowledge spillovers—energy crop-based first generation pathways are comparatively mature, but second generation biofuels from wastes, residues and lignocellulose feedstocks are associated with high innovative potentials. The same is true for specific applications, such as the use of biofuels in aviation. Path dependencies, meanwhile, are less relevant, because biofuels can be easily integrated into fossil fuel infrastructures and existing demand and supply patterns. Both first and second generation biofuels can make contributions towards an improved security of energy supply, but limited sustainable resource potentials reduce the extent of such contributions. For biofuels, it would therefore be recommendable to differentiate more strongly between pathways not only according to GHG balances, but also according to the learning and knowledge externalities they generate. For German bioenergy support, this would imply phasing out hierarchical interventions on behalf of first generation biofuels, focussing technology-specific support more strongly on second generation technologies where asset specificity combines with an expectation of significant knowledge and learning spillovers and future cost reductions. Also, biofuel policies should be accompanied by stronger efforts on behalf of other GHG mitigation and energy efficiency measures in the transport sector, using both market-based and hierarchical allocative principles depending on transaction characteristics.

In the heating sector, bilateral dependency between regulators and market actors is less pronounced, because biomass applications are closer to commercial competitiveness. Here, interventions which leave market actors the choice between different GHG mitigation options promise efficiency advantages. However, the non-identity of investors and heat consumers poses problems for the effectiveness of price signals, so that it is a sensible approach to complement governance structures close to markets with more hierarchical interventions, such as the EEWärmeG. Meanwhile, the EEWärmeG offers lower investment safeguards than EEG or biofuel quota, and generates higher incentive intensity to search for low cost options not only among RES technologies but also energy efficiency or district heating options. As far as bioenergy applications are concerned, this characteristic performs well when compared to theoretical recommendations.

Investments further down the bioenergy value chain, such as in the primary production sphere and intermediate processing stages, also tend to be characterised by low asset specificity, because the degree of bilateral dependency between biomass producers and buyers tends to be comparatively low. In German bioenergy policy, major hierarchical interventions focus on the utilisation sphere, again performing well in this regard.

Rationale for Hierarchical Interventions in Downstream Allocation Decisions in Bioenergy Value Chains

The question remains what further interventions in bioenergy value chains are required if an intervention on behalf of bioenergy aggravates other market failures and impacts other societal aims. The most efficient solution would be to ameliorate persistent market failures by policy measures which are aimed at all relevant sectoral allocation decisions, not just bioenergy. Even if first best solutions are infeasible, interventions which apply not only to bioenergy value chains but also other biomass uses have the advantage that allocation decisions between energetic and non-energetic biomass uses are not distorted. Here, the German and European policy context show clear scope for improvements. In particular, improvements of institutional framework conditions for primary biomass production and land use are needed, such as an adjustment and more stringent enforcement of good professional practice and cross compliance rules as well as a further greening of agricultural subsidies under the CAP. Furthermore, improvements in waste and recycling regulation could increase the profitability of developing a greater share of technically available waste potentials for energetic uses.

On the other hand, it is not recommendable to undertake further hierarchical interventions in downstream allocation decisions in bioenergy value chains to correct for side effects of the original intervention (e.g. bioenergy-specific environmental regulations in the primary production sphere). Not only do such corrective interventions distort biomass allocation decisions, their effectiveness is also severely limited by displacement effects. Furthermore, if additional interventions have unintended consequences of their own, displacement effects become obvious, or biomass demand increases due to other reasons than bioenergy policy, this approach would entail further interventions, leading to a complex system of end use-specific regulations with high transaction costs. In general, German bioenergy policy does not tend to use bioenergy-specific regulation to address interactions between utilisation-sided support measures and other aims and market failures. An important exception is the use of import tariffs on biofuels and bioliquids. These seem to be primarily motivated by the aim of domestic rural development; for differentiating between pathways according to sustainability characteristics, they do not prove effective. Given the hierarchy of policy aims argued for above, the distortionary impact of import tariffs argues for their abolishment.

Meanwhile, if comprehensive reforms of policy framework conditions are not possible at least in the short term, it is advisable to adjust utilisation-sided, GHG mitigation-oriented interventions to take adverse interactions with other aims and market failures into account. This can be done, for instance, by differentiating between bioenergy technology-feedstock combinations according to side effects such as environmental impacts when designing utilisation-sided interventions. While this is the approach primarily adopted by German bioenergy policy, it has proven problematic that instruments have frequently triggered a large-scale demand for certain pathways and were only adjusted afterwards in consecutive trial-and-error processes. To avoid associated transaction costs, policy uncertainty, and potentially irreversible impacts, it is recommendable to implement interventions on behalf of bioenergy gradually, and avoid the creation of large-scale demand for pathways associated with significant uncertainties.

5.5.2.3 Recommendations for Instrument Choice and Design

The NIE perspective suggests that a comprehensive bioenergy concept needs to consider several dimensions of instrument choice and design, including: (i) adjustments of environmental, agricultural and waste framework regulations, to address interactions between multiple aims and market failures; (ii) a strengthening of indirect instruments close to the market-based allocative principle, such as the EU-ETS or energy taxes, to incentivise the use of bioenergy and other GHG mitigation options with low asset specificity; (iii) direct instruments closer to the hierarchical allocative principle, such as sectoral deployment support, to incentivise bioenergy and other GHG mitigation options with high asset specificity which are affected by knowledge and learning spillovers and/or path dependencies; and (iv) adjustments of utilisation-sided direct instruments, to address interactions between multiple aims and market failures.

This breadth of scope makes a focus necessary. In German bioenergy policy, direct interventions in the utilisation sphere have so far been the most relevant for bioenergy expansion, and adjustments to their design play an integral part in taking interactions between policy aims and market failures into account. The analysis of allocative principles has shown clear scope for improvements when it comes to aligning interventions with transaction characteristics: a rationale for bioenergy-specific deployment support exists only in case of flexible bioelectricity pathways, where high asset specificity combines with interactions between GHG externalities, security of supply externalities and path dependencies; and second (and eventually third) generation biofuels, where high asset specificity meets interactions between GHG externalities and knowledge and learning spillovers. Among these two cases, recommendations for the electricity sector have currently the higher political relevance, given the ongoing discussion about the future development of the EEG and the planned transition from a feed-in tariff and feed-in premium to a competitive bidding scheme. In developing recommendations for instrument choice and design, this study therefore focuses on the further development of direct interventions in the German electricity sector, i.e. remuneration schemes for bioelectricity pathways. Nonetheless, interactions between remuneration schemes and the wider bioenergy policy mix (cf. Table 4.4 in Sect. 4.2) have to be taken into account, including effects on the cross-sectoral competition for biomass resources.

For instrument recommendations, the ability of alternative options to deal with uncertainty is found to be of central importance in bioenergy policy design. At the same time, the choice and design of instruments determines the exact balance between hierarchical and market-based elements, and the way in which trade-offs between investment safeguards and incentive intensity are solved. For handling the allocative challenges of bioenergy use, three elements are particularly important:

1. *The choice between price, quantity and hybrid instruments*: This choice affects the social costs of erroneous judgements about the private costs of bioelectricity expansion, the external costs associated with it, and the external benefits arising from bioelectricity's contribution to RES targets. The advantages of adopting price or quantity instruments under uncertainty depend on the relative slopes of the MC and MB curves of bioelectricity production, but estimating these is not straightforward. Besides potential correlation between cost and benefit uncertainties, the presence of multiple benefits besides GHG mitigation complicates the assessment of the MB curve, while the MC curve's slope depends on whether the scale of bioelectricity expansion aimed for is significant compared to the available resources. Under these conditions, hybrid instruments represent options for introducing elements of cost control into quantity instruments or quantity constraints into price instruments.
2. *The design of a mechanism for technology differentiation*: In order to reflect the heterogeneity of private and external cost characteristics of bioelectricity pathways, it is recommendable to establish a mechanism for differentiating between technology-feedstock combinations. Basic alternatives are a uniform support level with minimum sustainability criteria, or technology-specific support levels. The former option results in high incentive intensity to reduce production costs and costs of compliance with sustainability criteria. In case of technology-specific support levels, greater information requirements apply to policy makers,

and costs of errors are higher because decisions apply to all eligible bioelectricity projects; however, planning security for investors is high, and transaction costs are likely to be lower than under sustainability certification. Moreover, cost-based technology-specific support levels can reduce support costs compared to a uniform level of remuneration.

