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Susanne Hartard
Wolfgang Liebert *Editors*

Competition and Conflicts on Resource Use

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Competition and Conflicts on Resource Use

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Chapter 1
Preamble

Susanne Hartard

The publication “Competition and Conflicts on Resource Use” is based on interdisciplinary peace research activities at Technische Universität Darmstadt, Germany, supported by a TU Darmstadt funded conference in close co-operation with the Interdisciplinary Research Group in Science, Technology and Security IANUS—Interdisziplinäre Arbeitsgruppe Naturwissenschaft, Technik, Sicherheit.

The first editor of the book, Prof. Dr.-Ing. Susanne Hartard, worked 7 years as a post-doc researcher at the faculty of Civil Engineering, Institute WAR, Chair Industrial Material Cycles and was a member in the IANUS group in Darmstadt for several years. In 2008 she left for the professorship Industrial Ecology, Faculty of Environmental Business Economics, Environmental Campus Birkenfeld, Trier University of Applied Sciences. The editor is working on resilience strategies for resources management and advanced resources cascades and cycling solutions, both strategies intend to decouple companies from unsustainable and unsecure international resources supply.

The second editor of this book Univ. Prof. Dipl.-Phys. Dr.phil.nat. Wolfgang Liebert, Institute of Safety/Security and Risk Sciences, University of Natural Resources and Life Sciences (BOKU), Vienna Austria has been the scientific director of IANUS until 2012 and left TU Darmstadt for the professorship at BOKU, Vienna.

Natural Resource Management and Policy is increasingly pushed by resources access questions. Resources price peaks and volatility, trade embargos and civil wars on the African continent opened a new discourse on future resources security. The growing world population is confronted with limited resource availability.

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There is a risk of future armed conflicts with a resource background and growing competition over resource deposits (Klare 2002; Collier 2010; Collier and Hoeffler 2011; OECD 2011; Diamond 2005; Welzer 2012).

With the rising awareness on limited resources availability for innovative key technologies and increasing price volatility on scarce minerals, the research on the competition and conflicts on resource use has been upgraded all over the world. The ongoing national resource interests in the North Pole Region show that the research field is not losing its timeliness and is rated as a serious topic for future international peace work. The unequal distribution of fossil energy resources causes ongoing crises since the oil crisis of 1973 and natural gas pipelines have become one of the weak connections of gas supply and gas demanding countries.

The book combines contributions from several disciplines, nuclear energy professionals, peace researchers, environmental engineering scientists and experts on sustainable resources management. The broad-based approach of the book is intended and offers the reader the numerous different facets of resources competition and conflicts. The future organization of a sustainable and fair access to resources needs a holistic understanding of resource price dynamics, analysis of resource consumption and reserves, reflection on competitions of countries on new found natural resources, competition on single substances needed in emerging technologies and the understanding that the limitation to growth (Meadows et al. 1972) of economy in form of material extraction is also bound to emerging technologies. That means especially the consumption of rare earth elements and noble metals is related to a limited availability and high price. The competition between fossil energy carriers will increase in the ending fossil era, even if fracking technologies and new extraction areas like the North Pole and deep-sea will prolong the possible extraction time. There is a high risk of an increase of global land-use competitions on arable land, needed not only for food or biofuel, but used to produce fodder, construction material, pharmacy, dyes and industrial chemicals in general for a future bio-based economy. The book can be characterized by two main intentions:

The *first intention* is the *reflection on causes of resources conflict and competitions*, *which* is accomplished through general analysis of growing price volatility and the connection of climate change and resources conflicts (Part I).

The book is mainly structured according to resource, starts with classic conflicts in the energy sector, oil, gas and uranium as limited available energy resources (Part II). The perspective of uranium as a finite element is rarely part of the public debate on nuclear energy use and therefore a valuable additional information.

As a key area mineral resources and especially those materials, used in emerging technologies (cell phones, IT, electronic devices) are discussed. The survey of Angerer et al. (2009) can be seen as an important kick-off and motivator for opening a deeper discourse on HighTech and GreenTech material supply in Germany (Parts II and IV, Part I).

Especially critical public voices on energy transition (“Energiewende”) call for technology assessment of solar cells and wind power plants. That was the reason to also invite PV experts to analyse the material consumption of the solar cell generations outlined in Part VI. The worldwide expansion plans for wind power, especially off-shore plants with gearless drives are thus far bound to Neodymium as an input material, one of the elements been affected by rising prices and limited availability, and discussed in Parts III and VI.

The growing demand of renewable materials opens a competition for arable land, traditionally used for food and fodder production. Biofuels and the future need of energy crops, biopolymer crops (starch, cellulose, oil) and other crops for dyes, pharmaceuticals, construction material and textiles will intensify the land use competition. So far there is hardly a global regulation to prevent capital rich investors to appropriate land on other continents for future supply purposes of their home country. Capital market prices and attractive export market conditions lead farmers to decide with a one-sided view on their crop rotation. The result is often unsustainable monoculture for maize, oil-palms, sugar-cane and soya in whole states with a bad impact on ecosystem quality and water circulation.

The *second intention* is the *consideration of solutions* to reduce the resources risks and competition by several instruments. The solutions address both the macro-economic and micro-economic level. The book offers contributions on resources management policy of countries. Examples are the certification and control schemes for a responsible resources import of coltan and diamonds, based on the civil-war problems in Sub Saharan African countries (Parts I and IV).

General solutions for a secure and sustainable resource supply offer the contributions on waste management (Part IV), technological innovations (Part IV) and emerging technologies (Part VI). A limited availability of resources induces a responsible circular economy. Germany is internationally known for its excellent collection system for recycling material and recycling technologies. Responsibility on the global market means to set the example in developing countries. A challenge is the extension of the recyclability of vapour deposited materials, nanomaterials and composites. Waste management and water management are closing loops, supporting Circular Economy.

Water conflicts have increased due to rising demand of the growing world population and climate change. Known conflicts are between Israel and Jordan (river Jordan), Egypt and Sudan (Nile river), India and Pakistan (Indus river) and Turkey and Syria (Euphrates river). A recent monitoring of water resources conflicts has been published by Wolf (2013). International water conflict management programmes have been started (Wolf 2009). River basin management, used for big European rivers like the river Rhine is one sustainable approach to integrate national interests in a collective sustainable management system. Integrated water management, presented by the authors of TU Darmstadt IWAR (Part V) is an approach especially for arid and semi-arid countries like Namibia who fight over the general shortage of water because of special climatic conditions.

As water is one of the recurring problems on earth (polluted rivers and sea in China, missing sanitation systems in Asia and Africa, missing access in many developing countries, missing irrigation water, radioactive pollution) the contribution on the “overuse of fresh water” (Part V) from a known German water specialist refers to globally needed concepts to a sustainable water consumption and increases awareness of special critical consumption situations like fossil water use.

The contribution in Part IV on “energy security by renewable energy autarky concepts” refers to current questions of German energy transition (“Energiewende”) and their contribution to increase independency from energy imports. Villages and regions can even be exporters of renewable energy because of their high potential of roof space and natural capital. But there are limitations in urban areas which will also be supplied by central renewable energy supply solutions in the future.

To sum up, the introductory part on the motivation, main structure and contents of the book, have been divided into six Parts:

- The Role of Resources for International Conflict Constellations (Part I),
- Conflicts on Fossil and Nuclear Energy Supply (Part II),
- Perspectives of Strategic Material Resources Management (Part III),
- Sustainable Solutions for Resource Consumption (Part IV),
- Water Conflict Prevention by Water Resource Management (Part V) and
- Resource Aspects in Renewable Energy Technologies (Part VI).

Part I has a focus on *International conflict constellations* by resources price dynamics, climate change impacts and the general debate on the resources curse. Price volatility and recent peaks of resources prices are inducing international conflict constellations and competitions, presented by *Hartard*. The reasons of rising volatility are not transparent enough, but they affect the world community and increase international and sectoral competition for resources. Indicators, methodologies and monitoring instruments are shown to rise the information level and awareness of price risks in the manufacturing industry. The contribution of Hartard is closely linked to the articles of Hagelüken, Helmers, Schebek et al., Reller et al. and Jägermann, who refer to High Tech and GreenTech product material consumption.

Nordås and *Gleditsch* discuss a wealth of publications on climate change impact. There is no doubt by the authors about the influence of climate change on peace and security like increasing migration and transition effects. So far, armed conflicts cannot be directly linked to climate change and IPCC reports refer very little to the problem of resources competition and conflicts. Although the scientific opinion of some authors that climate change breeds violent conflicts, a systematic causual relationship is so far not really been identified (Koubi et al. 2012).

An international problem which addresses the responsibility of a global trade community is the resources curse. Resources extraction in resources-rich countries often results in civil war instead of increasing prosperity of the population. Brunnschweiler and Bulte (2009) do not regard resources as a general curse to peace and development. Volatile countries have dysfunctional institutions (Theisen 2008), lack of rule of law, corruption and underdeveloped financial systems (van der Ploeg 2011). “Overcoming the curse” could mean to work on resources distribution issues and natural resources management policies (Rustad and Binningsbø 2012). *Müller* and *Croll* present the examples of diamond and coltan, extracted and exported by Sub-Saharan African countries. They have investigated causal mechanisms linking natural resource wealth in Sub-Saharan Africa to violent conflicts. With the example of Nigeria and the Democratic Republic of Kongo and known civil wars related to diamond and coltan mining the authors discuss seven hypotheses on the implication of natural resources in the onset of civil war. Topics discussed are foreign interventions, land expropriation, state weakness by dependence on resources revenues, pre-emptive repression by the government to protect resources and separatism of residents in resource-rich areas. The article is closely linked to the contribution of Bleischwitz et al. in Part IV, who offer solutions like certifications and trading schemes to reduce the civil-war follow ups of coltan mining.

Part II is cohesive and focuses on *energy supply risks* associated with traditional fossil based energy supply and nuclear power. The limits of fossil based resources especially oil and the shortage of petroleum gas due to restricted supply by cross-national pipelines have been a repeatedly discussed topic actually in the public in the context of Ukraine energy supply. Especially since the first oil crisis in 1973 conflicts on fossil energy supply came to be noticed by the public via car-free Sundays and other impacts like price shocks due to market shortness of oil. *Ipsen* points out the problems and conflicts connected with the “life cycle” of oil. Oil conflicts are linked to both political and market instability backgrounds which will be exacerbated in the future. It is reasonable to assume that nations with high military capacities will use their “regions and power policy” to gain priority access to oil resources.

Uranium resource risks are often discussed in terms of the ultimate disposal of nuclear fuel rods and safety risks of nuclear power plants – less in the viewpoint of limited availability of uranium resources. *Liebert* and *Englert* characterize the nuclear fuel chain and identify eight related risks for nuclear energy production. This concerns for example the impact of uranium mining on human health and the environment, the dependence of most nuclear power using countries on uranium imports, and the reliance on uranium enrichment technology, which is a nuclear weapons proliferation prone technology. Hypothetic massive—or even larger—nuclear expansion scenarios as projected in “nuclear renaissance” scenarios, are not covered by the expectable uranium availability—neither in a mid-term nor in a long-term perspective. In the longer run, the need for mining companies to move to uranium deposits with lower ore-grade will make mining and nuclear power first more and more economically unattractive and later on energetically irrational. In sum, the inherent risk in uranium ore production and the availability of uranium itself will increase the future competition between states. *Sailer* has differentiated in his contribution that future nuclear conflicts are possible due to access to technical resources, know-how, differing opinions on safety and regional and political stability.

Parts III and IV both address *resources competition in connection to consumer products* and have a close interrelationship and linkage to Part VI. Emerging innovative markets have an increasing demand of mineral supply. Metal applications are discussed in terms of their rarity, scarcity and strategic interests, triggered by recent price peaks and restricted availability on the global market. The precious metals and rare earths might be the most sensitive market, needed for information technology, consumer electronics and sustainable energy production. *Hagelüken* gives a deep insight into application areas and future urban mining options for rare metals. Especially through innovative recycling solutions to close the loops in so far open cycles for cars, electronics, batteries, industrial catalysts, the “above ground mine" or "urban mine", are gaining in importance to increase the metal supply security. The dissipative losses of metals even in the recycling sector are still too high. That is the reason for a renewed discussion on different types of metal scarcities and several new methodologies to calculate criticality for the supply security of national economies. The contribution in this part has a close link to Hartard in Part I, showing monitoring instruments for criticality. The methodologies distinguish between supply risks and environmental country risk. Resource restrictions might also limit the transition to E-mobility as a significant technological change. This is the connecting content to Helmers contribution who is a researcher on E-mobility. *Helmers* discusses possible future material restrictions for E-car production and E-conversion. Lithium is already known in public as one of the key substances needed for different battery types in electric cars, but is attributed with a relatively low supply risk. The transition from combustion cars to Electric cars might use less stainless steel but more precious and expensive materials like Cu, Al, and Rare Earth Elements (REE) even for the electric motor. A temporarily supply bottleneck for E-car raw materials cannot be excluded but estimations later than 2030 have a high uncertainty due to technology changes and material substitution options in E-car batteries. Helmers contribution focuses on the core input risks of Lithium in car-batteries with a substance oriented view.

Parts III and IV are linked by Lithium used in the product examples in the contribution of *Schebek*, *Poganietz*, *Feifel* and *Ziemann* in *Part IV*. They discuss two case studies on Lithium and wooden based lightweight boards. In contrast to Helmers they have an analytical approach. The article shows the impact of material use in the technosphere, risks of anthropogenic materials flows in terms of environmental impacts like resource use (LCA methodology) and material flows in and between national economies (MFA methodology). Resources risks can be expressed with the parameters reserves, reserve base and the static range of resources. Resource assessment methodologies are an important contribution to future international agreements on sustainable resource use and provide security in the international family of nations.

The producer's responsibility includes the view on mining conditions and induced civil war by mineral extraction and exports as already addressed in the beginning Part I by Müller and Croll, focusing on the resources curse. Both author groups (Müller, Croll and Bleischwitz, Dittrich, Pierdicca) contribute to the backgrounds of the coltan conflict from different viewpoints. *Bleischwitz*, *Dittrich* and *Pierdicca* represent German researchers experience and give an insight into the supply chain of coltan and linked armed conflicts known especially from the Democratic Republic of Congo in Central Africa. Sound systems of supply chain management might use technical analytical support like Analytical Finger Printing (see following contribution of *Franken* et al.), certification schemes in mineral trading chains (ECGLR) or private sector activities (EICC, GeSI) and show limits (illicit trade, existing loopholes by neighbor countries and Chinese gateway) and chances of natural resources trade control mechanisms (Garrett and Piccini 2012). Promising results may be governance pilots in the region and capacitor based certification schemes; the final annex of the authors gives an overview of existing international initiatives and coverage of the value chain of coltan.

The activities of the German Federal Institute for Geosciences and Natural Resources (BGR) on participation in the development of a Certified Trading Scheme (CTS) in the mineral resources production supply chain is the motivation of the contribution by *Franken*, *Vasters*, *Dorner*, *Schütte*, *Küster* and *Näher*. The BGR initiative aims to implement ethical standards and transparency in mineral production, for example, in the supply chain of coltan, gold, diamonds, and gem stones. A pilot project has been started in Rwanda and aims to conflict prevention, supply security and poverty alleviation in the trading chain of coltan, tin and tungsten. The project experience was an important basis for the publication of the OECD Due Diligence Guideline for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas.

Hartard characterizes up-to-date cross-national resources competitions and conflicts of completely different type not mentioned by other authors groups like landgrabbing for food-security, rare earth trade barriers and the ongoing competing interests in the access to ore deposits in the North Pole Region, Greenland, and deep ocean resources out of black and white smokers. She offers a path to peace and security by decentralized renewable energy self-supply and energy autarky concepts, motivated by the successful Renewable Energy villages projects in Germany and the political debate on the chances and limits of decentral concepts and energy autarky of regions. Her contribution is linked to Part VI resources aspects in renewable energy.

Fellner shows the use of different tools to analyse waste management practices in developed and developing countries. Material Flow Analysis (MFA) (see contribution of Schebek et al. on assessment tools) and selected environmental and economic indicators are applied to Vienna, Damascus and Dhaka. An MFA of the three cities in comparison shows the efficiency of separate collection systems, material stocks and landfilled waste. The combination of material flow data with economic data gives additional information on the development of optimization strategies, which always have a regional specific character. Countries with a higher GDP focus on recycling and waste pre-treatment strategies whereas developing countries have to fulfil basic needs in waste management like the protection of human health.

Part V focuses on *conflicts in relation to water stress* one of the main environmental problems on planet earth today. Water shortage in agriculture, sufficient access to drinking water and water induced conflicts of neighbor countries on river water withdrawal are running problems of a growing world population and climate change. The increasing risks of flooded landscapes by rising sea level will cause migration and land-use competition in remaining liveable areas.

Kluge is discussing the global critical situation on water supply, the UN assumes a serious gap in the future water supply. The causes of the water gap are numerous: river-systems are overused (Jordan) and drying out (Aral sea, Dead sea), mega-cities have large catchment areas, groundwater recharge is not sufficiently regulated, fossil water is used for irrigation being non-renewable and "lost" by evaporation.

China is solving inter-regional water stress by river diversion, but world-wide river-interlinkage and canal projects might have an unknown impact on surrounding ecosystems. Water use for renewable energy production (dams, water turbines, pumped storage, irrigation for biofuels) is also endangering biodiversity of aquatic environment. Important topics for a safe future water supply are rain water harvesting, water banking, rainwater fed agriculture and irrigation limits in desert areas, water re-use, waste water separation and nutrients recovery. Integrated water resource management systems, the link to the second contribution on water of Zimmermann et al. will need sufficient investment and the public sector making long-term decisions. The case study of Namibia, presented by *Zimmerman*, *Brenda*, *Jokisch* and *Urban* shows Integrated Water Resources Management (IWRM) in practical application, the final outcome of a research project. The project improves the security of water supply especially by adapted decentral water supply technologies. IWRM tries to provide a spatial and temporal balancing of several water usages and resource conservation. The aim is a holistic concept for sustainable water use and use of adaptive technologies in semi-arid to arid climate conditions. Parts of the system are rainwater-harvesting, solar-driven groundwater desalination, evaporation cleaning, membrane distillation, reverse osmosis and subsurface water storage. The technologies applied rise safety against droughts and floods, ensured continuous access to clean fresh water by a multi-resource mix, using local construction materials and low maintenance overhead.

The motivation for Part VI was to clarify that even Renewable Energy projects are not free from direct and indirect induced resources conflicts. The examples given in the contributions are critical materials chosen in solar cells, the general high demand for critical materials in emerging technologies and the question of sustainable land-use. The contribution of Kluge in Part V. has already discussed the immense additional irrigation needed for biofuel production. *Hennecke* and *Rettenmaier* give a deeper insight into the problem of impacts of bioenergy crop production, in Germany already 15 % of total arable land is dedicated to bioenergy. Bioenergy will be a remarkable share of global energy supply but we already know it can far not feed the word energy demand. Biofuel production is promoted by policies in Europe, US and Mexico to be blended in form of a biofuel quota in gasoline cars. The effects of bioenergy crops on food security and Greenhouse Gas emissions are finally discussed on the basis of LCA results. LCA's are calculated for direct (dLUC) and indirect land use changes (iLUC), certification systems in Europe control the effect of bioenergy land use impacts on the Greenhoause gas effect by changes of the carbon stock. Finally, biofuels are the better alternative to fossil fuels if they do not induce land use changes. Future food security is closely linked to future food prices.

Hartard has addressed landgrabbing, buying arable land from the indigenous population by foreign investors, and reinforcing the competition on the remaining land. The ambivalent start of biofuel support by the German government, especially the background of known effects like direct and indirect land use, changes in biofuel exporting countries and alarming results of LCA studies results in a changed biofuel policy. Generally, the food or fuel question has to be extended to the general question of a future sustainable land use concept for food, feed, fiber, fuel, biomaterials and biochemicals.

Zepf, *Achzet* and *Reller* discuss the strategic resources of emerging technologies with a close relation to renewable energy. Their contribution is closely linked to the Parts III and IV and the aforementioned contributions on material demands of the future HighTech market. As there is no fixed definition for emerging technologies, a diverse list of technologies includes Renewable Energy Supply, Energy Storage and Mobility Technologies, the topics of this chapter. LED technology has a demand for a broad range of elements like aluminum, indium, gallium, but need also rare-earth elements (yttrium, europium, terbium, lanthanum and cerium), which have been limitedly available due to market policy of China in the last years. Mobile phones contain remarkable values like gold, copper and silver with a high future recycling potential. The 4-C market (camera, computer, cellular phone, cordless tools) has a high demand of batteries, dominated by the demand of Li-ion batteries, already discussed in the contributions by Helmers (Part III) and Schebek (Part IV).

A scarce resource relevant for renewable energy option is neodymium in permanent magnets (used in some types of wind power plants), mentioned also by Hartard in Part I and indium which is needed for liquid crystal displays of monitors and PV cells.

Elements for emerging technologies are often fabricated in far-east countries, have the highest demand in industrialized western countries, have a missing efficiency and dissipation of the recycling path, described also by Hagelüken in Part III.

Substitution of critical materials so far gives not a sufficient answer, as substitutes belong to the same metal family and are often critical themselves. The authors finally have allocated 19 elements to various energy pathways and highlighted three grades of criticality. So criticality can be a future “show stopper” for emerging technologies, not the efficiency and recycling limits. The existing methodologies to calculate and monitor criticality are offered in the contribution of Hartard in Part I and should be read together with this article by Zepf et al.

The contribution of *Jägermann* on PV cell development refers closely to the general problem of emerging technologies (see last contribution by Zepf et al.) with a rising demand of scarce minerals. It addresses three solar cell generations and organic PV cells. Semiconductor thin film solar cells have entered the market, with a growing demand of indium and tellurium considered to be not available in the needed amounts. Continuous improvements in technology development are made in efficiency increase and material reduction in thin film PV cells which will give more safety for a long lasting materials supply and cost reduction. But thin film cells might have a negative influence on recycling efficiency. Meanwhile, advanced research is looking for new absorber material, PV cell collection and recycling organizations have been established, for example, in Europe to close the loop (like PV Cycle).

Review and outlook: The 17 contributions show the broad perspective of resources competition and conflicts as an interdisciplinary, even transdisciplinary research field. The topic has not lost in its timeliness since the resources price peaks of 2008 which was the main motivation for inviting scholars having the ability to contribute to this topic from very different perspectives.

There is a shift from classic fossil era based conflicts to material supply shortages and competitions on future resources access with a completely different character. The contributions have confirmed in general that there are no direct armed conflicts in relation to resources scarcity, as civil wars often have multiple causes.

But the world is awaked by military threatening gestures at the North Pole Region, in connection with natural gas pipelines and oil supply unrests. Hidden competitions and latent crises are close linked to resources supply of emerging technologies. The knowledge is very little, how we will close the future loop and serve the growing demands in the field of noble metals, scarce minerals and rare earths. Competitions on land-use will probably increase as there is not a law of nations on equal access to food and resources supply for any citizen on earth.

The contributions give first answers to enhance resource supply security and responsibility by certification schemes in mineral supply chains and autarky concepts in renewable energy supply and a higher knowledge on resource consumption and recyclability of innovative products. Assessment tools like MFA and LCA analysing the functioning of industrial and urban metabolism will additionally help on the path of a future sustainable, safe and secure resource supply on planet earth by sustainable waste and water management systems.

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Part I
Role of Resources for International Conflict Constellations

Chapter 2
Risks by Volatility and Peaks of Resources Market Prices

Susanne Hartard

It can be observed in the last 10–15 years that the risks for national economies and producing companies have risen through an increasing volatility of resources market prices. The reasons and most important drivers of this development are not understood well-enough and intransparent. Therefore, research studies were ordered in industrial countries to get a deeper knowledge on coherences of the resources market (Bretschger et al. 2010; Gandenberger and Glöser et al. 2012; Deutsche Rohstoffagentur 2013).

The oil price shock and peak (contribution of Ipsen in Part II) of the last oil crises in 1973 and 1980/1981 (see Fig. 2.1) had not led to remarkable changes in renewable resources management, but made apparent the dependencies on the global market and market power of organizations like OPEC.

The last sensitive general price peak for several raw materials can be determined for 2008 (oil, phosphorus, metals) with an impact on many sectors and the expected subsequent recession. Not only producing and serving companies were affected, like the automotive industry which tried to compensate by increasing metal prices in the supply-chain. Also, private consumers paid extreme high energy prices in 2008, especially for oil, which started to be life threatening for low-income families.

There is a close relationship between the oil price and food price. A rising oil price induces the production and distribution of food (Deutsche Bank Research 2011). Non-ferrous metals like lead, zinc, tin and copper have a relatively homogenous price development, also dependent on oil price as an energy-intensive extraction sector. Another group are the light metals with aluminium, titanium and magnesium used in automotive companies, air and spaceship industry.

Rising oil prices also have an impact in the form of a switch from fossil energy use to biofuel production. This happened in the United States with a follow-up

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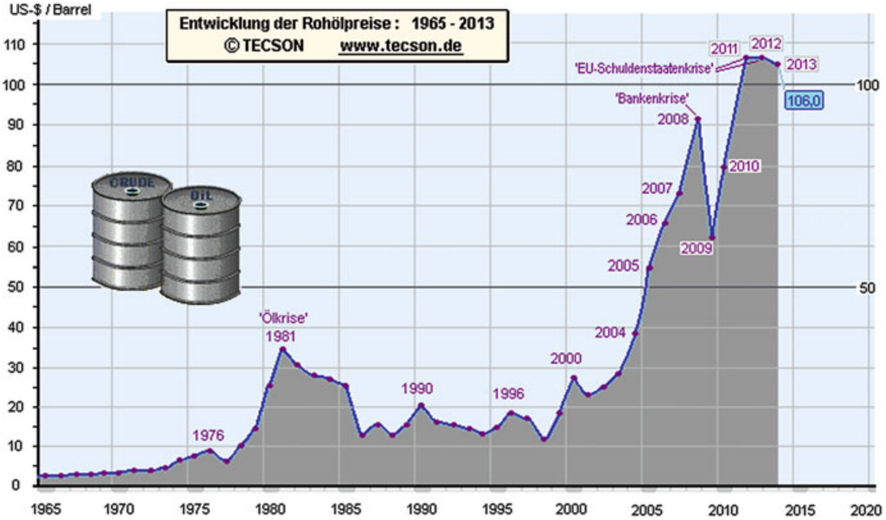

Fig. 2.1 Oil price development 1965–2014. Source: Tecson (2014)

food-crisis in Mexico, known as the Tortilla crisis. Imported US maize for Tortilla production in Mexico started to become very expensive, because the demand on maize as input material for US biofuel production had risen to substitute expensive oil in the US. The Tortilla crisis led to a price increase of 67–180 % of US export maize in 2006 (Hartard 2014). According to Pimentel (2010) the U.S. biofuel program was subsidized with $12 billion per year, finally 1.5 gallons of fossil energy were invested to produce 1 gallon of ethanol. The ethanol production had a follow-up on the U.S. food market: beef, chicken, pork, eggs, breads, cereals and milk became 10–30 % more expensive (Pimentel et al. 2009).

According to the Hotelling rule (1931), the long term prices of exhaustible resources should increase based on the market interest rate. That means the interest rate level determines the real market price and is somehow calculable through certain assumptions and predictions of the interest rate policy. But reality shows that the long-term resources price trend is influenced by a lot of surrounding factors and the expected price development by Hotelling rule has not been justified (Bretschger et al. 2010). Scientists have tried to adjust the Hotelling model to real market conditions with an inelastic resources demand (Acemoglu et al. 2012; Atawamba 2013). But the distortion of the market price development is influenced by a lot of factors so that the rule is called into question. The following factors are discussed to influence the market price development:

- Weak organizational structures and political unrests (state failure) in developing countries, where civil wars result in an incomplete competition on the resource market.
- The external effects of resource consumption e.g. climate change and loss of biodiversity are not expressed in market prices.

- Monopolies, cartels and oligopoly structures in resource extraction are misused for market manipulation. Pro-cyclical and time-lagged investments in market supplies distort regular market dynamics.
- The real quantity of extraction is limited by risks, such as rising extraction costs, differences to expected reserves, decreasing demands and lack of legal certainty in countries with political unrests.
- Pure speculations on the resources market are difficult to identify in their relevance, but nowadays are part of the intransparent resource market with rising price volatility.
- The backstop-technologies substitution potential, for example, the solar industry, will reduce the demand of fossil energy and change the structure of the energy supply sector.
- Technology development like fracking and new reserves (North Pole, deep sea) and general uncertainties about the existing reserves will influence the existing resources market.

As a result the complexity of influences on resources price dynamics requires additional interpretations and research for a sustainable and secure future economy. Research studies showed that physical scarcity is often not the background reason for price peaks. A German survey on the reasons of actual resources price peaks (DERA 2013) showed that there have been earlier price peaks for several mineral resources before 2008 and there can be several reasons for price increases like the global financial crises of the last years. Price drivers can also be the high demand of emerging countries, new technologies (screens, LED, Lithium-Ion batteries, solar cells, wind power generators). In addition to the above-mentioned factors, one can list speculation risks, monopoly structures and political unrests. The capital and resources markets are interdependent (Gandenberger and Glöser et al. 2012).

Germany has started a new information policy on the resources market to reduce the risks of raw material procurement. New publications like resources identity cards by the German BGR/DERA are complemented by price monitoring and volatility monitoring since 2014. First results show price increases for the rare earths Neodymium and Dysprosium by factor 20–30 from 2009 until 2011, but a decrease in volatility for many resources in 2012.

Reasons for this development are the rising demand of high-tech devices and technologies of the future like screens, PV-cells, LED lamps, batteries and other IT and electronic equipment (see Fig. 2.2).

The market for rare earths is different from the metals quoted on the London metals exchange. It is a small market, several elements are by-products from ore extraction which have a very low supply price elasticity (Liedtke/DERA 2014). Considering the years from 2009 until 2013, the price volatility was high for chromit (57,3 %), iron ore (32,5 %), cadmium (33 %), magnesite (36,9 %), molybdenum (31 %), phosphate (33,7 %), quicksilver (31,1 %) and several rare earths (cerium 75 %), dysprosium metal (46,7 %), europium oxide (51,5 %), lanthanum oxide (71 %), neodymium metal (40,9 %) and praseodymium metal (37,8 %), but has gone down the last year (2013–2014) (BGR/DERA volatility monitor 2014).

The contribution of Hartard in Part IV refers to price volatility and risks by resources price peaks and gives additional information on price peaks of copper,

Fig. 2.2 Development of copper price. Source: Oracle Mining Corp. 2012 http://www.oracleminingcorp.com/_resources/images/May_2012/copper_price_trend.jpg

phosphate and lithium which had an impact on the push of research activities to phosphorus recovery.

In conclusion resources price risk knowledge and management is a big challenge in a future economy. This has led to comprehensive activities by international researchers to define the criticality of resources by quantitative indicators, accumulated in a variety of studies (National Research Council of National Academies 2007; Angerer et al. 2009; EUCOM 2010; BGR 2010; Erdmann et al. 2011; EU 2014) and compared methodologies to measure the criticality of resources in national economies (Graedel and Erdmann 2012; Häußler and Mildner 2012).

Indicators to be defined are the ***geographical distribution of resources*** which leads to market power of countries (see Fig. 2.3); an example for this is the "Rare Earth crisis" regarding market shortages induced by China, negotiated by World Trade Organization after complaints of Industrial importing countries. The ***business concentration of resource extraction companies*** in countries can lead to monopoly structures, calculated by the Herfindahl-Hirschmann-Index. For example, a HHI of 10,000 expresses a monopoly of one firm with 100 % market share.

The closer a market is to being a monopoly, the higher the market's concentration (and the lower its competition). If, for example, there were only one firm in an industry, that firm would have 100 % market share, and the HHI would equal 10,000 (100^2), indicating a monopoly.

The ***political stability of countries*** is already traditionally calculated by the World Governance Index of the World Bank. There are six governance indicators that have been calculated for 215 economies for the following six dimensions of governance: voice and accountability, political stability and absence of violence,

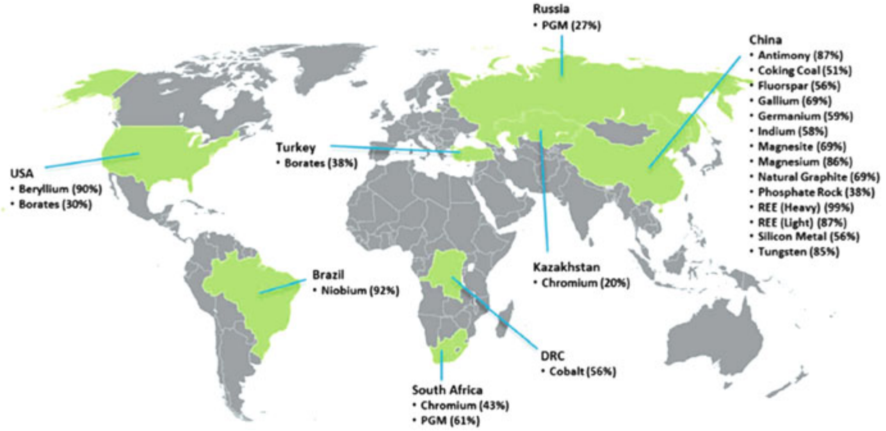

Fig. 2.3 The major producers of the twenty EU critical raw materials (2013). Source: European Commission Enterprise and Industry (2013) http://ec.europa.eu/enterprise/policies/raw-materials/media/photos/crm3.png

government effectiveness, regulatory quality, rule of law and the control of corruption.

The ***static reach of resources*** is not taken into consideration as a limitation factor by geologists who believe in new reserves findings in the long-term. But in general statistics of static reach are integrated as serious indicators in criticality calculations in many criticality analyses. The ***recyclability of resources*** is especially in the rare earth and noble metals group essential for their future usability.

Resources substitution potentials reduce scarcities and risks and make companies more flexible. Price risks haven influenced multinational enterprises to pick up substitution strategies and prove the necessity of rare earth and noble metals as input materials beside efficiency strategies. But in the metal high tech industry resource substitution seems to be least developed, whereas fossil-based polymers can be substituted by a rising biopolymer market.

Environmental policy influence on resource management is still primarily put into practice, with available options being resource taxes, trading certificates and funding (grant, subvention, subsidy). The strong sustainability strategy forces the replacement of finite resources by renewable resources and the strong conservation of natural capital. This strategy seems to be taken seriously on the pathway of energy transformation in Germany to a renewable energy-based economy but there are no real solutions to be seen for high-tech material supplies. The weak sustainability strategy of substituting exhaustible resources by capital (Hartwick 1977) cannot be a realistic strategy, because capital can never buy back consumed finite resources like fossil fuel.

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Chapter 3
Climate Change and Conflict

Ragnhild Nordås and Nils Petter Gleditsch

While it has been forcefully argued that the world is generally becoming more peaceful (e.g. Gleditsch 2008; Pinker 2011), the debate on climate change raises the specter of a new source of instability and conflict. In this field, the policy debate has been running well ahead of its academic foundation—and sometimes even contrary to the best evidence. A small but important literature of systematic research on possible security implications of climate change is now emerging. To date, however, the studies are inconclusive, often finding no or low predicted effect of climate change. The scenarios summarized by the Inter-Governmental Panel on Climate Change (IPCC) 2001, 2007, and 2014 are much less certain in terms of the *social* implications of climate change than in their conclusions about the *physical* implications. The few statements on the security implications found in the first two IPCC reports are largely based on sources of uncertain academic credit and relevance.

This chapter outlines some plausible scenarios for how climate change might influence conflict through mechanisms like an increased frequency of natural disasters, sea-level rise, and droughts, particularly when they interact with stagnating development and poor governance. The tentative conclusion based on evidence as of today is that, although climate change is likely to have other dire consequences, there is little cause for invoking apocalyptic scenarios for armed conflicts specifically as long as climate change stays within the most probable IPCC scenarios for this century. Nevertheless, interaction effects between climate change and other conflict-inducing factors deserve closer attention.

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3.1 A More Peaceful World or Climate-Induced Carnage?

A liberal peace seems to be in the making (Gleditsch 2008). Since the end of the Cold War the number of on-going armed conflicts has decreased by about one third (Gleditsch et al. 2002; Themnér and Wallensteen 2012). The severity of war as measured by battle deaths has also progressively, if unevenly, declined since World War II (Lacina et al. 2006; HSRP 2010). For over three decades, we have observed an increase in democracy, trade, international economic integration, and memberships in international organizations, as well as in international peacekeeping and mediation efforts. The ongoing financial crisis, the rise of fundamentalist religion, and other factors may delay the move towards a more peaceful world. But the greatest challenge to the global liberal peace, according to an increasingly widespread view, is the threat of climate change.

The idea that climate change will constitute a major security concern has surfaced in media and public discourse with increasing frequency over the last decade. The security scenario gathered particularly strong momentum in 2007 with the UN Security Council's debate on the security implications of climate change and the awarding of the Nobel Peace Prize to the Intergovernmental Panel on Climate Change (IPCC) and Al Gore. In this article, we review the evidence for the view that climate change is likely to produce a massive hazard to peace and security in the future.

3.2 Climate Change

Global climate change is likely to have profound implications for the quality of life of hundreds of millions of people. The prospect of human-induced climate change illustrates that humankind is now in a position to exercise a significant negative influence on the global environment. This is a testimony to our inventiveness and power on the planet, but also a warning about its potentially harmful consequences. The *Third Assessment Report* (*TAR*) of the Intergovernmental Panel on Climate Change (IPCC 2001) firmly established climate change as a political issue on the global agenda. The *Fourth Assessment Report* (*4AR*) (IPCC 2007) estimated it to be 'very likely' that human activities have contributed significantly to the observed temperature increase in the recent half century, i.e. an assessed probability in the interval 90–99 %. The IPCC reports have also outlined a series of probable effects of climate shifts on a plethora of natural systems, sea-level rise, droughts and floods, human health, and the incidence of other natural hazards. These changes in turn will inevitably impact on human activities. The AR5 states that 'human influence on the climate system is clear' (IPCC 2013: 15), and that 'warming of the climate system is unequivocal' (ibid.: 4).

Given the potential range and scope of consequences of climate change, it is not surprising that there is widespread concern about its security implications. Indeed, soon after the TAR was published the public debate accelerated, even though the issue is peripheral in the first IPCC reports. While priding itself of being a synthesis of the best peer-reviewed science, the IPCC fell prey to the temptation of relying on second- or third-hand information with little empirical backing in its scattered comments on the implications of climate change for violent conflict. Despite the breadth of the security concern in the public debate, statements about security implications of climate change are often based on speculation. This is less true for AR5.

3.3 Environmental Security

Climate change is not the first environmental issue to be framed as a security concern. Almost four decades ago, Falk (1971) warned about the potential for conflict between the rich and powerful and the poor and marginalized, as the wealthy will use violent means to secure their riches in times of environmental stress. Westing (1971, 1982) directed a research program on the environmental consequences of war and military preparations. Brown (1977), Westing (1989) and others argued for a new and broader concept of security, including an environmental component, a theme also picked up by *Our Common Future* (Brundtland et al. 1987). Brock (1991) discussed different ways in which the environment could be established as part of the peace research agenda.

In part, the movement for ‘environmental security’ aimed at raising the priority of the environmental agenda by framing it in terms of the ‘high politics’ of security. However, of greater interest for the current analysis is the attempt to establish empirically a link between environmental change and violent conflict. Pioneering work here was done by Homer-Dixon (1991) and Bächler and associates (Bächler et al. 1996; Bächler 1999). A number of case studies established plausible links between environmental degradation and internal violence, particularly when exacerbated by adverse economic, political, and demographic conditions (Homer-Dixon 1994; Kahl 2006) and a number of writers warned against a threat of international ‘water wars’ due to increasing scarcity of freshwater (e.g. Klare 2001). Gleditsch (1998) argued that a general environment-conflict link was still a conjecture, and that it was impossible to generalize from studies only of cases with conflict due to the problem of selection bias. Schwartz, Deligiannis and Homer-Dixon (2000), on the other hand, argued that case studies were particularly suitable for teasing out the relevant causal mechanisms. However, it has proved difficult to establish general relationships between environmental change and conflict (Esty et al. 1998; Theisen 2008) beyond case studies. We now turn from the broader concern with ‘environmental security’ to the specific issue of the security implications of climate change.

3.4 Climate Change and Security

Since climate change has more wide-ranging consequences than most environmental problems, does it also pose a greater challenge to security? The security threat from climate change has been presented in public debate in increasingly flamboyant wording. In October 2003 a report to the US Department of Defense (Schwartz and Randall 2003) received wide public attention for presenting a grim future scenario with warring states and massive social disturbance as a result of dramatic climate change. The authors argued that their scenario was not only *plausible*, but also that it 'would challenge US national security in ways that should be considered immediately' (ibid.: 1). A few years later, eleven retired US generals and admirals added more military authority to the issue, arguing that 'Climate change can act as a threat multiplier for instability in some of the most volatile regions of the world' and that this 'presents significant national security challenges for the United States' (CNA 2007). Meanwhile, the German Ministry of the Environment (2002: 4) stated that 'evidence is mounting that the adverse effects of climate change can, particularly by interaction with a number of socio-economic factors, contribute to an increasing potential for conflict', an argument later extended by the German Advisory Council on Global Change (WBGU 2008). Despite the strong wording however, it is not clear from these reports how much of a security risk climate change poses relative to other factors, or the specifics of how, where, and when climate change might predictably become such a threat multiplier. Indeed, there are few studies available that systematically analyze such complex interactions and what is implied when we speak of climate change as a 'threat multiplier'.

Climate change reached the highest level of the security agenda in 2007, when the United Kingdom used its position as chair of the United Nations Security Council to put the issue before the Council. Foreign Secretary Margaret Beckett argued that the impacts of climate change, such as crop failure and lingering drought, sea-level changes, and river basin degradation 'went . . . to the very heart of the security agenda' (UN 2007).[1] Former UN Under-Secretary-General for Humanitarian Affairs, Jan Egeland and Secretary-General Ban Ki-moon, have also linked the conflict in Sudan's Darfur region to climate change and have argued that similar environmental problems are increasingly causing violence in other African countries (Ban 2007). The President of the World Bank, Jim Yong Kim, promised to make climate change a priority of his 5-year term and warned that '[t]here will be water and food fights everywhere . . .'.[2] A number of NGOs have repeated similar claims. Academics who have claimed such a link include Sachs

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[1] However, a number of other governments, including representatives of the Group of 77 and the Non-Aligned Movement argued that the Security Council was encroaching on the agenda of other UN agencies and that the issue belonged in the General Assembly and the Economic and Social Council.

[2] See The Guardian, 26 January 2013, www.guardian.co.uk/environment/2013/jan/27/nicholas-stern-climate-change-davos.

(2005), Swart (1996) and Homer-Dixon (2007). Many academics such as Bächler (1999: 99), Barnett (2001, 2003), and Suhrke (1997) have voiced more nuanced and skeptical views. The report by the German Advisory Council on Global Change (WBGU 2008) offers a comprehensive summary of much of the literature and arguments for and against the climate change-security nexus.

The uncertainty of climate predictions and the very tentative nature of conflict prediction combine to make the study of the security implications of climate change a daunting task. Recently, however, a peer-reviewed literature on the subject has begun to emerge (Nordås and Gleditsch 2007a; Burke et al. 2009; Buhaug 2010; Theisen 2012; Theisen et al. 2012; Fjelde and von Uexkull 2012; Gleditsch 2012; Koubi et al. 2012; Scheffran et al. 2012), and a number of research projects are now under way. If taken seriously by the main premise providers of the climate-security debate, this new work could shift the debate to more nuanced and evidence-based predictions and recommendations.

3.5 The Premise Providers

The IPCC is by far the most important source laying the premises for the climate change debate. Despite the growing concern about the security implications of climate change, this issue was hardly dealt with in the IPCC reports, up to the release of AR5 in 2013/2014. The TAR, from 2001, a 1,000 pages long volume on 'Impacts, Adaptation, and Vulnerability' of socio-economic and natural systems, hardly mentions violent conflict and other traditional security issues. It deals with a wide range of other social issues, however, such as challenges of meeting key human needs for adequate food, clean water, clean air, and adequate and affordable energy services. The TAR focuses on how climate change can result in heat waves, flooding, storms, and drought, which in turn can cause famine, population displacement, the outbreak of diseases, and a decline in the agricultural productivity of rural areas that may accelerate migration to the cities. The relative vulnerability of different regions to climatic change is then largely determined by their access to resources, information, and technology, and by the stability and effectiveness of their institutions to deal with challenges to meeting human needs. Therefore, the IPCC states, 'climate change is likely to increase world and country-scale inequity, within the present generation and between present and future generations, particularly in developing countries' (IPCC 2001, Working Group II: 85).

The TAR suggests few concrete links between climate change and violent conflict.[3] The clearest statement refers to how climate-related migration may increase the risk of political instability and conflict (ibid.: 85). In the discussion of hydrology and water resources the TAR suggests a 'potential for international

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[3] For a more detailed discussion of the claims made in the 2003 and 2007 reports, see Nordås and Gleditsch (2013).

conflict (hot or cold) over water resources' (ibid.: 225), as reduced water availability may induce conflict between different users. The TAR also argues that present agreements about water allocations in absolute terms may create conflicts in the future if the total amount of water available is reduced (ibid.: 225). These statements are generally not backed by peer-reviewed sources. A literature does exist on water and conflict, although it is not cited by the TAR, and this literature comes to more sobering conclusions. The TAR also suggests that the fishing industry faces possible adverse effects of climate change (ibid.: 369 f.), and that since fish reserves are among the most important economic resources in many countries and fish stocks are trans-boundary resources, this could lead to conflicts between countries. To date, however, such conflicts have never escalated to large-scale violence.

In the *Fourth Assessment Report* (IPCC 2007) the bulk of the references to a link between climate change and conflict occur in the chapter on Africa. However, the evidence presented by the report and by the sources that it cites offer only qualified support for a climate-conflict link (Nordås and Gleditsch 2013). The evidence is unclear, particularly in terms of pinning down the relative importance that climate change might have over the existing challenges facing the continent. Indeed, although one might argue that climate change is a 'threat multiplier' in Africa, the evidence is not clear, particularly in terms of the relative importance of climate over other conflict-inducing factors on the continent.

The Fifth Assessment Report of the IPCC in its report from Working Group II, released on 31 March 2014 (IPCC 2014), provides a much more comprehensive review of the possible consequences of climate change from conflict. However, different chapters in that report present an inconsistent picture, ranging from to warnings of serious future climate-related conflicts in Chs 19 and 22 ('Emergent risk and key vulnerabilities' and 'Africa') via a balanced assessment in Ch 12 ('Human security') to complete dismissal in Ch 18 ('Detection and attribution of observed impacts').[4]

The influential *Stern Review* on the economics of climate change commissioned by the British government (Stern 2006) also refers to how conflict 'may' arise under certain circumstances.[5] This is seen mainly as a result of forced migration, which the report puts at up to 200 million people by 2100—but again this is not the main focus of the review. Later, on several occasions Nicholas Stern has warned that hundreds of million will have to move because of climate change, causing 'severe conflicts'.[6] Although he has not elaborated on his scenario or added any specifics on the nature of these conflicts, such statements serve to incorporate the climate-conflict link into the broad consensus process of the international climate debate, despite the lack of compelling evidence. In the next section, we examine the evidence to date.

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[4] For an assessment of the report, see Gleditsch and Nordås (2014).

[5] See Gleditsch and Nordås (2014) for a discussion of the use of 'may' and similar terms.

[6] For a recent statement by Stern along these lines, see www.permaculture.co.uk/articles/nicholas-stern-climate-change-and-alternative-route-mitigation.

3.6 The Evidence

While the hard science in the climate change debate is backed up by peer-reviewed studies, this has often not been the case for most of the literature relating climate change to conflict. The headline hitters are predominately reports from think tanks and governments. To the extent that they cite any relevant sources at all, these tend not to be peer-reviewed, and the quality of the evidence is uncertain at best, and sometimes little empirical support is provided at all. For instance, when IPCC (2001) links forced migration to conflict it cites Myers (1996), Kennedy et al. (1998), and Rahman (1999). Although titled ‘Climate Change and Violent Conflict’, Rahman (1999)—a chapter in an edited volume—contains little either on conflict or climate change. Norman Myers and Donald Kennedy, although their works are more substantial, are not specialists on conflict and several conclusions contradict findings in more reliable and carefully designed studies. Also, the cited works did not appear in academic journals. While Kennedy et al. (1998) is cautiously formulated, reflecting the tentative knowledge of the social consequences of environmental change, Myers (1996) is a journalistic account based on the assumption that we are on our way to ‘environmental ruin worldwide’ (ibid.: 17). Myers sees shortages of food and freshwater and deforestation as issues that could lead to conflict within and between nations. On all of these issues, there are academic literatures that could have served to temper his unremitting neomalthusianism, but these are cited neither by the author nor by the IPCC. In fact, although scarcities like these present major problems for livelihood and health, the possible link to armed conflict is at best highly contested (Hauge and Ellingsen 1998; Theisen 2008). Myers’ rough estimate for future environmental refugees (150–200 million) is cited by the *Stern Review*, with an acknowledgement that ‘it has not been rigorously tested’ (ibid.: 77).[7] An update to 250 million, based on communication with Myers, surfaces in a report by the organization Christian Aid (2007: 6, 50).

The IPCC (2001) reference to water conflicts cites Biswas (1994) and Dellapenna (1999). These sources address adaptation and cooperation as much as conflict. There is, indeed, a literature that suggests a potential for water wars (see e.g. Gleick 1993; Renner 1996; Klare 2001), but other sources emphasize the potential for technological innovation and human adaptation, including conservation and cooperation (Beaumont 1997; Wolf 1999; UNDP 2006). A statistical study not cited by IPCC finds that neighboring countries that share rivers experience low-level interstate conflict more frequently (Gleditsch et al. 2006), but a more recent study finds that most countries that share rivers are also neighbors, and that it is difficult to distinguish between the effect of sharing a valuable resource and other

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[7] The *Stern Review* seems on more solid ground when it notes that 200 million people live in coastal floodplains at less than one meter elevation (Stern 2006: 76), although no source is given. Apart from the fact that a one-meter sea-level rise is higher than the IPCC’s highest estimate for 2100, no consideration is given to countermeasures, such as dikes, or a gradual retreat from the most exposed areas.

neighborhood effects (Brochmann and Gleditsch 2012). Of course, neighboring countries also trade more (Hegre 2009) and have other forms of cooperation as well. Yoffe et al. (2003) argue that cooperation consistently trumps conflict in handling shared international water resources.

Finally, on the issue of shared fisheries resources, also raised by the IPCC, Myers (1996: 9) notes that nations bordering on the North Atlantic have gone ‘to the edge of hostilities over cod stocks’. But of course, the so-called ‘cod wars’ or ‘turbot wars’ (Soroos 1997) of the North Atlantic are remarkable for their lack of interstate violence. Coast guard and naval forces have been involved in these disputes, but so far not a single casualty has been reported.

3.7 The Causal Chains

The government and IGO-sponsored writing on climate change fails to cite convincing sources for a link to armed conflict. The academic literature (Barnett and Adger 2007; Nordås and Gleditsch 2007a, b; Buhaug et al. 2010; Bernauer et al. 2012; Scheffran et al. 2012; Theisen et al. 2013) outlines several possible causal chains from climate change to conflict. The starting-point for most of these is that climate change results in a reduction in essential resources for livelihood, such as food or water, which can have one of two consequences: Those affected by the increasing scarcity may start fighting over the remaining resources. Alternatively, people may be forced to leave the area, adding to the number of international refugees or internally displaced persons. Fleeing environmental destruction is at the outset a less violent response to adverse conditions than armed conflict or genocide. But when the migrants encroach on the territory of other people who may also be resource-constrained, the potential for violence rises.

Barnett and Adger (2007) review a broad range of studies of both of these effects, focusing particularly on countries where a large majority of the population is still dependent on employment in the primary sector. If climate change results in reduced rainfall and access to the natural capital that sustains livelihoods, poverty will be more widespread, leading to increased grievances and better recruitment opportunities for rebel movements. However, contemporaneous quantitative studies of conflicts in Africa (Hendrix and Glaser 2007; Raleigh and Urdal 2007; Meier et al. 2007) provided limited support for these hypotheses. For instance, Raleigh and Urdal concluded (2007: 674) on the basis of local-level data, that the effects of land degradation and water scarcity were negligible. Many of these early studies were inspired by a study by Miguel et al. (2004), which found a relationship between negative rainfall deviation and increased risk of civil war in Africa. This study used rainfall deviation as an instrument for economic shocks. But as Ciccone (2011) has pointed out, Miguel et al. look only at year-to-year rainfall deviations rather than deviations from a long-term mean. Using this indicator, which better reflects abnormality in rainfall and conforms more closely to the idea of climate change, their results evaporate. While some case studies provide support for a scarcity model of conflict (Kahl 2006), others do not (Adano et al. 2012). A series of new statistical studies published in a special issue of *Journal of Peace Research* (summarized in Gleditsch 2012) found mixed results for the effects of rainfall variability on conflict, but several found heavy rainfall to produce more conflict rather than drought, which would have been more consistent with the scarcity model of conflict. Theisen et al. (2012), using disaggregated data on conflict, also found little support for the thesis that drought breeds conflict.

A study by Burke et al. (2009) found a link between temperature and civil war in Sub-Saharan Africa for the period 1981–2002 and argued that over a 35-year period climate change would produce a major increase in the incidence of civil war, despite the expected conflict-dampening effect of economic growth and continued democratization during this period. However, Buhaug (2010) found several problems with their analysis, including that their results were not robust to standard control variables, to variations in the model specification, or to an extension of the time series to the most recent years. Buhaug concluded that climate variability is not a good predictor of civil war. Instead, civil war can be better accounted for by poverty, ethno-political exclusion, and the influence of the Cold War. A meta- study of this literature (Hsiang et al. 2013) finds a strong causal link between climatic events and human conflict 'across a range of spatial and temporal scales and across all major regions of the world', but this assessment has been sharply challenged by other scholars (Bohannon 2013; Buhaug et al. 2014).

Barnett and Adger (2007) also argue that climate change will reduce the capacity of states to mitigate these problems, an argument that parallels the argument by Fearon and Laitin (2003) that weak states are more prone to civil war. A plausible objection to Barnett and Adger's argument is that urbanization and the decline of employment in resource-dependent sectors is a world-wide phenomenon and one that is generally associated with greater prosperity and stronger states. For the first time in human history, a majority of the world's population now live in cities (Buhaug and Urdal 2013). Such countries are likely to be less vulnerable to the conflict-inducing effects of climate change. However, for many marginalized communities within growing economies, national economic growth has not reduced resource dependence. Since climate change is usually discussed in a 50–100 year perspective, a crucial question is how much of the climate-related reduction in agricultural and resource based employment can be absorbed by other sectors of the economy and on-going processes of economic change, which have been accelerated by the globalization of the world economy. Another great element of uncertainty is how warming will affect global agriculture. Some areas are likely to become more productive and in areas heavily dependent on traditional methods of rain-fed agriculture may be made more resistant to climate change through new technology and industrialization (Collier et al. 2010).

Gleditsch et al. (2007) present two stylized routes from environmental stress to conflict via migration—a direct path and an indirect path. The direct path assumes that environmental stress in location A will lead to migration B where conflict will break out between migrants and the host population. The indirect path assumes that environmental stress in location A will lead to conflict in A, thereby generating refugees who will flee to B, where in turn we could see additional conflicts. The indirect path is what most of the environmental conflict literature is concerned about, but the first half of this chain is fraught with conflicting evidence, and the second part of the causal chain has so far not been properly analyzed in systematic empirical studies. Barnett and Adger (2007) and even more so Reuveny (2007) point out that migration may lead to conflict in host communities in line with the direct path. Indeed, several studies have suggested Bengali immigration from the plains into the Chittagong Hills and Assam as an example of this. Suhrke (1997: 257f.), on the other hand, argues that this case is unique and that there is no systematic evidence for a general link between migration and conflict. In many cases, migrants may be valued for their skills and for their cultural contributions and actually decrease conflict risk by improving development in their host societies.

Reuveny (2007) analyzes the direct path by studying 38 cases of environmental migration in Asia, Africa, and Latin America. Half of these he classifies as 'no conflict' outcomes. In many, perhaps most, of the 19 conflict cases, the environmental pressures are clearly mixed with inter-ethnic violence that predates the migration, and some cases (El Salvador, Guatemala) were probably escalated by the ideological tensions of the Cold War and fueled by outside powers. A shortcoming of this analysis is that, in the absence of a multivariate analysis, it is difficult to conclude how much of the violence to attribute to the migration. Many of the violent cases also exhibit mostly unorganized violence or local conflicts which do not involve the state and therefore do not show up in compilations of data on of armed conflicts. In a study of 27 communities in Northern Nigeria, Nyong et al. (2007) find that drought conflicts in the Western Sahel have been increasing and that climate change could exacerbate such conflicts, but that the use of traditional institutions in conflict management can moderate such conflicts. Single case studies provide a mixed picture. Until recently, systematic time-series data on intercommunal violence were lacking, but using UCDP data Fjelde and von Uexkull (2012) find that large negative deviations in rainfall from the historical norm are associated with a higher risk of communal conflict and that this effect is amplified in regions inhabited by politically excluded ethno-political groups. Using data on violent events from the ACLED dataset for the period 1990–2009, O'Loughlin et al. (2012) found that much warmer than normal temperatures raise the risk of violence but that the temperature effect has only modest predictive power in a model which includes also political, economic, and physical geographic predictors.

A study by Salehyan and Gleditsch (2006) indicates that most countries with an influx of refugees since the 1950s remain peaceful, but the probability of organized armed conflict with more than 25 battle deaths[8] is nevertheless more than tripled in migrant-receiving countries. Many migrants come from conflict areas. They retain a direct stake in the outcome of fighting in their country of origin and they can easily

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[8] This is the threshold for inclusion in the UCDP/PRIO Armed Conflict Dataset, currently the most widely used global dataset on armed conflict, cf. www.pcr.uu.se/data/overview_ucdp_data/.

be mobilized for one side or the other. Militant groups often find it easy to recruit members among refugees, and transnational rebel networks may serve as conduits for the spread of armed violence. For instance, Rwanda became involved in the war in the Democratic Republic of Congo in the late 1990s after Hutu refugees began to organize opposition groups in the camps. We can assume, however, that purely environmental refugees do not have the same political agenda and grievances, nor do they have the same experience in organizing armed insurgencies. While competition for resources or jobs in the host country and inter-ethnic fears may lead to violence in various forms from murder to riots, large-scale organized armed conflict is perhaps therefore less likely.

3.8 The Way Ahead

Studies of the effects of climate change address the future but must learn from the past. Unfortunately, the precision in conflict prediction remains at the stage where meteorology was decades ago: the best prediction for tomorrow's weather was obtained by observing the weather today. Conflict models still have a hard time doing better than predicting that countries at war today will continue to be at war next year and that the peaceful will remain at peace. For instance, Ward et al. (2010) found that the two leading models of civil war (Fearon and Laitin 2003; Collier and Hoeffler 2004) do a very poor job of predicting the outbreak of conflict. With better theory, more accurate and detailed data, and more sophisticated methods for checking the robustness of the relationships found in individual studies (see e.g. Hegre and Sambanis 2006), we should be able to do better (Schneider et al. 2010). Hegre et al. (2013) predict a continued decline in the proportion of the world's countries that have internal armed conflict, from about 15 % in 2009 to 7 % in 2050, but climate change plays no role in their model. Five points are particularly important in the current move towards greater rigor in the study of the climate-to-conflict relationship:

First, we need a tighter integration of the climate science with social science models used in the study of conflict. The development of more fine-grained data for the physical effects of climate change, incorporating geographic variation, rates of change, and adaptive measures, will facilitate the scientific interface. The studies by Hendrix and Glaser (2007), Raleigh and Urdal (2007), Burke et al. (2009), Buhaug (2010), and O'Loughlin et al. (2012) demonstrate that insights from climate research can provide input to rigorous studies of conflict, but also that the uncertainties are considerable.

Second, we need to consider carefully what kinds of violence we expect to result from climate change. Most studies look for possible climate effects on state-based internal armed conflicts at the national level. Reuveny (2007) refers to several kinds of violence, including one-sided violence (genocide and politicide), non-state violence (between groups, but where the state is not an actor), and unorganized violence. The study of communal conflict (e.g. Fjelde and von Uexkull 2012) is probably the most promising in this regard. It seems plausible that this kind of lower-level violence is more likely to be affected by resource scarcity than state-based conflicts. However, increasing economic development and higher state capacity in relatively young states should contribute to the reduction of communal violence, so a climate-related increase may not be very visible in the aggregate.

Third, the study of climate change and conflict needs to balance the effects of climate change (positive and negative) as well as the effects of various strategies of adaptation. While the climate change models perform such an assessment for factors that lead to higher and lower rates of CO_2 in the atmosphere and in the effect on temperatures, the discussion on the social effects tend to focus only on an enumeration of possible negative effects, large and small. Although the global net effect of climate change seems likely to be negative, the effects would vary considerably both geographically and by sector. This must be taken into account to produce accurate estimates of risks and suggest the most effective policy measures. An analogy to the study of economic effects of disarmament, an area of both academic and public concern during the Cold War and after, may be instructive. Many on the right as well as the left of the political spectrum focused on the possible negative economic effects of disarmament such as unemployment in the military sector. However, most econometric studies, using established models of the national economies, concluded that the net economic effects of disarmament were likely to be positive and that the problems of unemployment could easily be overcome if the savings from reduced arms spending were channeled in the right direction (Klein et al. 1995; Gleditsch et al. 1996). In the event, the end of the Cold War led to massive reductions in defense budgets in both East and West and the worst-case scenarios did not materialize.[9] It seems less likely that such a balanced accounting will yield a positive outcome for climate change, whether measured by an economic yardstick or a conflict measure, but studies such as those by Hendrix and Glaser (2007), Burke et al. (2009), Buhaug (2010), and O'Loughlin et al. (2012) provide a foretaste of what such studies are likely to look like.

Fourth, we should continue to disaggregate the effects of climate change in our systematic conflict models, both in terms of geographical variation and types and rates of change. Climate change will have a plethora of different outcomes. Human livelihoods could be affected directly through factors ranging from sea-level rise, human health, and changing weather patterns, and indirectly via such factors as migration. These various causal chains need to be mapped and investigated. Also, the impacts are likely to vary considerable between different areas and societies, and even for different populations within the same society. For instance, although most areas are expected to become warmer, some will heat up more than others. Total rainfall is predicted to increase, but some areas will become drier. There will also be vast variations in terms of the technological and societal capabilities for meeting the challenge of climate change. Modeling these variations, particular

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[9] The transition problems were much greater in the former command economies than in the market economies, but not due to the degree of disarmament.

constellations of challenges in various locations, as well as adaptive capabilities will be a key to improve the capacity to foresee climate-related conflict hot-spots.

Finally, some writings on climate change and security focus mainly on consequences for the rich countries. If climate change leads to more deprivation in poorer parts of the world, it could also generate additional terrorism that impacts on the security in the wealthy part of the world (Homer-Dixon 2007). But as Barnett and Adger (2007) argue, regardless of the precise nature and size of the changes, they will primarily affect poor countries (and poor people in those poor countries). The security scenarios may well be constructed with the benign intention of arousing the world to greater attention to a global issue. But they could also lead to greater emphasis on a national security response to whatever degree of climate change is seen as unavoidable (Salehyan 2008). This would not be helpful to the primary victims of climate change.

Increasingly, it is now argued that we are already seeing the effects of climate change unfolding in conflicts in Africa, particularly in the Sahel and Darfur (Ban 2007). Few Sudan experts credit climate change as a major causal factor in the Darfur conflict, however (Flint and de Waal 2008) and a systematic study of rainfall patterns found climate change to be weakly related to the violence (Kevane and Gray 2008). While climate change may perhaps make a contribution in the future to exacerbating old conflicts between different groups, the conflict would not have gotten out of hand without a government more intent on fueling violence by aiding the perpetrators of violence rather than stopping them. Laying the blame for Africa's conflicts on the environment may provide a welcome excuse for actors that could otherwise have been held accountable. Also, while it is possible that climate change may lead to more conflict in the future, it has not so far challenged the reported trend towards a more peaceful world. While Africa is currently the continent most affected by armed conflict, the decline in state-based armed conflict has now reached this continent, too.

Concluding Remarks

Climate change will probably have many serious effects, particularly transition effects, on peoples and societies worldwide. The hardships of climate change are particularly likely to add to the burden of poverty and human insecurity of already vulnerable societies and weak governments. Thus, climate change can be seen as a security issue in a broad sense. However, the conjecture that climate change might pose a threat to security in the narrower sense is far less certain. So far the evidence is mixed in terms of whether we are going to see an increase in armed conflict as a result of climate change, and if so what types of conflicts we can expect. Assuming such a link without the necessary evidence may lead peacemaking astray and can eventually also undermine the credibility of the IPCC and the efforts to reach a consensus of knowledge about human-made climate change and a concerted

(continued)

global effort at mitigation and adaptation. The climate-conflict discourse is easily exploited by actors who would like to evade any direct responsibility for atrocities and violence they commit, and prefer to put the blame on greenhouse gas emissions and the changing climate. Above all, blind reproduction of 'folk wisdom' about the climate-conflict relationship will undermine serious research in this area and potentially leave us less well-prepared for dealing with the social effects of climate change once they really start kicking in. The more rigorous and empirical research that has started to emerge will provide a better basis for assessments than the earlier literature that the third and fourth assessment reports of the IPCC relied on. This is promising for the prospect of better preparedness to deal with the security implications of climate change.

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Chapter 4
Forging War or Peace? The Role of the State in Extractive Economies of Sub-Saharan Africa

Marie Müller-Koné and Peter Croll

In the heated discussions on worldwide competition over resources, German and European policy-makers and industry representatives nervously point to the growing demand for resources by emerging economies such as China, Brazil, and India. China produces more than 97 % of the global supply of rare earth minerals, which are used to produce high-tech consumer products and advanced military equipment like guided missiles. Reports in late 2010 showed that China was withholding shipments of rare earths resulted in increased nervousness of importing countries (Hagelüken, Chap. 8; Schebek et al., Chap. 10; Zepf et al., Chap. 18) . In these discussions, the role of Sub-Saharan Africa as an important producer of certain minerals is often overlooked. The Steenkamskraal mine in South Africa, operated by Canada's Great Western minerals Group for instance, is projected to produce 2,700 t of rare earth concentrate by 2013. World demand for rare earth elements was estimated at 136.000 t per year in 2012, with global production around 134.000 t in 2010 (Humphries 2012).

The discussion on the international availability of resources mostly does not take into account the consequences of resource exploitation in producing countries—often characterized as a 'resource curse'. In economically poor countries that rely on exports of extractive resources such as petroleum, mineral resources, and gems, the risk for civil wars tends to be higher than in countries less dependent on such resource exports (Basedau and Lay 2009; Ross 2004; Le Billon 2008). The extraction process and the management of revenue flows come with a myriad of social and environmental problems.

This article is on violent conflicts fueled by the exploitation of natural resources in Sub-Saharan Africa, seeking to determine how various causal mechanisms are related to each other (Bleischwitz et al., Chap. 11). It contends that the analysis of

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resource-related conflicts must go beyond the greed and grievance dichotomy that has characterized the debate for a long time. One cannot deny that greed was a factor in some violent conflicts in Sub-Saharan Africa, such as in the Eastern Democratic Republic of the Congo (DRC), and one equally cannot deny that in other instances, grievances provided the breeding ground for violence, such as in the Niger Delta. Motivations may change in different phases of the very same conflict: even if grievances of the local population of the Niger Delta had been a driver for violent conflict, major players of the Nigerian war economy have come to be driven by greed. As many grievances remain unresolved during conflict, greed and grievances can interact in complex ways. Neither greed nor grievances alone can account for the outbreak of civil war. It is therefore necessary to look at the causal mechanisms in more detail. None of the recent conflicts in Sub-Saharan Africa since independence have only been caused by resource wealth but by a combination of factors. At the same time, from a political economy perspective, struggles for national power (or secession) are also struggles for the resources channeled through the state. Hence, struggles within and around the state are important to consider when trying to understand the relationship of natural resources and conflicts. To a large extent state rents are generated from exploiting natural resources, for most Sub-Saharan African states depend heavily on primary exports of agricultural or mineral resources that bring in foreign exchange (Kappel and Pfeiffer 2013: 12–15).

As natural resources are tied up so closely with the working of African states, this article is concerned with the role of the state in resource conflicts. The question the authors seek to answer is thus how the state is involved in violent conflicts surrounding resource extraction. They will do so by reiterating some causal mechanisms identified in the literature so far, and by analyzing how those mechanisms relate to the state. Apart from secondary data from the literature, the article is based on empirical findings from interviews conducted in Nigeria in late 2009.

To disentangle the resource-conflict nexus, it is useful to distinguish different kinds of resources—extractive, agricultural and renewable resources such as water and land. Cash crop commodities and mineral resources share the common characteristic of generating foreign exchange due to their demand on international markets, which intrinsically links them to questions surrounding access to state revenues. However, the modes of production of agricultural and extractive resources differ distinctively, and even different kinds of extractive resources are linked to different dynamics of violence (Le Billon 2007). The authors focus solely on extractive resources in this article for reasons of clarity.

The article will first compare the importance of natural resource wealth in Sub-Saharan Africa to other world regions, in order to assess its relative resource wealth. Subsequently, it will give a brief overview of the causal mechanisms that link resource wealth and conflict in Sub-Saharan Africa as identified in the literature. A case study of violent conflict in the oil-rich Niger Delta will serve to analyze the role of the state on the road to violent conflict in the Niger Delta.

4.1 Natural Resource Wealth of Sub-Saharan Africa in Comparative Perspective

Resource-related wars in Africa—the civil war in Sierra Leone (1991–2002) fueled by so-called "blood diamonds" or ongoing conflict in mineral—rich eastern Congo—have conjured up a picture of Sub-Saharan Africa being cursed by an enormous wealth in natural resources. Relative to other world regions, however, Sub-Saharan Africa is not particularly rich in natural resources: the region holds 5.6 % of global hydrocarbons and 13 % of mineral and metal reserves by value (Jones 2008: 8). This, at least, is what existing data on production and reserves confer. Table 4.1 (ibid.: 9) lists the net present value of hydrocarbon, metal and mineral reserves per world region for 2005.[1] As these are aggregated values, the share in global production of some specific mineral and energy commodities produced in countries in Sub-Saharan Africa (SSA) can still be significant: In the case of diamonds, platinum group metals (PGMs)[2] and Cobalt, Sub-Saharan Africa represents 53.7, 63.0 and 55.1 % of world production respectively (Stürmer 2010: 6). Table 4.1 illustrates that, of the groups shown, SSA has the lowest level of total natural resource wealth (by monetary value).

This is not to dismiss the economic significance of natural resources relative to other economic sectors in countries in Sub-Saharan Africa, given the high share of primary exports in African economies. Exports of minerals and hydrocarbons account for 38 % of total exports in Sub-Saharan Africa, constituting the most important economic sector after agriculture (Stürmer 2010: 5). Total state revenues for Chad in 2008, for instance, resulted by 80 % from oil revenues (Frank and Guesnet 2009: 31). Also, the actual reserves of Sub-Saharan countries are poorly quantified due to limited capacity to explore and measure the countries' reserves (Jones 2008: 20; Stürmer 2010: 10–12). In addition to that, figures of production and trade can grossly misrepresent the volumes that are taken out of African sub-soils, due to recurrent undervaluation of resources and smuggling of great quantities when it comes to artisanally produced minerals (Africa Progress Panel 2013: 19).

What can be taken from the data on natural resource reserves is that the mere endowment with natural resources in terms of reserves or actual production cannot account for the violent conflicts that have ravaged the African continent in the past decades. If one were to follow the logic that natural resource wealth fuels civil war, OECD countries would be more prone to civil war than Sub-Saharan Africa. Hence, other factors than the mere resource endowment of a country must be more decisive in moving a country towards peace or war. It is assumed here that the way these resources are managed is crucial, that is how the access to the resources, their

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[1] Jones bases his calculations on production and reserves data from the US Energy Information Administration (EIA) and the US Geological Mineral Resources Survey (USGS).

[2] The six platinum group metals are ruthenium, rhodium, palladium, osmium, iridium and platinum.

Table 4.1 Estimates of natural resource wealth[a] by group (region)

		Hydro-carbons (US $[b], billions)	Metals and minerals (US $, billions)	Total (US $, billions)	Average per capital (US $)
High-income countries	OECD	6,026	374	6,400	11,864
	non-OECD	7,268	1	7,269	207,304
Developing countries	Latin America and Caribbean	2,106	467	2,573	5,378
	Middle East and North Africa	4,193	8	4,201	9,849
	Europe and Central Asia	5,997	211	6,208	6,946
	S.E. Asia and Pacific	2,800	320	3,121	1,644
	SSA	1,686[c]	199	1,885	4,577
TOTAL		30,075	1,582	31,657	17,654
High-income countries as % total		44.2	23.7	43.2	–
SSA as % total		5.6	12.6	6.0	–

Source: Jones 2008, excerpt, Table 9

[a] Note: resource wealth by monetary value (US dollars), not by production volume

[b] All dollar-data in this article are current dollars

[c] Due to recent oil finds in Ghana, Sao Tomé and Principe and Sierra Leone (2007–2010) and in Uganda, Liberia and Kenya (2011–2012), the oil wealth of SSA has been rising. While Africa accounts for 12 % of oil reserves, a third of new oil discoveries are being made here (Van der Westhuizen 2013)

extraction and the distribution of benefits from the extraction process is governed (Franke et al. 2007; Guesnet et al. 2009: 26–27).

4.2 Mechanisms Linking Natural Resources and Violent Conflict

The resource curse literature has so far produced contradictory results as to whether and how natural resources fuel civil war. Some results, however, seem to be consistent across many quantitative studies.

Several studies have shown that low-income countries are more prone to civil war than countries with higher per capita income (Thies 2010: 327). The mean per capita gross domestic product (GDP) in countries affected by civil war at any point from 1960 to 1999 is less than half that of countries with no civil war experience (Sambanis 2004: 165). It has also been shown by more recent studies that this equally applies to per capita resource wealth. A quantitative study on oil exporters using datasets provided by Collier and Hoeffler, Fearon and Laitin and Humphreys, found that all countries which produced more oil than 10 t per capita per year in 1996 did not experience violent conflict, as measured through cumulated internal conflict intensity by UCDP/PRIO conflict data for the period 1990–2005 (Basedau and Lay 2009: 768). Thus, according to these results, it is not resource wealth that is closely connected to civil wars in Sub-Saharan Africa but rather relative per capita resource poverty, coupled with a dependence on resource exports.

Another little disputed result is the fact that oil exporting countries are more prone to civil war than non-oil exporters—highlighting the usefulness of distinguishing between different kinds of resources (Soares de Oliveria 2007: 35–39; Collier and Hoeffler 2000; Thies 2010). Fearon and Laitin state that oil exporting states experience civil war onsets twice as often as others (Fearon and Laitin 2003: 75–90).

These quantitative correlations can be useful to test and refute some hypotheses about resource wars, such as the assumption that resource wealth increases the risk of civil war. They do not help much, however, in understanding the complex social and political dynamics that accompany resource extraction. The ensuing part of this article therefore lists and comments on the causal mechanisms linking natural resources and the onset of violent conflict, which the resource curse literature has identified with special emphasis on the role of the state.

Ross (2004: 39, 56–59) identifies the following hypotheses on the implication of natural resources in the onset of civil war:

1. Looting by potential rebels provides start-up funds for rebellion (“Looting”).
2. Resource wealth enables rebel groups to sell future exploitation rights to minerals they hope to capture (“Booty futures”).
3. Resource wealth increases the likelihood of foreign intervention to support a rebel movement (“Foreign intervention”).
4. Resource extraction increases the probability of civil war by causing grievances over insufficiently compensated land expropriation, environmental degradation, inadequate job opportunities, and labor migration (“Resource-related grievance”).
5. State dependence on resource revenues weakens its bureaucratic capacity (“State weakness”).
6. Preemptive repression by government to protect resources leads to more casualties in separatist conflicts (“Repression”).
7. Resource extraction provides residents in resource-rich areas incentives to form a separate state (“Separatism”).

4.3 "Conflict Resources": Greed

1. "Looting": Looting by Potential Rebels Provides Start-up Funds for Rebellion

The first hypothesis is based on the arguments advanced by Collier and Hoeffler (2000) that easily lootable resource wealth provides young disgruntled youth groups with the opportunity to start a rebellion; that rebellions are driven mainly by greed and not by grievances. They used a data-set of world-wide civil wars for regressions that measured the correlation between civil war and proxies for greed and grievance and found a high correlation with greed and a low correlation with grievances. Their studies have been criticized on several grounds, both theoretically and empirically. One such critique refers to the data they employed. Collier and Hoeffler used the share of primary commodity exports in total GDP, the share of 15-to-24-year-old males in the total population, and the average years of male secondary school enrolment (as a measure for unemployment) to reflect greed motives. These proxies are problematic for several reasons. They assume that rebellions are mainly led by unemployed youth that have nothing to lose and voluntarily join rebellions. In Sierra Leone, however, the ranks of rebel groups were also filled with employed people and forced recruitment played an important role. There also existed an age-related grievance in the countryside, where old chieftaincy structures dominated society and imposed arbitrary levies, but had lost legitimacy (Cramer 2006: 172–176). Lack of education and young age may therefore represent grievances as much as greed. The thesis of easily lootable resources providing the opportunity for rebellions is moreover contradicted by other scholars who contend that lootable wealth need not lead to political disorder. Artisanal diamond mining, for instance, is characterized by hierarchies providing order and security that are necessary for successful resource extraction (Le Billon 2008: 358).

Similarly, some quantitative and qualitative empirical studies could not find supporting evidence for the greed hypothesis on the onset of war. Ross analyzed 13 cases from Collier and Hoeffler's list of civil wars in the 1990s and found that "in these 13 cases, nascent rebel groups never gained funding before the war broke out from the extraction or sale of natural resources" (Ross 2004: 50). In Sierra Leone, war started in 1991, but fighters of the Revolutionary United Front (RUF) only occupied diamonds fields from 1994 onwards. RUF rhetoric also alluded to resource exploitation as "the raping of the countryside to feed the greed and caprice of the Freetown elite and their masters abroad" (quoted in Ross 2004: 51). This is not to say that the RUF rebels' main motivation were the grievances related to the diamond sector. In so far, Collier and Hoeffler are right to warn against confusing rebel rhetoric with reality. A concept that manages to recognize the role existing grievance play in stirring rebellion without assuming those to be the main motivators for individual rebels is that of "hidden transcripts" of Scott (1990). It suggests that rebel discourses are rarely novel but transpose widely shared "hidden transcripts" within aggrieved groups into the public realm. This means that rebel groups may publicly refer to existing grievances that resource exploitation creates, even if their main motivation to rebel did not directly emerge from the social and material practices of the diamond sector (Billon 2008: 359).

The grievances which stood at the onset of the rebellion and are related to the lack of perspectives for the younger generation and economic hardship of many, resulted from deleterious patron-clientelistic politics. This hints to the influence of political dynamics surrounding the state, which followed patron-client relations that continuously undermined its economic functions. Governing elites used the privatization of economic assets of the state to consolidate the relations to their clients instead of the institutions of the state (Reno 1995).

2. “Booty Futures”: Resource Wealth Enables Rebel Groups to Sell Future Exploitation Rights to Minerals They Hope to Capture

While greed may not have played a decisive role in motivating rebels in many African wars to take up arms in the first place, there is more evidence that greed of foreign actors often provided the financial means and the opportunity for rebellion or for continuing war. Instead of looting by rebels, Ross identified another mechanism that linked resource wealth to civil war: domestic actors—both government and rebel forces—sold off rights to exploit mineral fields that they did not yet control to foreign firms, thereby gaining the financial means to start a rebellion or to avoid close military defeat—hence prolonging the war. French oil company Elf-Aquitaine was reported to have paid Denis Sassou-Nguesso US $150 million to help him defeat the incumbent president Pascal Lissouba, to access Congolese oil under a Sassou-Nguesso government (Ross 2004: 58). African governments equally used booty futures: in March 1995, RUF, who at the time controlled the Kono diamond fields, advanced to within 20 miles of the capital of Sierra Leone. The government sold future mining rights to the Kono diamond fields to a South African company and used the proceeds to hire Executive Outcomes, a South African mercenary firm, to recapture these fields (Ross 2004: 58–60).