3. *The design of an adjustment mechanism*: Adequate adjustment mechanisms (e.g. revisions or ex ante rules) which allow for adaptations to changing framework conditions and the correction of errors are a prerequisite for robust regulations. In order to meet adaptive efficiency requirements, adjustment mechanisms should ensure the potential reversibility of policy impacts, and instruments should ensure openness to experimentation. However, as policy adjustments can lead to policy uncertainty, balancing flexibility and planning security is a challenging task. Adjustment mechanisms need to be considered both in the choice of instrument type and technology differentiation mechanism.

Below, main performance characteristics of the current FIT/FIP scheme and relevant alternatives for bioelectricity deployment support are summarised, followed by a short résumé of instrument recommendations.

Choice Between Price Instruments, Quantity Instruments and Hybrids: Performance of the Current FIT/FIP Scheme and Relevant Alternatives

FIT and MPS both offer a high degree of control over private costs, and provide investors with high planning security. This results in a high effectiveness when it comes to incentivising investments in bioelectricity technologies with high asset specificity, and also in low risk premiums. However, reference prices emerge from a political negotiation process characterised by diverse interests, and offer only limited control of the expansion level and associated total support costs and external costs. Introducing a breathing cap as a hybrid element can partially remedy this problem, but setting caps which balance an effective steering of bioelectricity expansion with planning security for project developers remains challenging. Like errors in setting reference prices, errors in setting caps require transaction-cost intensive revision processes, where the very non-reversibility of policy decisions for existing plants which is the basis for the scheme's high planning security results in low adaptive efficiency.

For the further development of bioelectricity support, the following instrumental alternatives have been identified as most relevant: a sliding feed-in premium, either administered as in the current market premium scheme or tendered as part of a competitive bidding scheme; a fixed feed-in premium, likewise either set administratively or tendered; and an administered or tendered fixed capacity premium.

Among these, it is found that neither an administered fixed FIP nor an administered capacity premium are promising options for controlling social costs of errors. For one, higher price risks for market actors result in higher risk premiums than under a sliding FIP scheme, and thus higher costs of target achievement; for the other, uncertainty about electricity price developments also applies to policy makers, increasing the difficulty of administratively setting price premiums and using them to control expansion levels.

When comparing an administered sliding FIP with a tendered sliding FIP, there is no unequivocal answer whether introducing a competitive bidding process would reduce the costs of errors and lead to increases in overall cost-effectiveness. A competitive bidding process could help to reveal the costs of implementing an expansion corridor, if sufficient competition for tendered quantities can be ensured. Control over support costs could be increased through price caps or the adoption of dynamic bidding processes, which allow for an adjustment of tendered quantities and bids based on information revealed in the bidding process. Both options, however, increase transaction costs of bidding schemes, potentially negating increases in cost-effectiveness compared to an administered sliding FIP. Also, competitive bidding schemes do not necessarily provide a higher level of control about expansion levels than an administered sliding FIP with a breathing cap, particularly if hybrid price elements are included.

A tendered capacity premium, meanwhile, could prove to be an interesting alternative. Higher price risks would still be likely to result in higher risk premiums than under either an administered or tendered sliding FIP. However, in making bids, market actors could take diverse income streams, for example on spot markets, balancing markets and heat markets, into account, about which they have better information than policy makers. A tendered capacity premium is therefore likely to perform better than its administered variant. Compared to a sliding FIP, a capacity premium sets incentives for a more efficient dispatch, but higher security of supply benefits would have to be weighed against the costs of higher risk premiums which would be reflected in bids.

Implementation of Technology Differentiation: Performance of the Current FIT/FIP Scheme and Relevant Alternatives

To varying degrees, FIT and MPS differentiate according to installation sizes, technology and feedstock costs, GHG balances and other environmental impacts, and security of supply benefits. This is done by differentiating reference prices and additional premium payments according to the technologies and feedstocks used; also, policy makers set requirements which need to be met as a precondition for support. Minimum sustainability standards in combination with a certification scheme as a further option for differentiation have so far only been implemented for bioliquids, which, since the EEG 2012, are no longer eligible for support.

Overall, German bioelectricity policy has adopted a rather hierarchical steering approach when it comes to technology differentiation. Policy makers decide which technology-feedstock combinations are deemed beneficial, and provide framework conditions which make them profitable given expectations about production costs. Even if the assessment of technologies or feedstocks changes, amendments in the EEG generally only apply to new plants, resulting in a high degree of planning security for existing plants. However, bioelectricity producers tend to optimise plant concepts according to policy makers' specifications, limiting the scope for decentralised search processes. Also, information requirements on policy makers are high, leading to frequent adjustments of reference prices and eligibility requirements. At the same time, dynamic incentives for existing plants to increase environmental and security of supply benefits are low.

The EEG 2014 has abolished differentiation according to feedstocks used, alongside most hierarchical requirements. Also, direct marketing has been made obligatory for all but small-scale plants. In this way, the EEG 2014 has moved towards a more market-based approach, where producers bear a higher share of price and dynamic cost uncertainties; as a result, they face higher incentive intensity when it comes to minimising costs and maximising the market value of their electricity. However, the instrument retains few control mechanisms for steering GHG benefits or environmental impacts. Furthermore, the abolishment of substrate tariff classes has led to strong reductions in support levels; at the same time, low cost biomass potentials are largely exploited. Breaking alignment of support levels with biomass supply curves has markedly decreased incentives for further bioelectricity investments.

Meanwhile, hierarchical or market-based approaches to technology differentiation can be adopted no matter whether reference prices are set administratively or tendered. Tenders which do not differentiate between technology-feedstock combinations promote cost-effectiveness and can, if sufficient competition exists and strategic bidding can be avoided, lead to reductions in bioelectricity generation costs compared to an administered price instrument. However, new plants are likely to achieve a higher ability to pay for biomass resources than existing ones receiving cost-based support, leading to increased competition for limited low cost resource potentials. This may cause existing plants to exit the market, illustrating the difficulties of changing from a cost-based FIT and FIP to a competitively determined remuneration. The effect is likely to be more pronounced in bidding schemes using a uniform price approach, but can also occur with pay-as-bid processes.

While inviting separate tenders for different feedstock-technology-combinations is not a promising approach, hierarchical elements can be introduced through eligibility requirements and technology- or feedstock specific price caps. The latter, however, increase complexity of the scheme and inhibit its price discovery function. Also, by introducing an additional limit to producer rents, on top of the competitive determination of remuneration, incentives for participation and investments decrease. Eligibility requirements, meanwhile, represent an alternative to sustainability certification, when it comes to a differentiation according to GHG and other environmental characteristics. It is found that hierarchical requirements prove advantageous as long as bioelectricity supply chains are predominantly based on domestic value chains. In this case, the main influencing factors for improving GHG and environmental balances can be controlled through a limited number of hierarchical requirements, such as technical requirements, for example, regarding covered digestate storage tanks, a cap on the use of energy crops grown with fertiliser input, and heat use requirements. Hierarchical requirements result in a lower incentive intensity to search for improvement possibilities than sustainability standards, but this disadvantage is balanced by lower transaction costs.

However, setting incentives for improving the environmental balance of existing plants without compromising planning security remains challenging—besides moral suasion and information instruments, cost-based compensation can be offered, but this increases support costs; alternatively, it may be possible to tie access to additional income opportunities (e.g. the flexibility premium) to compliance with environmental requirements. If competitive bidding schemes offered contracts which were shorter than depreciation periods, enhanced environmental requirements could also be applied when plants reapplied for remuneration. Meanwhile, both eligibility requirements and sustainability certification should be further accompanied by other instruments such as regional planning and the non-bioenergy specific adjustment of environmental and agricultural framework regulations.

When comparing the implementation of hierarchical requirements in an administered FIP and a competitive bidding scheme, the latter has the advantage of being more easily adjustable to new information. Furthermore, a competitively determined capacity premium could provide opportunities for differentiating between technologies and feedstocks based on income streams. A precondition, however, is that competition for tendered quantities is strong enough that producers do not bid for capacity premiums that cover a large share of their full costs, but have incentives to explore revenue streams from heat markets (potentially including cogeneration incentives), balancing markets, and agri-environment measures for feedstocks with high environmental co-benefits.

Summary of Recommendations for German Bioelectricity Support

The analysis shows that compared to an administered sliding FIP, the advantages of a tendered sliding FIP are highly uncertain. Cost-effectiveness improvements, for instance, depend crucially on the existence of sufficient competition for tendered quantities and the avoidance of strategic bidding. Attempts to minimise support costs alongside electricity generation costs are likely to result in a degree of complexity that is comparable to an administered option, with comparable information requirements but significantly higher transaction costs. At the same time, new problems arise with regard to the competition between new and existing plants for low cost resources. Furthermore, while in the absence of overly restrictive price caps, projects based on energy crops may still be profitable, no mechanism remains to incentivise the use of feedstocks with higher private costs but environmental co-benefits. Regarding incentives for security of supply benefits, there are no structural differences between a tendered or administered sliding FIP.

Among short-term instrumental alternatives, the EEG 2012s approach to make remuneration largely technology-independent but differentiate according to feedstock categories performs comparatively well. It allows further bioelectricity expansion and technology development, while performing better in minimising support costs than a competitive scheme without a price cap. Overly stringent price caps in a bidding scheme would cause a halt in further expansion, as is the case with the EEG 2014; in comparison, cost control in an administered sliding FIP with substrate tariff classes can be improved through the inclusion of a breathing cap as a quantitative constraint. To improve cost-effectiveness incentives within feedstock categories, a reduction in installation size-based differentiation would be promising. This would incentivise the use of economies of scale, and seems adequate to reflect the comparative maturity of technologies. Furthermore, it seems recommendable to further pursue the EEG 2012s approach to safeguard GHG benefits and limit external costs through the use of hierarchical eligibility requirements, at least as long as value chains remain predominately regional.

With an increasing cross-sectoral integration of RES-based energy production and a widening portfolio of RES flexibility options in the electricity system, however, an administered FIP is bound to meet limits. For the longer term development of bioelectricity policy, it therefore seems advisable to encourage producers to explore and combine a range of income streams in markets where they compete with other RES and low carbon technologies on a fair footing. In such a context, a tendered capacity premium could realise comparative advantages compared to other instrument options: besides other income streams from electricity, balancing, heat but also transport markets it could act as a compensation for bioelectricity's contribution to the system stability of a RES-based electricity system, without distorting cross-sectoral allocation decisions. Moreover, it would show good compatibility with capacity markets, if these were to be introduced in the electricity sector. Given the highly project-specific nature of income streams, the competitive determination of remuneration would fulfil an important price discovery function. However, an important prerequisite is that relevant markets offer higher revenues to dispatchable RES options than is the case today—this requires adjustments in market framework conditions, but also reforms of indirect instruments such as the EU-ETS, to improve bioelectricity's competitive position compared to fossil fuels. As an incentive for CHP production, a combination with remuneration from the Combined Heat and Power Act would be possible. The use of bioelectricity production for waste and slurry disposal could be incentivised through revisions of waste and agricultural law. Furthermore, to support feedstocks with added environmental co-benefits, an extension of agri-environment schemes would be desirable.

In the outlined scheme, a degree of differentiation between technology-feedstock combinations would be established through access to different income streams. Accordingly, projects with comparatively high costs would have to use decentralised information to develop projects with high revenues. To fully take advantage of the competitive bidding scheme's price discovery mechanism and cost-effectiveness incentives, tenders should refrain from introducing additional cost-based differentiation under these conditions. To reflect different remuneration needs, a pay-as-bid approach to price setting seems promising, and a dynamic descending clock tendering process may prove advantageous to allow for learning on the side of market actors and policy makers both. However, further research is required regarding design recommendations. To limit GHG emissions and environmental impacts, it would remain advisable to link the tendered capacity premium to eligibility requirements.

Problems regarding competition to existing plants would remain with a tendered capacity premium. In the context described above, bids would not be full-cost oriented, but total revenues may well come to lie above those of existing plants with low cost-based remuneration rates. As a consequence, it would be desirable to allow existing plants access to the scheme as well, to increase potential revenues. This would also set important incentives for an improved provision of security of supply benefits, and could set incentives for environmental improvements, if participation was tied to the same environmental requirements as for new plants. However, direct competition of plants whose investment costs were largely recovered on the one hand and new plants and extensions on the other might lead to distortions in price determination and could prevent further expansion; more research is necessary to determine whether an inclusion of existing plants in tenders, separate tender rounds or an administered capacity premium that was aligned with tender results could prove more promising.

In addition, instrument design has to pay attention to coordination requirements with direct instruments in heating and transport sectors, as well as with incentives for substituting fossil fuels for biomass. With RES targets for individual sectors, a strict alignment of bioelectricity support instruments with a common carbon price would not necessarily prove adequate, given that costs of alternative RES options differ between sectors; moreover, other relevant distinctions between pathways such as security of supply benefits may prove relevant. Nonetheless, instruments should be coordinated so as to avoid a strong distortion of cross-sectoral biomass allocation. Quantity instruments in particular can have strong distortionary effects, if a high level of demand is created. Hybrid elements, such as buy-out prices in the biofuel quota or price limits in a competitive bidding scheme, can improve coordination in this respect. Moreover, market prices for fossil fuel substitutes which do not adequately reflect associated externalities can distort biomass flows. To counter adverse developments, it is advisable to monitor cross-sectoral distortions in resource competition, and adjust instrument parameters (e.g. reference prices or tendered quantities in the electricity sector, buy-out prices in the transport sector, technology-specific minimum RES shares in the heating sector) if necessary.

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Chapter 6
Conclusions

Bioenergy can play an important role in the transition to a low carbon energy supply. However, as this study has demonstrated, both markets and policy makers are faced with significant challenges when attempting to steer bioenergy allocation decisions towards an efficient and sustainable outcome. Multiple interacting market failures, technological path dependencies, the role of incomplete and asymmetrical information and transaction costs in market transactions, uncertainty about the sustainable limits of the environmental carrying capacity and the preferences of future generations—all these factors combine in preventing the market outcome of bioenergy allocation to meet these normative criteria. Policy interventions, however, likewise have to deal with information problems and transaction costs of regulation, institutional path dependencies, coordination requirements between different governance levels from local to global, conflicts between various relevant policy aims, and conflicts between economic and political rationality. As a result, it is extremely unlikely that policy interventions will succeed in addressing market failures in such a way that the outcome is efficient in a Paretian sense; also, the identification, adoption and implementation of measures that will reliably guarantee long-term sustainability is exceedingly difficult. As a result, the focus shifts to a comparison of the respective advantages of markets and policy interventions in steering bioenergy allocation decisions.