3. “Foreign Intervention”: Resource Wealth Increases the Likelihood of Foreign Intervention to Support a Rebel Movement

Hypothesis 3 posits a higher risk of foreign intervention in resource-rich countries: neighboring countries are induced to militarily intervene in a mineral-rich country at civil war to occupy its mining sites and to profit from its riches. This has happened in the war that ravaged the DR Congo from 1998 onwards. Neighboring governments invaded the eastern DRC with their troops in support of rebel groups or government forces and exploited the mineral riches of the country.[3] Even after withdrawal they continued profiting from the country’s natural resources by setting up joint ventures and by using local militias as their surrogates (Ross 2004: 54). The greed of foreign actors exposed in hypothesis 2 shows that the benefiters of a war

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[3] In Zimbabwe, another neighbouring country that invaded the DRC and profited from its mineral wealth, personalities who had smuggled diamonds from the Congolese war economy, later became involved in shady diamond businesses in the Zimbabwean diamond fields of Marange (PAC 2010: 5; UN Panel of Experts on DRC 2002: 5–7).

economy can be more manifold than just neighboring governments, including foreign companies that expect to reap high profits, arms dealers, and other foreign governments that support certain armed groups.

Both hypothesis 2 and 3 point to international connections which facilitate civil war: a train of thought stressed by authors advocating the war economy strand. There are two ways one can look at war economies. One is to distinguish a wartime economy from a peacetime economy. The stress lies on the fact that during wartime, production and distribution depend on violence. Looting, informal taxation of the local population, and resource extraction provide the means to finance combatants, arms and ammunition, and to self-enrichment. Rebel or other armed groups are able to control natural resources in peripheral regions that can—like alluvial diamonds—be exploited with a minimum of capital and know-how and sold on the world market. War economies therefore also have an important international dimension. On a global scale, they are facilitated by international trade links and are thus intricately linked to the international trade and financial system and consumer demand (Winer 2005). International demand determines the price at which natural resources can be sold and which resource is most sought after by armed groups.

The second way of looking at war economies is to distinguish them from wars that are fought for political purposes. The systematic use of violence, others contend, becomes an end in itself, to allow for continued looting (Ruf 2003: 34). Political motivations of armed actors recede to the background and are replaced by mainly economic motives: "these wars tend to literally forget their own causes" (Schlichte 2003: 125; translation by authors). In this type of resource war, natural resources do not necessarily constitute the cause of war, but can be instrumental in continuing an ongoing war. This is why some researchers refer to such resources as "conflict resources" as opposed to "resource conflicts" (Richter and Richert 2009). "Resource conflicts" indicate that "the concern for access to and control of resources is the most important motivation" for conflict initiation (Strüver 2010: 9).

The first set of hypotheses (1–3) is closely related to situations of war economies that are driven by "conflict resources". It is possible that, in the course of war, enrichment through the control of trade in natural resources both by government and rebel forces can change the interests and motivations of major actors. This position of theorists of war economies does not clash with the idea of grievances providing the breeding ground for the onset of civil war in the first place.

The second set of hypotheses (4–7) relate to situations of "resource conflicts" where the onset of civil war is directly related to problems surrounding resource extraction. Hence, the hypotheses formulated by Ross are not mutually exclusive but can be complementary.

Hypotheses 4–7 point to the influence of the state in these "resource conflicts". In the following, the case of the Niger Delta will be used to analyze how the state is implicated in these mechanisms.

4.4 "Resource Conflict" in the Niger Delta: The Role of the State

With the help of a case study of Nigeria[4] the authors will scrutinize the causal mechanisms "resource-related grievance", "state weakness", "repression" and "incentive to separatism" and will analyze how they relate to each other. Hypothesis 1–3 ("Looting", "Booty futures","Foreign intervention") will be neglected because they do not apply to the onset of violent conflict in the Niger Delta, as will be clear from the following analysis.

4. "Resource-Related Grievance": Resource Extraction Increases the Probability of Civil War by Causing Grievances
Social and political protest against oil exploitation in the Niger Delta turned violent at the end of the 1990s, with a range of local militia groups pitted against each other and the oil installations. Between 2005 and 2009, the *Movement for the Emancipation of the Niger Delta* (MEND) regrouped such militia groups under its roof and challenged the state and oil companies with kidnappings, acts of sabotage, and "oil bunkering"—the systematic theft of oil. The estimated annual fatalities of fightings with the Nigerian army and among the militias in the Delta exceeded 500 after 1999 (Ibeanu and Luckham 2007: 63).[5]

People in the Niger Delta have long expressed various grievances related to oil exploitation in their surroundings, arising from persisting poverty of the majority in the midst of plenty and from the destruction of the environment and livelihoods through oil infrastructure and oil spills. While the hypothesis states that resource extraction leads to grievances among the local population in the resource regions, it does not say anything about the reasons for that. It is important to analyze the reasons because negative consequences from resource extraction do not occur naturally but are conditioned by certain circumstances. Why did oil exploitation operations lead to these grievances? Why did they degenerate into violence? To understand this process it is useful to distinguish between localized social and ecological consequences directly following from resource extraction and political grievances related to the national redistribution of resource revenues and to wider concerns of ethnic marginalization.

Most of oil extraction in Nigeria is onshore. Oil installations and infrastructure cover more than 1,500 communities in the Niger Delta. Over 5,200 oil wells in 240 oil fields are connected to export terminals via pipelines (Federal Republic of Nigeria n.d.: 72, 75). Direct challenges arising from onshore oil installation projects in the Niger Delta include the resettlement of villages, compensation for lost

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[4] The case study is based on field research undertaken by one of the authors, Marie Müller, in Lagos and Abuja, Nigeria, in October 2009.

[5] The numbers listed by the Stockholm Peace Research Institute (535 battle-related deaths in 2004) only account for fighting that involved the state military. As much of the violence in the Niger Delta is inter-communal, there is hardly any reliable data on annual fatalities and the numbers are contested (Mähler 2010: 11–13).

farmland and crops, health and environmental risks stemming from oil spills and gas flaring. As international oil companies are the operators of the production joint ventures with the state-held Nigeria National Petroleum Corporation (NNPC), they are the first to be blamed by the local population for the problems associated with oil drilling. A 2003 internal Shell report delineates clearly how Shell is about to loose its 'social license to operate' (WAC Global Services 2003) as local stakeholders complain about insufficient compensation, environmental destruction, the opaque distribution of payments from oil companies among community members, and little employment in the oil industry. UNDP recorded more than 6,800 spills between 1976 and 2001, totaling three million barrels of lost oil (Amnesty International 2009a: 15). A quote from an interview with a Nigerian NGO illustrates some of the consequences:

> I went to a community that is called Oporoza. It is the headquarters of 20 communities in Gbaramatu Kingdom of the Ijaw people. (. . .) Our visit was on 19–23 October 2009 (. . .). In that community, we couldn't get fish to buy, and their major source of income is fishing; that is their source of livelihood. The whole water is polluted because they say they had spillage. You see oil everywhere in the water. How was the oil spillage handled? No one is handling anything. All you see is oil in the water. The oil killed their fish, so there's no fish. (. . .) And they say you cannot farm because the water that is flowing around is salty water. You don't have potable water. (. . .) They drink their dirty water, another brown water that they drink. They think that the brown one is better than the salt one, and the salt one has the spillage on it, so people don't go near it.[6]

Another enormous problem is that 80 % of the gas associated to oil extraction in Nigeria continues to be flared, contrary to practices of the oil industry in other parts of the world. Not only are the resulting huge flames a great health risk to the local population (respiratory problems, 24 h of daylight, etc.) but also a major worldwide source of CO_2 emissions—about 70 million metric tons per year (Pöyry 2008: 40).

While the oil companies cause these environmental problems, the Nigerian government fails to fulfill its regulatory and oversight functions over the oil operations. With regard to compensation for lost crops on damaged land, the government rates mainly follow the recommendations of the national Oil Producer's Trade Section (OPTS), an organization of oil companies in Nigeria.[7] As a result of this, communities receive insufficient amounts of compensation (Amnesty International 2009a: 7). The fact that the ownership of land and underground resources is centralized in the government also puts oil-producing communities in a disadvantaged position as concerns legal entitlements to compensation for their land. The 1969 Petroleum Act, enacted by the military government in the course of

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[6] Extract from an interview by the author with Bridget Osakwe, WANEP, Lagos, Nigeria, 4 November 2009. The West Africa Network for Peacebuilding (WANEP) supports local peacebuilding initiatives in the Niger Delta and monitored the humanitarian impact of the 2009 fighting in the Niger Delta.

[7] Interview by the author with Reverend Kevin O'Hara, founder of CSCR, Lagos, Nigeria, 3 November 2009.

war and still valid today, places the complete ownership over oil resources in the federal government, and so does the Nigerian Constitution under its Section 44 (3) (Omeje 2005: 326). Moreover, the Land Use Act (LUA) of 1978 has removed the ownership of land from individual Nigerians to the state: "All land (...) is vested in the military governor of the state and such land shall be in trust and administered for the benefit of all Nigerians" (Section 1 of the LUA).

Hence, grievances related to the social and ecological consequences following from resource extraction are partly due to a lack of state capacity and willingness to exercise effective oversight over the oil sector. The Nigerian state has played a central role in creating grievances from resource extraction by determining the way the extraction process is governed—how local communities can partake in the benefits of the oil industry (or not) and what responsibilities international oil companies are made to fulfill (or not).

In addition to direct social and environmental consequences from oil extraction, rhetoric of militants from the Niger Delta often conveys concerns about marginalization of Niger Delta ethnic minority groups in the face of "Northern" domination. These political grievances reflect issues surrounding the national redistribution of resource revenues, as is seen in the debate over 'resource control' pushed by Ijaw militants in the Niger Delta who demand more direct control over the oil revenues generated by the oil industry. Oil and gas exported from the Delta region account for about 80 % of total federal government revenues (Technical Committee 2008: 102). They are then allocated to the different states according to certain criteria.[8] While the fiscal principle of 'derivation' ensured that the federation returned to each state the revenues that it itself generated, the military regimes during the 1970s and 1980s have eroded this federal character of fiscal allocation. The percentage of derivation was cut back from 50 % of the Federation Account allocation to 30 % in 1970, and then to a mere 1.5 % in 1984, to be increased to the 13 % at the time of writing by the first elected civilian President Obasanjo (Guichaoua 2009: 28; Ibeanu and Luckham 2007: 60). The discussion about ethnic marginalization, however, had started well before oil production. Nigeria's regional and ethnic divisions are a legacy of pre-colonial and colonial political divisions. The Yoruba-dominated southwest was placed under firm control of the British in the ninenteenth century, while the southeast, ethnically dominated by the Igbo, was subjected to indirect rule, just like the northern former Sokoto Caliphate,[9] dominated by the Muslim ethnic group of Hausa-Fulani. The (British) Lyttleton Constitution of 1954 grouped these three regions together in a federal structure, each with considerable autonomy (Guichaoua 2009: 21–25). This institutional structure that

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[8] In practice (Fiscal Year 2007), the revenues are divided in the following way: Statutory allocations to states (20 %), local governments (15 %) based on the criteria of equality, population and land mass; share of federal government (39 %), and 'derivation' money allocated to the oil-producing states based on their oil production volumes (9 %) (Guichaoua 2009: 30).

[9] Founded in the late 1700s, it was one of the most powerful empires in Sub-Saharan Africa prior to European conquest and colonization. The Fulani rulers had conquered former Hausa states.

favored the three main ethnic groups (Hausa-Fulani, Yoruba, Igbo) has characterized Nigerian politics even after independence.

To conclude, the lack of oversight and the centralized management by the Nigerian state were partly responsible for the negative consequences directly following from resource extraction and the political grievance of ethnic marginalization related to the national redistribution of resource revenues. The ethnic imbalances inherent in the process of Nigerian state formation created the basis for perceptions of ethnic marginalization, which were reinforced by the increasingly centralized management of oil revenues channeled through the federal government.

5. "State Weakness": State Dependence on Resource Revenues Weakens Its Capacity

In Nigeria, there is a clear link between oil-related grievances and weak state capacity, because perceptions of ethnic marginalization and unfair redistribution of oil revenues have been aggravated by ineffective state institutions. Despite the enormous revenues that the federal government—and since 1999, the states of the region—has received, namely US $95 billion from 1999 to 2004 (NEITI, n.d.), very little has transformed into developmental progress. Hypothesis 5 states that the dependence on oil exports can be blamed for this weak state capacity. Authors including T.L. Karl (1997), argue that state dependence on oil revenues tends to weaken its overall capacity, and that the high petroleum rents that accrue to the state tend to expand the state's jurisdiction, which, combined with low government capacity, weakens state authority, a phenomenon referred to as 'petro-state' (Karl 1997: 15). According to Karl, these centralizing tendencies tend to perpetuate traditional concepts of authority as the personal patrimony of rulers (ibid.: 62). The state apparatus depends on the rents extracted from oil exports and less so from internal taxes, which undermines democratic accountability. Political consent is ensured via political patronage, i.e. the distribution of state offices among political allies. Related to that is a lack of transparency in fiscal affairs, which favors corruption and ineffectiveness.

Contrary to hypothesis 5, which posits that state dependence on resource revenues weakens its overall capacity, a recent article on state capacity and civil war using a multi-case quantitative analysis finds that natural resource wealth has hardly any negative impact on state capacity (Thies 2010). The author defines state capacity by its ability to raise taxes. In Nigeria, however, it was not the state's inability to raise taxes but its weak capacity on the expenditure side combined with a propensity to repression, which increased grievances. As long as revenues are not sufficiently invested in overall development, the population in resource-rich areas tends to perceive the central governments' capacity to extract levies as a problem.

The case of Nigeria seems to corroborate the thesis of weak state capacity conditioned by oil dependency. At least, it shows many characteristics described by authors positing the weak state argument. The centralization of the management of oil extraction and oil revenues by the Nigerian state confirms the assumed expansion of the state's jurisdiction. Despite its federal character with 36 states, which mostly ensures that every state is represented in the federal government, Nigeria has developed a pronounced fiscal centralism (Heinemann-Grüder 2009: 40–46). The states are highly dependent on central government fiscal allocations, averaging 67 % of state budgets between 1980 and 2002 (Guichaoua 2009: 26–29). The federal fiscal budget, in turn, depends to 80 % on oil and gas exported from the Delta region (Technical Committee 2008: 102). This is accompanied by a concept of authority that comes close to that of a personal patrimony of rulers, illustrated by how all decision-making power relating to oil business is concentrated in the president and his advisors.[10] Related to that are high levels of corruption in Nigeria. Apart from the official oil revenues, bribes paid by international companies involve enormous sums that can be very attractive to state officials. The Halliburton Case revealed that the US company Halliburton and its former subsidiary Kellogg Brown and Root (KBR) had paid US $180 million to officials between 1994 and 2002 to secure a construction contract for the liquefied natural gas plant in Bonny Island in Niger Delta (Garuba 2009). Nigeria's rating on the global Corruption Perceptions Index by Transparency International (TI) worsened in 2009, dropping from 121st to 130th position out of 180 countries.

Despite the signs of a 'petro-state', this should not be taken as face-value. The process of centralization cannot be entirely attributed to oil exploitation, which commenced in 1957. The centralization process started under military rule 1966 and then subsided with the transition to democratic rule in 1999. In addition, the centralization process was accompanied by a proliferation of sub-national administrative structures that continues until today. Nigerian oil politics became a "state-making machine" to claim oil revenues, for which ethnicity was a political tool (Watts 2004: 72–73). This sometimes led to violent confrontations between ethnic groups over supremacy in new Local Government Areas (LGAs) (Anugwom 2005: 94).[11]

This parallel movement of centralized federalism seems to hold the key for understanding the weak state authority and lack of institutionalization. Financially dependent on the federal government and constantly recreated, the states and LGAs did not develop financial responsibility and institutional effectiveness. The continuous fragmentation and recreation of sub-national units reinforced the concentration of economic and political power in the center (Suberu 2001: 15). The constant recreation of sub-national state units also explains the lack of administrative institutionalization (Karl 1997: 63): As there is little routinization, state actors constantly redefine the way in which the system would operate. Hence, it is clear that the weak state capacity is also due to its dynamic federal character and ethnic

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[10] Interview by the author with Dayo Olaide, Coordinator West Africa Resource Watch at the Open Society Institute for West Africa (OSIWA), Abuja, Nigeria, 28 October 2009.

[11] Equally, the violent clashes between Ijaw and Itsekiri in Warri, Delta State, in 1997 to 1999 followed the creation of new LGAs. Since then, there has not been a crisis of that magnitude (Institute for Peace and Conflict Resolution 2008: 182–84).

mobilization to claim oil revenues within sub-national political units (states or LGA).

6. "Repression": Preemptive Repression by Government to Protect Resources Leads to More Casualties in Separatist Conflicts

This hypothesis refers to situations where repressive measures by government in the course of separatist movements increases the number of casualties (Ross 2004: 60). Violence in the Niger Delta after 2000 was not driven by a secessionist agenda as such. However, similarly, the brutality of the government's Joint Task Force (JTF), composed of troops of the army, navy, air force and the mobile police in 2004 to suppress the militant uprising, similarly increased the number of civilian casualties (Ikelegbe 2005: 223–225; Amnesty International 2009b).[12] But more importantly, government repression of protests in the oil region has also been a contributing factor to the degeneration into violence in the region. The grievances described above cannot explain the massive turn to violence in the region. How did mainly peaceful protests of the 1990s degenerate into violence?

The reluctant response to legitimate complaints by the Nigerian government, but suppression by force instead prepared the ground for a turn to violence by the protesters. The security apparatuses of the state have come to be known for the crushing of any kind of protests by the local population against the negative impacts of oil operations, especially during the period of military rule (Ibeanu and Luckham 2007: 62). Triggering factors included the mobilization of youth groups as protection agencies and the armament of youth groups by local politicians to win elections in the transition to democratic elections. Violence around governorship elections represented a new source of income for some Niger Delta youths and a new step on the descent into generalized violence in the Niger Delta itself (Ibeanu and Luckham 2007: 81–90).

7. "Separatism": Resource Extraction Provides Incentives for Separatism

In the "separatism" hypothesis, relations between the central government and the periphery are an important determinant. The unfair distribution of resource wealth is a recurring grievance that is brought forward by separatist movements (Ross 2004: 51).

The separatist civil war of Biafra in Nigeria (1967–1970) was driven by concerns about marginalization of ethnic minority groups of the Niger Delta in the face of "Northern" domination, and not by negative consequences of oil extraction that materialized only in later decades. The Biafra War began with the attempted secession of the Igbo-dominated South-East region from the Nigerian Federation. Control over oil resources found in the region was one of many aspects of this war (Guichaoua 2009: 20), but oil extraction certainly constituted an incentive, as

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[12] For example, in August 2007, the JTF intervened in a clash between two rival militia groups in Port Harcourt, Rivers State, using helicopters and machine guns and killing at least 32 gang members, members of the security forces and bystanders. The extent of the preceding gang violence is not to be neglected either (Amnesty International 2009a; Human Rights Watch 2008).

suggested in hypothesis 7. Towards the end of the Biafra War, Colonel Gowon replaced the former regions with 12 states to undermine further secessionist efforts (Ibeanu/Luckham 2007: 60).[13] The opportunity structure changed in a way that made a secessionist movement no longer an option.

This is why violent uprisings in the late 1990s targeted oil installations in the region as a surrogate of the central state. People in the Niger Delta were politically divided into ever more sub-unit thus reinforcing ethnic divisions among a population that had never formed a coherent united entity. Political mobilization against the negative impacts of oil extraction was therefore based on ethnic affiliation: the movement of Ken Saro Wiwa represented the Ogoni people, a minority group in the Igbo-dominated South-East region, whereas the armed militant movements since the end of the 1990s have mainly been driven by the Ijaw, the majority ethnic group in the South-South region.

The analysis of the Niger Delta conflict has shown that grievances related to oil exploitation and other factors degenerated into violent conflict by the end of the 1990s, initially financed by Nigerian politicians during election periods. Grievances, weak state capacity and separatist ambitions, however, did not only stem from oil exploitation, but were related to early ethnic in-fighting in the state. The case suggests that grievances directly related to resource extraction such as issues of compensation and environmental degradation only lead to more large-scale violence if they link up with wider concerns of political marginalization on a national level. Therefore, the hypotheses 4–7 do only make sense if analyzed against the backdrop of state formation and political fissures within state. The analysis corroborated hypotheses 4–7 to the extent that they aggravate existing conflicts between factions of the state and certain social groups.

Neither “Looting”, “Booty futures”, or “Foreign intervention” (Hypothesis 1–3) were responsible for the onset of violent conflict in the Niger Delta. This is not to say that the profitable theft and illegal trading of refined and crude oil, so-called ‘bunkering’[14] did not finance the armed groups later on and consequently, changed the local conflict dynamics. The Niger Delta militants turned to the profitable theft and illegal trading of oil, when they were dumped by politicians after elections (Ikelegbe 2005: 221–225).

Conclusion

This article has investigated the causal mechanisms linking natural resource wealth in Sub-Saharan Africa to violent conflicts. Its aim was to go beyond the greed and grievance dichotomy that has characterized the debate for a

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[13] As a consequence, the oil-bearing communities of the Niger Delta (today’s South-South region) were separated from the Igbo-dominated southeast (today’s South-East region).

[14] The term ‘bunkering’ is used in Nigeria to designate the theft of oil more generally, while as a nautical term, it is usually defined as the taking onboard of bunker fuel.

long time. Commenting on the causal mechanisms identified thus far, the authors have found that hypotheses about the causal connections between resource wealth and armed conflict that stress either greed or grievances are not mutually exclusive. On the contrary, they may refer to different phases of resource-related wars.

The greed of actors, stressed by theorists of war economies, does not clash with the idea of grievances providing the breeding ground for the onset of civil war in the first place. It is possible that, in the course of war, enrichment through the control of trade in natural resources both by government and rebel forces can change the interests and motivations of warring factions. This being said, it is unlikely that the greed of local rebels, governing elites or foreign actors (hypothesis 1–3) is able to account for the onset of civil wars. Existing qualitative case studies and the present analysis of the Niger Delta conflict do hardly provide evidence for the first hypothesis scrutinized here, which posits that looting by potential rebels provides start-up funds for rebellion ("Looting"). Greed apparently plays a more decisive role in ongoing violent conflicts than in causing them.

Scrutinizing hypothesis 4–7, which represent the grievance argument, the authors argued that they are all related to the performance of the state. The analysis of the relation between different causal mechanisms in Nigeria suggests that the state has played a central role in steering the oil-rich Niger Delta towards conflict. Lack of governmental oversight over the oil sector, a highly centralized management of oil revenues, weak bureaucratic capacity in terms of developmental outcomes, high levels of corruption, and repression of protest by force are some elements mentioned here. But to think of the state as a coherent actor would not be correct. The process of Nigerian state formation as such, tainted by the colonial experience, has to be taken into account. The flawed federal system that was contested from the beginning has had a considerable influence on the consequences of oil extraction and their perception by the local population. The political grievances conjured up by oil exploitation cannot be understood without considering the ethnic imbalances contained in the federal structure of the state. Hence, high horizontal inequalities between different ethnic groups have to be taken into account when investigating the resource-conflict nexus. Resource-related grievances seem to remain confined to the local/ sub-national level and so does the violence fueled by them, as long as they do not link up with wider concerns of political marginalization at the national level. This is why they hardly appear in the datasets used by scholars who investigate the relationships between outright civil war and natural resources.

More research is needed into how resource governance impacts upon the likelihood of civil war. State capacity is one often-mentioned factor, which is still ill-defined. State capacity meaning its ability to raise taxes may not be

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affected by natural resource wealth. Weak state capacity, however, in managing its financial resources (expenditure side) can produce negative effects. As long as revenues are not sufficiently invested in overall development, the population in resource-rich areas tends to perceive the central governments' capacity to extract levies to be a problem. There are many aspects of state capacity, ranging from raising revenues and effective spending for development to redistribution through patronage networks that have an impact on political stability. Hence, more research is needed into what aspects of state capacity are most relevant to causing collective violence.

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Part II
Conflicts on Fossil and Nuclear Energy Supply

Chapter 5
The Lifecycle of Oil: Problems and Conflicts

Dirk Ipsen

There are four basic characteristics of the oil resource that have an impact on the working of the "oil system" and its governance: energy density and viscosity, oil as a hydrocarbon and related emissions, the geography of oil, and its non-renewable character. The following contribution shows that the interaction of these oil basics with the major societal and political trends of our times gives rise both to the dynamic growth of oil use and to two problems inherent in the oil system: the ambiguity of oil governance with its market and political rules and the conflict between oil dynamics and climate policies in a pre-peak oil period. My review of the relevant literature on oil history, oil politics, and the economics of oil is designed to facilitate the discussion of two main topics: the empirical relevance of the hypotheses on political versus market instability and the capability of the oil system to adjust to expected peak of oil production.

5.1 The Oil Basics

The oil basics are those characteristics of oil responsible for the build-up of patterns and trends in the use of oil. They are not institutions in themselves but they foster the evolution of institutions in the oil system. Its hardware consists of the technical equipment required to find, lift, transport, and transform oil on its way to the end user. The software of the oil system is equivalent to the institutions that govern oil use from initial prospecting of oil all the way to regulations about emissions. There are four oil basics that I shall take as a starting point for my remarks:

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1. Energy density and the viscosity of oil, which give it a competitive edge over the former dominant energy source—coal.
2. Oil as a hydrocarbon linking oil use to the environment.
3. The geographical distribution of oil sources, which sets the stage for international relations in the oil business and oil politics.
4. The non-regenerative character of oil, which enforces adjustment processes required to deal with the physical limitations of oil.

Oil history is the process in which these natural properties of oil have been connected and combined with the major trends operative in modern societies: growth of populations, industrialization, globalization of markets, the postcolonial trend toward independent nation-states, and increasing awareness of environmental hazards.

Energy density is one example of this nexus between oil and major societal trends. The industrialization process has been marked by the use of energies of increasing energy density from firewood (4.3 kWh/kg) and hard coal (8.2 kWh/kg) to light oil (11.9 kWh/kg). Comparatively high energy density, the respective heating value, and its liquid form made oil the ideal fuel for the newly developed internal combustion engine in the twenties century. Thus oil escaped the shrinking demand for lamp oil, which was the main usage for oil at the end of the nineteenth century. The combination of oil and the internal combustion engine was the starting point for the dynamic trend in oil demand of our days. The use of oil spread to other industries, especially the chemical industry, and oil became an essential raw material for some 6,000 products, many of them indispensable factors in our everyday lives. With the expanding traffic sector and the huge variety of oil-based products, oil was directly linked to economic growth and the growth of per capita income. In terms of consumption, oil outperformed all other sources of energy. The USA is an example of this trend (see Fig. 5.1).

In the USA and Europe, there have been clear indications of saturation in per capita energy use since the 1970s. But due to rapid economic growth in Asia, these trends in world oil consumption are still very much a firmly established feature of our oil system. Oil has become a ‘basic commodity’.

The key economic characteristic of basic commodities is that demand for them is more or less independent of short-term price changes, i.e. the price elasticity of oil demand is low. Usually, market prices are simultaneously determined by changes of demand and supply; low price elasticity restricts the short-term adjustment processes on the demand side and shifts the emphasis to the supply side.

Hamilton (2009: 179–206) cites statistics that confirm the low demand response to price changes. Demand for basic commodities is more closely correlated with other factors like the growth of income. High values for income elasticity in different countries reveals a pattern in the oil life cycle: More recently industrialized countries with comparatively low per capita income display income elasticities of oil above unity, i.e. oil demand increases faster than the per capita income due to substitutions for other energy sources and links to fast growing-markets. As income levels get higher over time, the income elasticities decrease, which is another

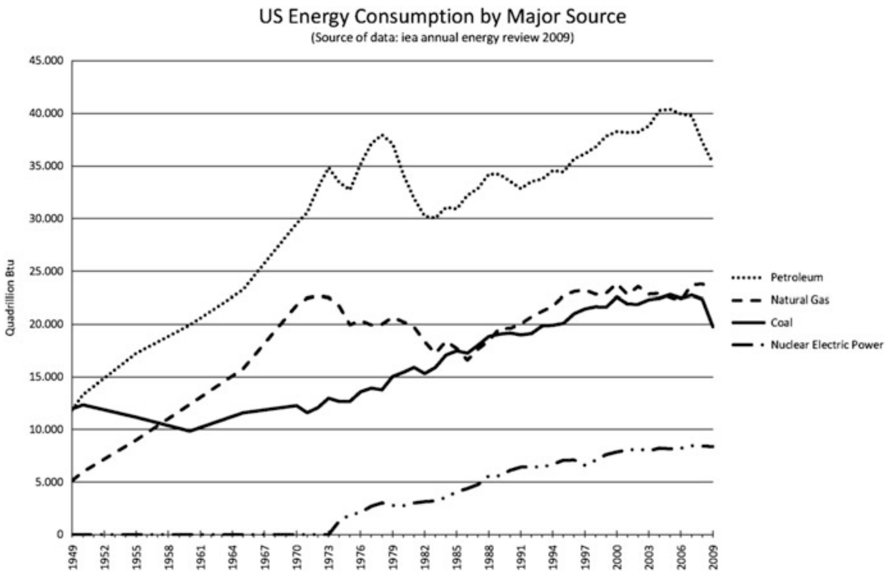

Fig. 5.1 US energy consumption by major source. Source of data: International Energy Agency (IEA): annual energy review (2009) Table 5.4

indicator for saturation tendencies in the oil life cycle. In this way, newly industrializing countries take the lead in pushing the overall oil demand up to higher rates of growth offsetting the saturation processes elsewhere.

Oil as a basic commodity has a twofold impact on the working of the oil system. First, low price reactions diminish the capacities for short-term market adjustments. Adjustment processes take a longer time to approach a new equilibrium, or strong price movements are needed to enforce a change in oil demand. The second impact is on the relation between the stable trend of growing world oil demand and the supply limitations of a non-renewable resource. The higher the population density of newly industrializing countries, the more long-term adjustments like alternative energy resources are needed to meet the growing demand.

5.2 Oil as a Hydrocarbon

Looking at oil as a hydrocarbon focuses on the links between oil use and the environment. The increase of greenhouse emissions in the last few decades (i.e. since sector-related greenhouse gas emission data became available) is closely linked to both the use of coal in the power generation industry and the use of oil in the transportation sector and in industry. Instructive is the change that has taken place in greenhouse gas emission in the European Union with an active climate policy at work. In the period 1990–2008, the EU succeeded in cutting climate gas emissions in many industrial sectors, including manufacturing. But the emissions in the transport sector increased in the same period, and this almost outweighs the success of all other sectors together (EEA 2010). The extremely powerful trend in oil consumption was able to outgun the combined effects of huge price swings, major price increases, and the environmental policies of the EU member states. Given the emission increases in the rapidly industrializing economies in Asia and Latin America, the conflict between actual energy use and the requirements of an international climate policy becomes evident.

5.3 Geography of Oil

Another line of development in connection with oil that dates back to the early the twentieth century is referred to by Yergin (2009: 134) as the “fateful plunge”. It was the decision by the British Government in the face of WW I to build a new class of battleships solely powered by oil and internal combustion engines. The aim was to stabilize British maritime superiority against the rapidly growing navy of the German Kaiserreich. The pros and cons of the oil-powered battleship were carefully weighed up: less fuel consumption and storage space, higher acceleration of oil-powered battleships and the option to refuel at sea on the one hand, the disadvantage of losing a secure energy base in the homeland on the other. Britain would have to rely on the less secure oil supply from Persia. The decision taken favored a fuel switch, which indicates that from a military perspective risky oil supplies from the Middle East were outweighed by the advantages set out above. This was the first time that the geographic distribution of oil figured as a potential risk factor in the political decision-making process. The geography of oil favored the USA and Russia, while Europe and Japan lacked an oil supply of their own. For them, oil became a ‘strategic commodity’. The question of oil supply security became more important after WW II, when word got about that the Middle East possessed the majority of all proven oil reserves. The USA reached its peak oil in 1972 and became a major player in the Middle East indicating that oil became a strategic good for the USA, too. Today, the importance of oil for military operations is far greater than what it was at the time of the initial battleship decision, thus greatly increasing the significance of oil supply security. The advantages of oil have created a specific brand of modern mobile warfare marked by the increasing energy intensity of military operations. In World War II, an American soldier needed 1 gallon of oil per day (g/day), in Vietnam 9 g/day, in the Gulf war 10 g/day, and in Iraq 15 g/day (Karbuz 2007). The history and the geopolitics of oil are well documented by Klare (2004, 2008), while the political risks of securitizing oil, especially in the Middle East, are being widely discussed.

One aspect of the decision to make oil supply a matter for a US military command of its own is the creation of a network of permanent military installations in the Gulf region costing an estimated $100 billion, i.e. 20 % of the military budget in 2009, not counting the cost of the military operations themselves—a kind of external cost of oil (Dancs et.al. 2008). In this way, a new element has found its way into the oil system, a new kind of form of governance with its own mode of action. The military and strategic planning connected with future oil supplies is no longer a wartime affair. It has become a permanent institution parallel to the market. In a report for the European Commission (Correlje and van der Linde 2006), the two key approaches to oil politics were referred to as the ‚market and institutions approach‘and the ‚regions and empire strategy‘. These two governance forms are by no means complementary or mutually supportive. They represent quite different ways of dealing with central issues posed by oil governance. The market approach relies on the self-interest of foreign oil suppliers to earn money by selling oil. The regions and empire approach is based on a perception of political risks of oil supply and thus on mistrust.

The market approach sets out create an atmosphere of trust as a basis for long-term contracts with trading partners. The regions and empire approach divides the oil suppliers into allies and adversaries. It pays with weapons and not with financial incentives. The market approach does not try to gain regional dominance as a way of getting access to oil but uses the opt-out strategy to punish an unreliable partner. The regions and empire approach ties in very well with the perception of oil as a weapon.

The two parallel existing governance forms are not only different, they actively interfere with each other and distort the relations between oil suppliers and oil importers with negative consequences for the working of the oil market. This ambivalence of governance forms is at the heart of the oil system. But long-term investment in the exploration, lifting and transporting of oil requires a stable governance form. The future will decide whether the market form has a chance of succeeding in times of declining oil reserves or whether the regions and empire strategy will take over. Since the two different governance approaches are based on different risk perceptions of instability in the Middle East, the question of their empirical relevance will be a major part of our discussion below.

5.4 Oil as a Non-renewable Resource

In recent history, the “end of oil” message has attracted public and political attention on several occasions. In 1919, US officials forecast the depletion of US oil in the years to come. In 1943, the fear of oil supply restrictions raised its head again, with visions of the USA being the only supplier for the needs of all allied countries during WW II (Yergin 2009: 178, 377).

Many of these prophecies of doom fizzled out completely. A new wave of oil discoveries flooded the oil market a couple of years later, or peak oil was a regional affair, as in 1972 in the USA. But the mere expectation of oil supplies drying up had its political effect, given the dependency on the Middle East reserves and fostered the development of a regions and empire policy.

The peak oil studies of the present are the preserve of geologists, who have the requisite expertise to assess the ‘expected utilizable reserves’ (EUR) of oil in combination with scenarios of oil demand in the coming decades. The crucial point is the estimation of EUR. It is not only dependent on future oil discoveries but also on re-evaluations of the existing proven oil reserves (the amount of usable oil in existing fields) and on technical improvements in exploring and lifting oil. Critics of this geological approach are mostly economists with a strong belief in market forces. In a situation of long-term scarcity, they argue, the oil prices would rise and thus induce processes of adaptation and foster investments in exploration, energy conservation, or new technologies favoring a switch of energy sources (Adelman 2004). According to Adelman, the real problem is not the finite nature of oil supplies but the political obstacles that prevent the market from working as it should, chief among them the OPEC cartel and other forms of political intervention like energy subsidies. Underlying this argument is a theory of political instability emphasizing that oil prices are not indicators of economic scarcity but of political power. In the next section is demonstrated that neither of these positions shape up very well to empirical testing.

What conclusions can we draw from this controversy about the finite nature of oil supplies?

We should not focus on the question of “when” a global Peak Oil ‘happens to be effective’ nor should we rely on economic visions of how an unrestricted market would overcome supply limits. Instead, we should observe the ongoing adaptation processes from an empirical perspective. Given the non-regenerative nature of oil, there are three possible outcomes for the future course of oil supply. First, the ongoing adjustments to oil price shocks would be strong enough to overcome short-term supply bottlenecks. Prices would tend to decline to a lower level. This would be a repetition of earlier events in oil history, in other words another limit of oil episode. Second, there will be a prolonged period of oil scarcity during which adjustment processes are at work but take a long time to become effective. In this case a prolonged period of high oil prices can be expected with negative economic side-effects on growth and the further development of low-income countries, in other words a scenario of economic and/or political crisis. In the third conceivable scenario, the adjustment processes are strong enough to change the energy base toward unconventional oil (oil sand or shale oil) in a way that will satisfy growing demand but at the expense of serious climatic side-effects. This would be a dilemma scenario.

5.5 Oil and Conflicts

Two questions result from our considerations of the oil basics: the question of how the ambivalent governance forms tackle the problem of oil supply security, and the question of adjustment processes mitigating the conflicts between oil supply, economic growth, and climate policy. Both questions revolve around the capability of the oil system to master the problems of political or market instability and the challenge of sustainability.

Discussion on energy security policy in the last few years has often addressed a confusing mixture of different risks and measures for handling oil supply security. On the one hand, these risks are referred to by terms like “disruption of oil supply” or risk of growing “oil dependency” on the Middle East. This betrays an understanding of the supply problem as a matter of physical and political access to oil. The implicit aim is to gain secure access. On the other hand, oil security problems are associated with oil scarcity, high oil prices, or the volatility of oil prices, indicating that market instability is at the center of the oil security problem and the implicit aim is market stabilization. These differing understandings of oil security problems can be regarded as two forms of risk perception that in turn function as guidelines for political action. The political instability thesis is at the heart of the “region and empire” approach, while the market instability position is at the heart of the “market and institutions” approach. If they are to succeed, political activities designed to mitigate the instability problems need to be geared to an appropriate understanding of the problem. So what is the empirical evidence for these different risk perceptions?

5.6 Political Versus Market Instability

The political instability hypothesis comes in different forms (Yergin 2012). The first variant dates back to OPEC policy in 1973. The oil embargo against the USA and the Netherlands as the entry port of oil for Western Europe was not seen as a one-off event but as an example of a politically governed oil market with OPEC’s power to set oil prices enacted by the newly created national oil companies in many oil-exporting countries. The critical point of this kind of risk hypothesis is ‘voluntary’ political action in the context of an international conflict. The resulting supply shocks are expected to occur in an erratic way depending on international political events. This was exactly the risk perception of the western oil importers in 1973 and led to the installation of emergency oil reserves in the framework of the International Energy Agency (iea). These strategic oil reserves were to be released if a negative oil shock of minus 5 % threatened oil supply. This situation has never materialized in the last 35 years. Kilian (2009) lists seven episodes in the years 1973–2006 with at least a 3 % reduction of OPEC oil supplies in combination with political events (see Fig. 5.2) Hartard in Part I. This list covers a wide variety of different political events. Only one of them is a voluntary political decision by the oil suppliers (1973), one shock is due to the revolution and regime change in Iran, three due to warfare in the Gulf (two of them western-backed), and one event is related to civil unrest in Venezuela. So, at first glance, the empirical evidence for the risk of the voluntary use of oil as a weapon would appear to be rather weak so far Hartard in Part IV.