To reflect this, this study has specified requirements for a rational bioenergy policy, which strives for efficiency and sustainability under all of the mentioned constraints, while acknowledging the likely non-optimality of outcomes. This approach highlights the necessity of identifying solutions for a rational handling of uncertainty in political decision making, policy design and implementation; moreover, in order to ensure the practical relevance of recommendations, political feasibility considerations have to be taken into account.

In the literature, a theoretical framework for developing comprehensive recommendations for a rational bioenergy policy under real life conditions is still missing. Economic policy recommendations are either based on neoclassical economics, with its rather abstract assumptions, at least as far as long-term recommendations

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are concerned (SRU 2007; WBA 2007; Kopmann et al. 2009; Frondel and Peters 2007; Klepper 2010), or they focus on the incremental further development of individual, existing bioenergy policy instruments (e.g. Scheftelowitz et al. 2014). Even when recommendations deviate from neoclassical findings (e.g. WBGU 2008, cf. Sect. 4.5), the theoretical basis for such a deviation is not explicitly developed.[1]

This book has filled this gap by developing a theory-based analytical framework for economic bioenergy policy advice which takes multiple real-world constraints on policy making into account, with the aim of deriving concrete recommendations for the case of German bioenergy policy. Parallels between the German bioenergy policy mix and bioenergy policies of other EU and non-EU countries ensure the relevance of results for other institutional contexts. Furthermore, with adjustments, the analytical framework can be transferred to other problems of environmental policy making where multiple market failures meet multiple risks of government failures, and uncertainties associated with the environmental costs and benefits of measures are high. Below, major results of the study are summarised, followed by a discussion of their transferability and an outlook.

6.1 Major Results

In addressing its research questions, this study has arrived at four major results, which will be summarised in turn. From a methodological perspective, it has been found that insights from new institutional economics in particular have a high relevance for providing a theoretical basis for economic policy advice on complex environmental policy problems, such as those posed by bioenergy policy (Sect. 6.1.1). Furthermore, the application of the study's analytical framework to the case of German bioenergy policy has generated recommendations for the three elements of a rational bioenergy concept, which differ significantly from recommendations based on neoclassical theory (see Table 6.1).

1. *Setting of a system of policy aims* (Sect. 6.1.2): Interactions between market failures have to be taken into account when formulating policy recommendations, as does the political relevance of distributive aims. This leads to different recommendations for allocative principles and instruments than a neoclassical approach, which would typically focus on one market failure and efficiency-based aim in isolation. However, a prioritisation of aims remains necessary.
2. *Choice of allocative principle* (Sect. 6.1.3): For correcting market failures, neoclassical theory recommends the use of market-based interventions which leave technology choices to market actors. Building on findings from second-best and NIE-based literature on the use of policy mixes in RES policy, this

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[1] One reason for this is the primarily interdisciplinary nature of existing studies which undertake comprehensive efforts to develop recommendations for bioenergy policy, where a discussion of theoretical considerations is not in the focus.

Table 6.1 Overview of major conclusions

Element of bioenergy policy concept	Neoclassical recommendations for bioenergy policy	German bioenergy policy in practice	Recommendations for a rational bioenergy policy concept
System of policy aims			
Consistency and completeness	Focus on GHG mitigation, as an individual efficiency-based rationale for policy interventions	Broad range of relevant efficiency-based and distributive aims, with unclear prioritisation	Simultaneous relevance of multiple efficiency-based and distributive policy aims needs to be taken into account; prioritisation is nonetheless required, with GHG mitigation as recommended priority aim
Operationalisation	GHG emission reduction targets, cross-sectoral and preferably global	Mix of EU- and national-level GHG emission reduction targets and sectoral RES targets	Mix of GHG emission reduction targets and sectoral RES targets justified in case of the electricity sector; in heating and transport sectors, sectoral GHG mitigation targets would perform better in balancing planning security and flexibility
Allocative principles			
Rationale for direct interventions in GHG mitigation choices on behalf of RES	None; internalisation of GHG externalities through technology-neutral, market-based interventions	Mix of direct interventions in technology decisions and internalisation approaches with hierarchical elements	Mix of allocative principles performs well; interactions between GHG externalities, knowledge and learning spillovers, path dependencies and further market failures justify direct interventions on behalf of RES technologies with high asset specificity
Rationale for direct interventions in GHG mitigation choices on behalf of bioenergy	None; if RES deployment support exists, it should be technology-neutral	Technology-specific support for bioelectricity and biofuel pathways; RES deployment support in the heating sector is less technology-specific	Rationale for bioenergy-specific support in case of (i) flexible bioelectricity pathways, to reflect option value in a future, renewables-based electricity

(continued)

Table 6.1 (continued)

Element of bioenergy policy concept	Neoclassical recommendations for bioenergy policy	German bioenergy policy in practice	Recommendations for a rational bioenergy policy concept
			system; (ii) second generation biofuels pathways, to reflect strong role of learning and knowledge spill-overs Biomass-based heating and first generation biofuels: less hierarchical approaches which leave technology choices to market actors preferable
Rationale for further direct interventions in bioenergy value chains	None; market failures in primary biomass production and processing spheres should be addressed through first-best measures of their own	Bioenergy-specific interventions are mostly utilisation-sided, with exceptions (notably import tariffs on biofuels)	Non-bioenergy specific reforms necessary to increase sustainability incentives in the land use and waste sectors; if not feasible, utilisation-sided interventions should be adjusted, rather than combined with bioenergy-specific interventions further down in bioenergy value chains
Instruments			
Instrument choice	Cross-sectoral, ideally global emissions trading system or emissions tax	Policy mix of EU-ETS, energy taxes and sectoral, technology-specific deployment support	Policy mix is justified, but direct instruments should be aligned more strongly with relevant market failures and transaction characteristics of bioenergy pathways
Instrument design	Not focus, instruments are theoretical archetypes in transaction cost-free world	Design differs considerable from theoretical ideals; design elements have high impact on instrument performance and on how trade-offs are solved	Second-best NIE approach provides analytical framework for analysis of trade-offs and generation of detailed, theory-based recommendations for instrument design

study has demonstrated that there is a rationale for implementing a bioenergy policy mix which combines a range of hybrid governance structures between markets and hierarchies, with the balance depending on transaction characteristics. Specifically, there is not only a rationale for combining market-based GHG mitigation instruments with more hierarchical interventions on behalf of RES technologies, but in some cases technology-specific support for bioenergy utilisation is justified as well.

3. *Instrument choice and design* (Sect. 6.1.4): Compared to the neoclassical approach, the analysis emphasises the importance of detailed instrument design choices for the performance of policies. This is demonstrated using the example of bioelectricity deployment support, for which recommendations were developed.

6.1.1 Relevance of NIE Insights for Providing a Theoretical Basis for Economic Policy Advice on Complex Environmental Policy Problems

New institutional economic theory addresses several of the major limits of neoclassical theory when it comes to developing realistic policy recommendations for bioenergy policy: it (i) takes the institutional context of allocation decisions and policy making into account; (ii) explores the implications of uncertainties and transaction costs associated with market processes and regulation; (iii) accounts for interactions between institutional and technological path dependencies; and (iv) includes political rationality considerations. By integrating these factors in the policy analysis, the focus is shifted away from the optimal solutions of the neoclassical approach to a comparison of flawed institutional alternatives. The relevant question for economic bioenergy policy advice is therefore whether, compared to the status quo, feasible alternatives can be described which would achieve policy aims at lower overall costs of production and transaction and perform comparatively better in setting sustainability incentives. In this study, findings from transaction cost and contract economics, the theory of institutional change, as well as principal-agent and public choice approaches have been found to be of particularly high relevance for the development of bioenergy policy recommendations.

To allow for a structured analysis of interactions between market failures, NIE insights need to be combined with findings from the theory of second-best. The latter emphasises that if not all relevant market failures can be solved simultaneously by first-best solutions, the correction of one market failure in isolation may not necessarily increase economic welfare, because other, unresolved market failures may be exacerbated by the corrective intervention. Under these conditions, a coordinated policy mix can improve efficiency compared to an individual instrument. Information economics, the theory of economic order, ecological economics and neoclassical economics also provide relevant implications for bioenergy policy advice, but these need to be placed in the context of specific limitations that arise when applying these approaches to the bioenergy context. For developing realistic bioenergy policy recommendations, a second-best NIE approach is found to provide the most comprehensive analytical framework into which insights from other economic theories can be integrated.

6.1.2 Recommendations for Setting a System of Policy Aims

In neoclassical theory, only aims derived from the efficiency rationale are acknowledged as a justification for government interventions in market processes, i.e. aims associated with the correction of market failures. Moreover, neoclassical policy analyses focus on individual aims, which are operationalised through one quantitative target, and implemented through one first-best instrument according to the Tinbergen rule. This results in policy recommendations which are very clear cut, but also far removed from political realities, with low implementation chances. A prime example of this are recommendations which focus on GHG mitigation as the sole relevant aim and the implementation of an "ideal" cross-sectoral and global emissions trading scheme as an instrument for the cost-effective achievement of GHG emission reduction targets (Frondel and Peters 2007; Klepper 2010; Kopmann et al. 2009; Weimann 2008: 153ff. Sinn 2008: 417ff.).

In contrast, a second-best perspective reveals that policy recommendations cannot focus on one aim in isolation. Given that an intervention on behalf of one aim can ameliorate or exacerbate different market failures, its impacts on other efficiency-oriented aims need to be taken into account—assuming that all other market failures but GHG mitigation are addressed by first-best solutions proves highly unrealistic. In addition, the legitimisation of distributive aims which emerge from a democratic decision making process cannot be neglected in economic policy advice. In fact, public choice theory implies that the consideration of distributive aims can be highly important for gaining political majorities for measures which are aimed at the correction of market failures, such as climate policy instruments.

Rather than focussing on one aim, the formulation of a bioenergy concept therefore requires a transparent reflection of trade-offs. However, politically it can be rational not to commit to a clear hierarchy of aims, so that different ones can be emphasised when addressing different voter and interest groups. Nonetheless, this study agrees with the neoclassical approach that a prioritisation of policy aims is a central requirement for an economically rational bioenergy policy. Compared to a first-best solution, the consideration of multiple efficiency-based and distributive aims may imply different recommendations as to the choice of allocative principles, instruments and instrument design. However, without a prioritisation, the effectiveness and cost-effectiveness of measures in achieving aims cannot be assessed, and the resolution of trade-offs becomes subject to temporary shifts in political majorities. This gives rise to exactly the kind of “muddling through” that can be observed in German bioenergy policy, where shifts in political priorities have led to abrupt policy changes in biofuel and bioelectricity policies in recent years. The resulting policy uncertainty is particularly problematic for energy sector investments with long amortisation periods, whose profitability depends on political framework conditions. Here, a stable hierarchy of aims is an important prerequisite for providing the planning security necessary for incentivising asset-specific investments and initiating long-term structural changes.

The hierarchy of policy aims must in the end emerge from the political process; from an economic perspective, neoclassical economists’ arguments for a prioritisation of GHG mitigation hold. For transitioning to a low carbon energy supply, bioenergy can make more significant contributions than to other efficiency-based or distributive aims, such as security of energy supply, technological development, the protection of the environment, rural value creation, or employment creation in RES industries. Moreover, a prioritisation of GHG mitigation allows for the greatest potential for synergies between aims—given the heterogeneity of bioenergy pathways in terms of GHG balances, an alignment with other priority aims does not preclude adverse impacts on the GHG mitigation aim.

Concerning the operationalisation of targets, the analysis agrees with second-best analyses that combining targets for GHG mitigation with separate targets for RES and other GHG mitigation options, such as energy efficiency, is justified in the presence of multiple relevant policy aims and multiple unresolved market failures (see Sijm et al. 2014; Gawel et al. 2014; Lehmann and Gawel 2013; Lehmann 2010; Bennear and Stavins 2007; Fischer and Newell 2008; Jaffe et al. 2005). However, in order to provide reliable long-term guidance for market actors, targets need to be formulated at a level which is sufficiently technology-neutral to support decentralised search processes for solutions under changing framework conditions. If this is not the case, frequent adjustments of targets are required, which increases policy uncertainty. In the electricity sector, a number of feasible technological RES alternatives are available; as a result, the current combination of RES and GHG mitigation targets provides a sensible balance between maintaining flexibility in how targets are met, and offering planning security for investors. In the transport sector, however, RES targets act practically as technology-specific biofuel targets, given the absence of major RES alternatives to date. Here, a sectoral GHG emission reduction target would allow for greater flexibility in choices between RES use, energy efficiency improvements and absolute reductions in energy use. In the heating sector, where feasible GHG mitigation options depend crucially on building stock characteristics, a sectoral GHG emission reduction target would likewise be preferable to a sectoral RES target.

6.1.3 Recommendations for the Choice of Allocative Principles Between Markets and Hierarchies

When implementing policy aims, policy makers can choose either to intervene in market processes indirectly by changing framework conditions or relative prices, leaving allocative responses to market actors, or they can take a more direct role in steering allocation decisions. Neoclassical economic theory provides clear recommendations as to the allocative principle that policy interventions should adopt: cost-effective outcomes are brought about by market-based, technology-neutral interventions which aim to restore the price mechanism's functionality in the presence of market failures. For implementing GHG mitigation targets, an emissions tax or emissions trading scheme are instrument choices which are consistent with this allocative principle: with both instruments, emitters can choose between paying taxes or buying permits on the one hand, or reducing emitting activities and investing in GHG mitigation options on the other. Following the principle of profit maximisation, the least costly options are chosen; GHG mitigation targets are not only implemented cost-effectively, but mitigation efforts are also allocated efficiently among all emitters subject to the instrument.

Based on this argument, neoclassical policy advice sees no case for additional, more hierarchical interventions on behalf of specific GHG mitigation technologies, as these would only distort allocation decisions and prevent targets from being implemented cost-effectively (Frondel et al. 2010; Frondel and Schmidt 2006; Weimann 2008: 118f.; Weimann 2009; Sinn 2008: 161ff.). The preference for a technology-neutral approach to GHG mitigation is also supported by the theory of economic order, which stresses the advantages of markets in coordinating decentrally available information and discovering innovative, cost-effective solutions. Policy makers adopting a direct steering approach, on the other hand, are bound to make erroneous decisions that give rise to large-scale inefficiencies, given a constitutive lack of knowledge (Hayek 1945; Hayek 1945/2005). Both approaches therefore see no rationale for technology-specific interventions directed at bioenergy use.

What can be found in practical policy making, however, is a mix of direct interventions in technology decisions (e.g. the EEG's FIT and FIP schemes, the biofuel quota, and the EEWärmeG's renewables obligation for heat use in new buildings), and more market-based, indirect ones (such as the EU-ETS and energy taxes). Moreover, these existing market-based instruments do not represent the "pure" market-based allocative principle, due to numerous hierarchical elements such as exemptions or restrictions in the scope of emitters included. Conversely, direct interventions do not usually represent an inherently hierarchical approach which prescribes certain technology choices, but leave scope for decentralised decision making on the side of market actors.