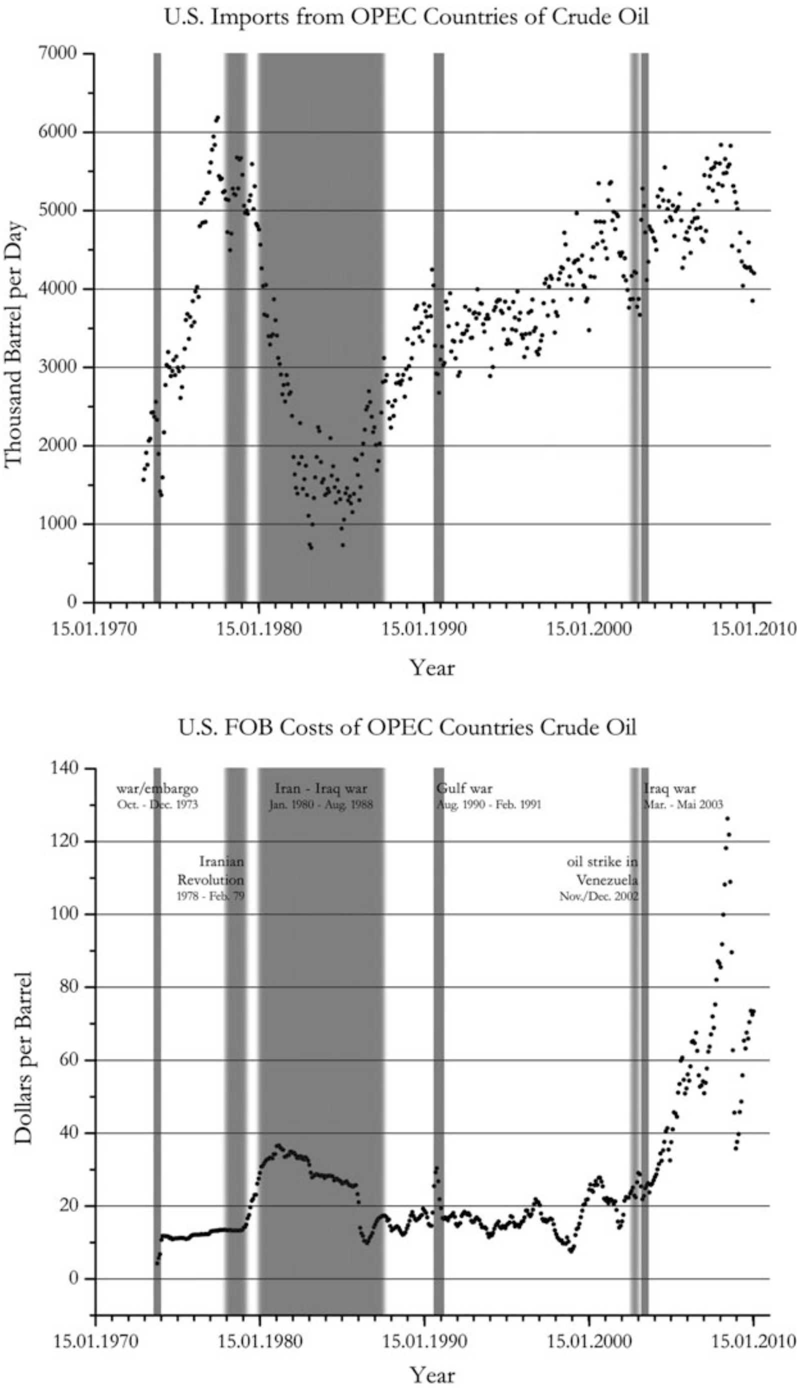

Fig. 5.2 Political events—U.S. supply and price shocks since 1970. Source: Modified from Kilian 2009: 1053–1069, Source of data: eia AER 2009, Table 1.3

This weak evidence gave rise to a second variant of the political instability hypothesis based on the concept of resource wars (Le Billon 2001; Ross 2004). The research on resource wars deals with the many local and intrastate military conflicts in resource-exporting states and inquires into their inherent logic. High-value resources in global markets play a major role in internal power struggles in post-colonial resource-exporting countries. Historically, the oil-exporting countries were among the first to establish centralized political states, mostly with authoritarian regimes. The political instability hypothesis expects these regimes to be inherently unstable and thus prone to abrupt regime changes, as in Iran. From this perspective, a supply shock is a by-product of regime change and is no longer dependent on voluntary political action and international conflicts. These conflicts would still be erratic and are extremely hard to predict. Thus a permanent network of installations for political interventions might be justified in the perspective of oil importers.

Empirical research in this field started in the 1990s (Byman and Green 1999; Skinner and Arnott 2005). This body of literature focuses mainly on the unexpectedly high degree of stability of authoritarian regimes in major oil-exporting countries with their strategies for discouraging opposition movements and keeping the populace quiet. As of the 1980s, the OPEC countries came under strong pressure in a period of falling oil prices, which triggered losses in governmental revenues. In a study of 21 export-dependent countries, Smith (2006) analyzes 23 crises of this kind and finds only five cases of a regime change. Most of the authoritarian regimes remained stable despite falling oil rents. The Iranian revolution seems to be a singular event in an oil state. Since the loss of oil rents strikes at the heart of authoritarian power, the resilience of the regimes is a tough test of their stability. Accordingly, the empirical evidence for this variant of the political instability hypothesis is also comparatively weak. The political instability hypotheses seem to be generalizations on some special events rather than conclusions drawn on the basis of inherent characteristics of the oil-supplying countries. This holds true even during the Arab rebellions since 2011. The loss of Libyan oil exports has been mostly substituted for by additional OPEC and non OPEC exports (EIA 2011 Petroleum supply monthly). The second case of an oil-supply shock is the breakdown of oil exports of Iraque as a consequence of the second Gulf war.

Turning to the rival hypothesis of market instability, we find ourselves in the domain of the economists. For them, the oil market is an example of a market with serious market failures producing negative consequences for the working of the market. One line of research is on the institutional changes that have taken place since the 1970s. The other level of discussion attempts to explain oil prices and the huge swings they display as an indicator of market instability. If we follow this research, market instability is characterized by (a) institutional anomalies and/or (b) unstable price setting. In contrast to the political instability hypothesis, the market in this perspective is distorted but nevertheless a working system.

Institutional studies help to explain the different price-setting behaviors before and after the 1970s. In the time before 1970, an informal but effective cartel of major western oil companies managed to control the complete chain from the oil-well to the end-consumer. Oil prices were set in the framework of the so-called concession system almost independently of an oil market (Parra 2004). To do so, the informal cartel had to align the growth rates of oil production and demand in all major oil countries and allocate the amount of oil production among the oil companies. This usually meant restricting supplies when the discoveries of big new oil fields threatened to spoil the market. The ways and means of doing that are described in Parra's "History of Petroleum" (see above).

Under this system, the international oil companies managed to keep oil prices at a low level for some 20 years up to 1973. This effective system of coordination and control came to an abrupt end when OPEC took over and inherited the task of coordination (see Fig. 5.3). But OPEC had no strong position and no instruments for control. The oil chain was now split into an upstream part—from the oil-well to the shipping of crude oil—and a downstream section outside OPEC control, from oil refining to distribution. Within OPEC the contract partners were now sovereign states. Even with declared internal agreements to reduce OPEC's oil supply, there were no ways of controlling the fulfillment of these obligations and safeguarding against free riders. The immediate effect of these institutional changes was loss of control. Adelman (2004: 30) therefore calls OPEC a "clumsy cartel" whose price-setting power varies with the changing global demand for oil. OPEC prices are higher than competitive prices and lower than monopoly prices—both possible equilibria—and fluctuate in the zone between them (Adelman 1995: 327). Price shocks are only to be expected. Figure 5.3 shows several price shocks, two of them extreme forms of price volatility.

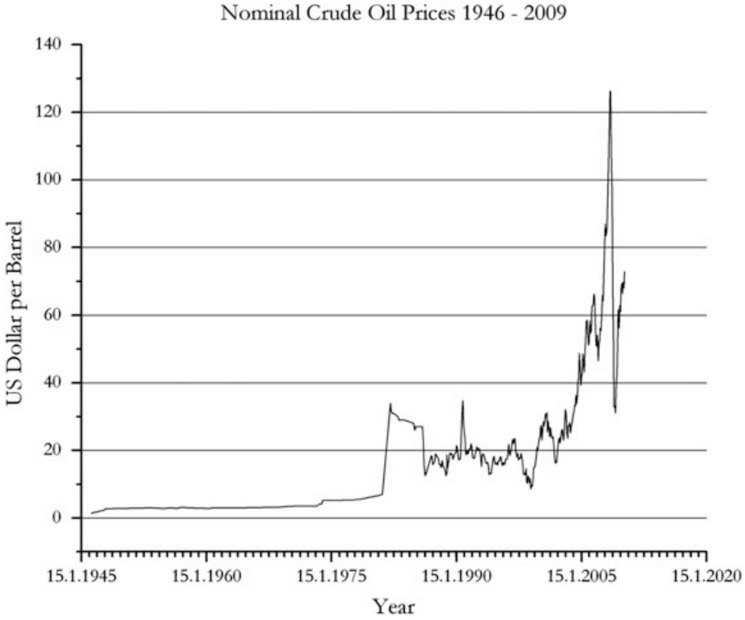

Fig. 5.3 History of crude oil prices 1945–2009. Source of data: ioga.com/Special/crudeoil_Hpst.htm

Further empirical evidence of market instability is provided by statistical research on oil price volatility (Barsky and Kilian 2004; Jones et al. 2004; Kilian 2009; Kilian and Hicks 2013). Kilian uses four different explanatory variables as conceivable explanations for changes in oil prices: political supply shocks, other supply shocks (i.e. additional oil supplies from non OPEC countries), and two kinds of demand shock. Political supply shocks are the only exogenous variable, the other variables are endogenous. The different shocks can interact over a time span of 2–4 years. For instance, a political supply shock could create an additional demand shock and these combined could explain a specific oil-price shock. This approach allows for a multitude of combinations that can explain price changes. Some of his results are important for our question about the comparative relevance of political versus market instability in the last four decades (1970–2010).

All major oil price increases can be traced to the two demand shocks, i.e. to increased global demand for industrial products and additional precautionary demand in scarcity situations. These two demand factors can occur in combination and together explain most of the variance in oil prices. Political supply shocks are of minor relevance. They only reduce oil supply temporarily because the losses are compensated within 6 months by additional supplies from non-OPEC sources or from free riders elsewhere. This is one reason for the comparatively small impact of political oil shocks in general.

Kilian’s analysis reveals that there are both stabilizing and destabilizing factors at work in the oil market. The “additional supply factor” referred to earlier has a stabilizing effect owing to existing and unused capacities of oil production. The “additional demand factor” is a precautionary measure in situations of expected oil scarcity and has a destabilizing effect on oil prices without future increases of oil supply.

It thus transpires that the crucial condition for the working of the oil market is the existence of spare capacity. Spare capacity has the double effect of mitigating price shocks and compensating political supply shocks.

If policy-makers were prepared to ensure spare capacities in the oil system, this could replace the regions and empire strategy and economize on the costs of military installations in the Middle East. In the same way, the coordinated selling and buying of public strategic oil reserves could be used to mitigate oil price shocks.

5.7 Limits of Conventional Oil Supply

But these political options are dependent on another crucial condition. The basis for spare capacities could evaporate if there is a long-term scarcity due to a Peak Oil constellation and thus no room for excess capacities, anyway. So the crucial issue is the future of oil-supply shortage.

New empirical evidence circumventing the uncertainties and fallacies of measuring the ultimate recoverable reserves for the global oil supply comes from field

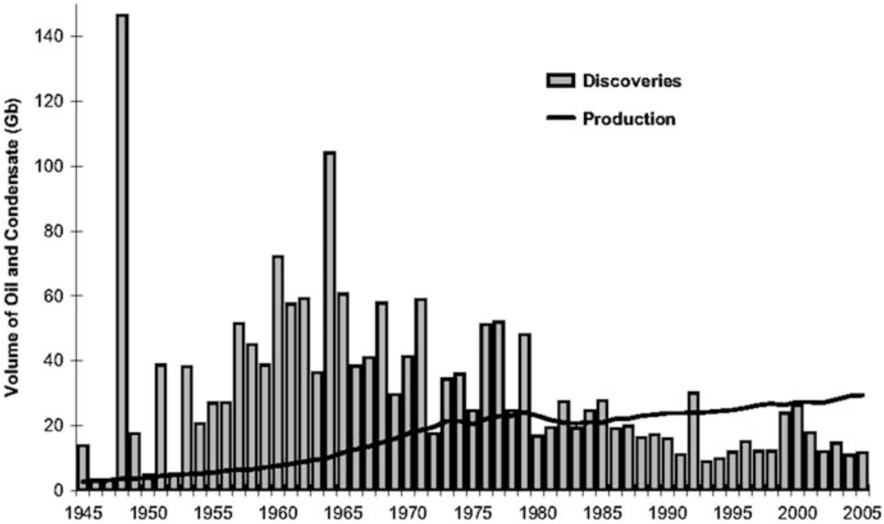

Fig. 5.4 Global annual discoveries of both oil and condensate, and oil production. Source: Robelius (2007: 70)

studies—a bottom-up approach that draws upon increased knowledge about the life cycles of oil fields (Babadagli 2007; Robelius 2007; Simmons 2002; IEA 2008). A starting point for these studies is the growing number of mature oil fields whose oil production is either on its plateau or has gone beyond peak and is now declining. Age, size distribution, and typical decline behavior allow for extrapolation on the future of oil supply.

One indicator for the aging of oil fields is the comparison between discoveries of new oil fields and oil production. In Fig. 5.4, Robelius shows that since the 1980s the tendency (with very few exceptions) is for oil discoveries to be lower than the annual production of oil. This means that for three decades we have been consuming the accumulated oil reserves from earlier oil discoveries (see Fig. 5.4).

This discovery decline also applies to discoveries of giant oil fields—1 % of all operating oil fields with an ultimately recoverable reserve of 500 mill. barrels and a daily production of more than 100,000 barrels for longer than 1 year. According to Höök et al. (2009), these giant oil fields fuel more than 60 % of the global oil production. The overall production from giants is declining due to the aging of these oil fields with an average decline rate of −6.5 % in the post-peak giants. Robelius (2007) shows that the sheer size of the giants determines the overall peak for conventional oil sources. In theory, decreasing oil production in all aging oil fields could be compensated for by stepping up the development of the so-called "non-conventional" oil resources, i.e. oil sands and shale oil. But in practice, such huge development programs themselves require a high degree of time and energy. So in the period up to 2030, we cannot count on their ability to compensate for decreasing oil production from conventional oil sources. The oil system anticipates any prolonged period of oil scarcity, and there are good reasons to interpret the aging of the oil fields and especially the aging of the oil giants as the long shadow of a coming peak and a prolonged period of oil scarcity (see Friedrichs 2010 for different regional scenarios and reactions to a global energy crunch).

Two Conclusions

This situation implies that the two conflicts embedded in the oil system will be exacerbated in the future. Market instability will increase because of the absence of the stabilizing effects from additional oil supplies in the event of short-term crises, while on the other hand the destabilizing effects of additional precautionary demand will be more pronounced. Also, political instabilities in the oil-exporting countries will have a more direct impact on the market, which cannot easily compensate for politically induced supply losses. In this constellation, a shift toward the military "regions and empire" strategy will gain even more political attention. It is reasonable to assume that nations with high military capacities will be tempted to use a regions and power policy to gain priority access to oil resources (see Friedrichs 2010).

The second line of conflict is the tension between energy security and environmental problems, especially in the face of climate change. On the one hand, all political measures designed to foster energy conservation will mitigate the energy-environment conflict. But the market will also provide strong incentives to develop oil substitutes (non-conventional oil from oil sands and shale gas, and their impact on the environment is even higher than that of conventional oil. There is also an ongoing trend toward increased coal use, especially in the rapidly growing Asian economies and in countries that cannot afford high oil prices. Adjustment processes in the market appear to encourage for the time being a substitution of oil and gas and a backward substitution toward coal. The resultant climate effect is still open. So, the IEA's World Energy Outlook (2008: 49) closes its overview and the projection of adjustment processes as follows: "The world energy system will be transformed, but not necessarily in the way we would like to see." And also in the most recent ,energy outlook the summary of diverse market adjustments and policy measures sounds skeptical:

> "Taking all new developments and policies into account, the world is still failing to put the energy system onto a more sustainable path" (IEA 2012).

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Chapter 6
Nuclear Fuel Chain: Uranium Resources and Associated Risks

Wolfgang Liebert and Matthias Englert

Already in the 1950s King Hubbert pointed out the limited availability of fossil and uranium resources for energy usage.[1] Many agree that reserves of oil will become scarce within this century and that to meet the world's increasing demand for energy while simultaneously mitigating climate change, carbon intensive fossil fuels must be replaced by decarbonized energy sources. Thus, at least theoretically, nuclear energy could play a relevant role in the future energy system. However, uranium still is the main source material for all nuclear programmes world-wide and one should carefully examine its future availability before investing in a nuclear renaissance. Furthermore, uranium enrichment, a technology necessary to fuel today's nuclear reactors, can be used to produce highly enriched uranium for nuclear weapons. This sensitive technology is already a cause of conflict in the international arena due to the fear that additional states get access to the bomb (nuclear proliferation).

In this article we focus on the most important risks associated with the indispensable role of uranium in nuclear power programmes. This concerns the risks of sufficient availability of uranium in the medium and long term, the timely production of uranium even under a massive nuclear expansion scenario, the impact of uranium price, the influence of the ore grade, the risks caused by the dependence on uranium resources in countries using nuclear power, the environmental risks

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[1] Hubbert introduced the famous Gaussian bell-shaped depletion curves of exhaustible resources, modelling the production cycle by depicting production rate over time (Hubbert 1956). Such models provide also the base for "peak-oil" or "peak-uranium" prognosis.

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associated with uranium mining, and risks to international security due to the necessary use of enrichment technology (cf. also Sailer in Part II).

6.1 Current Status: Nuclear Energy and Uranium Usage and Resources

Current nuclear energy usage for electricity production is dominated by the operation of light water reactors (LWR). A fleet of 440 power reactors with a capacity of 370 GW of electricity (GWe) is currently installed in 31 countries. At the end of 2011, nuclear energy had a share of 5.6 % out of the total demand for primary energy. The global share of nuclear generated electricity at the end of 2011 was 12.3 %.[2] The annual uranium demand for the installed nuclear capacity is about 68,000 t.

A peculiarity of the global uranium mining is that the decades before 1990 were marked by an "overproduction" (Fig. 6.1) compared to reactor demand. Since 1990 uranium production does not meet the civil demand anymore and dropped considerably. The gap between demand and production was covered by so-called secondary resources. After dropping to 60 % in the 1990s in recent years the annual production of uranium from mines covers roughly 80 % of the demand.

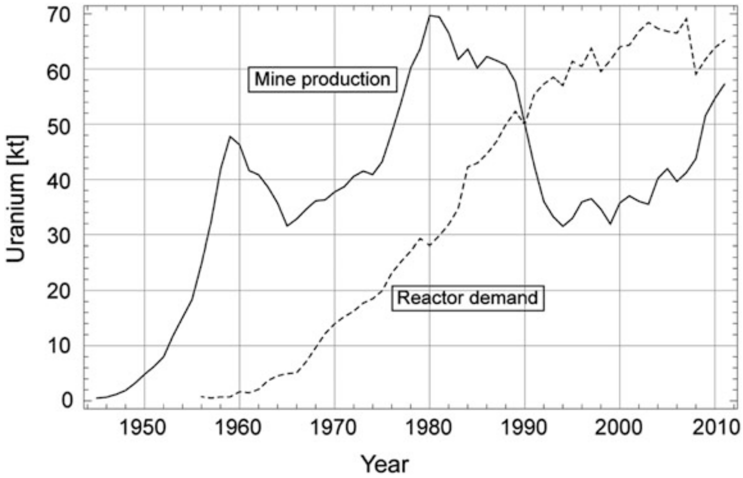

Fig. 6.1 Annual uranium production from mines and civilian annual uranium demand 1945–2011. Source: OECD-NEA/IAEA (2012), OECD-NEA/IAEA (2010), OECD-NEA 2006)

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[2] Note that most of the Japanese reactors were not in operation in the aftermath of the Fukushima accidents.

6.1.1 Secondary Uranium Resources[3]

Most of the "overproduction" stemming from the time period prior to 1990 went to highly enriched uranium production and plutonium production in the weapon programmes. Later, it became partially available for the civilian market and helped to substitute global demand in the last 20 years by diluting highly enriched uranium (HEU) from military origin to low enriched reactor fuel. In particular, based on a Russian-American agreement from 1992, the amount of 500 t HEU has been converted to fuel the US market accounting for an equivalent of natural uranium of about 100,000–110,000 t. The contract expired in August 2013 and no continuation is to be expected. The US Department of Energy is planning to convert HEU from weapons programmes in the time frame 2010–2017 equivalent to about 21,000 t uranium. This can contribute to fill the uranium gap in that time for the US reactor fleet.

It is unclear which fraction of „overproduction"before 1990 was stockpiled and subsequently transferred to the civil market. Today, relevant stockpiles of already mined uranium are only held by mining companies, fuel manufacturers and reactor operators. Based on a survey by the World Nuclear Association under nuclear operators and uranium fuel suppliers (WNA 2009) one can assume that about 130,000 t of uranium are still in the hand of reactor operators and some 25,000 t are stored at mining and uranium processing companies. Most of this uranium has to be counted as strategic reserves and only about 20,000 t are regarded as non-strategic reserves, which can be made available for the uranium market.

The theoretical potential to re-enrich uranium from depleted uranium tailings at enrichment facilities is high, but due to its cost and energy inefficiency it has nearly never been done so far. Similarly it is possible to re-use reprocessed uranium. However, today this secondary uranium resource only substitutes an annual natural uranium equivalent of about 2,000–2,500 t and the International Atomic Energy Agency (IAEA) expects that this will not change in the foreseeable future (IAEA 2007).

Saving natural uranium by plutonium usage could also contribute to meet the uranium demand for reactors. But due to its economic unattractiveness plutonium usage in form of uranium-plutonium-mixed-oxid (MOX) replaces only 1,000 t of natural uranium annually. Likewise the planned use of "weapon-plutonium" from US and Russian excess military stocks in the years between 2017 and 2025 will also substitute not more than 1,000 t natural uranium a year.

Historically, secondary uranium resources have contributed to fill the gap between uranium production and demand. But this contribution is expected to shrink in the next years and it is unlikely that secondary sources alone will guarantee the uranium supply required by the nuclear industry.

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[3] This is discussed in much more detail in (Englert et al. 2011).

6.1.2 World Uranium Resources

OECDs Nuclear Energy Agency (NEA) together with IAEA publishes the latest global estimates on uranium resources in a biennial book known colloquially as the "Red Book".[4] The figures reported in the Red Book rely on reports provided by official governmental organizations that in turn receive information from their respective survey organizations or commercial exploration/mining companies. Reported information is not always complete and not all information might be unbiased by industrial or other interests. Furthermore, information given in the Red Books does not fulfil usual scientific standards. Nevertheless this compilation of information on uranium deposits, production and demand is the standard reference to base upon scenarios for the future availability of uranium resources. Figure 6.2 gives a global overview.

According to the Red Book in 2011 about 4.4 million tonnes uranium are classified as Reasonably Assured Resources (RAR), deposits where the size and location is assumed to be well known. 3.5 million tonnes of RAR resources can be mined for less than 130 US dollar per kilogram, making it the economically most important resource class. From the knowledge of existing deposits additional 2.7 million tonnes is inferred to exist (Inferred Resources—IR). Together RAR and IR are estimated therefore to total to 7.1 million tonnes Identified Resources, those resources which are very likely to exist and are minable for production costs up to 260 US dollar per kilogram. The Red Book lists also more speculative Undiscovered Resources of about 11 million tonnes. Economically much more important are so-called "proven and probable" reserves, for which more concrete cost estimates and projections on what is actually minable are feasible. Unfortunately, no global figures on proven and probable resources are available, but one can estimate that this resource class might count for about 1.4 million tonnes.

Most uranium deposits mined today have uranium ore concentrations between 0.01 and 0.5 %. Ore concentrations below 0.01 % are usually commercially attractive only with uranium as by-product (e.g. copper or gold mines).[5]

The world's single largest known deposit is Olympic Dam in South Australia, making Australia by far the most uranium rich country. In that mine, uranium is a by-product of the copper and gold mining activity, the ore has an average concentration of 280 ppm (0.028 %) uranium.

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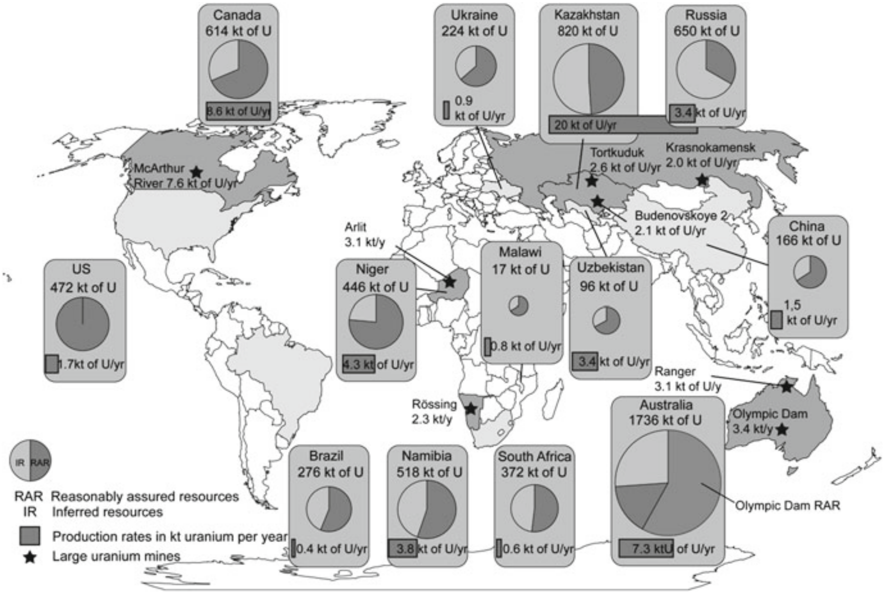
[4] We refer in particular to the last two issues of the Red Book: (OECD-NEA/IAEA 2010, OECD-NEA/IAEA 2012).

[5] One exceptional deposit type is the large Canadian unconformity type in the Athabasca Basin. These deposits have an unusually high ore concentration in the per cent range (up to 20 %) and are therefore very attractive for mining even though the mining in wet sandstone is technically very challenging and energy intensive.



Notes: They comprise 98% of global production in 2011 and hold 90% of global identified resources. Eight large uranium mines (located in Canada, Russia, Kazakhstan, Niger, Namibia, and Australia) alone had a share of 45% global production in 2013. Olympic Dam is with 940 kt of uranium the world's largest deposit.

Fig. 6.2 Important uranium producing countries with their estimated production in 2011 and their respective identified resources, shown as reasonably assured resources (RAR) and inferred resources (IR). Source: Geoscience (2013), OECD-NEA/IAEA (2012), WNA (2013)

6.2 Eight Risks Associated with Uranium Mining and Use

6.2.1 Security of Supply

Although the argument is frequently being made that nuclear energy use "is indispensable to reduce import dependency" on raw materials[6], fact is that all countries having a considerable nuclear power programme (with exception of Canada) are highly dependent on uranium supplier states. In particular the dependency of European states is dramatic. Only 2 % of their annual uranium demand is provided by mines located in European countries.

In eleven countries (like France or Germany), which were active in uranium mining during the last century, uranium resources are already exhausted. In 2009, only seven mines (McArthur, Ranger, Rössing, Tortkuduk/Moyunkum, Olympic Dam, Krasnokamensk, Arlit) produced more than half of the world uranium

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[6] Cf. e.g. Deutsches Atomforum (ed.): Gute Gründe für die Kernenergie [Good reasons for nuclear power]. Berlin, Sept. 2007.

Table 6.1 Share of world uranium production by the 12 leading states in 2003 and 2010

Country	2003 (%)	Country	2010 (%)
1. Canada	29.4	1. Kazakhstan	32.6
2. Australia	21.3	2. Canada	17.9
3. Kazakhstan	9.3	3. Australia	10.8
4. Russia	8.9	4. Namibia	8.2
5. Niger	8.8	5. Niger	7.7
6. Namibia	5.7	6. Russia	6.5
7. Uzbekistan	4.5	7. Uzbekistan	5.2
8. Ukraine	2.2	8. USA	3.0
9. USA	2.2	9. China	2.5
10. S. Africa	2.1	10. Ukraine	1.5
11. China	2.1	11. Malawi	1.2
12. Czech Rep.	1.3	12. S. Africa	1.1
Sum	97.8		98.2

Source: OECD-NEA/IAEA (2012)

production. This fact indicates a vulnerability of global supply by regional or local events inside or close to these major mines.

Industrial concentration in the mining business to only a few companies, which operate in only a few states is also remarkable. Nearly two thirds of the world production is in the hand of only four companies (Cameco, Rio Tinto, Areva and KazAtomProm). More than 75 % of uranium production takes place in five states (Kazakhstan, Canada, Australia, Namibia and Niger). The remaining quarter can be allocated to seven other countries. The most dramatic change over the last years is the rise of Kazakhstan to the main supplier state (one third of world production) and the descent of Canada and Australia (cf. Table 6.1).

But not only current uranium production, also uranium reserves and resources are concentrated on few states. In 2009, 53 % of the most important RAR-resources with production costs up to 130 $/kg were reported to be in Australia, Canada and Kazakhstan. Additional 40 % are located in only nine other countries (in order of deposit size): Niger, United States, South Africa, Russia, Namibia, Brazil, China, Ukraine and Uzbekistan (OECD-NEA/IAEA 2010).

6.2.2 *Uranium Price and Nuclear Electricity Costs*

Nuclear electricity production costs are dominated by the considerable upfront construction costs of a nuclear power plant and the associated financial costs. The uranium price has only very modest influence on the nuclear electricity costs. Today, only 5 % of the levelized production cost of electricity is based on the price for natural uranium. Assuming an uranium price of about 50 €/kg this leads to costs of about one seventh Euro-Cent per kWh (kilowatthour). If uranium production costs rise to 260 $/kg the contribution of uranium to the electricity production costs could increase to about one Euro-Cent or more. This would have an influence on the production price of electricity in nuclear power plants in comparison to other electricity providing technologies. Thus in the future there is a certain risk that fading uranium resources and higher mining costs could significantly influence competitiveness of nuclear power.

In the last years, a drastic drop in RAR uranium resources with production costs up to 40 \$/kg was reported (OECD-NEA/IAEA 2010 and 2012), which cannot be explained by the actual mining of uranium but only with a significant increase in production costs and a subsequent re-declaration of resource estimates to higher cost categories. Whereas 1.77 million tonnes were assigned to this category in 2007, today only 494,000 t are listed. Also the RAR resources with production costs between 40 and 80 \$/kg are considerably decreasing since the last issue of the Red Book. This indicates that the risk might have some relevance for the mid-term future.

6.2.3 Uranium Ore-grade Dependencies

Uranium is abundant in earth crust (and seawater) and in theory huge amounts could be extracted. But technically and economically sound uranium production on industrial scale is highly dependent on the ore-grade (percentage/share of uranium in uranium ore). The energy and technological sophistication needed to extract the uranium will have the most influence on mining costs depending on the assumed cut-off grade, which is the concentration for which uranium mining would become uneconomic, technically or ecologically unfeasible or even energetically irrational. Therefore extraction of uranium from low concentration deposits poses the question at which point the economic, energy, and environmental costs for extraction are too high to justify mining operations.

Storm van Leeuwen (2008) has argued that the mass of rock to be processed is increasing proportionally with decreasing ore grade. If the grade is decreasing by a factor of ten the rock to be mined and transported increases by a factor of ten too and the mining energy input per kilogram mined uranium is at least ten times as large. Further processing of mined ore leads to further losses which is reflected in a recovery or extraction yield $y < 1$. In consequence, there should exist a cut-off grade ("energy cliff") so that more energy is needed to produce uranium fuel than can be gained from a nuclear power reactor. Van Leeuwen's arguments are convincing at least for open pit and underground mining.[7] He estimates that this limit is reached at ore grades lesser than 0.02 % and believes that all deposits with higher grades will be depleted until 2060, assuming a constant use of nuclear power on the

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[7] In principle, this is supported by a study of the University of Sidney (ISA 2006) and a report of the Austrian Energy Agency and the Austrian Eco-Institute (AEA/ÖÖI 2011).

current level.[8] However, more research on this aspect of the uranium cut-off grade is necessary and highly recommendable to analyse under what conditions the energy-cliff will be reached in the upcoming future.

In general, the log-normal distribution of uranium deposits depending on the ore grade indicates that statistically new deposits will likely have lower concentrations. That the ore grade has already a decreasing tendency on a global scale is indicated by the trend in exploration outcomes (OECD-NEA/IAEA 2012) and possibly by the fact that underground mining and open pit are not any more the major uranium extraction technologies. Instead In Situ Leaching (ISL) is the method mostly used and contributes with about 39 % to global production in 2010 (OECD-NEA/IAEA 2012). ISL is typically used for lower ore grades.

Like the energy cliff a similar argument was made that the CO_2 reductions from nuclear power could be affected by increasing energy demand for uranium mining using fossil fuels for mining operations (van Leeuwen 2008). Thus the CO_2 argument in favour of nuclear power could be reversed ("CO_2 trap"). The answer how energy use and CO_2 emissions depend on the ore concentration is still debated in the scientific community. An indication of this are for example the wide range of CO_2 emission estimates on the full nuclear fuel cycle ranging between 1.4 and 300 gCO_2/kWh depending on the uranium origin and other factors (Sovacool 2008).[9]

6.2.4 Future Production and Exploration

Since the gap between production and demand cannot be filled anymore with secondary uranium resources and existing stocks (cf. Sect. 6.1.1 above) primary uranium production by uranium mining must be increased. This strategy was only partly successful in recent years—and only due to the huge expansion of ISL uranium mining in Kazakhstan.

Over the last years annual production worldwide was always behind projections of the Red Books. While in 2008 projections for 2010 estimated a production of 80,685 or 86,720 t of uranium, and in 2010 projections for the same year were in the range of 70,180 and 75,405 t, the actual global production in 2010 reached only 54,670 t of uranium (close to the 2009 Figure of 51,526 t).

The question is whether the risk that the necessary expansion of mining activities will not take place can be compensated by intensified exploration. Although it is

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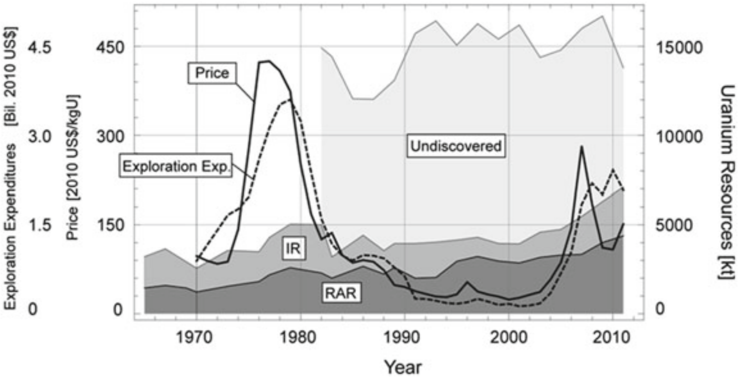
[8] "If no new rich uranium resources of significant size are discovered during the next decades, the nuclear system will fall off the energy cliff in the period 2050–2080, within the lifetime of new nuclear build, depending on the capacity of the world nuclear capacity." (van Leeuwen 2012) Of course, the "energy cliff" will be reached quite earlier if nuclear power will be expanded in the near and mid term future.

[9] The mean value is 66 gCO_2/kWh (Sovacool 2008). As a comparison natural gas in a combined cycle turbine emits 440 gCO_2/kWh over the life cycle.



Notes: Although exploration expenditures have a stronger correlation to uranium price development, the finding of new resources does not correlate with the price. Most of the increase in recent years is due to the inclusion of resources in the cost category of 130–260 $/kgU and not due to new findings of deposits.

Fig. 6.3 Development of worldwide resource estimates on identified (RAR and IR) and undiscovered resources, the uranium spot market price and exploration expenditures (inflation adjusted). Source: OECD-NEA/IAEA (2012), OECD-NEA/IAEA (2010), OECD-NEA (2006), ESA (2013)

clear that new discoveries can only be made if uranium is explored there is historically no clear indication for a strong correlation between new discoveries and exploration expenditures (Fig. 6.3). There were only two large global uranium exploration campaigns when uranium prices peaked after an initial decline during the 1950s and 1960s. The first such peak was in 1976 followed by an exploration peak in 1980. In this case large new resources where discovered at that time, e.g. in Canada, which were unknown before (greenfield exploration). The second larger exploration campaign began in the mid of the last decade. Whereas around the turn of the century only few 100 million dollars were spent annually worldwide, in 2010 about two billion dollars have gone into uranium exploration (OECD-NEA/IAEA 2012). However, no completely new large uranium deposits have been reported so far, but some resources have been identified in the vicinity of already known deposits (brownfield exploration). In particular, additional low grade ISL amenable sandstone deposits have been reported. Hopes to find really new deposits seem to be weak, correspondingly more than 60 % of today’s efforts are invested in brownfield exploration (OECD-NEA/IAEA 2012).

Even if considerable new deposits will be discovered within the current exploration campaign one has to consider that the lead times until a new mine can be opened are rather long. At least 15 years or more are necessary for the extensive preparations.

Sometimes the access to so-called unconventional resources is promoted. Indeed, large amounts of uranium in phosphates could theoretically be extracted. But a realistic strategy to produce uranium as by-product of phosphate mining could only provide up to 3,700 t of uranium annually (IAEA 2001). There is another "technological dream" to extract uranium from seawater containing about 3 ppb uranium. However, the technology researched so far is not viable for large scale, cost effective uranium production. Furthermore, the scale and huge size of such a future operation will likely prohibit this method from meeting global demand (MacFarlane/Miller 2007). Also the thermodynamic sense is in question due to the expected gigantic need of energy input for this technology.

6.2.5 *Short- and Mid-term Supply*

In recent years, several warnings were expressed that within the next one or two decades uranium supply could actually fall beyond the needs of nuclear industry (e.g. IEA 2006, 377; Zittel and Schindler 2006; Deutsch et al. 2009). Presenting the 2008-issue of the Red Book an OECD press declaration from 3rd June 2008 reads: "Given the long lead time typically required to bring new resources into production, uranium supply shortfalls could develop if production facilities are not implemented in a timely manner." Actually in 2013, there are indications that larger mine projects or mine expansions with a significant expected share of world production are delayed or in question.

Illustrative is the case of the Canadian "Cigar Lake" mine. This deposit has been discovered some three decades ago in 1981. Mine development started already in 1987. The amount of proven uranium reserves in the range of 100,000 t and the uranium concentration in minable ore in the range of 2 % to more than 20 % makes this mine especially attractive. In 2004, the mine was licensed by the authorities and construction started in the following year. The beginning of production was planned for 2007 and a mining rate of about 7,000 t uranium per year (about 13 % of current world production) was scheduled. However, in spring and autumn of 2006 two severe water inflows led to a first substantial delay (until 2011) and increased the investment costs to estimated 1.8 billion dollar (including remediation costs). In summer 2008, it turned out that water inflows were not stopped causing again additional remediation costs of about 100 million dollars. Two years later, the operator Cameco began to freeze parts of the mine underground and to prepare a new mining technology. Cameco was convinced that production would start in late 2013 but this did not happen.

The world's single largest known deposit is the Olympic Dam mine in South Australia with 0.94 million tonnes RAR (Geoscience 2013), making Australia by far the most uranium rich country. Here, uranium is just a by-product of the copper and gold mining activity. The ore has an average concentration of 0.028 % uranium. It was planned to quadruple production capacity to 16,000 t per year and to convert the underground mine into an open pit mine (OECD-NEA/IAEA 2010). Olympic Dam would have become the most productive mine in the world and would have helped to close the gap between uranium production and uranium demand. However, in summer 2012 the deadline to decide over this 30 billion dollars expansion project was postponed for another 4 years.

In the face of obvious difficulties to sufficiently increase primary uranium production and the expected decrease of availability of secondary resources in the future, uranium supply in the next two decades might become problematic. A more rigorous analysis (Englert et al. 2011) has revealed that only under favourable assumptions regarding future mining the current annual demand can be met until 2030 under the assumption of a constant global demand. More conservative assumptions reflecting the actual slowness of production increases lead to the possibility of supply gaps in the years beyond 2022 even if uranium demand do not increase over the level of today.

6.2.6 Nuclear Expansion Scenarios

In the last decade, interested circles have repeatedly talked about a "nuclear renaissance". A massive expansion of nuclear power in terms of more global capacity and more countries using nuclear energy was and still is proposed. One central argument is that nuclear power could help to mitigate climate change due to its low carbon characteristics.

It is important to assess whether a massive expansion of global nuclear energy usage could be covered by available uranium resources. To that aim we briefly discuss two hypothetic, very simple linear expansion scenarios.[10] To make the low carbon nuclear contribution more significant than today a four-fold and a ten-fold nuclear expansion in the time period of 2015 until 2050 and 2015 until 2070 respectively is assumed. This leads to a global nuclear capacity of 1,500 GWe and 4,400 GWe in 2050 and 2070 respectively (cf. Table 6.2). The achievable nuclear share of global electricity production and primary energy usage results also from assumptions about the assumed growth rate in global electricity demand (2 % and 2.5 % rsp.).

It turns out that such a massive nuclear expansion alone can not solve the greenhouse gas emission problematic. But its contribution to mitigating climate change could be more significant than today, which is in particular reflected in the nuclear share of primary energy usage in the target years 2050 and 2070 leading to contributions of about 12 % or close to 20 % respectively.