In this context, a combined NIE and second-best approach offers analytical tools for generating more differentiated and more realistic policy advice. Two important differences to the neoclassical approach can be distinguished:

1. The choice of allocative principle is not seen as a dichotomous one, but as one that encompasses a continuum of governance options between markets and hierarchies as extremes. Under certain conditions, interventions leaning to the hierarchical side of the spectrum can be more efficient than ones closer to markets, once transaction costs, actors' ability to handle uncertainties and path dependencies are taken into account.
2. Economic policy advice should not focus on interventions which seek to implement an individual efficiency-based policy aim in isolation. Choices among GHG mitigation options are not only distorted by GHG externalities, but various market failures. These are only partially addressed by existing instruments, so that policy advice needs to address potential interactions.

For developing recommendations about what allocative principles should guide bioenergy policy interventions, three questions are therefore relevant: (i) Is there a general rationale for hierarchical interventions in the choice of GHG mitigation options, for example, on behalf of RES technologies? (ii) Is there a rationale for hierarchical interventions on behalf of bioenergy use as a GHG mitigation option, specifically? (iii) Do interactions between market failures and efficiency-based and distributive policy aims justify bioenergy-specific interventions further down the value chain, i.e. in the primary biomass production or processing spheres? Results for these questions are presented in turn.

6.1.3.1 Rationale for Hierarchical Interventions in the Choice of GHG Mitigation Options

Technology choices in the energy sector are not only distorted by GHG externalities, but also by knowledge and learning externalities and path dependencies. Indeed, a significant amount of research has been done showing the rationale for a policy mix combining indirect instruments like an emissions trading system with direct RES support under these circumstances (Lehmann and Gawel 2013; Lehmann 2010, 2013; Kalkuhl et al. 2012; Matthes 2010; Kemfert and Diekmann 2009; Fischer and Newell 2008; Jaffe et al. 2005). Technology-neutral market-based interventions would only promote the adoption of those GHG mitigation options which minimise costs from a static perspective, resulting in underinvestment in innovative technologies which would bring down the costs of GHG mitigation over time. Moreover, technology decisions do not take place in an institutional vacuum, but are influenced by technological and institutional path dependencies, which influence allocation decisions in favour of incumbent technologies; in the case of the energy sector these are reinforced by market power on the side of incumbents with sunk investments in fossil fuel-based production capacities. More hierarchical interventions in technology choices, like direct RES support, are therefore necessary to promote technological diversity, reduce the long-term costs of GHG mitigation and overcome the institutional and technological lock-in.

Further relevant interactions arise with externalities associated with a secure energy supply; the reduction of market power in the energy sector through the introduction of new market entrants; and environmental externalities associated with other pollutants than greenhouse gases or impacts on biodiversity. These interactions can argue for excluding certain technologies from the range of permissible GHG mitigation options—an example is the German phase-out of nuclear power. Moreover, interactions can be addressed in the design of technology-specific support instruments, by differentiating support not only based on learning spillovers but also based on environmental externalities or security of supply contributions. Also, further instruments can be introduced into the policy mix, such as sustainability standards and certification.

NIE insights add further arguments for conditions when hierarchical interventions on behalf of specific GHG mitigation technologies can be justified. This is the case when the achievement of aims requires highly asset specific investments—that is investments which are costly and irreversible and whose profitability depends on the continued existence of policy incentives. For instance, capital-intensive RES technologies in the electricity sector have high asset specificity—the more so, the further they are removed from commercial competitiveness. Such investments will only be undertaken in the presence of reliable investment safeguards, which reduce income risks as well as uncertainty about future policy changes. Furthermore, direct interventions on behalf of RES can be required to overcome political resistance against path changes. A policy mix which includes measures directed at several efficiency-based aims, but also distributive aims can help to overcome barriers to institutional change by creating a coalition of winners and including compensation measures to losers.

However, hierarchical interventions require policy makers to choose what technologies are considered promising enough to warrant hierarchical support; this entails considerably higher information requirements than indirect interventions close to markets. Also, market oriented interventions set more intense incentives for cost-reductions and search processes which use dispersed information. Consequently, hierarchical interventions should only be employed when strong investment safeguards are required. From an NIE perspective, the mix of allocative principles which can be found in German bioenergy policy therefore performs quite well. Indirect interventions close to markets, such as the EU-ETS, should be used to govern transactions with low asset-specificity (e.g. investments in efficiency improvements or co-firing of biomass in fossil fuels power plants); whereas for investments with high asset specificity, such as capital-intensive RES technologies in the electricity sector, direct RES support with higher safeguards is appropriate.

6.1.3.2 Rationale for Hierarchical Interventions on Behalf of Bioenergy as a GHG Mitigation Option

Direct RES support, meanwhile, can likewise be implemented in a technology-neutral fashion, or be directed at specific RES technologies. Common arguments for technology differentiation are differences in knowledge and learning spillovers (Lehmann et al. 2012; Foxon et al. 2005), and reductions in overall support costs (del Río and Cerdá 2014). Technology-neutral support favours comparatively mature, low cost RES options; if investments in innovative technologies with higher costs are to be incentivised, high remuneration levels would be necessary, with windfall profits for low cost producers. In the case of bioenergy, an additional factor is that contributions to various efficiency-oriented and distributive aims can differ strongly between technologies: this is not only the case for different sectoral biomass utilisation options, but also different bioelectricity, biofuels or biomass-based heating technologies. Also, transaction characteristics such as the asset specificity of investments differ, as well as the relevance of path dependencies.

In contrast to neoclassical theory, insights from NIE and the theory of second-best therefore provide arguments for a differentiated bioenergy policy mix, where separate instruments for electricity, transport and heating sectors may be justified on the basis of different transaction characteristics. Moreover, recommendations can be derived as to when there is a rationale for technology-specific interventions on behalf of bioenergy in a given sector. High asset specificity applies especially to investments in biofuel production facilities and dedicated bioelectricity plants, which would not be able to compete in the absence of state interventions. If these are to be realised as GHG mitigation options, hierarchical interventions would be required. Whether there is a rationale for such interventions on efficiency grounds is determined by interactions between relevant market failures.

Bioelectricity technologies are comparatively mature, but interactions between GHG externalities, security of supply externalities and path dependencies can argue for technology-specific support for flexible bioelectricity pathways, to reflect their option value for balancing intermittent RES generation in a future, renewables-based electricity system. Biofuel pathways show strong differences not only in GHG balances, but also in learning and knowledge spillovers; it is recommendable to focus technology-specific deployment support more strongly on innovative, second generation technologies, whereas established first generation biofuels should be exposed to stronger competition with other GHG mitigation options in the transport sector. In the heating sector, bioenergy applications are close to commercial competitiveness; here, a less hierarchical approach like the EEWärmeG, which leaves choices between RES technologies, energy efficiency investments or district heating to market actors is preferable.

6.1.3.3 Rationale for Hierarchical Interventions in Downstream Allocation Decisions in Bioenergy Value Chains

Investments further down in bioenergy value chains, such as in the primary production sphere and intermediate processing stages, tend to be characterised by low asset specificity, because the degree of bilateral dependency between biomass producers and buyers tends to be comparatively low. Also, the diversity and complexity of allocation decisions imply that central information gathering and coordination efforts would be costly. Outcomes are likely to be more efficient, if market actors can make use of dispersed knowledge and adapt autonomously to new information or changes in framework conditions. Allocation decisions further down in bioenergy value chains should therefore not be governed through hierarchical, bioenergy-specific interventions. Since the abolishment of the CAP's energy crop premium, bioenergy-specific interventions in Germany tend to focus on the utilisation sphere, performing well in this regard—an exception are EU-level import tariffs on biofuels and intermediate products, which distort sourcing decisions in favour of domestically produced products with higher costs. Here, an NIE approach does come to the same conclusion as a neoclassical approach, that is, that greater openness towards an international division of labour would improve efficiency.

To address interactions between utilisation-sided incentives for bioenergy use and market failures further down the value chain, the most efficient solution would be to ameliorate persistent market failures by policy measures which are aimed at all relevant sectoral allocation decisions, not just bioenergy. These need not be first-best solutions in the neoclassical sense—the critical factor is rather that interventions do not only apply to bioenergy value chains, but also to other biomass uses, so that allocation decisions between energetic and non-energetic biomass uses are not distorted and displacement effects are avoided. Here, the German and European policy contexts show clear scope for improvement, in particular regarding sustainability incentives in the primary biomass production and land use sector. Also, improvements in waste and recycling regulation could increase the profitability of developing a greater share of technically available waste potentials for energetic uses.

Meanwhile, if comprehensive reforms of policy framework conditions are not possible, at least in the short term, it is advisable to adjust utilisation-sided, GHG mitigation-oriented interventions to take adverse interactions with other aims and market failures into account. This approach has been primarily adopted by German bioenergy policy, for example, through differentiating between bioenergy technology-feedstock combinations in utilisation-sided interventions. However, the performance of such measures is strongly dependent on instrument design. In the German case, instruments have frequently triggered a large-scale demand for certain pathways and were only adjusted afterwards in consecutive trial-and-error processes. To avoid associated transaction costs, policy uncertainty, and potentially irreversible impacts, it is recommendable to implement interventions on behalf of bioenergy gradually, and to avoid the creation of large-scale demand for pathways associated with significant uncertainties.

6.1.4 Recommendations for Instrument Choice and Design, Focussing on Bioelectricity Policy

Compared to neoclassical instrument recommendations for bioenergy policy, which focus on first-best emissions trading or emissions taxes, the development of instrument recommendations in an NIE and second-best framework is a more complex task. Recommendations need to be developed for a mix of instruments, which correspond to the allocative principles which were found to be advantageous for the governance of different transactions. Moreover, compared to the neoclassical approach, an NIE perspective emphasises the importance of instrument design—as hybrid governance structures, policy instruments offer a large range of possibilities for combining market elements and hierarchical elements. As a result, trade-offs between the benefits of market-oriented or hierarchical interventions are solved not only through the choice of instrument types, but also through detailed design choices.

6.1.4.1 Implications for the Design of a Bioenergy Policy Mix

Based on an analysis of the German bioenergy policy mix, this study has found that a reform of the German bioenergy policy mix should encompass the following elements in order to comprehensively address the allocative challenges of bioenergy use:

1. Adjustments of environmental, agricultural and waste framework regulations to improve the extent to which interactions between multiple market failures in the primary production sphere are addressed.
2. A reform of indirect, market-based instruments, such as the EU-ETS and energy taxes, to set stronger incentives for GHG mitigation and govern the use of bioenergy options with low asset specificity.
3. A revision of direct instruments which support bioenergy deployment, to focus support more strongly on options where high asset specificity interacts with significant knowledge and learning spillovers, security of supply externalities and path dependencies.
4. An assessment of whether additional sustainability safeguards need to be installed in utilisation-sided, direct support instruments, if adjustments to framework conditions in the primary production sphere are not feasible.
5. An improved coordination of sectoral instruments.

Combined with the importance of detailed instrument design, the large number of relevant instruments in the bioenergy policy mix has made a focus necessary for the development of more detailed instrument recommendations. This study has placed the focus on direct deployment support for bioelectricity, where major revisions are currently under way.

6.1.4.2 Recommendations for Bioelectricity Instrument Choice and Design

For handling the allocative challenges of bioelectricity use, three elements of instrument choice and design were identified as particularly important: the choice between price, quantity and hybrid instruments, which affects the social costs of erroneous judgements about marginal cost and benefit curves of bioenergy production; the design of a mechanism for differentiating between technology-feedstock combinations according to their private and external cost characteristics; and the design of adjustment mechanisms, where a balance needs to be found between adaptive efficiency requirements and planning security for investors.

In the absence of significant knowledge and learning spillovers, the rationale for technology-specific bioelectricity support is based on security of supply considerations in combination with the path transition to a low carbon electricity system with high shares of intermittent RES (see Sect. 6.1.3.2). A direct bioelectricity support instrument should be able to incentivise new investments to realise further incremental innovations; also, it should deliver greater incentives for existing plants to generate positive security of supply externalities. At the same time, recommendations have to take into account that the future competitiveness of bioelectricity with other flexibility options (e.g. storage systems with high learning curve potentials, or demand flexibilisaton) remains uncertain. Moreover, as the energy transition progresses, a stronger cross-sectoral integration of RES-based energy production becomes likely, as well as a stronger coupling between material and energetic biomass uses. Under these conditions, a sector-specific, cost-based administration of prices, which has been adopted in the German FIT and sliding FIP schemes to date, is bound to meet limits, due to the high information requirements of cross-sectoral policy coordination.

In this context, a tendered capacity premium for bioelectricity plants in combination with a diversification of income streams represents an instrument option with several potential efficiency advantages. As a hybrid instrument which is balanced more strongly towards the market-side of governance options, a tendered capacity premium would allow bioelectricity producers to explore and combine a range of income streams in markets where they compete with other RES and low carbon technologies. Complementing income streams from the electricity spot market, balancing markets, and heat and transport fuel markets, it could act as a compensation for bioelectricity's contribution to the system stability of a RES-based electricity system, without distorting cross-sectoral allocation decisions. In this sense, the instrument would show good compatibility with capacity markets, if these were to be introduced. The level of the capacity premium should be determined competitively rather than administratively, because income streams and costs are highly project-specific; here, a competitive bidding process can fulfil an important price discovery function. To reflect different remuneration needs, a pay-as-bid approach to price setting seems promising. Further research is needed regarding the design of the tendering process.

However, potential efficiency advantages of the scheme depend on two central conditions. Firstly, there has to be sufficient competition for tendered capacities, to avoid full-cost oriented bids and strategic bidding. Secondly, reforms of relevant market framework conditions and indirect instruments are necessary, to ensure a fair competitive footing between bioelectricity and other low carbon flexibility options, and reduce competitive advantages of fossil fuel-based technologies. In the electricity sector, this includes reforms of the electricity market design and the EU-ETS. Moreover, it would be desirable to use non-bioenergy specific instruments to open up income streams which compensate for environmental co-benefits: for example, the use of bioelectricity production for waste and slurry disposal could be incentivised through revisions of waste and agricultural law. To support feedstocks with higher costs but positive environmental externalities, an extension of agri-environment schemes would be desirable.

As an intermediate solution, transitioning from an administered sliding FIP to a tendered variant would allow policy makers and market actors to gain experiences with competitive bidding schemes; however, efficiency advantages compared to an administered sliding FIP are highly uncertain. Cost-effectiveness improvements depend crucially on whether strategic bidding can be avoided, and on the transaction costs associated with the bidding process. Moreover, a competitive determination of remuneration increases competition for low cost resources. With remuneration based on bids, new plants are likely to achieve a higher ability to pay for biomass resources than existing ones which receive cost-based support; this may force the latter to exit the market. These problems also arise for a tendered capacity premium; however, a tendered capacity premium with a diversification of income streams promises efficiency advantages in coordinating dispatch decisions and cross-sectoral allocation decisions. Allocation signals set by a competitively determined or administered sliding FIP, on the other hand, display no structural differences.

At the same time, the design of a technology-specific bioelectricity support instrument has to ensure favourable GHG and environmental balances. Eligibility requirements and sustainability certification represent basic alternatives for differentiating between pathways accordingly. Eligibility requirements are found to be advantageous as long as bioelectricity supply chains are predominantly based on domestic value chains. In this case, main determinants of GHG and environmental balances can be controlled through a limited number of requirements, such as technical requirements regarding covered digestate storage tanks, a cap on the use of energy crops grown with fertiliser input, and heat use requirements. Compared to sustainability certification, this results in significantly lower transaction costs. Both sustainability standards and eligibility requirements should be further accompanied by other instruments such as regional planning and the adjustment of environmental and agricultural framework conditions.