It has to be underlined that massive nuclear expansion scenarios are hypothetic and probably not feasible as investment costs per reactor unit[11] are comparatively high resulting in economic disinterest of utilities and unwillingness to build reactors

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[10] Within these scenarios a linear increase of nuclear capacity worldwide over the coming years is assumed which is covering also the drop in capacity by decommissioning of old reactors (a lifetime of 40 years is assumed). For simplicity it is assumed that nuclear capacity will be constant after the expansion period of 2015–2050 and 2015–2070 respectively.

[11] An illustrative example are the current AREVA rector projects in Finland and France striving for the construction of Generation III type European Pressurized Water Reactors (EPR). Cost overruns and time delays will lead to specific overnight construction costs of at least 5,300 Euro per kW.

Table 6.2 Two hypothetical, simple massive nuclear expansion scenarios

	Scenario I	Scenario II
Time period	2015–2050	2015–2070
Target capacity in 2050/2070	1,500 GWe	4,400 GWe
Necessary annual built-up	55 GWe	110 GWe
Assumed growth rate of global electricity demand	2 %/year	2.5 %/year
Achieved nuclear share of global electricity production in 2050/2070	~1/3	~1/2
Expected nuclear share of global primary energy usage in 2050/2070	~12 %	~18–20 %

without governmental support (at least loans), and necessary resources and infrastructure for reactor build-up are lacking today (ISR 2013).

According to the Red Books (OECD-NEA/IAEA 2010, 2012) identified uranium reserves and resources total to about 6–7 mio. tonnes. Undiscovered and speculative resources are estimated to be 10–11 mio. tonnes. In expansion scenario I (1,500 GWe in 2050) all of today's identified uranium resources (production costs up to 260 $/kgU) would be exploited in 2050. 2.7 mio. tonnes uranium would be consumed in each decade after 2050, more than the sum of all uranium mined since the 1940s. In scenario II (4,400 GW in 2070) the demand would total to about 24 mio. tonnes uranium until 2070 which is by no means covered by currently identified and prognosticated resources. Only with a plutonium economy such a scenario could be viable, but breeder reactors are expected to be industrially mature not before 2050 (ISR 2013). Uranium demand for scenario II until 2050 would total to about 12 million tonnes. It is highly improbable that mining efforts within the next decades could meet such a huge demand.

Further, analysing available secondary resources and the expected mining operations of 29 representative operational or planned mines shows that massive nuclear expansion scenarios, like scenario I and II, are not covered by primary and secondary uranium production during the next two decades until 2030 (Englert et al. 2011). This might be even true for somewhat moderate expansion scenarios (low and high) developed by the IAEA (OEACD-NEA/IAEA 2012).

Furthermore, it is questionable whether a nuclear expansion makes sense at all in terms of climate change mitigation. Nuclear investments to provide CO_2 savings might be not competitive in comparison to other possible investments in the energy sector (energy saving, renewables, etc.) aiming at the same goal.[12]

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[12] This cannot be discussed here. More detailed information can be found in (ISR 2013).

6.2.7 Environmental and Human Health Impact

Uranium production and specifically uranium mining and processing pose risks to damage human health and the environment. The radioactive legacy of past and—despite several improvements—modern mines is still relevant for mine workers and the local population. Contaminated dust from mines and tailings spread over landscapes, radioactive effluents and waste water ponds pollute rivers and aquifers. In several mining regions the massive water demand causes problems for groundwater balance and competes with other needs.

The environmental legacy of uranium mining cannot be described in detail here, but the case of the East-German mining company Wismut can serve as an illustrative example (Wismut 2006). From 1947 to 1990, Wismut produced a total of about 230,000 t of uranium[13] at more than 40 mining sites in the populated region of the city of Gera. Up to more than 100,000 workers were employed (later in the 1980s only 45,000 and less). In the first two decades nearly all produced uranium had to be delivered to the Soviet Union (9,550 t in 1946–53 and 34,000 t in 1954–1960) feeding mainly the Soviet nuclear weapons programme.

After the fall of the German Wall in 1990, uranium production came to a halt, documentation efforts started and a huge programme of environmental remediation and restoration began. An unprecedented effort to achieve transparent information provided relevant facts. About 800 deadly accidents in the mines have been documented now, more than 9,000 radiation induced diseases (in particular cancer) are attested so far[14] and more than 16,500 cases of silicosis. The restoration programme had to deal with 310 million cubic meters of tailings and 160 million cubic meters of radioactive sludge. Over two decades more than 6 billion Euros were spent for the program. Expenditures of in sum 7.1 billion Euro are expected until 2040.

Due to these landscape restorations needs an extra cost of 30 Euro per produced kilogram of uranium can be estimated which were eventually paid by the German tax payer.[15] This does not include the costs to treat the medical effects, which were paid mainly by the German health care system.

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[13] That is about one tenth of the global uranium production until now, having made Wismut for several decades one of the biggest uranium producers of the world.

[14] Ärzte-Zeitung, 30th April 2012.

[15] If one assumes that all uranium from the Wismut mines would have been used for electricity production, which is definitely not the case, the restoration costs would correspond to about 0.1 Euro-Cent per kWh. (Assuming an uranium demand of 180 t per GWel and a load factor of 0.8, 1 t uranium provides 7000/180 GWh electricity. Hence, 230,000 t uranium mined at Wismut could have produced 9,000 million kWh. The remediation costs of more than 7 billion Euro lead to about 0.1 Euro-Cent per kWh hypothetically produced electricity in (light water) nuclear power reactors.)

6.2.8 Proliferation Risks

Fissile materials like highly enriched uranium (HEU) and plutonium and technologies for their production like enrichment and reprocessing can be used for military nuclear weapons programs. For their production natural uranium is needed as source material. During the Cold War uranium mining was even dominated by military needs to fuel the nuclear weapons programs in the East and the West. Until the 1990s uranium production from mines was higher than the demand in the civil power reactor fleet (Fig. 6.1) and only after military production was stalled in the nuclear weapon states the civil market became the dominating factor in uranium production. One can estimate that roughly 1/5th of global uranium production of 2.5 million tonnes until 2008 was used for military purposes, mostly for HEU production and some for plutonium production in reactors. Uranium mining, milling and processing as well as access to natural uranium was and still is an essential part in a nuclear weapons program.

Especially uranium enrichment and the use of highly enriched uranium pose serious proliferation concerns. To use uranium in Light Water Reactors (LWR) the natural enrichment of only 0.7 % in the isotope U-235 has to be enriched to 3–5 %. However, enriching further to 90 % makes the material weapon usable and once enriched to 5 % about 2/3 of the separative work to get to HEU is already done (Hecker et al. 2012).

Today uranium for LWR is enriched with fast spinning gas-centrifuges. Due to their economic advantages gas centrifuges replaced diffusion technology almost completely and are today the workhorse to enrich uranium for the global market. However, in comparison to diffusion plants, gas centrifuge enrichment plants do use much less energy, do not emit thermal, electromagnetic or radioisotopic signatures which could be detected remotely and are much easier to convert from a civil to a military use posing almost no technological hurdles to do so. Centrifuges are proliferation prone[16], as can be also seen historically because centrifuges played an integral part in the nuclear weapons programs of Russia, Pakistan, India, Iraq, and North Korea and their dual-use characteristics were explored by e.g. Lybia and Iran and by other states.

Most commercial enrichment plants are either Russian or are and will be supplied with URENCO[17] centrifuge technologies (Germany, UK, Netherlands, USA, France). Except for URENCO plants in Germany and Netherlands and the Japanese enrichment plant in Rokkasho, all other large commercial scale plants are in nuclear weapon states.[18] New players might enter the market in case of global nuclear expansion scenario.

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[16] Not only small clandestine uranium centrifuge facilities are undiscoverable, but also declared facilities are very hard to safeguard by the IAEA (Boyer 2007).

[17] URENCO was established as a trilateral uranium enrichment consortium (Germany, Netherlands, U.K.) in the 1970s.

[18] Iran, Argentina and Brazil also have enrichment facilities, however they are still small.

After mining, milling and processing uranium ore to produce yellow cake, enrichment technology is the next step in the front-end of the nuclear fuel chain. Proliferation analysis often concentrates on enrichment as it is the critical step to produce weapon-grade HEU and enrichment technology is often termed as a sensitive technology therefore. Even the possession of enrichment technology can cause international concerns about a latent capability of a state to acquire fissile material for nuclear weapons if that state is not in compliance with its agreements with the International Atomic Energy Agency (IAEA). However, without access to natural uranium a nuclear weapons program is throttled down. Historically it was not only security of energy supply driving geostrategic planning to account for uranium deposits, but also military demand. The Soviet Union e.g. fueled its early weapon program with the large uranium resources in East Germany. Access to the resource and mastership of the mining technology is therefore a strategic asset for a state with latent intentions and influences geopolitical security agendas.

Another aspect of the proliferation risks is that the availability of uranium is driving the development of nuclear technology. Closed fuel cycle and separation of plutonium from spent fuel are economically not very attractive as long as uranium prices are low and uranium resources are considered to be plenty. This could change in the future if uranium prices rise and uranium becomes more scarce, raising again the interest in plutonium reprocessing and bringing back the possibility of large material flows of separated plutonium. From the standpoint of nonproliferation this would dramatically increase the accessibility of fissile material for weapons use and should be avoided.

Summary and Conclusions

In the contribution “Nuclear fuel chain: uranium resources and associated risks” the front end of the nuclear fuel chain and in particular uranium mining were analyzed. Eight related risks for nuclear energy production were identified.

1. Dependency on uranium supply is a high risk for nuclear power using countries. Nuclear power does not really contribute to energy security since all larger nuclear power countries (with exception of Canada), and in particular the EU, are highly dependent on uranium resources from a small number of foreign uranium supplier states.
2. Diminishing uranium resources world-wide will cause higher mining costs which in turn might become relevant for the competitiveness of nuclear power. A drastic drop in listed uranium resources with production costs up to 40 $/kg in recent years is a first indication that this risk might become serious in the medium term.
3. Uranium availability is limited by the cut-off grade of uranium ore where mining becomes either uneconomic, or technically or ecologically unfeasible, or even energetically irrational. First estimates claim that an

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"energy-cliff" could emerge in about 50 years (assuming a constant global demand) when energy costs for uranium production could exceed the energetic output from nuclear reactors. Consequently, there also might exist a "carbon-cliff" and the argument of the climate-friendliness of nuclear power might have to be reversed.

4. The significant gap between uranium production and demand since 1990 has not been closed. Uranium mining could not be sufficiently increased during recent years. Secondary uranium resources filled the gap over the last two decades, but will shrink in the very near future. A significant increase in uranium mining is necessary therefore. Even more so if nuclear power can or should be expanded in the upcoming future.
5. Tendencies in uranium exploration and realisation of new mining projects show a probability for severe difficulties to meet the demand, which could occur already in the 2020s.[19]
6. Massive nuclear expansion scenarios with many-fold increase of global nuclear capacity compared with today are probably not covered by the availability of uranium. Even the huge increase of uranium demand during the first two decades of such an expansion could not be met by the expected growth in uranium production. This might be true also for more moderate expansion scenarios.
7. The impact of uranium mining on environment and human health is serious. The well-documented case of the East-German mining company Wismut is a dramatic example. Including the actual environmental remediation costs alone add virtual costs of 30 Euro for each kilogram of uranium ever mined there.
8. Uranium mining has been an indispensable part of nuclear weapon programmes providing the source material for the production of weapon-grade fissile materials (highly enriched uranium or plutonium). Uranium enrichment, essential for civilian nuclear power programmes, is of particular concern today. The current technology of choice, centrifuge enrichment, is a proliferation prone technology allowing for a covert or latent nuclear weapon option. Even possession of enrichment technology can cause international concern and conflict.

In sum, not only the risks posed by uranium production and processing like environmental and health risks due to nuclear waste production within the nuclear fuel chain are relevant risks but also the availability of uranium itself is at risk. Current nuclear power programmes in a number of states and projected expansions of nuclear power might be affected. The dependence

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[19] Today Japan does not make full use of it's existing nuclear capacity. If this policy is prolonged possible shortages might be postponed for a couple of years.

on foreign uranium resources will increase for virtually all nuclear energy using countries, which will in turn stimulate competition between states for access to uranium. The myth of security of supply for nuclear energy will vanish as well, with consequences for national energy choices. Other conflict scenarios driven by growing uranium scarcity are imaginable in the future as well. As nuclear weapon programs and proliferation strategies to acquire a latent nuclear weapon potential are linked to uranium production, already civil mining operations influence existing international conflicts. This concerns in particular conceivable conflicts over and between nuclear weapons aspiring states.

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Chapter 7
Conflicts on Nuclear Energy Use

Michael Sailer

Nuclear power plants are operated in about 30 countries. The implementation of nuclear power plants in the future is being discussed in a similar number of other countries. Some of these plans are at an advanced stage; many others are at the stage of very preliminary considerations.

The use of nuclear energy can lead to conflicts. The history of the last fifty years and current political situations in different regions of the world provide a number of examples of these conflicts. An in-depth analysis of different factors and dependencies shows even more areas of possible conflicts in the future (Liebert/Englert in Part II).

Such conflicts tend to centre on two key issues:

- The possibility that nuclear technology and materials could be used for military purposes; and
- access to the resources needed for the operation of nuclear facilities, especially nuclear power plants.

7.1 Technical Background

To operate nuclear power plants the availability of manifold resources is a necessary requirement. These resources include knowledge specific to the field, the relevant technology, and access to corresponding materials. It is helpful to understand the technical background of these dependencies in more detail.

A basic resource for operating a nuclear power plant is the supply of nuclear fuel elements. The construction of reliable fuel elements requires special know-how,

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which is currently only available in a few countries. Other countries are dependant on the delivery of such elements from suppliers in these countries. Although some of these suppliers are private companies, they are very much bound by the nuclear policy of the country in which they are situated. Any delivery to another country without the political or official consent of their own country is unthinkable.

The uranium itself has to go through several technical steps before it can be used in the fuel elements. Mining and chemical concentration of the ore are the first of these steps, which culminate in an intermediate product called "yellow cake". The next step is the chemical conversion to uranium hexafluoride; conversion plants for this purpose also only exist in a few countries.

The most critical step is then enrichment, a physical process which concentrates the isotope uranium-235 to a grade which is necessary for the nuclear chain reaction in the reactor.

Enrichment is a very challenging process, both in terms of the technology itself and its potential for military use. With an enrichment plant two products can be produced: reactor-grade uranium with a content of 3–5 % uranium-235 or weapon-grade uranium. The weapon-grade uranium has a minimum concentration of 20 % uranium-235; the standard content is generally 93 % uranium-235. The latter can be used in the construction of weapon devices, which do not require much space or weigh a great deal. Only minor modifications in the enrichment plant are necessary to change the production from reactor-grade uranium to weapon-grade uranium. Therefore, the existence of an enrichment plant always also means a potential for producing weapons based on highly enriched uranium.

There are three key enrichment processes.

The older gas diffusion process is very energy consuming and is only practised by the traditional nuclear weapon states. Up to now most of the world's supply of reactor fuel has stemmed from these facilities.

The more modern process uses high speed centrifuges. This process was developed in a cooperation of European countries (D, UK, and NL); these plant types are in operation in these countries and provide a significant share of the total global supply of enriched uranium. However, in the 1970s essential pieces of the know-how were leaked to a Pakistani, who distributed it in the meantime to other countries. The past and ongoing conflicts relating to high-speed centrifuges in different countries (e.g. North Korea, Iran) can be traced back to this unplanned transfer of know-how.

For a certain period of time a third method played a role. It was developed in Germany, but was never operated there. This know-how was exported to South Africa and formed the technical basis for the former nuclear weapon program of this country during apartheid. Brazil also attempted to operate such a plant back in the 1980s; many supposed that its function had a military background.

Besides fuel, the operation of nuclear power plants also depends on the supply of spare parts, in particular those needed to ensure safety. For the more sophisticated parts there are a small number of suppliers in the world; these suppliers are mainly the same companies which also supply the power plants themselves. The same situation applies if changing the construction or retro-fitting becomes necessary.

The design of these measures, the related safety analyses and the delivery of the necessary equipment are all only available from a few companies.

A key issue in the field of nuclear energy is that—as has already been mentioned in the case of enrichment—a real separation of civil and military use is not possible. There are many reasons for this:

Firstly, in principle the physics of the military use and civilian use of nuclear energy is the same. This means that any nuclear scientist is able to apply his or her knowledge in both sectors. There are many examples of experts all over the world who work or have worked in both areas, especially in the case of those based in the nuclear weapon states. To work in the civilian sector only is a voluntary decision made by the expert, which can be revised at any time and for any reason.

Secondly, some types of nuclear plants—most notably, enrichment plants and reprocessing facilities—can be used for both purposes. Reprocessing facilities separate plutonium from spent reactor fuel by means of chemical treatment. Plutonium can be used to make nuclear weapons in all technically available isotopic compositions. This means that the possession of a reprocessing plant, even one of a laboratory size, enables a country to produce the fissile material for a plutonium weapon. Beside enrichment plants and reprocessing facilities, some other specific research facilities and laboratories could also be used for military purposes.

In terms of potential conflicts on an international level, nuclear waste management, and in particular the final disposal of nuclear waste is not regarded as a key issue. In technical terms there is an absolute need for interim storage facilities for spent fuel in the next decades. Experience gathered with the operation of such facilities shows that interim storage technologies have no major technical problems. Nevertheless, there are still some possible areas of conflicts:

- Countries supplying the fuel often set obligations for the transfer of waste/spent fuel after it has been used. A country which does not fulfil such obligations for reasons not accepted by the supplying country can result in a conflict.
- Unsolved waste issues in one country can in principle lead to a conflict, or hamper relations, with neighbouring countries.
- If a country sees reprocessing as a part of a national waste management program, this can raise concerns in other countries of the region since technically military activities are possible.

7.2 Dependencies

The construction of a nuclear power plant creates a number of dependencies, for example in terms of

- The supplier/constructor. For most countries, the supplier/constructor is a company from a foreign country because there are only a few of such companies worldwide.

- The financing. The necessary capital investment of several billion dollars demands a framework for financing, which in the case of most countries cannot be realized within their own national economy. Thus, dependence on international sources of financing is unavoidable.
- Obligations laid down in international treaties, namely the Nuclear Non-Proliferation Treaty, the Convention on Nuclear Safety and nuclear liability treaties. Each country which wants to become a nuclear power country has to decide whether it will become Parties to these agreements or not. Such decisions can influence the tensions between countries in the respective regions.

In terms of the technical background, the application of nuclear technologies entails many dependencies between the different stakeholders. Since the stakeholders are either states or are closely related to the states (e.g. important national companies such as French or Russian nuclear suppliers) problems in the framework of dependencies can easily cause conflicts between countries.

A country which operates or intends to operate nuclear power plants depends on the “good will” of deliverers and the countries in which they are located. If the “good will” disappears, the country has to look for new allies or engage in their own technical developments.

One example of this is Iran. In the 1970s Germany was contracted to supply the nuclear power plant in Bushehr. When the political system in Iran changed, the contract was terminated before construction had finished. Iran finally succeeded in gaining a new ally to complete construction—Russia. Germany and other Western countries were embarrassed by the behaviour of Russia and Iran in this case. A similar change but one occurring “in the other direction” took place in what is now known as the Czech Republic: the Temelin plant, which was originally been delivered by a Russian supplier, was ultimately fulfilled by a US company.

India is an example of a country being forced to carry out its own technical development following earlier dependence on US suppliers. Following India’s testing of its first nuclear device in the late 1970s, international supply to India’s civilian nuclear sector was terminated. Step-by-step India has developed the means to construct its own nuclear power plants. The country is now thought to have a well-developed civil and military nuclear engineering sector.

The major problem in this context is that supply companies depend on markets and are bound by international restrictions. Countries with nuclear suppliers with an important national role could be forced to extend their markets internationally. Because of the narrow market such countries can also choose possible customer countries, which are problematic in terms of possible tensions or possible military use.

In the past there were several examples of companies which had only limited access to the international market and did so with the support of their respective governments. In the 1970s Germany supplied nuclear power plants to Brazil and Argentina, both of which were military dominated countries with ambitions to build nuclear weapons at that time. The CANDU reactor, developed by the national Canadian industry, was delivered to countries like Argentina, Romania, and

India, who also had military ambitions at the time of delivery. France's more recent announcement that it will supply reactors to Libya also belongs to the same category.

Nuclear suppliers may also argue against international restrictions. One example here is the recent development regarding India. After international suppliers realized that India had successfully developed its own nuclear industry following an international nuclear boycott, they pressed their national governments to ease the restrictions. Their interest was to gain access to the emerging Indian nuclear market. Finally they succeeded, even though the original reasons for the boycott—India's manufacture of nuclear weapons and the fact that it has not signed the Nuclear Non-Proliferation Treaty—have not disappeared.

7.3 New Nuclear Countries

The current list of nuclear power countries of the International Atomic Energy Agency (IAEA) comprises 30 (+1 = Taiwan) countries. The majority of them have a long background in terms of nuclear experience. Most of them also have a developed state of administration of industrial safety, including adequate separation between promotion and surveillance, and long experience with industrial safety culture. In contrast, many of the countries more recently interested in nuclear reactors have no such background in relevant administration and safety.

Therefore, the following needs to be implemented in the case of these countries:

- a suitable national legal and administrative framework needs to be created,
- the role of the regulator and the operator has to be clearly separated,
- the civilian and military system must be clearly separated.

Tensions can arise if a country declares that it has an appropriate system, but other countries (neighbouring states, parties of international nuclear conventions) have the impression that this is not the case. How should a country with shortcomings in this area be handled? This issue is very complex since it does not only include safety concerns but also the risk of discrimination. Nevertheless, the acceptance of lower safety levels in one country results in higher risks for neighbouring countries. Additionally it lowers the level of international safety since countries also rely on the acceptance of lower standards in another country.

A further aspect is that a nuclear newcomer will automatically change the respective regional balance of power. The reason for this is the possibility of military use. Whether the country at hand actually intends to make use of the military option or not is immaterial—the possibility alone is the decisive factor.

7.4 Changing Times

Nuclear power projects typically go on for decades. The typical operational lifetime of a nuclear power plant is 30–40 years. The duration of construction ranges from 6 to 20 years. This means that decisions on nuclear use not only influence the present situation; they also create boundary conditions for the future. In most cases the actual decision makers do not take into consideration the future boundary conditions shaped by their nuclear related decision-making.

One important group of possible problems concerns major changes in the situation of a nuclear power country. Past experience provides many examples of this.

The political changes in Eastern Europe in the early 1990s resulted in new problems for the former allies of the Soviet Union which operated nuclear power plants. The Soviet Union had a monopoly on nuclear fuel supply, which was also used to control any military options and other activities of the Soviet allies. At the same time the Soviet Union took back all spent fuel from those countries. This gave a clear pattern regarding the possible use of the plutonium contained in spent fuel either from nuclear power reactors or from research reactors.

Following the collapse of the Soviet Union the countries had to organise new fuel supply options to establish increased independence from Russia. The change of suppliers also followed a similar pattern (see the Temelin example mentioned above). At the same time these countries also had to develop their own scheme for dealing with their spent fuel.

Other problems have arisen on the basis of changes of borders. The nuclear program of the former Czechoslovakia had to be divided amongst the successor countries. Tensions arose because, for example, the former waste management program had established a specific distribution of tasks between both parts of the former country. Following the dissolution of Czechoslovakia, the two successor countries interpreted the technical and financial duties differently, which resulted in long-lasting negotiations and tensions.

The issue of ownership and interpretation of duties also rose when the former Yugoslavian states of Slovenia and Croatia became independent countries while the nuclear power plant Krško was commonly owned. Problems emerged in the fields of waste management, the distribution of costs, and safety. Even two decades after the change of borders, the problems have still not been solved completely.

Changing situations in political alliances and regional balance of power can also be more complicated when a nuclear country features strongly in that region. The situation today with Iran mainly stems from a decision on nuclear energy taken in the period of the former Shah regime and from its very different political status on a regional and an international level.

On the basis of these examples, possible scenarios of future political changes can be discussed which are of an even more complicated nature:

- What happens if after hostilities a part of one country is passed to another country and in that part a nuclear power plant or a waste management facility is located?
- What happens if a formerly peaceful, democratic country changes to a military dictatorship when it has a developed nuclear industry?
- What happens if the political situation in a nuclear country destabilises for a long period of time (imagine a nuclear Somalia)?
- What happens if major war breaks out in the areas surrounding a nuclear facility?

There are also other types of future changes which can lead to changing balances of power and related conflicts:

- A general shortage of nuclear fuel supply is possible if the quantities of available uranium or fabrication capacities do not cover the needs of the nuclear countries as a whole. What will the decision process look like and what will be the factors influencing the distribution amongst the countries?
- The aftermath of a serious accident, especially when it has severely affected the territories of different countries. Are the existing liability conventions really sufficient to avoid tensions between the affected countries arising?
- Changes in the international non-proliferation regime can also lead to changes in the regional balance of power. The possible lowering of standards and restrictions can lead to a higher level of suspicion that a neighbouring country may indeed have secret military intentions. Increasing such standards can cause suspicion that they are being used to discriminate against certain countries.
- Lowering technical safety standards and safety policy can increase fear in other countries. Increasing international safety standards can result in tensions arising with countries which do not comply or cannot comply with increased standards.

Conclusions

In terms of possible conflicts arising from the nuclear energy use, many factors have to be taken into account, including:

- technical boundary conditions such as the need for specific materials, technical supply, technical know-how;
- current and potential stakeholders such as countries, industries, military, scientists, etc;
- political patterns both in terms of the current situation and changing patterns in the nuclear country or on an international level and
- the need for safety (technical, supply, military) for the respective country and for other countries.

(continued)

Conflicts are possible in the field of nuclear energy due to:

- access to technical resources,
- access to know–how,
- differing opinions on safety,
- changes in the regional balance of power, and/or
- changes in the international balance of power.

Part III

Perspectives of Strategic Material Resources Management

Chapter 8
Closing the Loop for Rare Metals Used in Consumer Products: Opportunities and Challenges

Christian Hagelüken

8.1 Booming Metal Demand: Building the Mine Above Ground

Metals are classical examples of non-renewable resources, and their extraction from Earth by mining of ores cannot be seen as sustainable in the strict sense of the word. Mining, by definition, depletes the ore reserves. Through mineral processing and subsequent smelting and refining, ores are disintegrated, and the desired metals are isolated for use in the technosphere. Special and precious metals play a key role in modern societies as they are of specific importance for clean technologies and other high tech equipment. Important applications are information technology (IT), consumer electronics, as well as sustainable energy production such as photovoltaic (PV), wind turbines, fuel cells and batteries for hybrid or electric cars (contributions of Helmers (Part III), Schebek et al. (Part IV), Zepf et al. (Part VI) and Jägermann (Part VI). They are crucial for more efficient energy production (in steam turbines), for lower environmental impact of transport (jet engines, car catalysts, particulate filters, sensors, control electronics), for improved process efficiency (catalysts, heat exchangers), and in medical and pharmaceutical applications (Hagelüken and Meskers 2008; Angerer et al. 2009).

Figure 8.1 provides an overview of these main application areas for selected metals and illustrates their significance for modern life. For example, electronic

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The article is an updated and extended version of a contribution by the author entitled "Sustainable Resource Management in the Production Chain of Precious and Special Metals" to the book International Economics of Resource Efficiency, Bleischwitz, Welfens, Zhang (eds.), Heidelberg: Springer, 2011.

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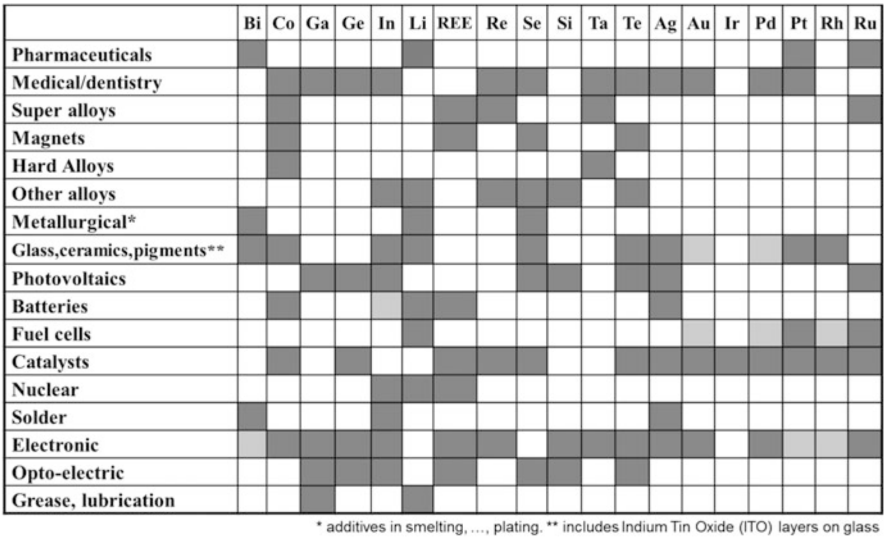

	Bi	Co	Ga	Ge	In	Li	REE	Re	Se	Si	Ta	Te	Ag	Au	Ir	Pd	Pt	Rh	Ru
Pharmaceuticals	■					■											■		■
Medical/dentistry		■	■	■	■			■	■		■	■	■	■		■	■		
Super alloys		■					■	■			■								■
Magnets		■					■		■			■							
Hard Alloys		■									■								
Other alloys					■	■		■	■	■		■							
Metallurgical*	■					■			■										
Glass,ceramics,pigments**	■	■			■	■			■			■	■	▨		▨	■	■	
Photovoltaics			■	■	■				■	■		■	■						■
Batteries		■			▨	■	■						■						
Fuel cells						■								▨		▨	■	▨	■
Catalysts		■		■			■	■	■			■	■	■	■	■	■	■	■
Nuclear					■	■	■												
Solder	■				■								■						
Electronic	▨	■	■	■	■		■	■		■	■	■	■	■		■	▨	▨	■
Opto-electric			■	■	■		■		■	■		■							
Grease, lubrication			■			■													

* additives in smelting, …, plating. ** includes Indium Tin Oxide (ITO) layers on glass

Fig. 8.1 Important applications for technology metals (originally published in Hagelüken and Meskers 2010)

products can contain up to 60 different elements and in their entity are major demand drivers for precious and special metals: Just the annual sales of mobile phones and computers account e.g. for about 4 % of the world mine production of gold and silver, and for about 20 % of palladium and cobalt.

Driving forces for the booming use of these technology metals[1] are their extraordinary and sometimes exclusive properties, which make many of these metals essential components in a broad range of applications. Building a more sustainable society with the help of technology hence depends to a large extent on sufficient access to technology metals.

Products like cars, electronics, batteries or industrial catalysts thus have evolved into a future potential "renewable" metals resource for society, an "above ground mine" that should not be wasted. Thoroughly extracting these "urban mines" is the only sustainable solution to overcome long term supply disruptions. Moreover, compared to mining, metal concentrations in many products are relatively high. For example, a typical primary gold mine will yield below 5 g per ton of gold. In electronic scrap, this rises to 200–250 g/t for computer circuit boards and even to 300–350 g/t for mobile phone handsets, making it a much richer source. An autocatalyst even contains some 2,000 g/t of PGMs in the ceramic monolith, compared with average PGM concentrations in the mines of below 10 g/t. If we

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[1] Technology metals are crucial for the functionality of many high tech processes while—other than base metals—often are used in low concentrations only. They comprise the precious metals and most special metals, many of which are also regarded as "critical" by the EU [EU Commission 2010].

factor in the high CO_2 impact of primary production due to the low ore concentration, difficult mining conditions and other factors, the recycling of scrap becomes even more beneficial from a sustainability standpoint. Recycling of scrap metals usually has a much lower CO_2 impact if state-of-the-art technologies are used (Hagelüken and Meskers 2008).

8.2 The Debate on Potential Metal Scarcities

In the context of raising metal prices and the boom in demand for many technology metals, a discussion on potential metal scarcities restarted 7 years ago (Gordon et al. 2006, Tilton and Lagos 2007; Wolfensberger et al. 2008). More than 30 years after the Club of Rome's "The Limits to Growth" publication from 1972, it put again more emphasis on the finite character of our natural resources, a debate which had calmed down for almost two decades in between. Since the 1970s, a lot has happened specifically with respect to the use of the "technology metals". 80 % or more of the cumulative mine production of platinum group metals (PGM), gallium, indium, rare earth elements, and silicon, for example, has occurred over the last 30 years. For most other special metals, more than 50 % of their use took place in this period, and even for the "ancient metals" gold and silver use from 1980 onward accounts for over 30 % (Fig. 8.2). In many cases the booming demand especially from consumer mass applications drove up metal prices significantly. For example, the significant increase in demand of platinum and palladium was mainly caused by automotive catalysts (50 % of today's platinum/palladium demand) and electronics (Fig. 8.3). So more often the question is raised: "How soon will we run out of key element resources?" and occasionally: "Are severe shortages of certain critical metals within the next decade threatening?" Governments in the US, Japan and Europe undertake efforts to define which metallic resources are specifically critical

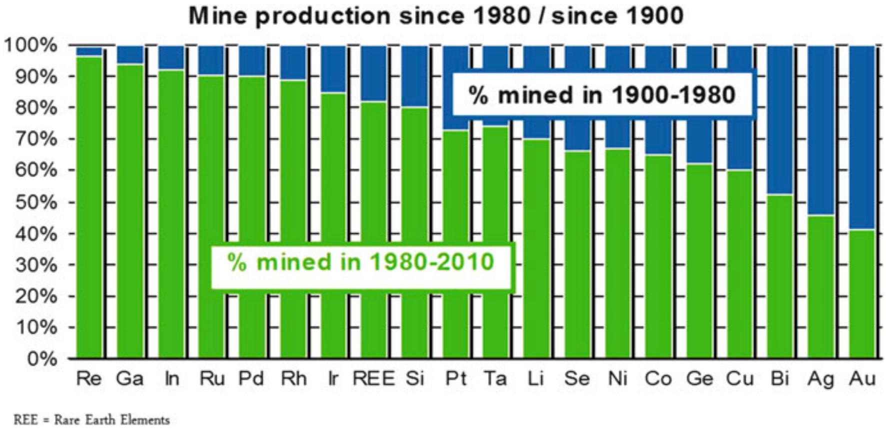

Fig. 8.2 Global cumulative mine production 1980–2010 in relation to production since 1900 (published with kind permission of © Hagelüken 2010)

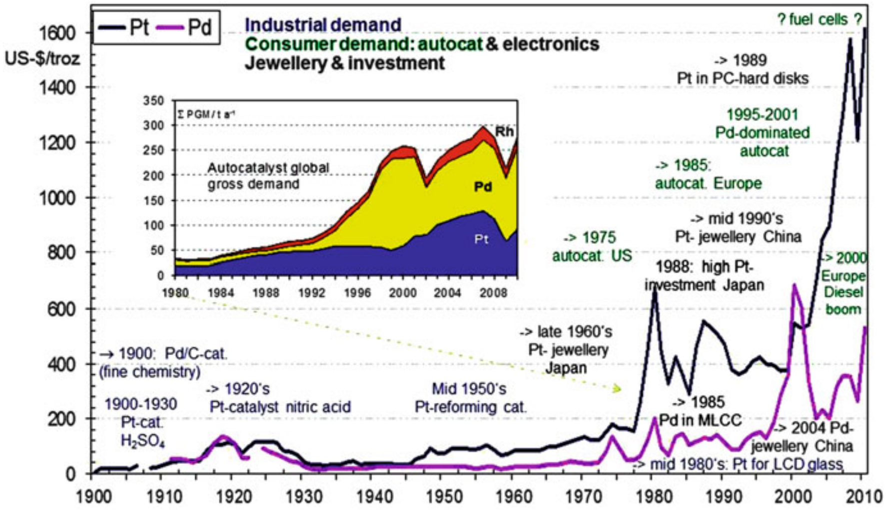

Fig. 8.3 Long term development of nominal prices for platinum (Pt) and palladium (Pd) and milestones in applications. *Insert*: global demand Pt, Pd, Rh for automotive catalysts 1980–2010 (published with kind permission of © Hagelüken 2010)

for their economies and which measures should be taken to improve their long-term supply security (NRC 2008; EU COM 699 (2008); EU Commission 2010; EU Commission 2012).

The current debate takes place between two extremes—resource optimists versus resource pessimists. Optimists argue that in principal market mechanisms will help to overcome supply shortages. Increased metal prices will lead to new exploration and mining (of so far uneconomic deposits) and technical substitution will be able to replace scarce metals by others with similar properties, or by thrifting and innovative technologies. Pessimists start with information about ore resources, compiled by the US Geological Services (USGS 2012) among others, and then divide these numbers by the current and projected annual demand. For some metals such as indium this leads indeed to rather short “static lifetimes”. While the scientific debate is open to the many facets of the matter, media sometimes tend to bring this in rather black and white statements. This contribution follows a pragmatic “resource realist” approach, without diving into detailed discussions on statistics and single metals. The aim is to discuss the main parameters and mechanisms that impact metal scarcities and what can be done to prevent them.

8.3 Dimensions of Resource Scarcity

Three types need to be distinguished, namely absolute, temporary and structural resource scarcity, and in this context the understanding of the primary supply chain is crucial (Hagelüken and Meskers 2010).

Absolute scarcity would mean the depletion of economically mineable ore resources. In this case all ore deposits of a certain metal—including the ones which have not yet been discovered by exploration—would have been widely mined out, and the total market demand for a metal would exceed the remaining mine production. This would first lead to extreme price increases and finally force substitution of that metal (or technology) in certain applications, or would put severe limits to the further technology distribution (as worst case a good technology, e.g. for energy generation, is endangered because a key metal is not available). However, within the foreseeable future such an absolute scarcity is rather unlikely, and here the arguments of the resource optimists count. Extremely high prices would make deep level mining and mining of low grade deposits, which are currently left aside, economically feasible. Also it would trigger more exploration, leading to the discovery of new ore bodies. Exploration is very costly and time consuming, so as long as mining companies have enough accessible deposits for the next two decades there is not much incentive for them to conduct additional exploration. Accordingly, the data reported by USGS and other geological services do not report the absolute availability of metals on the planet but compile the known deposits that can be extracted economically already today (reserves), or where it is expected to be potentially feasible (resources). If exploration and mining efforts extent deeper into the earth's crust or oceans and cover a wider geographical area, maybe even into arctic regions, substantial new metal resources are very likely to be accessible, however this will not come without trade offs as shown below (Wellmer 2008).

In contrast, *temporary or relative scarcity* is a phenomenon which has been already experienced. In this case, metal supply is for a certain period in time not able to meet the demand. Reasons can be manifold. New technological developments, strong market growth in existing applications, or speculative buying of investors can drive up the demand significantly within a short time so that mine supply lags behind. Also the supply can be disrupted by political developments, armed conflicts, natural disasters or other constraints in the mining countries itself, within the transport of ore concentrates, or also at major smelters/refineries. Temporary scarcities are a main reason for the sometimes extreme price volatility in metal markets (contribution of Hartard in Part I). The risk on temporary scarcities increases with increasing concentration of the major mines or smelters in few and/or unstable regions, or in few companies. Also a low number of applications in which the metal is used increase the risk. Often, different factors come together and then accelerate the development. For instance, in the first quarter of 2008 a soaring demand for PGMs from automotive catalysts and (speculative) investment coincided with a reduced supply from South African mines due to shortages in electric power. The prices of platinum and rhodium went to record heights within a short time as South Africa produces over 75 % of platinum and rhodium supply.

Speculation about potential depletion of indium resources started when from 2003 onwards the sales boom of LCD devices (monitors, TVs, mobile phones etc), which use indium-tin oxide (ITO) as transparent conductive layer, drove up indium prices significantly. The supply could not follow the sudden jump in demand and indium demand and prices went up by factor 10 between 2003 and 2006. After 2006 an increased primary supply (mainly through better extraction efficiencies triggered by higher prices) and a significant secondary supply (working down large amounts of production scrap that was accumulated during the boom phase) drove down the indium prices again, however today's level is still factor 6 higher than before the LCD boom. On the long run, for the indium supply the structural scarcity as described below will become an important factor (indium is a by-product from zinc mining). In future, a takeoff in thin film photovoltaics would boost again the demand for indium, but also for silicon, silver, tellurium, selenium, and gallium. Mass applications of electric vehicles will require large amounts of lithium, cobalt and some rare earth elements, and fuel cell cars would need significantly more platinum than is used today in a catalytic converter. Developing and expanding mining and smelting capacities is highly capital intensive, risky, and it takes many years to materialize. Hence, temporary scarcities are likely to happen more often in future.

The *structural scarcity* is most severe for many technology metals, which are often not mined on their own but occur only as by-products from so-called major or carrier metals (Wellmer 2008). Indium and germanium, for example, are mainly by-products from zinc mining, gallium from aluminum, and selenium, tellurium from copper (and lead). The PGMs occur as by products from nickel- and copper mines and as coupled products in own mines. Within the PGMs ruthenium and iridium are by-products from platinum and palladium (Fig. 8.4). Since the by-product ("minor metal") is only a very small fraction of the carrier metal, here the usual market mechanisms do not work. An increasing demand will certainly lead to an increasing price of the by-product metal, but as long as the demand of the major metal does not rise correspondingly, mining companies will not produce more, because this would erode the major metal's price. In this respect, the supply of by-product metals is price-inelastic, even a "ten-fold increase" in its price could usually not compensate the negative impact on total revenues when there is oversupply of the major metal. Moreover, many technology metals are important ingredients for several emerging technologies simultaneously (Fig. 8.1), so a competition between applications becomes likely and increasing demand from various segments will intensify the pressure on supply.

Substitution is not likely to become the solution for many of these metals either since the required functional properties can often be met only by metals from the same metal family. For example, substituting platinum by palladium in catalytic applications will just shift the problem from one temporary/structural scarce metal to the other, which was experienced in the second half of the 1990s, pushing the before cheaper palladium to record heights in 2000/2001 (Fig. 8.3). In emerging opto-electronics the crucial metals are silicon, tellurium, gallium, selenium, germanium, and indium. They can partially substitute each other, though this will not really mitigate the problem (Fig. 8.5). It can only be overcome by increasing the efficiencies in the primary supply chain (possibly leading to considerable gains) and, above all, by comprehensive recycling efforts as pointed out hereafter.

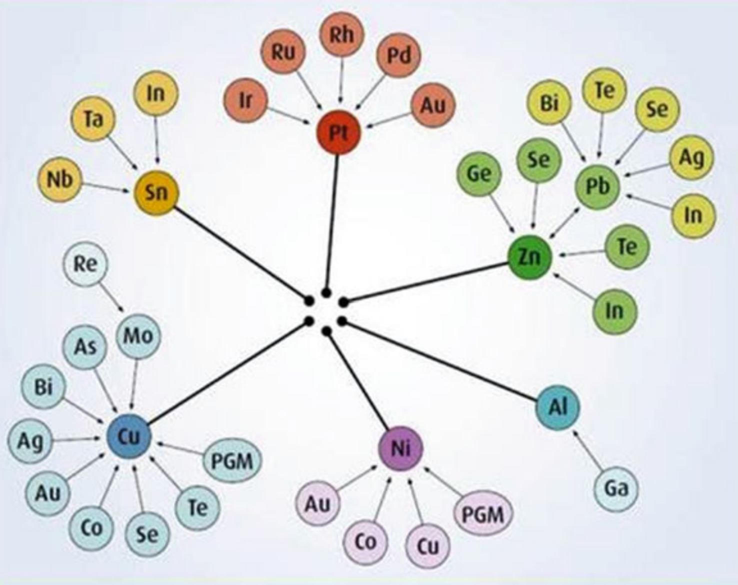

Fig. 8.4 Coupling of minor and major metals in primary production. The figure indicates, which minor metals are produced as by-products of major metals. Source: © Hagelüken and Meskers, modified after Hagelüken and Meskers (2010)

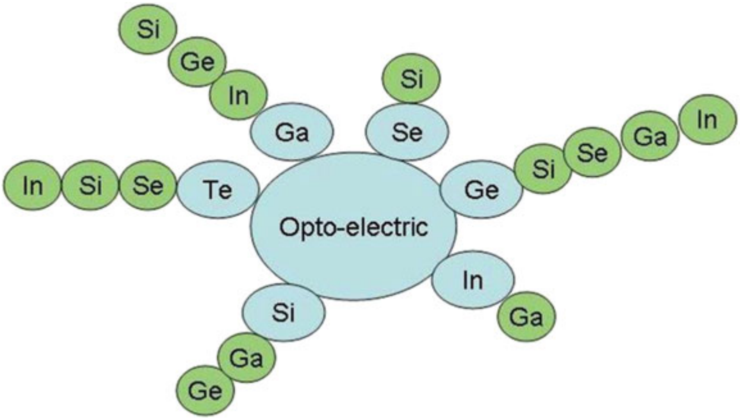

Fig. 8.5 Potential substitution of metals in opto-electrics. *Inner spheres* show the elements used in the application, *outer spheres* depict possible replacement elements (originally published in Hagelüken and Meskers 2010)

Omitting the fact that many technology metals are by-products and that structural scarcity is possible is thus the weak point in the resource optimists' argumentation.

Independent of whether or not supply constraints are likely, the impact of mining of lower grade ores and from more challenging locations must not be overlooked. It will inevitably lead to increasing costs, energy demand, and raising emissions, it will impact the biosphere (rain forest, arctic regions, oceans), and it can increase the dependence on certain regions ("battle for resources"). Hence it has to be ensured that our future clean technologies do not carry an over-proportional environmental burden deriving from extracting the metals needed for such technologies. These challenges altogether can imply significant constraints on emerging technologies, unless effective life cycle management enables the use of recycled (secondary) metals in the forthcoming years.

8.4 Conflict Metals and Critical Raw Materials

More recently a new issue has entered the debate on metals supply. Starting with the discussion on "blood diamonds" from African conflict areas like Sierra Leone and Liberia the topic has now widened to conflict metals in general. In focus today are tantalum (respectively its mineral coltan), tungsten, tin and gold from the Congo and neighboring regions, but the concept is likely to be extended both from a regional as well as from a metal perspective. Some mining of such conflict metals is brutally controlled by the conflicting parties and revenues obtained are financing purchases of weapons, hence further fanning the conflict. For manufacturers, e.g. of electronic devices, it becomes increasingly important to prove the ethical sourcing of these metals contained in their products. Hence, the traceability of the raw materials supply chain gets high attention and the manufacturers are delegating the responsibility down the row of their suppliers on the different tier levels. First policy measures have already been taken, e.g. in January 2011 the US regulation on metals supply from Africa came into force (Dodd and Frank 2010) and OECD is preparing a guideline on minerals from conflict areas in general (Draft Due Diligence Guidance on Minerals). Industry has already responded with e.g. the ITRI Tin Supply Chain Initiative or the Conflict Free Smelter Program developed by GeSI and the Electronic Industry Citizenship Coalition (CICC). Being able to prove that raw materials used in a product derive from environmentally sound recycling operations hence will become of increasing importance for manufacturers in this context as well.

Furthermore, in recent years a number of studies (e.g. NRC 2008; Buchert et al. 2009; EU Commission 2010) systematically looked into which metals from a certain country or region perspective need to be regarded as critical. Although the scope and the methodologies used were not identical, criteria to assess criticality were considering the economic/strategic significance on the one side and the degree of supply security on the other side. A number of metals were identified as critical in most of the studies, among which are the Rare Earths Elements, the Platinum Group Metals, indium and germanium. During 2009 and 2010 the Ad Hoc Working Group on Defining Critical Raw Materials of the European Commission evaluated 41 non-energy raw materials, out of which 14 were identified as critical for the EU economy. The report follows a relative concept of criticality, which means that

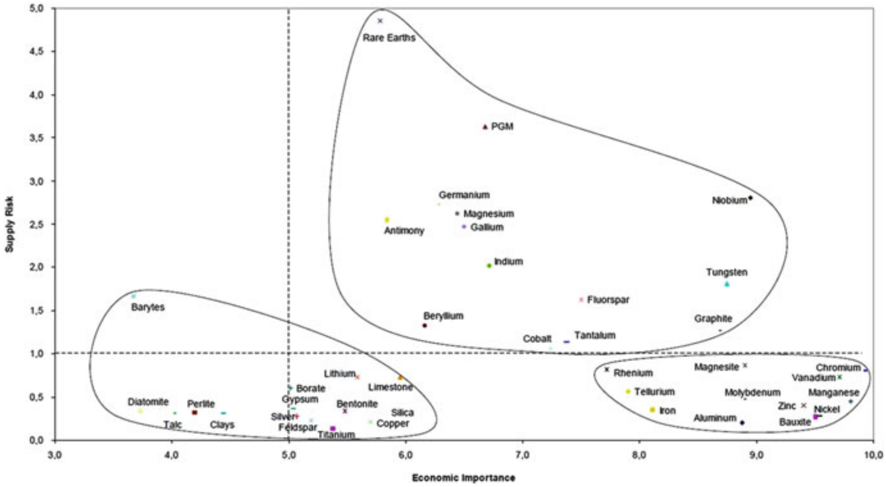

Fig. 8.6 Materials investigated by the EU Critical Raw Materials Working Group. The *top right* cluster comprises the 14 raw materials identified as critical. Source: EU-Commission (2010)

a raw material is labeled as "critical" when the risks of supply shortage and their impact on the economy are higher than for most other raw materials. Two types of risks were considered. The "supply risk" took into account the political-economic stability of the producing countries, the level of concentration of production, the potential for substitution and the recycling rate. The assessment used a quantitative aggregation of indicators. Additionally, the "environmental country risk" was assessed qualitatively which addresses the risk that measures might be taken by countries with weak environmental performance in order to protect the environment and, in order in doing so, endanger the raw material supply to the EU. Figure 8.6 shows the results, the identified 14 critical raw materials fall in the top right cluster with a high relative economic importance and a high relative supply risk.[2] The environmental country risk metric did not change the list of critical raw materials, which are in alphabetic order: antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, platinum group metals (PGM), rare earth elements (REE), tantalum and tungsten. The report includes a number of recommendations for follow-up and further support, as well as for policy oriented measures in the fields of mining/exploration, trade, recycling, substitution and material efficiency (EU Commission 2010).

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[2] In 2013 a review process for the EU critical elements list was started, the updated list of critical materials was published in May 2014 and is accessible under http://ec.europa.eu/enterprise/policies/raw-materials/critical.

8.5 Enhanced Recycling to Secure Metals Supply

Metals are not consumed, they are only transferred from one manifestation into another, moving in and between the lithosphere and the technosphere, where they accumulate and form an "urban mine" on the mid to long term. Today there is a rather broad consensus that recycling the products and infrastructure at its end-of-life offers significant benefits, both from an environmental perspective as well as by increasing the supply security of metals, as it:

- Prevents the environmental burden of non-recycling (by preventing emissions from discarded products or landfills into soil, water and air; reducing land use for waste deposits etc.).
- Mitigates the environmental impacts of mine supply (by a reduced energy need/ CO_2 impact, land and water use; less impact on biosphere).
- Extents/preserves the geological resources (and contributes to buy time to develop improved extraction techniques, which one day might enable less burdensome mining of poor or deep ore bodies).
- Reduces the geopolitical dependence in case of a high concentration of certain (critical) metals on few mining countries/companies (while creating a significant intra-European metal source).
- Further contributes to supply security by partially decoupling the supply of minor metals (if deriving from recycled products) from the primary production of major carrier metals.
- Supports the ethical sourcing of raw materials from a transparent supply chain.
- Dampens the metal price volatility (by improving the demand—supply balance, and limits speculation, as a broader supply base is less vulnerable to disruptions).
- Creates a significant job potential, among which are a number of "high tech" jobs and infrastructure.

However, metal combinations in products often differ from those in primary deposits, which results in new technological challenges for their efficient recovery. In products such as electronics or catalysts, the precious metals (Au, Pt, Pd, . . .) have become the economic drivers for recycling ("paying metals"), while many special metals (Se, Te, In, . . .) can be recovered as by-products when state-of-the art treatment and refining operations are used. A very low concentration of technology metals in certain products or dissipation during product use sets economic and technical limits in many cases, and technical challenges exist especially for complex products like vehicles, computers, etc. (Reuter et al. 2005; Van Schaik and Reuter 2010; Hagelüken 2012b). Due to these technical challenges and severe deficits in collection and in-praxis treatment of end-of-life products, today the effective recycling rates for many technology metals are very low, as has been documented in a report of the International Resource Panel (UNEP 2011). A new report now analyses in depth the technical opportunities and challenges to improve recycling (UNEP 2013).

Effective recycling requires a well-tuned recycling chain, consisting of different specialized stakeholders: Starting with collection of old products, followed by

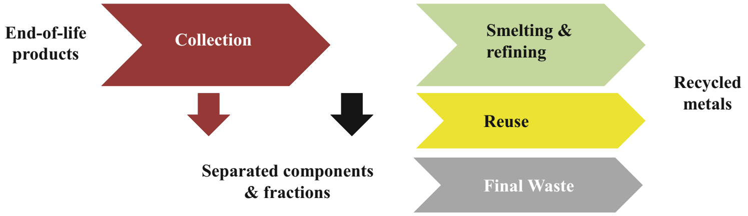

Fig. 8.7 Main steps in a recycling chain for consumer products (published with kind permission of © Hagelüken)

sorting/dismantling and preprocessing of relevant fractions, and finally recovery of technology metals (Fig. 8.7). The latter requires sophisticated, large scale metallurgical operations like the Umicore integrated smelter-refinery in Antwerp, Belgium where currently seven precious metals (Ag, Au, Pt, Pd, Rh, Ru, Ir), as well as ten base and special metals (Cu, Pb, Ni, Sn, Bi, As, Sb, Se, Te, In) are recovered in a versatile process sequence and supplied back to the market. Additional dedicated processes are installed at this location to recover cobalt, nickel and copper as well as a rare earth concentrate from rechargeable batteries, or indium, selenium, copper and gallium from high grade PV manufacturing residues (Meskers et al. 2010). Most of these metals are recovered with high yields; in the case of the precious metals yields close to 100 % of what was contained in the feed material to the plant are achieved. The plant input of approximately 1,000 metric tons per day comprises over 200 different categories, the majority of which consists of recyclables (car catalysts, various process catalysts, cell phones, circuit boards, photographic residues, fuel cells, batteries, etc.) and smelter by-products (slags, flue dust, anode slimes, effluent treatment sludges, etc.) (Meskers et al. 2009).

Recycling technology has made significant progress and further improvements extending the range and yield of metals are underway. When required, recycling technologies are adapted to new products, as has been successfully the case e.g. for certain petrochemical process catalysts, fuel cells, diesel particulate filters, batteries, or high grade residues from thin film solar cell manufacturing. Design for sustainability based on a close dialogue between manufacturers and recyclers can further support effective recycling as it starts already in the design and manufacturing phase and proceeds all along its lifecycle.

However, the biggest challenge to overcome is the insufficient collection of consumer goods, and inefficient handling within the recycling chain. As long as goods are discarded with household waste, stored in basements or ending up in environmentally unsound recycling operations, the total recovery rates will remain disappointingly low, as it is the case today for most consumer goods. Legislation can be supportive but monitoring of the recycling chain, tracing and tracking of material flows, as well as tight enforcement of the regulations are crucial for success. For example, in spite of a comprehensive European legislative framework ("Directive on waste electrical and electronic equipment/WEEE-Directive"; "Directive on end-of-life vehicles/ELV Directive"), a significant share of end-of-life computer, cell phones, cars, etc. are currently not recycled properly. Instead they are discarded or (illegally) exported to Asia or Africa under the pretext of "reuse" to circumvent the Basel Convention regulations on transboundary shipments of waste. The same happens in North America and Japan (Puckett et al. 2005). This leads to a situation where state-of-the-art, high financial investment recycling facilities in industrialized countries are underutilized because 'recycling' and the associated environmental burden of environmentally unsound treatment is 'outsourced' to the developing world. Except some inefficient gold and copper recovery, technology metals are lost in such primitive "backyard recycling processes" (see Rochat et al. 2007), the "urban mine" is wasted irreversibly.

8.6 The Challenge of Open Cycles

A striking example is the automotive catalyst. Due to the high prices of the contained PGMs platinum, palladium and rhodium, its recycling is economically highly attractive (several tens of US-dollars per piece paid to the scrap yard). An autocatalyst is easy to identify and remove from an end-of-life car, a comprehensive collection infrastructure exists, and state-of-the-art metallurgical treatment operations achieve PGM recovery yields of 98 %. Nevertheless, on a global scale only some 50–60 % of the PGMs originally used for automotive catalysts are finally recovered, the rest is lost inevitably (Hagelüken 2012a). The main reasons are global flows of end-of-life cars (e.g. in Germany from a little over 3 million annual car deregistrations only about 0.5 million cars are recycled within Germany, the remainder is exported largely out of Europe) and a high degree of intransparency and "informal" business practices in the early parts of the recycling chain (even in industrialized countries) (Hagelüken 2007). Figure 8.8b shows the typical structure of so called "open cycles" for consumer goods. The insufficient cooperation along the life cycle, combined with insufficient tracking of product and material streams along the entire chain explain why inefficient open cycles continue to exist.

To effectively close the loop for consumer products, new business models need to be introduced that provide strong incentives to hand in products at their end-of-life into professional recycling systems. This can include deposit fees on new products, or product service systems like leasing or other approaches. Especially for emerging technologies setting up "closed loop structures" will be essential and manufacturers who put successful models in place can hereby secure their own supply of technology metals in the future.

Such closed loop structures exist successfully already in most industrial applications of precious metals. For example, PGM-catalysts used in fine chemistry or oil refining are turned around very efficiently at their end-of-life. Usually well over 90 % of the PGMs used in the fresh catalysts are finally recovered, even at long catalyst use times (up to 10 years in some applications), several regeneration cycles, and difficult operating conditions in the chemical reactor or oil refinery. The metallurgical steps to recover the PGMs from the spent catalysts are similar to the ones used for automotive catalysts. The decisive differences lie in the lifecycle

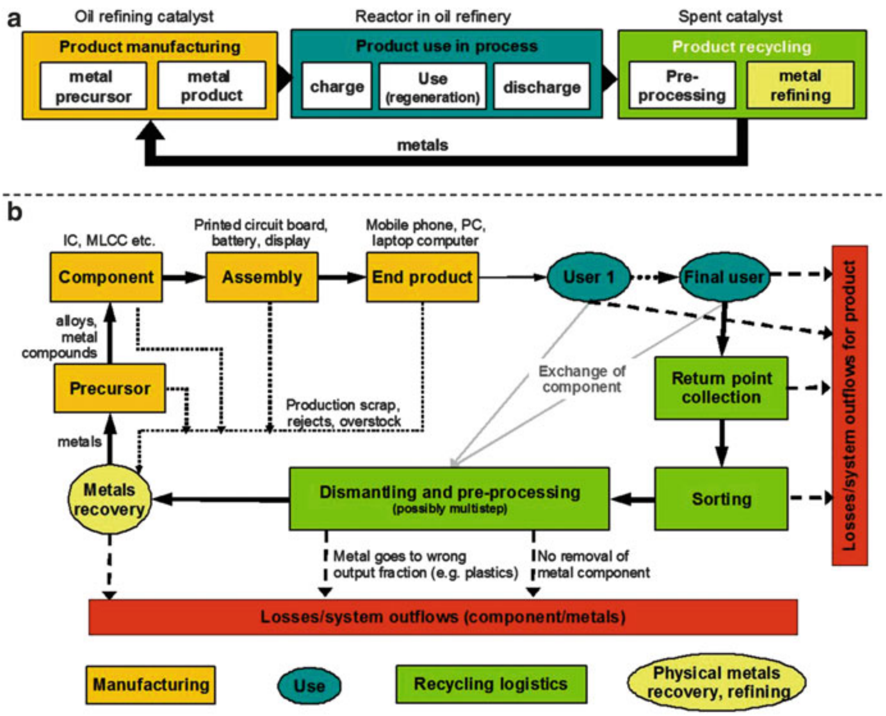

Fig. 8.8 (**a**) Closed loop systems for industrial applications (example process catalyst) versus. (**b**) Open loop systems for consumer goods (example consumer electronics). (originally published in Hagelüken et al. 2005)

structure and the steps prior to metallurgical recovery. Here, for industrial process catalysts the complete lifecycle is handled very transparently in a highly professional way between the industrial actors involved (Fig. 8.8a). Catalyst manufacturers, users, and recyclers work closely together, the location of the catalyst is always well defined, and a profound knowledge exists about the properties and use history of a specific catalyst. Usually catalyst users (e.g. chemical plants) maintain the property of the PGMs throughout the entire lifecycle. Recycling is contracted with a precious metals refinery as a "toll refining operation" with a physical credit of the PGMs back to the user who provides them directly to a catalyst manufacturer for the production of a fresh catalyst. From there, a new lifecycle starts. As a consequence, the net demand for PGMs from the (petro)chemical industry as a whole is low. It is used to cover market growth, new application and the small losses that occurred during the catalyst lifecycle. The gross demand, however, i.e. the annual use of PGMs for process catalyst manufacturing, is as high as for automotive catalysts. A transformation of "open cycles" in consumer applications into "closed cycles" as prevail in many industrial applications would be a big step towards a secured supply of technology metals (Hagelüken et al. 2005).

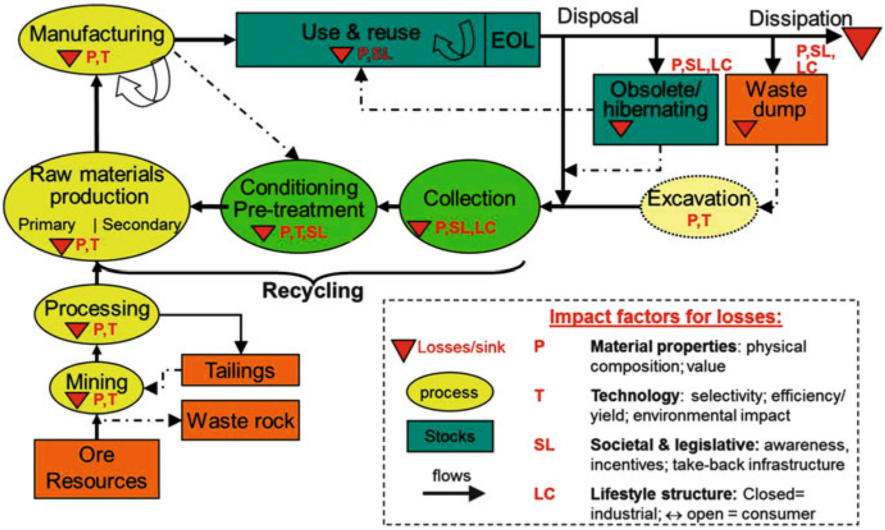

Fig. 8.9 Lifecycles of metals/products and impact factors for losses at various stages (originally published in McLean et al. (2010)

Conclusion

In an ideal system, the sustainable use of metals could indeed be achieved by avoiding spillage during each phase of the product life cycle. As illustrated in Fig. 8.9, such losses occur at various stages and it needs to analyze the specific impact factors to identify the most appropriate measures for each stage. It is important to understand that universal means to improve recycling do not exist. If material properties or technology constraints have the main impact, then completely different measures will be required than if societal or life cycle issues are the main loss driver. Individual measures need to be worked out for the various steps in the lifecycle and in most cases an interdisciplinary holistic system approach is crucial for success.

To summarize, whether a product/material/metal will be recycled efficiently or not depends on a whole chain of conditions on different levels. These comprise in a logical (if . . . then . . .) sequence: (1) technical recyclability (basic requirement); (2) accessibility of the relevant components; (3) economical viability (intrinsically or externally created); (4) necessity to be collected; (5) feed into an appropriate recycling chain and remaining therein up to the final step; (6) optimal technical and organizational set-up of this recycling chain, and finally; (7) availability of sufficient capacities along the entire chain to make a comprehensive recycling happen. This is illustrated hereafter on some simple examples:

(continued)

1. 17 different metals can be recovered from a printed circuit board if the Umicore process is used (but never all substances; e.g. tantalum or rare earth elements are currently not recoverable from this mix due to thermodynamic limits).
2. A PC-motherboard board e.g. is easy accessible for dismantling, a circuit board used in car electronics (e.g. engine management) usually not. I.e., if the latter will not be removed before a car shredder process, the technology metals will get widely lost (although an isolated/dismantled board would be well recyclable).
3. The dismantled PC-motherboard has a positive net value, recycling is viable by itself. In contrast the screen of a LCD monitor has—after dismantling of its circuit board—a remaining negative net value. Even if technical feasible, recovering the indium from it would currently not be economically viable (unless it is externally paid/subsidized).
4. If an old PC or mobile phone is not collected but is stored in households or discarded into the waste bin for land-filling or municipal incineration, conditions 1.–3. will not help and technology metals will get lost.
5. In case the old PC or the mobile phone is collected, but then gets illegally or dubiously exported, ending up in an "African" or "Asian" dump or backyard recycling operation, conditions 1.–4. will not help.
6. In case the PC or mobile phone remains within the European recycling chain, but—maybe mixed with other (electronic)scraps—is channeled into a shredder process without prior removal of the board, the technology metals will get widely lost.
7. In case conditions 1.–6. all are run in an optimal way but recycling capacities would not be sufficient, still a portion of the recycling potential would be lost.

The various end-of-life products and materials will reach various steps in this hierarchy; the higher they get the easier it will be to find appropriate measures to utilize this recycling potential. Usually it is less a certain substance which is recyclable or not but it's about the substance combination, i.e. the product.

To fully utilize the recycling potential in our urban mines it needs a paradigm shift on different approaches:

Attitude needs to change from a waste management to a resource management perspective, reflecting the significance which our scraps have for society. This will foster collection, appropriate treatment and enforcement of legislation. Specifically for critical technology metals measures need to be installed to promote their recycling even in the absence of (current) value, volume and environmental drivers.

(continued)

Targets need to be adapted accordingly. The current focus on mass is insufficient; instead much more emphasis must be placed on quality/efficiency of recycling and the recovery of critical metals. This goes in hand with a certain prioritization, it is indeed reasonable to recover less mass (e.g. of plastics or steel) if this leads to a real improvement in the recovery of technology metals.

Recycling practice needs to reflect the new requirements. Since this industry has a key role for our future needs the traditional structures of a (somehow dirty) scrap business do not fit any more. High tech recycling plays in the same league as clean-tech manufacturing and renewable energy generation. Company structures, appearance and stakeholder cooperation in recycling must fit to this, with more emphasis on transparency and business ethics as it is the case today.

Finally, the *vision* from a manufacturer's perspective needs to change. Until today, producer responsibility and recycling is often more seen as a burden, implied by law. In fact it is an opportunity for manufacturers to sustainably get access to the raw materials needed for their future production. To fulfill this vision creative business models to close the loop are essential.

Mining and recycling need to evolve as a complimentary system, where the primary metals supply is widely used to cover inevitable life cycle losses and market growth, and secondary metals from end-of-life products contribute increasingly to the basic supply. Efficiently recycling our old products today is insurance for the future. Effective recycling systems would thus make a significant contribution to conserve natural resources of scarce metals and secure sufficient supply of technology metals for future generations. It would further mitigate metal price volatility and decrease the climatic impacts of metal production. Finally, a much better closing of the loops for rare or critical metals would significantly reduce the dependence on a few potentially critical mining regions, hence mitigating the risk of political tensions and conflicts about access to mineral resources.

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Chapter 9
Possible Resource Restrictions for the Future Large-Scale Production of Electric Cars

Eckard Helmers

9.1 Introduction

On a worldwide scale about a quarter of primary energy consumption, as well as energy related greenhouse gas emissions, are due to transport activity. Road traffic represents a share of 74 % in the transport sector worldwide (IPCC data from 2007, as summarized in Helmers 2010). In Germany, for example, cars are responsible for 60 % of all traffic related CO_2 emissions (German Federal Environment Ministry data from 2010, summarized in Helmers 2010). In the future, traffic is expected to grow considerably worldwide, particularly in developing Asian countries. The worldwide vehicle stock of 630 million may grow to one billion in 2030 (data from Shell 2007, reviewed by Angerer et al. 2009a). Vehicle production may accordingly grow from 63 to 100 million cars per year until 2030 (Angerer et al. 2009a). In addition to CO_2 emissions, modern ICE (internal combustion engine) cars are still responsible for dangerous toxic emissions like fine dust and nitrogen oxides resulting in high health costs even in industrialized countries (reviewed in Helmers 2009; Cames and Helmers 2013). In view of emission reduction and also strategic implications ("peak oil"), a technology change towards a more sustainable mobility seems to be indispensable.

With electric cars, such more efficient technology is available since California's Zero Emission Mandate has yielded competitive electric cars followed by hybrid cars in the 1990s (reviewed in Helmers 2009). The introduction of electric cars will also in the future be driven by emission regulations. CO_2 emission thresholds of lower than 40 g/km require electric cars to be fueled by electricity at least partially

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from renewable sources. The transition from ICE cars to electric cars has already started, but worldwide mass production will develop much slower than expected in earlier studies. For example, electric hybrid cars make up just about 1 % of global vehicle production, 16 years after they arrived on the market.

The term “electric cars” in this article stands in the narrow sense for “battery electric vehicles” (BEV). In a broader sense, the term “electric cars” also includes hybrid cars with both combustion and electric engines in a variety of technical concepts such as series hybrid cars in which a combustion engine operates as a range extender (electric generator), or mild hybrid cars in which an electric engine is only assisting an ICE. Electricity needed for an electric car may also be provided by a hydrogen fuel cell on board a car (FCEV, fuel cell electric vehicles). However, to date there is no mass production of FCEV, nor is there a sufficient hydrogen filling station infrastructure available in any country, nor FCEV do have a favourable energy efficiency (Helmers and Marx 2012). FCEV are therefore not addressed here.

Two recent German studies on possible resource restrictions pointed out that some details of the materials shift as a result of the transition from ICE to electric cars are highly unknown so far (Angerer et al. 2009a, b). The quantification of possible future material restrictions for electric car production is complicated by several factors:

- the diversification of technical concepts for electric cars (as indicated above);
- the time frame for the transition from ICE to electric cars is highly unknown. It will depend on public incentives by single states, future oil prices, future model politics of the automobile industry, energy density improvements of the batteries and battery prices;
- battery technologies are in a sense variable while Lithium (Li) will be the most important element for them in the foreseeable future (see below);
- raw materials markets have been turbulent in the last few years revealing massive price changes. However, increasing prices for raw materials are generally expected for the future;
- possibly vulnerable metals like Cu (Copper), Li and REE (rare earth elements) are consumed by a variety of technologies and products, besides electric cars (see e.g. EU 2010a)
- the wealth gap between regions producing the raw materials on the one hand and industrialized countries consuming them is believed to generate a factor of insecurity (Angerer et al. 2009b)

Altogether, the quantification of far future demand and supply of raw materials needed to build electric cars is difficult, if not misguiding to date. However, car industry needs to have planning security since massive investments into battery and electric motor production plants have to be undertaken. From the data available so far, nevertheless it seems to be possible to identify metals associated with possible higher risks of resource restrictions and to discuss the level of possible threat.

9.2 Change of Materials Associated with the Shift from ICE to Electric Cars

Electric cars consist of a much lower number (70 % or less) of components compared to ICE cars. However, they are not lighter: The Nissan Leaf, the world's first mass product and non-converted electric car weighs 1,580 kg. In comparison, the current Volkswagen Golf model with comparable dimensions has a curb weight of between 1,140 kg and 1,400 kg. The greater weight of electric cars is due to a battery, which, however, differs remarkably by size. Nissan Leaf is equipped with a high capacity battery (24 kWh) that weighs around 300 kg. Electric cars may be equipped with much smaller batteries. For example, a 14.5 kWh battery mounted in an electrified SMART allows for an electric range of about 100 km, sufficient for local/urban mobility (Helmers and Marx 2012). During an "e-conversion" process (i.e. the conversion of an ICE car into an electric car) the combustion engine and associated components are removed, then an electric motor, a battery (12 kWh capacity or more), a controller, a charger and other smaller parts are installed. The gearbox is usually kept. In summary, compared to an ICE car a European small or mid-size electric car can be heavier by up to 300 kg or 23 %. On the other hand, the capacity of batteries necessary to propel an electric car has been partly overestimated (Helmers and Marx 2012) and thus, the need for possibly vulnerable metals.

Although the range of currently available electric cars is limited to mostly 80–120 km, this would be sufficient to replace a large portion of the current car fleet. In Germany, for example, there are 41.7 million cars on the streets (Federal Motor Transport Authority, Annual Report 2009). Around 22 % of about 40 million German households have more than one car (Federal Statistical Office 2006). Accordingly, there are around 8.8 million "family second cars", constituting a huge electric car market which could already be covered by the existing technology.

During the transition from ICE to electric motor, a car will contain less stainless steel, but more of other, more precious and more expensive metals. However, even stainless steel alloys may be regarded as a possibly restricted material since it contains some metals other than Fe as mainly Nickel (Ni). Ni is among the metals seen as partly critical (Saniere and Vinot 2009). However, Ni is not among the list of 14 materials defined as critical by EU (2010b). And fortunately, Ni mining is well distributed over a number of different regions and countries (Saniere and Vinot 2009).

It should thus be emphasized that even the production of a standard ICE car needs a lot of possibly critical materials, e.g. some 25 kg of Cu per car (Angerer et al. 2009b). Due to the increasing number of electric components in modern cars, automation as well as additional safety devices and the expected increase in worldwide car production there will be future pressure on some metal markets such as Cu and Ni even without electromobility.

The transition from ICE to electric cars is accompanied by a shift of metals used in cars since electric components, including the battery, will consist of higher proportions of metals such as Cu, Al (Aluminum), Li and REE instead of stainless steel. In this context the battery is of special importance.

9.3 Materials Needed for Electric Car Batteries

It is still possible and useful to equip electric vehicles with lead-acid batteries. Cars of the Californian interim electric vehicle boom in the 1990s were partly propelled by huge lead acid batteries (Table 9.1), nevertheless they already offered a driving performance comparable to ICE cars. Today, for example, there are small electric trucks commercially available that are equipped with lead (Pb) acid batteries with a capacity of 13–26 kWh allowing for a maximum range of up to 200 km and a maximum speed of 60 km/h (numbers taken from a prospectus of Alkè company, Italy, 2010). Also, a certain share of electric cars (e.g. from the Indian company REVA) are equipped with Pb batteries. In order to diversify the future battery technology and materials it would be useful to keep Pb traction batteries. Electric cars for smaller ranges and lower speed, e.g. for in-town driving or so called neighborhood electric vehicles (NEV), are much cheaper to operate with lead-acid batteries. Additionally, there are new performance improvements for the lead-acid batteries thanks to gel matrix and gasing charge (Podewils 2010).

Table 9.1 Materials commercially used in traction batteries for electric vehicles

Battery type	Active chemical components	Energy density (Wh/kg)	Costs (Euro/kWh)	Cars (examples)
Lead acid	Pb/PbO_2 H_2SO_4	30–35[b]	up to 100[c] 100–150[b]	GM EV1
Nickel metal hydrides	various alloys as e.g. LaNdNiCoSi[a]	60–70[b] 80[a]	300–350[b]	Toyota RAV4EV-I Toyota Prius
Zebra	NaCl-Ni	150[a]	500[d]	Th!nk City
Lithium-ion	Li-Ni-Co-Al (NCA) Li-Ni-Mn-Co (LNMC) Li-Mn-oxyd (LMO) Li-titanate (LTO) Li-Fe-phosphate (LFP)	120–150[b] around 200	500–750[e] (year 2011) 300[e] (year 2013)	Mitsubishi i-MIEV Nissan Leaf

Data sources

[a] www.chemie.de (2011)

[b] http://nachhaltigkeit.daimler.com/reports/daimler/annual/2010/nb/German/30201060/elektrische-antriebe.html

[c] Podewils (2010)

[d] Gerschler and Sauer (2010)

[e] Own survey, retail cell prices

Nickel-metal hydrides batteries work successfully in hundreds of thousands of Toyota Prius cars (Prius I–III) as well as they already had done in some of the 1990s Californian electric vehicles. However, their energy density is less than half of a Lithium-ion battery, and there are further disadvantages including self-discharge.

The ZEBRA battery (ZEBRA = Zero Emission Battery Research Activity) is cheap, has a high energy density and its materials are reliably available. Unfortunately, the chemistry of this battery type is based on a molten salt at a working temperature of around 300 °C. Therefore, this battery can only be useful under the continuous operation conditions as to be expected for certain companies' car fleets or public busses. Another disadvantage is that only one company in Switzerland produces this type of battery for use in cars to date.

Yoshio et al. (2009) list 12 Lithium-ion battery types with different chemistry, which were first developed between 1978 and 1991. In a recent report by Dinger et al. (2010), five different types of Lithium-ion batteries are identified to be the most promising in the market up to the year 2020 (Table 9.1). In a subcategory of Li batteries, the lithium-salt electrolyte is not contained in an organic solvent but in a solid polymer composite material (Lithium-polymer battery, LiPo).

The Lithium-ion battery is the most powerful, not only with respect to its energy density but also to its high charge/discharge efficiency and cycle strength. However, this technology is still expensive to date, although the price is expected to fall by 60–65 % until 2020 (Dinger et al. 2010). These authors also summarize an actual price of 990–1,220 \$[1]/kWh (2009) for a ready-made battery sold by an original equipment manufacturer (Dinger et al. 2010). Herein, the raw materials (Li and others) sum up to only 12 % of these costs (Dinger et al. 2010). According to Angerer et al. (2009a), a Lithium-ion battery with 20 kWh capacity contains 3 kg of Lithium, respectively 150 g Li/kWh (confirmed by Konietzko/Gernuks 2011).

Based on the data from 2009 (5.5 \$/kg), the necessary 31.5 kg Lithium carbonate to produce a battery of this size sums up to 170 \$, equivalent to only 0.8 % of the complete battery market price. Other raw materials such as Al, Cu, Fe plus further electrochemical components (Table 9.1) are also needed to fabricate the Lithium-ion battery. From this data, it is obvious that raw materials make up only a small part of the battery costs, which is particularly true for Lithium.

Table 9.1 lists electrochemically employed metals besides Li it can be Co, Al, Ni, Mn, Ti, and Fe in various combinations. Why particularly Lithium is publicly discussed as a possibly critical element so far? Li is the most important component of every Li-ion cell. A recent EU-report identified 14 critical raw materials for the EU (2010b). Lithium in this study was assigned a low supply risk (not included in the list of 14 critical raw materials). Graphite is also used as an electrode material in Li batteries, which is—together with Co and REE—well among the 14 materials identified as critical raw materials at EU level (EU 2010b). However, the supply risk for Co and graphite is among the lowest in the group of 14 critical materials (EU 2010b). There have been produced 75,900 t of Cobalt in 2008, as well as 1.6

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[1] All dollar-data in this article are current dollars.

million tons of Ni, and 1.1 million tons of graphite, respectively (EU 2010b). This has to be compared to only 17,700 t of Lithium produced in 2009 (EU 2010b). Interestingly, 72.3 % of the graphite was processed in China in 2008 (EU 2010b). However, there are alternative materials available other than graphite as anodic material in Lithium batteries (Gerschler and Sauer 2010).

The possibly critical supply of Lithium has been intensively discussed in recent years (link to contribution of Schebek et al. in Part IV with case study Lithium). Actually, Lithium seems to be the basics electrochemical material for electric car traction batteries probably for the next 20 years due to the massive investment in its mass production. In a very detailed study, Angerer et al. (2009a) summarize Li availability scenarios published so far and develop optimistic and conservative scenarios for electric/hybrid car penetration into the market. For the conservative scenario the authors conclude that until the year 2050 only 20 % of the today known Lithium reserves will be consumed by all technology sectors needing Lithium (recycling considered). In the optimistic scenario (domination of electric cars, complete worldwide exchange of ICE cars by electric/hybrid cars), up to 49 % of the today known Li will be consumed by 2050, whereas Lithium contained in seawater is not considered (Angerer et al. 2009a). Angerer et al. (2009) deduced from these findings that up to 2050 there is no fundamental supply risk for the Lithium-ion batteries as mobility technology, if additional (already known) Li resources are made available and a recycling system is applied. In the conservative scenario of Angerer et al. (2009a) 25 % of the needed Lithium is covered by secondary (recycled) Li from used batteries. However, almost no Li is being recycled to date (Table 9.2) because of its low price. In a more recent report published by Konietzko and Gernuks (2011), a moderate scenario reveals a worldwide Li production twice as high as the demand until 2050. In an optimistic scenario with electric and hybrid electric cars strongly dominant on the market

Table 9.2 Strategic data for probably critical metals

	Increase of worldwide demand until 2030 (Mc Kinsey 2011); present = 1	Global demand for specific technologies (a–d) in relation to recent total world production (=1) as calculated by Angerer et al. (2009a, b)		Recycling rate (EU 2010a)
		2006	2030	
Al	2	n.a.	n.a.	35–95 %
Cu	13	0.09[a]	0.24[a]	40 %
Nd	120	0.55[b]	3.82[b]	1 % (REE)
Li	200	0.2[c]	n.a.	very low today
Co	n.a.	0.19[d]	0.4[d]	32–68 %

Data sources: McKinsey (2011): Press release, January 5, 2011
Demand calculated for future technologies as: (a) electric motors, RFID; (b) Permanent magnets, laser technology; (c) batteries; (d) Lithium-ion batteries, XtL (gas, coal, biomass to liquid conversion)

until 2050 the Li demand is higher than the production (Konietzko and Gernuks 2011). However, the latter is highly speculative for the reasons explained above, praticularly due to the unknown future price development of electric car components, ICE cars and crude oil. Also, scenarios dominated by electric cars similar to those by Konietzko and Gernuks (2011) lack very much the technology diversification expected in passenger car technology in the future (see e.g. IEA 2010).