For existing plants, the question of how to incentivise the provision of security of supply benefits and improvements in environmental balances remains challenging. Besides information and moral suasion instruments, additional economic incentives are required. This can be done by offering premiums which compensate for additional costs of measures when there is little uncertainty about associated benefits, with the EEG’s flexibility premium as an example. Of course, the benefits of such measures have to be balanced against their costs. On the other hand, an increasing resource cost pressure may incentivise a change from old FIT or FIP rates to a capacity premium in combination with a diversification of income opportunities. In this case, participation for existing plants should be tied to improvements in environmental and GHG balances.

6.2 Transferability to Other Policy Contexts

For transferring results to other policy contexts, two main perspectives present themselves. The analytical framework can be applied to other policy problems where multiple market failures, path dependencies, and conflicting policy aims play a decisive role, and where impacts of policy measures are associated with significant uncertainties. Particularly, although not exclusively, this is the case for environmental policy problems, where the complexity of human-environment interactions and the existence of tipping points make the handling of uncertainty an integral part of policy design. On the other hand, findings for the German case study can yield important insights for the bioenergy policies of countries which apply similar bioenergy policy mixes.

Concerning the first perspective, the governance of allocation decisions in the bioeconomy context represents an area to which this study’s analytical framework could be fruitfully applied. The substitution of fossil fuel inputs in material and chemical industries has been identified as a strategic focus and an important field of future growth by the EU and many national governments (cf. Dieckhoff et al. 2015; COM 2012). At the same time, in governing bioeconomy allocation decisions, the problems of the bioenergy context are compounded. Besides bioenergy expansion, material and chemical applications represent another source of potential large-scale demand for biomass resources, with associated pressures on land use and the environment. Path dependencies and market failures, particularly incompletely internalised externalities, inhibit the transition from a fossil fuel-based production system to a closed-loop economy based on renewable resources. However, regulative interventions have to deal with an even greater complexity than in the bioenergy context, because of the broad range of bioeconomy pathways and the heterogeneity of their environmental and socio-economic impacts. Under these circumstances, hierarchical interventions face considerable constraints; on the other hand, the generation of political momentum for a path transition poses interesting problems. Moreover, just as with energetic biomass uses, ensuring the sustainability of developments will be a considerable challenge. Under these conditions, an institutional analysis of bioeconomy governance problems promises useful insights for policy design.

Furthermore, the study’s analytical framework is applicable to other policy problems, where the aim is an initiation of a path transition towards greater sustainability, and government interventions are carried out under uncertainty. Examples are the reform of electricity market framework conditions for the integration of large shares of intermittent RES and the setting of flexibility incentives for electricity producers and consumers, the reform of the climate policy mix, where both adjustments of the EU-ETS as well as the introduction of additional, more hierarchical instruments for GHG mitigation are under discussion (e.g. Oei et al. 2014), or the implementation of sustainable land use policies, where the policy mix is shaped by interactions between the EU's CAP regulation and national agricultural and environmental policy instruments. For these policy problems, the study's NIE-based analytical framework could make a contribution towards structuring governance problems and showing relevant trade-offs, but also an application to more specific questions of instrument choice and design seems promising.

Secondly, recommendations for German bioenergy yield insights for bioenergy policy mixes in other countries, although the specific institutional contexts need to be taken into account when transferring results. As outlined in the introduction to this book, the transferability of findings to other EU member states is particularly high, because elements of climate and RES policy have been harmonised. All EU member states employ direct RES support instruments in combination with the EU-ETS, and in doing so most differentiate between RES technologies (Winkel et al. 2011; RES LEGAL 2015). Moreover, several countries, such as the UK, the Netherlands, Finland or Ireland have adopted specific strategies to expand the use of bioenergy in the electricity, transport and heating sectors, with varying sectoral focuses (DG Energy 2015). Although there are differences in the design of bioenergy policy mixes, the instrument choices and design options that are discussed in the context of individual countries overlap to a large extent; for example, the choice between energy content-based or GHG-based biofuel quotas in the transport sector, or the choice between FIP and FIT, renewable energy quotas and competitive bidding schemes in the electricity sector. Besides ensuring a good transferability of results from the German case study, this situation also lends itself to comparative analyses of national bioenergy policy mixes; by focussing on implications of different policy choices, insights can be derived for the performance of different alternatives concerning, for example, social cost of errors, adaptive efficiency, and the balancing of trade-offs between incentive intensity and planning security (cf. Purkus et al. 2015). At the same time, the EU state aid guidelines' stated preference for competitive bidding schemes has important implications for the future development of member states' bioenergy and renewable energy policies in the electricity sector. Here, NIE-based analyses comparing existing instruments and competitive bidding schemes, different design alternatives for bidding schemes, and transition options can make a valuable contribution.

6.3 Outlook

This work has shown that governance problems such as that of bioenergy policy, with its multiple interacting market failures and various relevant policy aims, do not lend themselves to easy solutions. Individual instruments aligned with one market failure and one policy aim prove inadequate. Rather, a coordinated policy mix is required, combining different instrument types depending on the characteristics of the transactions in question. Moreover, instruments which drive bioenergy demand may need to be adjusted to take as yet unresolved market failures into account.

A second-best, NIE-based approach to policy analysis moves recommendations closer to the realities of policy making—effectively, it allows for a distinction between elements of a policy mix which can be justified based on efficiency grounds, and others which are motivated by distributive aims or are necessary to gain political majorities for institutional changes; yet other elements and design characteristics may be determined by institutional path dependencies. However, compared to a neoclassical policy analysis, this closer proximity to real-world conditions of policy making also poses risks: once distributive aims, path dependencies, and political feasibility considerations are taken into account, it becomes easy to rationalise the "muddling through" of actual policy making. To avoid this, it is necessary to clearly distinguish between positive and normative policy analyses. As part of the latter, economic recommendations which are based on a realistic set of assumptions can identify scope for improvements, and point out development perspectives in the direction of more rational policy design.

With its clear focus on efficiency, the neoclassical approach yields procedural suggestions which allow economic policy advice to remain distinct from a "muddling through" approach. By outlining what solutions would be efficient under abstract model conditions, neoclassical first-best recommendations offer useful theoretical starting points for policy analyses. As policy recommendations in and of themselves, they are inadequate—however, they serve well as theoretical ideals, against which real-world conditions can be compared. In this way, it is possible to analyse what efficiency-based modifications in recommendations are required, once implications from second-best theory, NIE and other relevant theoretical approaches are taken into account. In a second step, an alignment can take place with the question of what options are actually feasible, once institutional and political constraints and distributive considerations are taken into account.

Furthermore, a second-best, NIE-based approach highlights the importance of the dynamic perspective. When it is not feasible to identify unequivocally efficient and sustainable solutions from the outset, how to improve outcomes' efficiency and sustainability over time becomes a central question. More research is required on how to loosen constraints that prevent comparatively more favourable solutions from being implemented—examples are comprehensive reforms of land use and waste regulations, which could address environmental externalities of waste and biomass production more effectively and efficiently than mechanisms for differentiating between technologies and feedstocks in deployment support instruments.

Moreover, policy recommendations should account for the adaptive efficiency of measures: both targets and instruments should allow scope for learning and avoid new lock-ins into what might turn out to be inefficient outcomes, while equipping investors with as much planning security as necessary.

By providing an analytical framework that allows for a structured analysis of trade-offs between dimensions such as planning security and adaptive efficiency or cost-effectiveness and political feasibility, and applying it to the case of German bioenergy policy, this book aims to make a useful contribution to the work of economists and policy makers who are faced with these challenges when developing policy recommendations and making policy decisions.

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