The year 2050, moreover, is 37 years from now and it is highly probable that batteries made from alternative electrochemically active materials (such as ZnAir, NaAir, AlAir, MgSn, and many others being possible, see e.g. Gerschler and Sauer 2010) will be available for commercial use within this period. It is to be expected that systematic research on alternative battery materials will be massively funded during the coming decades. For example, carmaker Toyota revealed in February 2011 that it is developing a MgS-battery capable of holding twice the energy of a Lithium-ion battery. If such technological alternative is available for mass production within the next 10 or 15 years, then the current estimations of future Lithium demand may be largely misleading.

Possible critical materials needed for electric car components apart from the battery are discussed in the following.

9.4 The Electric Motor: Rare Earth Elements

Besides the battery, the most important component of an electric car is the electric motor. Modern, highly efficient electric motors are based on permanent magnetic materials; those with the strongest magnetic property are alloys containing the Rare Earth Elements (REE) Neodymium (Nd) and Samarium (Sm). Usual alloys are for example NdFeB- and SmCo-magnets (Angerer et al. 2009b). A typical hybrid car contains up to 12 kg of REE (Angerer et al. 2009b). Another source claims that a Toyota Prius electric motor currently uses 1 kg of neodymium plus dysprosium (www.agmetalminer.com/2011/). According to Angerer et al. (2009b), there are no studies available so far that clearly quantify the consumption of REE by electric/hybrid cars. Nevertheless, recent studies suggest there will be a strong increase in REE demand due to a future electromobility boom (Table 9.2).

Actual concern rises from the fact that China produces 95 % of worldwide REE (number for 2009 by Wäger and Lang 2010). In contrast, China possesses only 38 % of worldwide reserves in REE (Wäger and Lang 2010). It has been reported that China shortened REE exports in 2010 due to strategic reasons and announced further reductions for 2011; this seems to have doubled the prices. In other parts of the world REE mines were closed within the last years due to low REE market prices. That has changed—e.g. the reopening of the Molycorp Inc.-mine in southeast California has been announced which was the world's dominant producer of rare earth elements such as Sm and Nd (www.geology.csupomona.edu/, 22.2.2011) until 1984 (Angerer et al. 2009b). We can conclude that China's dominance in worldwide REE production is a temporary phenomenon. However, strategic studies concluded that most of the present Nd production is consumed by the two future technologies permanent magnets and laser technology (Table 9.2). Up to 2030, the model suggests that the 3.82 fold of the current world production may be needed for these two applications, which could imply a significant shortage (Table 9.2). However, on the commodity markets, the supply follows demand as the example of Copper exhibits (see below). The implementation time for new mining projects (lead time) is 5–10 years (Angerer et al. 2009b).

However, the predicted need of REE for electric motors should be assessed critically. There are several types of electric motors, usually devided into Alternating Current (AC) and Direct Current (DC) types. There are both AC and DC electric engines built with and without permanent magnets (C. Loehr, personal communication 2011), depending on the individual use. The smaller the application or the more specific power (per volume and weight) and the more sophisticated the control response, the more a motor with permanent magnet is needed. Electric drive motors without permanent magnets for automobiles may be of bigger size; however, they are still smaller than combustion engines and therefore fit easily into the regular body of a car. Additionally, according to internet sources, the Japanese industry is developing electric motors without REE based on ferrite; which are reported to be competitive to REE containing motors (www.agmetalminer.com/2011/, 22.2.2011). In electric cars traction motors without magnets are quite usual since they are cheaper (C. Loehr, personal communication 2011). A subcategory of AC motors is induction motors using no REE. The Tesla Roadster is equipped with an induction motor without REE so will be the Tesla Model S and the Toyota RAV4EV (www.hybridcars.com, 22.2.2011). In a more detailed view, it can be stated that there are several electric engines available operating without REE magnets: conventional mechanically commutated DC machines, the asynchronous machines, the load controlled synchronous machines with electrical excitation and the switched reluctance (SR) motors (W. Gerke, personal communication 2011). This gives the motor industry some flexibility.

Moreover, it is quite usual that the industry changes components of high-tech products due to resource shortage. For example, the catalyst industry switched from Platinum to Palladium as catalytically active components of automobile catalysts in the 1990s when Pt prices peaked (Helmers et al. 1998).

9.5 Further Electrical Components: Copper

An electric car comes with further additional electrical components such as a controller, a charger and additional power lines. Similar to several servo motors and the more complex electrical equipment of modern ICE cars, they contain a lot of copper. Angerer et al. (2009b) estimated that the Cu content of an ICE car will double from 20 kg to 40 kg between the years 2006 and 2026. They also expect that in 2026 a hybrid car may contain between 55 kg and 65 kg of Cu. Consequentially, a strong increase in the demand for Cu is expected, but by 2026 it is expected to be still below one quarter of the current total world production (Table 9.2). Since Lithium for batteries may be replaced by Mg or Zn in the long term and REE-free electric motors are already available or will be developed in the next years, Cu may be the only indispensable metal in the construction of (electric) cars.

Mass raw materials like Cu (15.4 million tons were produced worldwide in 2008, according to EU 2010a) are more driven by the world economy (Angerer et al. 2009b) rather than by emerging new technologies. Due to the high reserves, EU assessed the strategic Cu supply risk as very low (EU 2010b). Also, Cu recycling rate is very high and this stabilizes the supply side (Table 9.2).

Conclusion

In conclusion, the supply of critical raw materials is not primarily a problem of future electric car manufacturing, rather a general strategic problem for the (high) technology sector in some industrialized countries, particularly Japan and the European states. The European Commission, therefore, has started an initiative tackling the challenges related to commodity markets and raw materials (EU 2011).

This review has confirmed that a temporary supply bottleneck for raw materials cannot be excluded when the mass production of electric cars starts in the USA, Japan, China, and Europe in the next decade. In the long-term, fundamental supply risks are unlikely:

Lithium: Particularly, the demand for Lithium will distinctly increase since several production sites for Lithium-ion batteries will be opened in the next years. In the medium-term, there is no alternative to Lithium as electrochemically active component in batteries for high performance electric cars; however, there are alternatives in the long-term. Therefore, the demand for Lithium calculated for the future beyond 2030 is highly uncertain. Presently, there are investments into new Lithium production in geopolitically stable countries such as Canada and Chile; this will make supply problems in the near future unlikely. Although, higher prices for Lithium salts are expected, however, raw materials represent only a small share of Lithium-ion battery production costs. The development of a Li recycling is nevertheless useful to ensure Li supply in Europe and Japan. Several studies about future Li supply have been published recently, among them is the work by Angerer et al. (2009a); based on the conservative scenario, they conclude that there is no fundamental supply risk until 2050. However, the size of an average Lithium-ion battery seems to be overestimated (20 kWh) in the work of Angerer et al. (2009a). Also, a minor part of electric vehicles in countries such as India and China may be equipped with lead-acid batteries. Therefore, the demand for Lithium should be lower than predicted by Angerer et al. (2009a).

REE: The current slightly critical supply situation for REE is expected to change in the medium-term since new production sites will be opened and REE-free electric motors are already available or are currently being developed.

(continued)

Climate, nature and health resources: One category of important resources which was not yet addressed is natural resources. New mining activities are probably endangering unique landscapes such as Li-rich Bolivian salt lakes. These costs should be reduced to a minimum or avoided. On the other hand, widespread electromobility in the future can reduce the dependance on fossil fuels and thus, considerably reduce CO_2 emissions of motorized mobility. Electric cars operated with central European grid electricity can already reduce CO_2 emission during operation, while in combination with renewable electricity production the reduction can be dramatic in comparison to ICE cars (Helmers 2010; Helmers and Marx 2012). Electromobility in the long term helps to avoid environmental catastrophes of all scales occuring presently all over the world where crude oil is produced (e.g. the 2010s oil spill in the Gulf of Mexico). Human health may be regarded as another resource, perhaps the most important one. Air pollution causes more than one million premature deaths worldwide per year (www.who.int/mediacentre/factsheets, 26.2.2011), largely due to ICE vehicle exhauts. Electric cars can substantially reduce the exposure to these toxic emissions.

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Part IV
Sustainable Solutions for Resource Consumption

Chapter 10
Technological Innovation and Anthropogenic Material Flows

**Liselotte Schebek, Witold-Roger Poganietz, Silke Feifel,
and Saskia Ziemann**

10.1 Introduction

Throughout its history, humankind has made use of the earth's natural resources. Humans have done this not only in the very basic sense as food for mere survival, but as a means of handicraft, industry, and cultural techniques that have shaped human society. The exploitation and use of resources depend on the available technology and on society's stage of development. Technological progress and societal progress have always been closely interconnected, one enabling the other. Today the standard of living and social welfare in the most developed countries have reached a level that is unique in history although large parts of the world's population still do not participate in the abundance of goods and of welfare.

One consequence of the progress made by technology is the global impact exerted by humankind on material flows. Here are some examples to enumerate this:

– Chemical fertilizers based on ammonia synthesized using the Haber-Bosch process have increased the production of food and ensured the high productivity of agriculture. As a result, during the 1990s the flow of anthropogenic nitrogen surpassed natural nitrogen fixation (Vitousek et al. 1997).
– The chemical and pharmaceutical industry has introduced a multitude of novel synthetic compounds which support medicine, our well-being, and the provision of high-tech products for many applications of everyday life. Today, synthetic

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persistent compounds can be found everywhere in natural cycles and accumulate in faraway locations of the globe and in food chains (UNEP 2007).

– To provide energy for industry, mobility, and housing, large amounts of energy resources are extracted from the lithosphere, where at least in the case of crude oil it is assumed that half of the existing resources have already been consumed (Bardi 2009/www.peakoil.net). At the same time, the flow of carbon from the lithosphere to the atmosphere is the main driver of climate change with its global impact on sea level, agriculture, and weather (IPPC 2007).

Although it is technology that has enabled humankind to affect material flows on a global scale, it is also technology on which hopes lie that it can decouple the increase in social welfare from the impact of mankind on nature. Technological innovations resulting in a more efficient use of resources—materials or energy carriers—are a prominent option in many policies, e.g., for climate mitigation (Dechezleprêtre et al. 2008). However, many experiences in the last decades have helped us to recognize that losses in the process chain, rebound effects, and interferences on the macroeconomic scale from substitution effects may induce countercurrent effects and jeopardize expected savings from the introduction of novel technologies. Consequently, if technology shall be used successfully to mitigate the negative effects on nature, it is indispensable to have a holistic understanding of the complex system of anthropogenic materials flows from nature to the technosphere and within the technosphere. This article undertakes a survey of terms and methods for analyzing the impacts of material flows due to innovations and provides two case studies for assessing material flow systems.

10.2 Technological Innovation and Its Material Basis

The term "innovation" (in particular, technological innovation) is omnipresent today and has even been incorporated as the overarching goal in the EU's long-term policy, the Lisbon Strategy, where "sustainable innovation" stands for the policy of making "*the European Union the world's most competitive and dynamic economy*" (Euractiv 2011).

Looking at the literature on innovation, it is possible to discern diverse kinds of technological innovation. A well-known classification is that into radical and incremental innovation. However, many more typologies are used in the literature, which often lack in consistency (Garcia and Calantone 2002). Notwithstanding the plethora of typologies, Schumpeter's basic definition holds for all kinds of innovation in the sense that innovation is not only invention, i.e., a new idea, but the introduction of the idea into the market (Schumpeter and Dockhorn 1982). Following the general definition of the OECD (1993), technological innovation is the transformation of an idea into a new or improved product introduced into the market, a new or improved operational process used in industry and commerce, or a new approach to a social service. Similar interpretations denote technological innovation as the first commercially successful application of a new technical idea

(Ashford 2001). Innovations may have non-material components. Yet, even an innovation that is "non-material" at first glance, such as related to services or IT-related issues, generally relies on material-bound products, components, or infrastructure. Consequently, even today innovation is associated with increased demand for (novel) products and increased material flows for these products (Grübler 2000).

Materials are generally grouped in four aggregated groups, namely fossil fuels (coal, oil, gas), metals or metal ores, minerals (for construction and industrial purposes), and biomass (agriculture, forestry, and fishery) (EUROSTAT 2001). While previously the global consumption of material, just like the global population, had risen only slightly over many centuries, since the industrial revolution in the mid nineteenth century an exponential growth has been observed for both (Grübler 2000). The rise in material consumption applies for each of the above-mentioned groups, and a clear acceleration of global material consumption flows can be observed in the second half of the twentieth century (Krausmann et al. 2009) (Fig. 10.1).

Looking more closely, the interest on specific materials has changed over time, which is connected closely to different waves of innovation and their related key technologies (see Fig. 10.2).

At the beginning of the industrial revolution, coal and iron was what we might today call strategic materials, being at that time the backbone of key technologies and the energy supply. Later, non-iron metals such as aluminum became more important and both the energy supply as well as the basis of the chemical industry changed from coal to crude oil and gas. In recent decades, our understanding of the

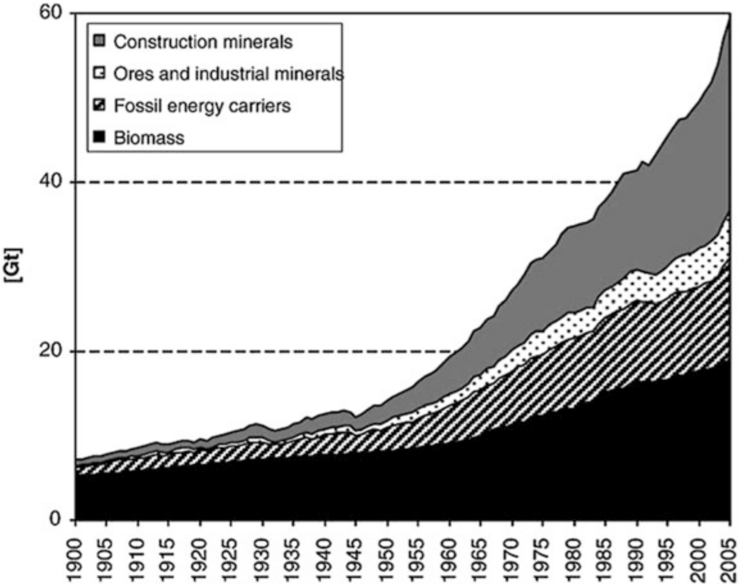

Fig. 10.1 Materials use by material types in the period from 1900 to 2005. Source: Krausmann et al. (2009)

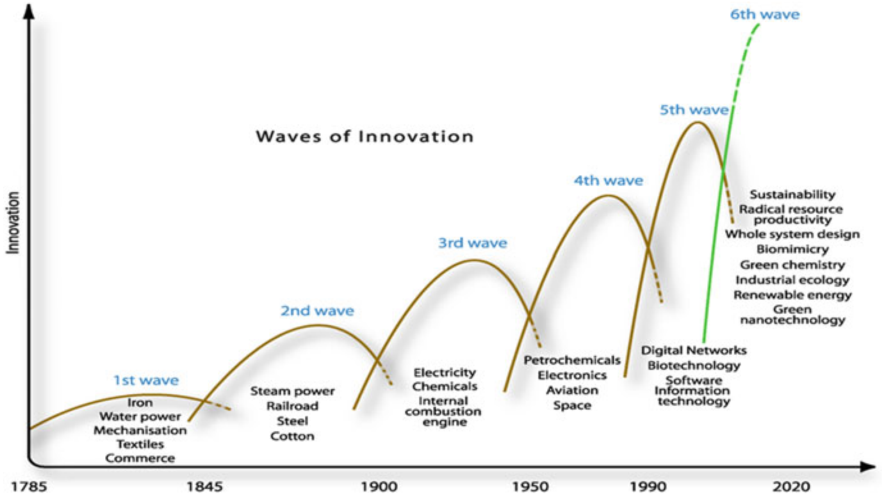

Fig. 10.2 Waves of technology innovation. Source: www.naturaledgeproject.net/Keynote.aspx; Accessed 14.07.2011

term "key technologies" as well as of related materials has shifted to specific elements that had not been noticed much before but that have become indispensable for many novel technologies such as photovoltaic or information technology. The term "strategic metals" today indicates that technological innovation in modern societies relies more and more on specific and scarce metals such as tellurium, gallium, or the rare earths. Although such metals are generally used in low concentrations in products, the demand for them has risen significantly due to mass production and is expected to rise even faster in coming years (Angerer 2010). Concerns are consequently growing that their potentially limited availability may be an important constraint on innovation and economic growth.

To describe the availability of raw materials, the categories of reserves, reserve base, and resources are generally used. These are defined in USGS 2009 as follows:

- A resource is a concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such a form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.
- A reserve base is that part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth.
- Reserves constitute that part of the reserve base that could be economically extracted or produced at the time of determination.

It has often been noted, e.g., by Wellmer and Becker-Platen 2002, that these definitions are not used in a consistent way in literature. This has been illustrated for lithium by Weil et al. 2009.

An important indicator measuring the availability of resources is called the static lifetime. It indicates how long a specific material will be available based on its known reserves and its present annual consumption. For many metals, both bulk and strategic ones, the static lifetime is less than 100 years—a very short period of time, which immediately raises concerns that these resources might be exhausted in the very near future. This concern was first pushed into the public's awareness by the famous study of the Club of Rome "The Limits to Growth" in the 1970s (Meadows et al. 1972). However, these resources are still available today, which shows that the static lifetime is often used in a misleading way: due to the fact that new resources are detected and that resources may shift to reserves as technology improves, the figures for the static lifetime have remained the same for most important metals over the last 30 years (Grübler 2000). Instead of ultimate exhaustion, however, other issues may become a concern. From an economic point of view, availability means that a material is provided on the market in a sufficient amount at an economically feasible price and exactly at the time when it is needed for production. These requirements may be jeopardized by several developments. For many economically important resources, reserves and production capacities are concentrated at just a few places on earth (Berendt et al. 2007; Dorr and Paty 2002), some of which are in politically unstable regions. This may become critical specifically in the situation where the growth in application and market demand due to technological innovation outpaces the increase of supply (Dorr and Paty 2002). The term "relative scarcity" has been defined for this case (Frondel et al. 2007).

From the point of view of the environment, the demand for materials has to be fulfilled in a way which is compatible with the carrying capacity of nature. The provision of a resource is often connected with a high consumption of energy and the related impact on the climate. The exploitation of resources may furthermore contribute to the severe local impact on the environment, specifically if deposits lie in an ecologically fragile environment, which for example is reported to be the case for lithium (Emke 2010).

In summary, there are economic and environmental reasons supporting the necessity for a sustainable management of resources even if absolute scarcity is not the case. Deeper insight into material cycles and their interconnection with technology is necessary to clarify this.

10.3 Systems Analytical Approaches for the Assessment of Material Cycles

10.3.1 Systems of Material Flows

In any systems analytical approach, the definition of the system is the first and most basic step of a study. Systems boundaries may be specified using any of several characteristics, namely geographical, political, economic, temporal, organizational, or institutional ones. In any case, the definition of a system cuts one piece out of the real world and focuses on this piece while neglecting the rest. The choice of the system consequently must directly reflect the research interest or the goal of the systems analytical investigation.

Two major approaches for analyzing material flows have evolved. Material Flow Analysis (MFA) is a method based on the understanding of mass balances of the natural sciences. It is applicable to a large variety of systems, and its aim is to provide a comprehensive assessment of the flows of one material within a chosen system and between the system and its environment. The second major approach has evolved from a specific perception of the system to be investigated. The method of Life Cycle Assessment (LCA) focuses on one product or service and on its product system, which comprises all the relevant processes of the life cycle of that product or service. Life cycle here denotes the physical life cycle from resource extraction, along the value chain of production, during use, until the end-of-life phase and disposal, i.e., where materials are transferred back into the natural environment. LCA assesses material flows within the product system and between product system and the environment. In contrast to MFA, only material flows induced by the product or service are studied. This makes it easy to compare alternative products or services with the same application. On the other hand, however, restricting the investigation to a product system means that the effects of different opportunities for using a material will not be included. For this reason, MFA and LCA may well be seen as complementary instruments of research.

10.3.2 Material Flow Analysis

MFA has evolved from the use of material balances in areas of application as diverse as engineering science and economics (Baccini and Bader 1996). It is essentially based on the law of the conservation of matter. Each process within a system is assessed by a mass balance, comparing all inputs and outputs for a specified period of balances. This also makes it possible to detect the emergence of stockpiles. Balancing inputs and outputs for all a systems' processes permits the flows of the chosen material through the economy and environment to be visualized.

Baccini and Bader 1996 as well as Brunner and Rechberger 2004 have published descriptions of MFA. The conceptual steps of a MFA consist of systems definition, analysis of processes, schematic modeling, and interpretation of results (Brunner and Rechberger 2004). The first step includes the systems boundaries and the interior structure of the system, i.e., identifying processes and their interconnections by means of the relevant flows. The system needs a spatial boundary, typically set by the geographical area of the processes, and a temporal boundary, which is the time span for systems investigation and balancing and which is determined by the type of the system being studied and by the given problem (Brunner and

Rechberger 2004). The second step (the analysis of processes) is devoted to gathering data about the system. In most cases, MFA uses existing information from the literature as well as statistics on inputs and outputs and on processes and material flows (Baccini and Brunner 1991). Therefore, data quality evaluation and error calculation are indispensable parts of the assessment. Schematic modeling encompasses both, that is the balancing of inputs and outputs of all the processes and the graphic representation of the whole system. As a last step, interpreting the results consists in explaining the model and deducing the consolidated findings for the chosen material flow and the factors influencing them.

10.3.3 Life Cycle Assessment

The LCA method is based on the modeling of process chains along the chain of adding value to a product or service. As a result, the input and output material flows are summed up, which is referred to as the functional unit, which expresses the benefit of the product or service (Bauer and Poganietz 2007). In addition, the aim of LCA is also to assess the environmental impact of material flows induced by the respective product or service, determined on the basis of several modeling approaches developed in environmental science.

The way to perform an LCA has been documented in two international standards, ISO 14040 and ISO 14044 (ISO 2006a; ISO 2006b). It comprises four steps or phases of analysis: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation.

The initial phase of defining the goal and scope specifies the research question and the audience of the study, identifies the systems boundary, and defines the functional unit. The latter "*defines the quantification of the identified functions* (*performance characteristics*) *of the product*" (ISO 2006a). It is used as a reference to which all the assessment results are related. If the function is transportation, for example, the results will be specified per weight of the good transported for a certain distance, e.g., one ton of a product transported for 1 km.

During the next phase, the Life Cycle Inventory (LCI), all the flows of materials and energy into and out of the system and within the system are compiled. An essential component of this work is the construction of a flow model, whose purpose is to capture the (flow) relations between the processes of the system, collect data, and calculate the results. Accounting is descriptive, that is flows are compiled for each process input and output from diverse sources of data or information but are not necessarily connected by a mass balance. This approach even makes it possible to model non-material inputs and outputs such as radiation energy or area as a flow. Due to the multitude of flows which may be encountered in a complex product system, data availability and the restriction of work capacity may it make necessary to restrict the study to the relevant flows. According to the ISO standard, *relevant* flows may be identified by using "cut-off-criteria" such as weight, energy, and environmental significance. Material flows—inputs and outputs of the system—are included in the assessment if their cumulative contribution is more than a defined percentage of the overall input or output or the environmental impact, respectively, of the system. The results of the Life Cycle Inventory will be specified as the amount per functional unit, e.g., the amount of carbon dioxide (CO_2) resulting from transporting 1 t of a product for 1 km.

The third phase, Life Cycle Impact Assessment (LCIA), is devoted to the overall goal of LCA not only to account for material flows but also to assess their environmental relevance. This requires an understanding of complex cause-effect chains, starting for example from the emissions of a certain substance into the environment and ending with possible damage to humankind or the environment, such as to an ecosystem. Each flow resulting from LCI is assigned to the corresponding impact category ("classification") and multiplied by a so-called characterization factor ("characterization"). For example, CO_2 and methane (CH_4) both contribute to the impact category "Global Warming". Their characterization factors are 1 and 25, respectively, which means that CO_2 is the reference substance and CH_4 can be compared to it for a certain characteristic, such as the absorption of infrared radiation. CH_4 absorbs 25 times the amount of this radiation. After multiplying, both can be expressed in the same unit of CO_2 equivalents and can be summed up.

The interpretation phase transfers the detailed and often complex results from Life Cycle Inventory and Life Cycle Impact Assessment to a clearly comprehensible message for the audience of an LCA study. Overall, the interpretation should investigate the robustness of the results and provide "*a readily understandable, complete and consistent presentation of the results of an LCA*" (ISO 2006a).

10.4 Innovation and Material Flows: Case Studies

10.4.1 Material Flow Analyses of Strategic Metals: Global Lithium Flows

10.4.1.1 Motivation

The chemical element lithium is a silvery-white light metal whose density is about half that of water and which has the most negative redox potential of all the elements (Kunasz 2006). Despite this unique combination of physical and chemical characteristics, its application in chemical and pharmaceutical products and in glass, ceramics, aluminum, or lubricant production processes used to be very limited. In recent years, however, the demand for lithium has risen considerably due to the growing market for lithium-based rechargeable batteries in mobile information and communications technologies (contribution of Helmers on Lithium in Part III). Today, as an additional area of application, rechargeable batteries are being developed for electromobility: The issue of lithium resources has consequently moved to the focus of public interest, initiating controversial discussions on the element's future availability (Tahil 2007). A first MFA has been conducted in order to support the investigation of global lithium flows, particularly their interdependencies and the relevant factors exerting influence on them (Ziemann et al. 2012a).

10.4.1.2 Systems Definition and Analysis of Processes

Following the general methodological approach, as a first step the systems boundary is defined as the global lithium flows for one year. Due to the availability of data, 2007 is chosen as the most recent reference year. The second step is the analysis of processes. Here, the well-known distinction between production, manufacture, use, and end of life as often applied for analyzing metal cycles is employed (Harper et al. 2006).

Production

Today the main source of lithium is subsurface brines. Natural lithium-containing brines are pumped from deep wells into a series of solar evaporation ponds, where the concentration is increased and the composition altered for further processing in factories. After impurities have been removed, the brine is reacted with a soda ash solution to precipitate lithium carbonate (Seidel et al. 2005). Further processes for lithium recovery from pegmatite ore containing the lithium minerals spodumene, lepidolite, and petalite involve concentration by froth flotation, hydrometallurgical extraction, and, finally, precipitation with soda from aqueous solution (Averill and Olson 1978).

Both types of production processes yield predominantly lithium carbonate and mineral concentrates, which can be further processed to lithium hydroxide, butyl lithium, lithium metal, lithium chloride, and other lithium derivatives (Yaksic 2010).

Manufacture

Lithium compounds are required for the manufacture of various lithium products. Lithium carbonate is mainly used for ceramics glazing, polymer fabrication, and battery and aluminum production. Lithium mineral concentrates are the major source for reducing the melting point in the glass industry. Butyllithium is required for the fabrication of synthetic rubber. In addition, butyllithium together with lithium metal is used in pharmaceuticals. Lithium metal is also used in making organic chemicals, batteries, alloys, and other products. The dehumidification processes in air conditioning devices need lithium bromide and lithium chloride. Considerable quantities of lithium hydroxide are used in making lubricants (Ebensperger et al. 2005; Garret 2004).

Use

Dissipative applications and recyclable applications can be distinguished in the use phase, irrespective of whether recycling is economically feasible or not. In the case of dissipative applications such as pharmaceutical products and lubricants, pool chemicals, sanitation, and dyestuffs, the lithium is released into the environment during the use phase. In contrast, non-dissipative applications such as primary and secondary lithium batteries, glass and ceramics, air conditioning, aluminum production, chemicals, and alloys are transferred to the recycling and waste management process.

According to Miller (2008), about two third of all applications are in glass and ceramics, batteries, and in alloys and other industries.

Recycling and Waste Management

It is necessary to distinguish between two groups of lithium uses with differing recycling abilities:

1. Applications where lithium recovery is practicable
2. Applications where only the recycling of lithium-containing products without any lithium recovery seems possible (Ziemann et al. 2012b).

The first group is represented by primary and secondary lithium-based batteries since the existing recycling processes may make recovery of lithium possible (Xu 2008; Kinsbursky 2008; Tytgat et al. 2008). The secondary lithium could then be used in production (USGS 2009), but data about the amount of lithium recovered is relatively sparse.

Since the existing recycling processes for spent batteries from consumer products such as the Val’Eas recycling solution (Tytgat et al. 2008) are currently concentrated on the cathode materials cobalt and nickel, they typically do not enable lithium recovery. Instead, slags are formed which might be used in the concrete industry (Dewulf et al. 2010) or be returned to the environment. Judging from these facts, lithium recovery is not efficient at present due to the low lithium content in batteries (approximately 5–7% in lithium-ion secondary batteries) and to the low price of lithium as a raw material. The lithium flow from recycling back to production can hence only be thought of as being insubstantial.

The second group consists of the sectors glass and ceramics, chemicals, aluminum production, air conditioning, alloys, and other uses. Within these sectors, recycling of the lithium products should be possible (e.g., for air conditioning) or is to some extent already being carried out (e.g., for glass and alloys). These processes may result in products containing recycled lithium being used in manufacturing and, thus, may reduce the amount of primary lithium required for these applications. Otherwise, recycling in these sectors will possibly generate lithium-containing secondary products suited for other uses. Since the processes for lithium waste management remain unclear, no data can be given on the amount of either lithium-containing recycled and secondary products or even waste.

10.4.1.3 Schematic Modeling and Interpretation of Results

The static material flow model of lithium (Fig. 10.3) is designed to show the flow of lithium throughout the entire process chain (Ziemann et al. 2012a). The data for lithium flows have been compiled on the basis of the available literature and statistical data. Comparing inputs and outputs of the individual processes, it was necessary to amend existing data on the basis of mass balances. With regard to the manufacturing process, the material flow model revealed a disparity between lithium production of 25,750 t/a and consumption of 21,620 t/a (Miller 2008). The sector entitled “Unknown” was thus inserted for the remaining 4,130 t/a lithium (Fig. 10.2). This discrepancy could either indicate that certain sectors have not been considered or that stocks of lithium are growing (as in strategic stockpiling) (Roskill 2006; USGS 2008).

The model makes it possible to differentiate between lithium applications that are pre-dominantly dissipative and those that could in principle be recycled. The lithium content of products that are dissipated during their use reaches about 3,892 t/a. The mass flow of recyclable products from the sectors of batteries, glass and ceramics, chemicals, aluminum production, air conditioning, alloys, and other uses adds up to 21,859 t/a. Yet not all recyclable and sold products will be collected—a good example being cell phones—and, furthermore, there might be losses during the use phase. The total amount of actual recycled lithium will therefore be below the above-mentioned figure. The problem remains to find a variety of lithium products in sectors such as glass and ceramics or chemicals, where it may be difficult to obtain high-quality recycled products instead of merely

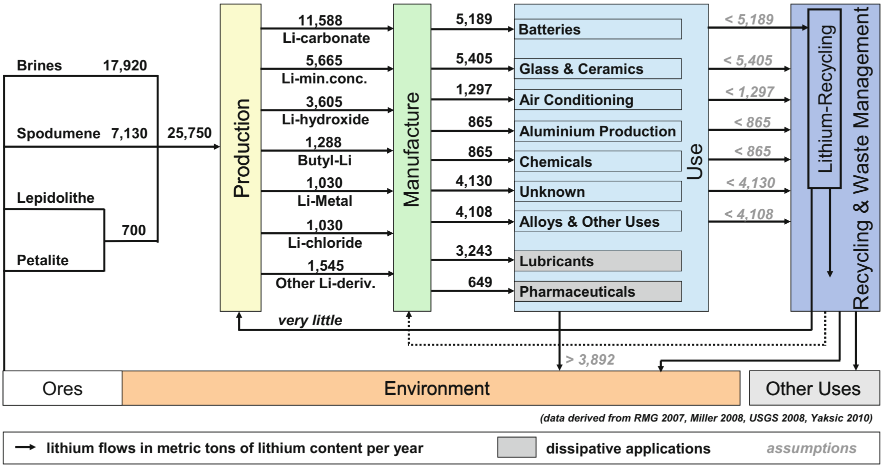

Fig. 10.3 Material flow model of lithium for the year 2007

low-quality ones. Since the recycling industry does not provide detailed data, it is only possible to ascertain such lithium flows qualitatively.

The difference between dissipative applications and non- or slightly dissipative ones gives a good picture of the recycling potential of lithium waste management. In fact, battery recycling is the only means by which primary lithium can be replaced on a large scale in the future, whereas the potential contribution of recycled lithium-containing products to saving primary-metal consumption is unclear. Since different uses of lithium exhibit different levels of dissipation, it is possible to identify sectors where recycling activities should be enhanced.

Lithium-containing products such as rechargeable batteries, glass, and ceramics can be considered durable goods with a lifetime of more than 10 years. These manufactured goods can therefore presumably reach recycling and waste management after a certain time lag. Thus, regarding the lithium material flow model for the time span of one year, the amount of purchased products will be greater than the amount of end-of-life products transferred to recycling and waste management. Consequently, stocks may increase within the respective sectors.

10.4.2 Life Cycle Assessment of Innovative Products: The Case of Lightweight Boards

10.4.2.1 Motivation

The forest-based sector comprises the forest and wood industries. Although the generation of value by this sector is based on the renewable resource of wood, the minimization of resource consumption is also a crucial issue for this industry. The demand for wood has increased substantially during the last few years due to the efforts to replace fossil resources as energy carriers and mineral resources for material uses. It was to be expected that this increased demand would lead to increased competition in usage and to price increases. A non-sustainable use of forests may be expected, and the more efficient use of wood is an important goal of product innovation.

One recent innovation in the forest-based industries is the so-called lightweight board for use in the furniture industry. Lightweight boards are defined by their density. Generally the density of lightweight boards is less than 600 kg/m^3, compared to more than 600 kg/m^3 for conventional boards. Using density as a criterion allows for very different designs:

- Sandwich constructions (Fig. 10.4). Cover layers are made of wood-based panel, e.g., chipboard, and a core layer of paper, synthetics, or other renewable resources like corn.
- Homogenous panels made of wood or wood-based composites, e.g., in combination with polystyrene.

Since designs vary, production processes also differ. Although the use of wood is reduced in all variants of the new type of board, the question is whether overall

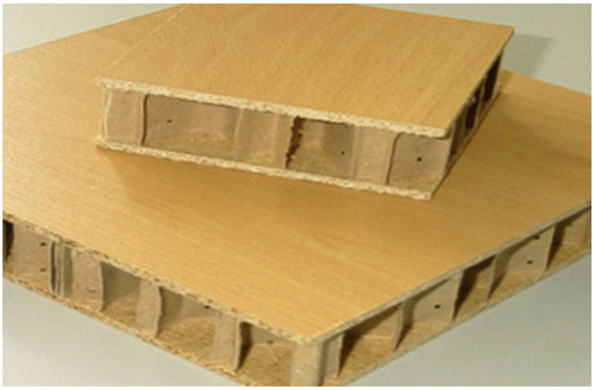

Fig. 10.4 Lightweight boards in sandwich construction

resource consumption and the environmental impact are reduced compared to conventional boards.

10.4.2.2 Goal and Scope

The scope of the study is to identify environmentally friendly designs of lightweight boards. The method used is LCA. This generally makes it possible to single out those product components and production processes with a high potential for lowering the environmental burden as promising points of research and development in companies (Feifel et al. 2011).

The different types of lightweight boards to be compared are presented in Table 10.1 (types A to F). They are complemented by well-established chipboard (type G) and fiberboard (type H). The functional unit is defined as 1 m^2 board provided at the producer's gate. The thickness of the board being studied is 19 mm.

10.4.2.3 Inventory Analysis

Life Cycle Inventory is based on companies' information and complemented by the literature (Poppensieker and Thömen 2005), all referring to the territory of Germany. Resource use of wood and other resources are taken into account as well as machine technology and energy consumption (Fig. 10.5). In addition to the products themselves, the gaseous, liquid, and solid emissions are calculated and assessed. The calculation was carried out in umberto® using the ecoinvent 2.0 database (Frischknecht and Jungbluth 2007) for generic data such as for adhesives and binders.

To ensure the correctness of the ranking, the material flows going out of the system were additionally assessed using two different LCIA methods, namely Impact2002+ (Jolliet et al. 2003) and Eco-Indicator 99 (Goodkoep and Spriensma 2001; Hischier and Weidema 2009).

Table 10.1 Types of lightweight boards

Type	Cover layer	Core layer: structure and material	Gluing cover with core layer
A	Solid wood	Corrugated paper recycled paper fibers	PVAC
B	Particle board	Honeycomb structure recycled paper fibers	PU
C	High density fiberboard	Corrugated paper recycled paper fibers	PVAC
D	High-pressure laminate	Honeycomb structure Polypropylene	PU
E	Plywood	Solid wood light wood	PVAC
F	High-pressure laminate	Hard foam Polyurethane	PU
G	Chipboard		
H	Fiberboard		

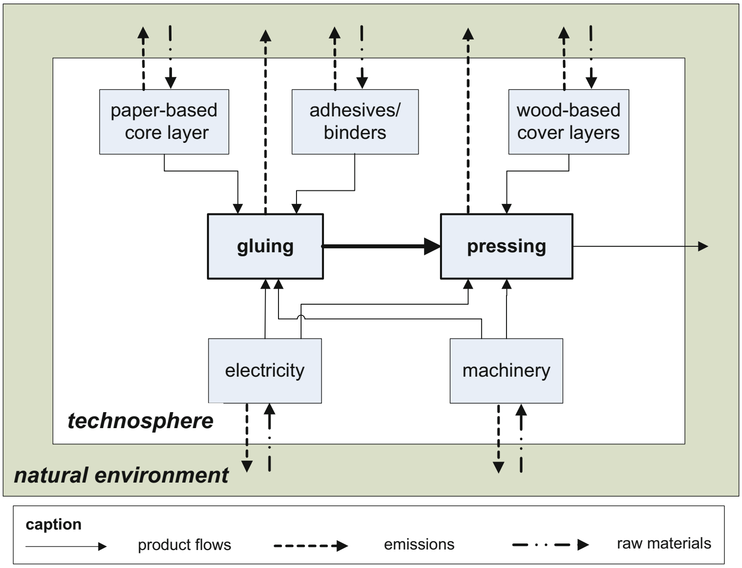

Fig. 10.5 Modelled process "sandwich construction with paper-based core layer"

10.4.2.4 Impact Assessment

Figure 10.6 shows the results of the LCIA according to Impact2002+ for the impact categories human health, resources, ecosystem quality, and global warming potential.

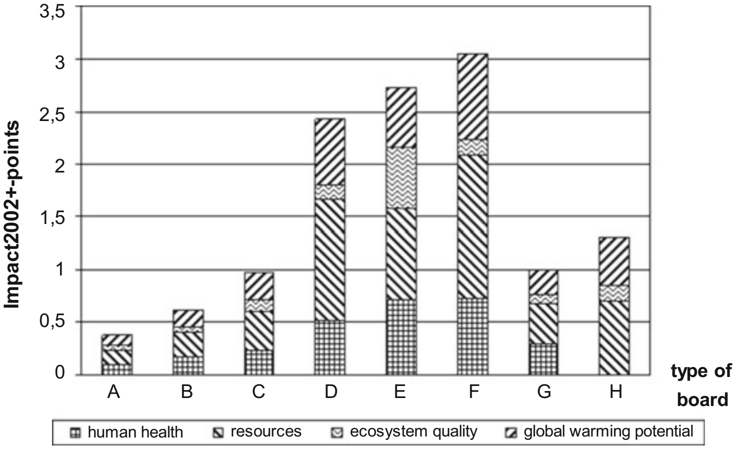

Fig. 10.6 Normalized results for different board types according to the impact assessment method Impact 2002+

Clear differences between the several types of lightweight boards can be observed. Both LCIA methods classify the boards into one of two groups with respect to their environmental impact: sandwich boards with paper-based core layers on the one side and boards with core layers made of synthetics or of solid wood on the other side. The latter shows significantly higher environmental burdens than the former and conventional boards. The reason is the chosen core layer, either PUR, PP or—unexpectedly—light wood. Conventional boards, i.e., chipboard (G) and fiberboard (H), are ranked between the two groups of lightweight boards.

Figure 10.7 shows the results of the LCIA according to the Eco-Indicator 99 for the impact categories human health, resource use, and ecosystem quality.

10.4.2.5 Interpretation

With regard to resource efficiency, this analysis shows that boards with paper-based core layers offer a promising perspective to the forest-based industries, in particular for the furniture industry. These boards all have lower environmental burdens than the well-established board types. These findings are independent of the chosen LCIA method.

The chosen systems boundary does not include the downstream processes, e.g., processing of the boards in the furniture industry, with their environmental impact, which could influence the overall assessment in a noteworthy manner.

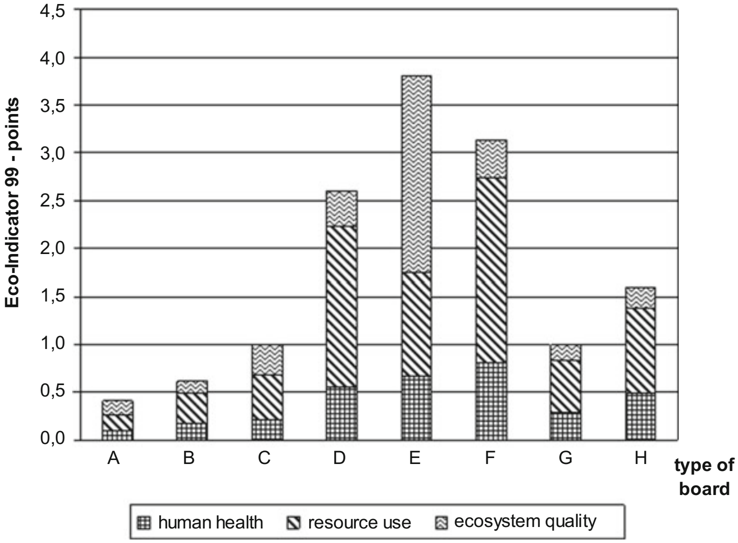

Fig. 10.7 Normalized results for different board types according to the impact assessment method Eco-Indicator 99

Conclusion

In conclusion, two methods were presented for identifying material flows with their respective interdependencies and impact on the environment. The methods, however, analyze material flows from different perspectives, fulfilling different analytical goals.

Material Flow Analysis is material flow oriented. The focus of MFA is thus to identify all the processes (including extraction and disposal) of a chosen material and the interrelationship between the processes and between the system and the environment. Its perspective is more global or with regard to the entire economy.

Life Cycle Assessment is product related. This means that the main goal is to identify all the material flows associated with one product or service and their impact on the environment. The perspective of LCA is more enterprise related.

Because of their diverging perspectives, both approaches can be seen as complementary.

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Chapter 11
Illicit trade with Coltan and Implications for Certification

Raimund Bleischwitz, Monika Dittrich, and Chiara Pierdicca

11.1 Introduction

Coltan mining in Central Africa and especially in the Eastern Kivu region of the Democratic Republic of Congo (DRC) has often been viewed as a case for a conflict over the control of raw materials in a failing state (contribution of Müller, Croll in Part I). Rebel groups and others are fighting over access to minerals and profit from illicit trade, and the state fails to provide social order resulting in unchecked criminal activities. The easy access to coltan and other minerals, combined with weak property rights in a country with weak basic institutions and a long history of civil war, and a high demand on world markets can be assumed as main determinants of insecurity and conflicts.

There is a clear pledge for international action from various sides. The United Nations have established evidence and given recommendations by means of several Expert reports. A recent one (S/2010/596) and the ensuing UN Security Council resolution (S/RES/1952) of late 2010 call on governments, markets and companies to establish sound systems of supply chain management as well as to impose asset freezes and travel bans for groups and individuals involved in the conflict. In a similar spirit, the G8 resolution of Heiligendamm has started a process to establish certified trading chains in minerals production (CTC); a first activity has been the development of a new geochemical method called "Analytical Fingerprinting" (AFP) since 2006 that will allow exact pinpointing of the extraction source of a mineral used in products. Initiatives have also been taken by the private sector (ITRI, EICC and GeSI) aiming at improving the traceability along their supply

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chains. The annex of this article contains a number of such initiatives. Needless to say, however, all these initiatives are voluntary, pledges and the few commitments are not yet implemented and the willingness to take serious action seems low compared with the pressing situation.

It is the intention in this contribution to analyse the international trade dimension of this conflict. The authors acknowledge the work that has been done to analyse the regional conflict and to provide evidence for an involvement of different actors. Doing new analysis on the Kivu region however is beyond the scope. Bearing on latest findings and focussing on the international trade dimension, this scientific work raises the thesis that any certification scheme is faced with a number of challenges. In doing so the following issues are addressed: What is the dimension of illicit trade? What actors are involved in the international supply chain? What can be concluded for certification and any international governance?

These questions will be addressed in the following manner: the next two sections will give brief and up-to-date overviews about coltan markets and the mining situation in the DRC. A subsequent section will deal more extensively with international trade of coltan. It addresses mechanisms, actors and measurement issues. The last part will draw lessons for certification and conflict analysis and offers some guidance for future research.

Going beyond coltan, a study by the World Economic Forum (2011: 23) refers to illicit trade of minerals in general as a major geopolitical risk with a market size of some 20,000 million US $ annually. Thus we believe that such research is of relevance for international research too.

11.2 Profiling Coltan

Coltan is the nickname of a mineral extracted in Central Africa and belongs to a group that is internationally known as tantalum.[1] This element of the 5th group of the 6th period of the chemical periodical system occurs in the Earth crust with a share of roughly 2 ppm (parts per million), i.e. three times more often than silver. It has a strong geochemical coherence with niobium. The United States Geological Survey (USGS 2011), Roskill (2009) as well as the Tantalum-Niobium International Study Center (TIC) locate large reserves in Australia and Brazil, where new discoveries have been made in recent years. The global reserves were estimated to have been in the order of 110,000 t of contained tantalum in 2011 and considered adequate to meet projected needs. Worth noting: DRC, Rwanda and Ethiopia have not been included in the calculation due to lack of reliable data.

The tantalum industry, traditionally shrouded in secrecy, is comprised of (in order of material flow) a mining component that typically extracts ore and produces a

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[1] Tantalum minerals comprise e.g. tapiolite, wodginite, ixiolite, bismutotantalite, fermsite, stibiotantalite, simpsonite, microlite and minerals of the complex fergusonite, aeschynite and euxenite mineral groups.

concentrate, a processing segment that converts concentrate into an oxide or metal, a parts manufacturing segment that uses the oxide or metal material to produce such components as capacitors or superalloys, and an end-product manufacturing sector that uses the parts, such as capacitors, in electronic devices, such as cellular telephones (USGS 2011: 2). Product range features tantalum oxide, powder, and Tantalum Carbide (TaC). Tantalum is also produced as a byproduct during tin smelting. Research must use all data with caution since they may capture different forms of tantalum.

For quite a long time, Australia had dominated the world market with shares being in the order of 60 % or even above. The production situation has changed significantly over the recent years. The largest producer, Australian-based Talison (formerly Sons of Gwalia) has suspended its production in late 2008 due to difficulties of financing necessary investments and market uncertainties during the financial crisis. USGS (2011) estimates the production amounts for 2009 as follows: Brazil (180 t), Mozambique (110 t), Rwanda (100 t) Australia (80 t), Canada (25 t), other countries (170 t, including Burundi, DRC (Kinshasa), Ethiopia, Somalia, Uganda, and Zimbabwe). Further supply may have been provided by others.[2] It is evident that in 2009 the region in central Africa (including Mozambique) has been a major, if not the largest supplier of tantalum on the world market! This situation is very likely to continue in 2010–2011 (Fig. 11.1).

Some supply is also provided by synthetic concentrates produced from tin slag (7 % in 2008, Roskill 2009: 12). Secondary production and recycling do not play a major role yet. Within industry, 20–25 % of annual production inputs result from recycling activities done along production routes in attempts to reduce losses and minimize waste. Any approach to closing international material loops and to recycle tantalum from electronic goods and other products however barely exists. Reasons are related to

- Technology issues—the shares within products are tiny, challenges of pulverization during dismantling processes are huge, hence a need to develop new recycling technologies has been expressed;[3]
- Economic issues—establishing collection and dismantling systems requires an international approach implying high upfront transaction and investment costs while no regulation exists;

Thus, material leakage and dissipative losses are quite high.

Market demand for tantalum has been increasing over the last 10–15 years. Some 60 % of tantalum is being used for capacitors in electronic goods and devices such as mobile phones, pagers, PCs etc (Roskill (2009: 110ff). In addition, tantalum carbide is used for high-tech cutters, in air and space technology, and for turbines.

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[2] Further estimations cover China (112 t), Russia (35 t), other Asian countries (57 t) as well as supply provided via tin slag (145 t) without changing the statement; we owe this information to Philip Schütte. See also Roskill (2009).

[3] Eurometaux's proposals for the EU's Raw Materials Initiative as of 11th June 2010, pp. 49–50 (written with Institute for Applied Ecology).

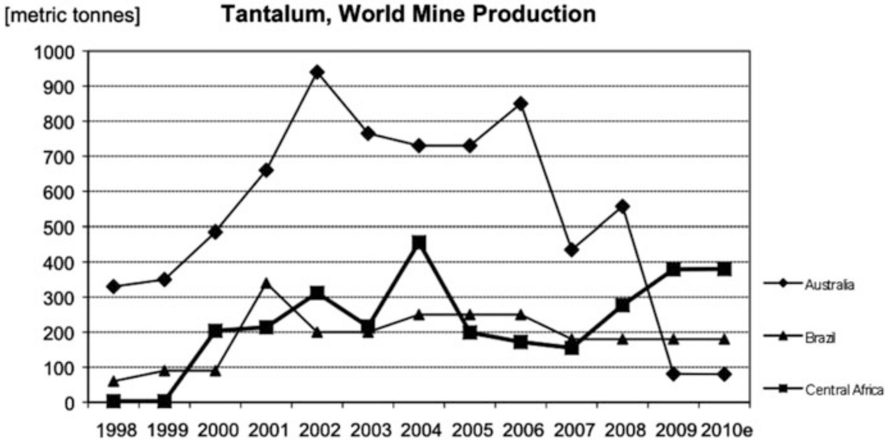

Fig. 11.1 Tantalum, world mine production (unit: tantalum content, Ta_2O_5). Sources: USGS (2011) and various other years of its tantalum report; data for 2010 preliminary

Future demand is expected to grow, with new applications in ICT, machinery, energy production turbines, energy storage, aircrafts and optical industry. Possible substitutes in those areas exist, such as niobium in carbides or rare earth elements for high temperature applications. But none of these possible substitutes performs as effectively as tantalum so far, they may pose other challenges, and rare earth elements are regarded as critical metals too. For these reasons, tantalum ranks in the upper right quadrant of the EU's Raw Material Initiative[4] where the most critical minerals are listed; its economic importance is very high, the supply risk must be taken serious, and the environmental dimension should not be overlooked.

Thus, coltan mining in the DRC cannot be isolated from international markets and can hardly be focused on one application only (e.g. mobile phones). Since it is not an end-product in itself and the production chain is complex, research can hardly transfer lessons from a conflict mineral such as diamonds.

11.3 Coltan Mining in the DRC

Due to specific geological conditions—deposits are too small to be amenable to large-scale industrial mining—, Coltan mining in eastern DRC is mainly done as artisanal and small-scale mining (ASM). ASM differs considerably by mineral and province in terms of how the sector is governed, how the economy and society are structured, and the form of the mining groups. The sector is dynamic in its

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[4] European Commission (2010): Critical raw materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials. See also: Annex V to the Report, pp. 188 ff. Accessible at: http://ec.europa.eu/enterprise/policies/raw-materials/documents/index_en.htm.

proliferation, with new ASM sites springing up regularly, frequent power shifts and mineral-specific reconfigurations of actors and local informal governance regimes.

Employment is mainly for low-skilled local people. Estimations vary on the number of artisanal miners between 500,000 and 2 million in DRC. With an average of four to five dependents for each digger, the total number of persons whose livelihood depends on this activity could be as high as 8–10 million or up to 16 % of the total population of DRC (World Bank 2008). The majority of miners subsists on US$ 1–5 per day, and is often locked in debt to local traders and strongmen. Children are often employed too. Some mines operate on a barter economy, which makes it risky or impossible for miners to save and invest. Nevertheless, in many parts of the DRC, ASM remains the sole income opportunity. Garett and Lintzer (2010: 401) characterize ASM as the "safety net to support people and economies even under adverse circumstances".

Mining activity in DRC normally doesn't follow environmental protection measures; it also takes place for example in Kahuzi Biéga National Park, one of the last resorts of mountain gorillas worldwide. As indicated by a study on the mining sector in DRC (World Bank 2008), the polluting effects of this artisanal activity include possible decadence of unsafe mine tailings and waste dumps, water pollution caused by acid mine drainage, improper closure of pits and mines, dumping of toxic effluent into the water, mining waste, etc. Landscape alterations are often irreversible, with secondary effects on local agriculture that is devastating if peasants hire themselves out as diggers.

In addition to the environmental consequences directly caused by mining, the presence of armed groups and their control over several areas can aggravate the destruction of natural habitats. In fact, the armed groups don't limit themselves to profit from the extraction of minerals, but they finance themselves through the illegal exploitation of other natural resources too (minerals such as gold, cassiterite, tungsten and other natural resources such as timber trade, meat, illegal fishing and poaching, UN 2010). Focusing regulation on one issue thus gives incentives to shifting illegitimate activities rather than abandoning them.

There is robust evidence on how rebel groups are profiting from the minerals extraction and trade. Of the 13 major mines, 12 are said to be controlled by armed groups (Nathan and Sarkar 2010: 22). The weakness of DRC's institutions and the lack of an effective and paid national army, are responsible for the proliferation of military groups, which replace this vacuum with alternative forms of governance. ASM is often controlled by small, locally-based armed groups or militias, collectively called the *mai mai*. The larger armed units and the mai mai both "tax" the mines directly and indirectly extort money or minerals at the check-points they control. Especially two groups, the *Congrès National pour la Défense du Peuple* (*CNDP*), a political movement with a military wing called the Congolese National Army (CNA), and the *Forces Démocratiques de Libération du Rwanda* (*FDLR*) have been investigated by UN Expert Panels. CNDP presence is limited to few coltan mines. The Bibatama Coltan mine e.g. is owned by a national senator who seems to accept the presence of the CNDP and pays a price of $0.20/kg[5] exported at checkpoints. FDLR, on the contrary, has been present in the two Kivus for at least 14 years. The group can count on a strong business network that enables the militia to receive the supplies needed, including weapons. The UN panel estimates that FDLR is reaping profits worth millions of dollars a year from trade of minerals in eastern DRC. For these relations they are described as "*les grands commerçants*" and they often involve Congolese civilians that are forced to act or trade on their behalf. More in general, the typologies of involvement of these armed groups in the mineral trade can vary, including taxation, payment of protection fees, commercial involvement in the mining activity and pillage.[6] Worth noting that these groups also profit from other minerals such as gold and cassiterite.

The recent UN report (S/2010/596) establishes evidence on the involvement of the Congolese national army. Congolese army units are competing among themselves for control over mineral-rich areas; they collude with armed groups in order to attack rival commanders, and they have gained control over large areas rich in natural resources in North and South Kivu provinces. In Walikale territory, the part of North Kivu richest in cassiterite (tin ore), control of the minerals trade was "awarded" to the CNDP to encourage it to integrate into the Congolese army, as agreed in an early-2009 peace deal.

This situation of increasing involvement of armed groups in mineral trade and the difficulty of getting rid of it has been used as official justification by the Government of DRC for its temporary freeze in the mining activities of the provinces of South and North Kivu and Maniema on 11 September 2010 (UN 2010). The consequences of this action on production are still unknown. The UN claims that mining activity is still ongoing at night. It is sure that those who will be mostly affected are the people who depend on this activity for their living. Main actors in coltan mining in the DRC are as follows (Fig. 11.2).

It is thus not just a conflict over mining activities. Resource rents can be accrued throughout a number of subsequent transportation stages and intermediaries at local markets within the region. The number of actors involved (see graph) and the fact that official representatives and armed groups often cooperate make up for an intransparent situation. Even like-minded actors have difficulties to get evidence on whether any permission or certificate is legally correct and complies with basic laws. As a result, many actors benefit from the current situation, and there is hardly an incentive to change this from within: a self-perpetuating lock-in situation within a failing state (Fig. 11.2).

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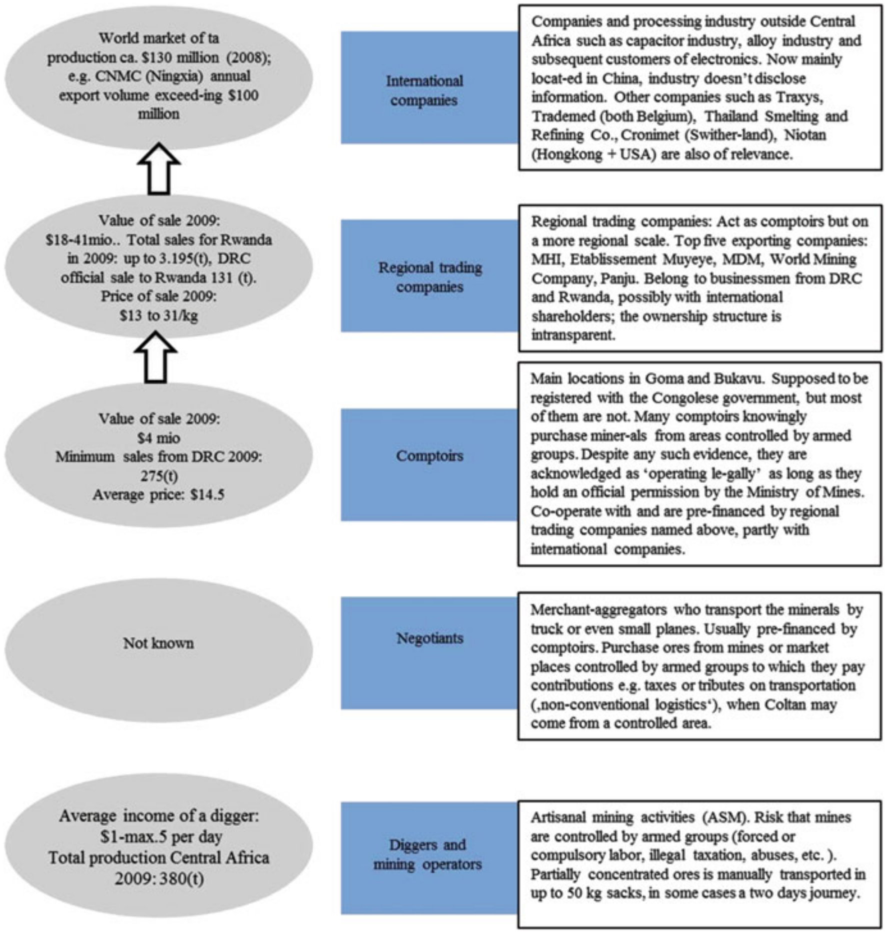
[5] All dollar-data in this article are current dollars.

[6] See OECD (2010: 20f), UN report 2010 S/2010/596, pp.48–49 and UN S/2008/773, paras 73 and 779 for a more detailed description.



Companies and processing industry outside Central Africa such as capacitor industry, alloy industry and subsequent customers of electronics. Now mainly locat-ed in China, industry doesn't disclose information. Other companies such as Traxys, Trademed (both Belgium), Thailand Smelting and Refining Co., Cronimet (Swither-land), Niotan (Hongkong + USA) are also of relevance.

Regional trading companies: Act as comptoirs but on a more regional scale. Top five exporting companies: MHI, Etablissement Muyeye, MDM, World Mining Company, Panju. Belong to businessmen from DRC and Rwanda, possibly with international shareholders; the ownership structure is intransparent.

Main locations in Goma and Bukavu. Supposed to be registered with the Congolese government, but most of them are not. Many comptoirs knowingly purchase miner-als from areas controlled by armed groups. Despite any such evidence, they are acknowledged as 'operating le-gally' as long as they hold an official permission by the Ministry of Mines. Co-operate with and are pre-financed by regional trading companies named above, partly with international companies.

Merchant-aggregators who transport the minerals by truck or even small planes. Usually pre-financed by comptoirs. Purchase ores from mines or market places controlled by armed groups to which they pay contributions e.g. taxes or tributes on transportation (‚non-conventional logistics'), when Coltan may come from a controlled area.

Artisanal mining activities (ASM). Risk that mines are controlled by armed groups (forced or compulsory labor, illegal taxation, abuses, etc.). Partially concentrated ores is manually transported in up to 50 kg sacks, in some cases a two days journey.

Fig. 11.2 Actors involved in coltan mining in DRC. Source: Own compilation, Garrett and Mitchell 2009; Global Witness 2009; Nathan and Sarkar 2010; TIC 2010; UN reports 2008, 2010. Data refer to tantalum content, Ta_2O_5

11.4 Coltan and International Trade: Dimension and Actors

Tantalum materials are not openly traded. Purchase contracts are confidential between buyer and seller. Current data evidence reveals that the region of DRC and its neighbors Africa has become the major supplier for coltan/tantalum on world markets in 2009/2010—and possibly even earlier. However any estimation of the total amount of coltan produced in the DRC and traded internationally is limited by data availability, comparability and reliability as well as by difficulties of tracing illegal trade in Eastern Congo. Thus, tracing any illicit trade and estimating the real amount of coltan produced in and exported by DRC remains a central challenge.

The following part starts from the assumption that any illicit trade with coltan sooner or later enters the markets and is hence reflected in statistics downstream. Going beyond inconsistencies of DRC data, three possible gateways for such laundry mechanisms will be investigated:

1. Neighbouring countries: they may declare exports that are not entirely covered by adding up domestic production and imports (and possible stockpiles).
2. Importing countries: especially huge economies may declare imports that are not equal to exports of that respective country.[7]
3. Business reports: since coltan /tanatalum is input to specialized capacitor production with few producers worldwide it might be possible to get evidence for inconsistencies.

This contribution calculates coltan exports of DRC based on the information of those trading partners who reported to UN Comtrade;[8] this is compared with other available estimations (Roskill 2009; USGS 2011; UN Expert Report 2008; Global Witness 2009; Garrett and Mitchell 2009). Mass units are used because they are not biased by monetary valuation and price volatilities.[9] Due to the fact that not all countries report their trade, bilateral trade results have to be considered as minimum exports from DRC.

In addition, trade of coltan from DRC is estimated by analysing the trade flows of the neighbouring countries in the African Great Lake region, especially Rwanda, which have been mentioned as preferred trade routes of illicit trade with coltan and other minerals (e.g. Garrett and Johnson 2008; Garrett and Mitchell 2009; Global Witness 2009, 2010; UN Expert Panel 2008).

Available data give apparent evidence that DRC has been increasingly producing and exporting coltan especially since 2006 (see Fig. 11.3). Trade data doesn't specify content and concentration of the ores and concentrates; but the results are in line with other studies referring to gross mass of tantalum / niobium production. USGS (2011: 52, 13) shows an increasing production from 52 t (2006) up to 267 t (2007), 380 t (2008) and 330 t (2009, gross mass). While Roskill (2009) does not quantify tantalum production of DRC separately, Global Witness (2009) quoting official government statistics from North and South Kivu reveals that 428.4 t of coltan (gross mass) were exported in 2007 and at least 270.79 t in the first half of 2008. The UN Expert Report 2008 estimates that DRC produced and exported at least 393 t in 2007 and 300 t between January and July 2008. Finally, a study by Garrett and Mitchell (2009) sums up the official figures[10] from North and South

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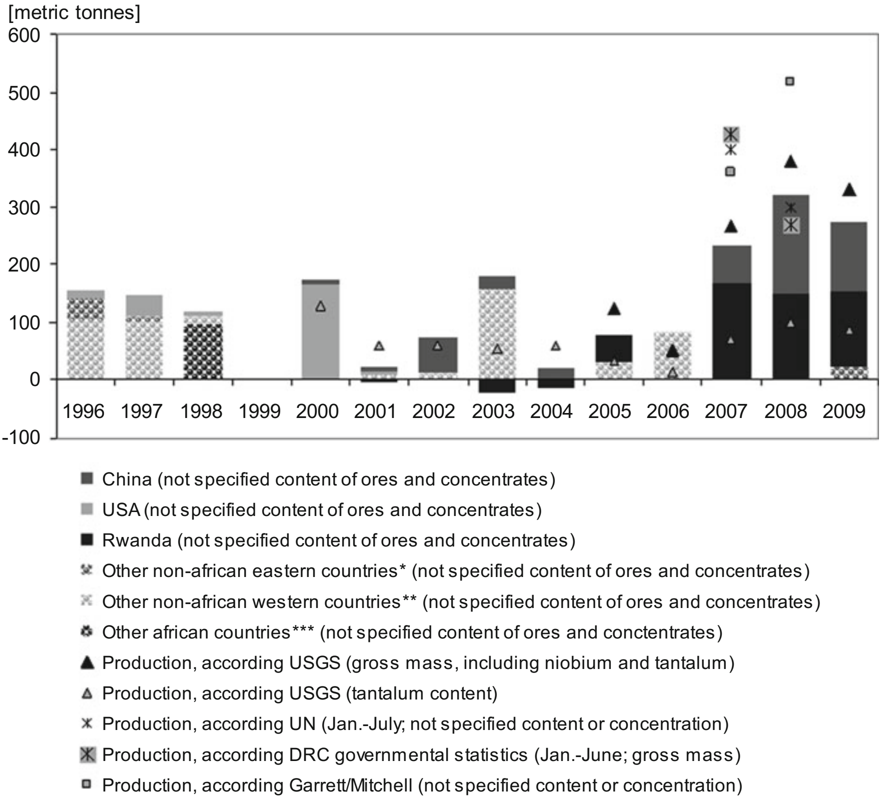
[7] It is refered, for example, to the comparison between exports figures from DRC and import figures from China.

[8] The DRC hasn't been reporting trade figures to international organisations since 1987.

[9] See e.g. Dittrich (2009) on the physical dimension of international trade.

[10] The sources of data are Division des Mines of North Kivu and the private sector federation of Bukavu.



*Please note: the classification includes tantalum, niobium and vanadium; numbers don't specify content and concentration of ores and concentrates. In line with other sources we assume that DRC does not export vanadium ores and the share of niobium and tantalum is around 50:50); *Singapore, Hong Kong, Japan, Rep. of Korea; **Brazil, Germany, Estonia, Belgium; ***South Africa, Uganda (each in order of relevance). USGS (2011) and various years; gross mass is mass of concentrate before metal is extracted; UN Expert Report 2008 (2008 only Jan-July); Global Witness 2009 (2008 only first half); Garrett/Mitchell 2009.*

Fig. 11.3 Estimated production and trade of coltan ores of DR Congo. Sources: UNComtrade (here and in the following: SITC-3-28785

Kivu for 2007 and 2008 (total + Dec est.) and adds to these data a 35 % estimation based on calculations on transport volumes. The values obtained are 360 t for 2007 and 517 t for 2008. These data differ by some 47 % (USGS vs. UN Expert Panel in 2007) and 36 % (USGS vs. Garret and Mitchell in 2008), and show clearly an upward production trend.

In 2009, bilateral trade data (see footnote 3) indicates that DRC exports mount up to a minimum of 275 t with a value of around 4 million US$ – comparable to the combined production of Brazil and Australia in that year.

As mentioned above, Rwanda is deemed to be the preferred trade route for illegally traded minerals financing the conflict parties for several reasons. Besides geographical reasons, exports of tantalum concentrates aren't taxed in Rwanda while DRC has been taxing official mineral exports. Thus, trade via Rwanda is more profitable than legal exports via Kinshasa (Garrett and Johnson 2008). According to Rwandan law, imported minerals could be declared as minerals produced in Rwanda if they are further processed in Rwanda and enhanced in value of about 30 %. Thus, coltan imported from DRC to Rwanda could be legally exported as coltan from Rwanda without separating whether it was imported legally or illegally. Global Witness (2010: 13) even goes as far as to name Rwanda a laundering centre in international trade.

Though Mozambique is according to USGS (2011) the most important producer of tantalum ores in Central Africa,[11] Rwanda is the most important exporter of tantalum and niobium in Central Africa[12] supplying around 75 % of all exported ores and concentrates of these metals in 2009 according to trade statistics. A comparison of trade and production information for Rwanda shows remarkable incoherencies[13] (see Fig. 11.4). Obvious are high net-exports compared to very moderate production figures. However because of different definitions of tantalum ores and concentrates in UN Comtrade and USGS statistics the mathematical difference should be interpreted with caution. Eye-catching is the rising gap between Rwanda's information on exports and the information given by the trading partners since 2006. According to Rwanda's sources, it imports 131 t of tantalum and niobium ores from DRC in 2009 with a value of around $ 1.1 million, and exports around 949 t of tantalum with a value of around $ 18 million. According to its trade partners, however, Rwanda's net-exports of these ores and concentrates mount up to 3.195 t with a value of $ 41 million in 2009. The difference of a factor 3.3 in production and 2.3 in value is striking but the interpretation is not unambiguous. The data seems to indicate an increasing illicit trade since 2005 from Rwanda for an amount that could hardly be quantified exactly.[14] However the differences

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[11] TIC (2010) refers to misreporting of production figures in Mozambique. Comparing Mozambique's trade data, our analysis is that relevant difference occurs in trade with USA; USA imports around 50–80 t more according to its own trade data than according to Mozambique's trade informations in 2007–2009.

[12] Burundi, Central African Republic, DR Congo, Ethiopia, Kenya, Mozambique, Rwanda, Tanzania, Uganda Zambia, Zimbabwe. Note: none of these countries are mentioned in USGS as important producer of vanadium; therefore it can be assumed that data quantify tantalum and niobium ores and concentrates. Wolrdwide, Brazil is main supplyer for niobium (≈95 % of the world market).

[13] Analyzing production and trade data of Mozambique, Kenya and Uganda also brings to light incoherencies which could be indicating (partly or fully) illicit trade from DRC but they are minor compared to Rwandan statistics.

[14] See also Global Witness (2010: 13) on Rwanda and cassiterite from DRC.

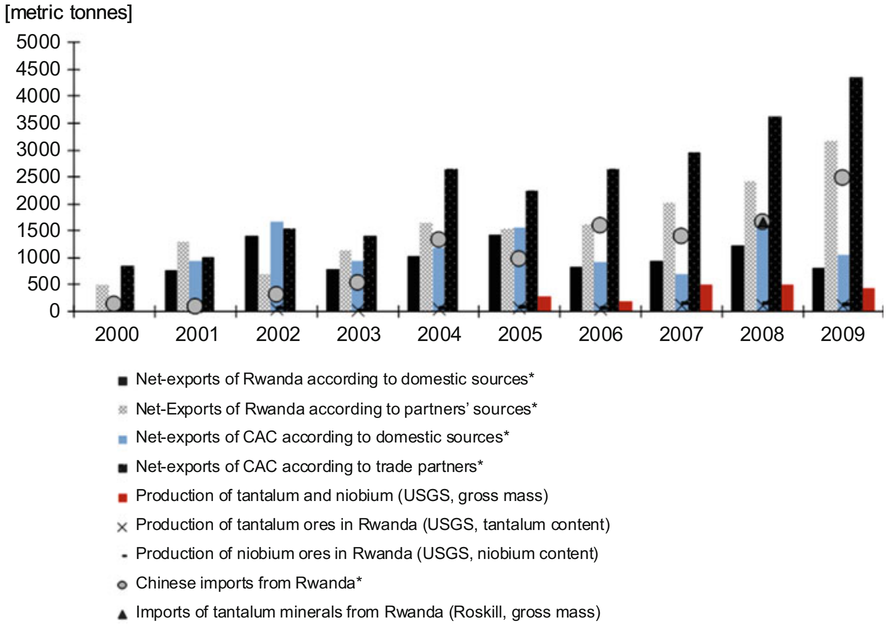

Fig. 11.4 Estimated coltan production and trade of Rwanda and Central African Countries. Sources: UNComtrade, USGS; *asterisk,* Unspecified contents of tantalum, niobium and vanadium ores and concentrates

could also be caused (partly) by double-counting and implausible data reported by importing countries,[15] most importantly Chinese imports that dominate the figure.

There is no doubt that a regional shift of trade pattern can be observed: during the nineties, western countries had been the dominant importers of coltan from DRC. Since 2000, Asian countries, most dominantly China, increasingly import coltan directly from DRC. According to data from the Congolese Ministry of mines collected by the NGO Global Witness (2010), the coltan imported by China constitutes 60 % of the North and South Kivu's production. In 2009, China has purchased 121 t of coltan (most probably: gross mass) with a value of around 2.6 million US$ directly from DRC.

China is also by far the most important importer of tantalum produced in the Central African region. Since 2000, China's imports of tantalum and niobium ores from this region rose from 435 t or 11.3 million US$ to 3.154 t with a value of 36.3 million US$ in 2009. Direct imports from DRC are minor compared to other suppliers, among which the most relevant is Rwanda (see Fig. 11.5). In physical terms, China imported around 73 % of all exported tantalum and niobium ores of the region (assuming that vanadium is rather negligible).

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[15] Differences in monetary values may also (partly) be caused by different use of INCOTERMS: cif (=cost, Insurance freight) values are often used for imports, fob (free on board) values are often used for exports. However in our view this cannot capture such differences.

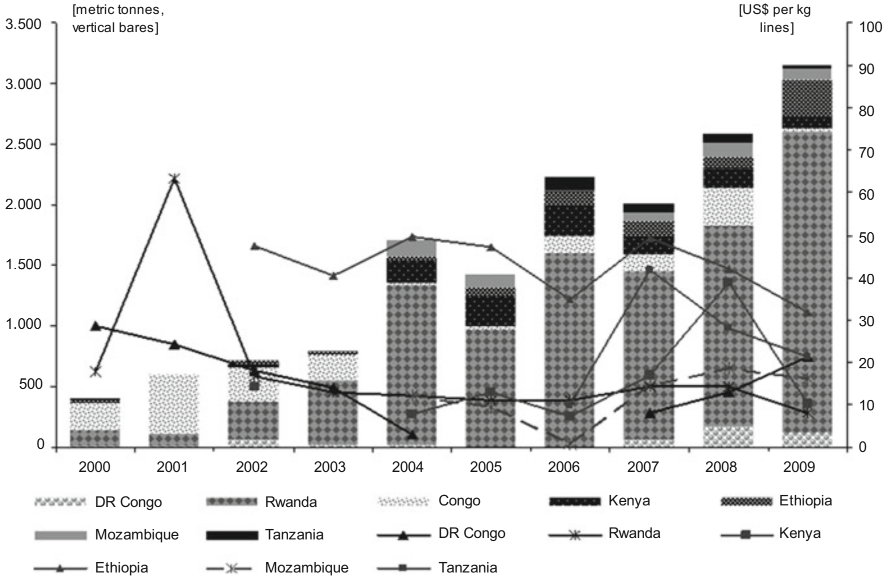

Fig. 11.5 China's imports of tantalum and niobium from selected African countries. Source: UN Comtrade (SITC-3-28785)

Roskill (2009: 105) reports 1,656 t of imported tantalum minerals from Rwanda in 2008—roughly 4,6 times the amount of Rwanda's production according to USGS (2011: 52.13, 120 t ta content ≈ 490 t gross mass). Roskill's numbers, based on private sector information, lies between Rwanda's information of its net-exports of ores and concentrates of tantalum as well as niobium and information of trading partners about its net-imports of these ores and concentrates from Rwanda. If one assumes an import from DRC in the order of 131 t (data for 2008, including ca. 50 % niobium ores ≈ 262 t gross mass), the difference is significant. Their report also estimates main smuggling activities via Rwanda. With all uncertainties involved, one may thus estimate that 914 t of these minerals might stem from illicit trade—a share of some 55 %.

Compared to other importers like Hong Kong or Singapore, China's imports have a significantly lower price ($ 11.33 per kilogram tantalum and niobium ore versus $ 24.26 paid by other Asian importers). In this context, it is also interesting to note that prices for coltan from DRC have been increasing since 2007 while prices have been rather decreasing for exports from the other countries in this region. Prices for coltan imported from Rwanda had been constantly low. In 2009 China purchased coltan for even less than $ 8 per kilogram according to its trade report while coltan exports from Rwanda costs between $ 13 and 31 per kilogram on a monthly average, depending on tantalum grades.[16] Roskill (2009: 148) reports that

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[16] Personal information Philip Schütte, BGR.

the average price of China's imports from Rwanda has been 2–2.7 times lower than the import price of Australian tantalite. In the first half of 2009 it was 3.7 times lower. That enormous difference is a key reason for the strong position of Rwanda, the shifting of capacitor manufacturing to China, and the currently miserable situation of the conventional supply chain of tantalum. And, indeed, it fuels alegal and criminal activities of all kinds.

The typical supply chain of coltan produced in DRC and sold by illegitimate means thus looks as follows: it is exported via Rwanda or other Central African Countries, and is bought by Chinese processors. These processors are often smaller companies who do not have pressure to disclose information or to report. They, in turn, produce and export downstream products such as K-salt used to make capacitor-grade powder. Those products do enter the global market while their origins are obscured.

According to the official statistics reported by Global Witness (2010), three Chinese companies figure among the main importers of coltan from the Kivus in 2009: Fogng Jiata Metals, Star 2000 Services and Unilink Trading Hong Kong. The UN report (2010) doesn't consider these companies as involved in the minerals trade from areas controlled by armed groups, but it is unclear how the Chinese government intends to meet any responsibilities in such trade.

The case of CNMC Ningxia Orient Nonferrous Metal Group seems illustrative for these concerns. The state-owned enterprise is one of the world's top three smelters and producers of tantalum. The tantalum it produces is used by the largest capacitor manufacturers such as the US based AVX, that in turn supply electronics to companies such as Dell, Intel and RIM ('Blackberry') and Hewlett-Packard. Although the company claims to have transparent sourcing practices, Global Witness (2010) has raised concerns that the K-salt[17] that the company uses to produce tantalum and that it claims to come from refineries in China, can be used to cover the Congolese origin of the tantalum they use. Nathan and Sarkar (2010: 23) claim that Ningxia continues to import coltan from DRC despite all concerns. Ningxia has not responded to a questionnaire that was done by Resolve (2010: 39) in a attempt to address supply chain challenges for electronics industry and their use of critical metals.[18] It is also interesting to see that capacitor production in China and exports thereof have been increasing rapidly over the previous few years, meaning that any supply chain management with certification rests more and more upon the credibility of China.

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[17] K-salt is tantalum ore that has been chemically refined to make the compound called potassium tantalum fluoride.

[18] According to Resolve (2010: 39), all major producers of electronic goods responded on tantalum (Apple, Dell, HP, IBM, and others), roughly half of the component manufacturers, only one of the processors (Cabot), and none of the actors involved in earlier stages (except Talison, the Australian mining company). The study was done on behalf of the Global e-Sustainability Initiative (GeSI) and the Electronic Industry Citizenship Coalition (EICC).

Concluding Lessons for Conflict Analysis, Illicit Trade and Any Certification Scheme

This analysis reveals inconsistencies in tantalum data and indicate a remarkable scope for hiding illicit trade. Both the neighbouring countries and the Chinese gateway show a dimension according to which the total amount of coltan traded may outweigh the official DRC production, possibly by a factor of three. This magnitude is in line with UN expert group estimations that have been done domestically in the DRC in 2008 and 2010 and trade data. To illustrate this: if one assumes illegitimite imports from DRC/Rwanda to China in the dimension of 914 t (gross weight 2008, see above, not to mention other illicit routes) and a market price of $ 87/kg Ta_2O_5, the value of such illicit trade of tantalum comes close to $ 27 million annually, roughly one fifth of the estimated world market volume for tantalum production. Though these gateways are merely a first indication and not a robust result yet, the result underlines the urgent need and possible directions for further research.

Production and trade data on minerals involved in armed conflicts are needed in an internationally comparable scheme with open access. This should include detailed information about local origin, prices and ore concentrations (contribution of Franken et al. in Part IV). In the short term, it could be organized by an international group of experts in charge with collecting, comparing and evaluating available data. In the medium term, it would be favorable to harmonize international statistical methods and classifications, and to develop full material flow accounts including secondary production and recycling as well as financial flows. The ICGLR certification (see annex) is a useful initiative in that regard.

Conflict analysis may however draw useful lessons from our case of coltan mining in the DRC and related international markets: Firstly, coltan (tantalum) has interesting characteristics for a number of technology applications. Focusing on one application (e.g. mobile phones) may raise awareness but bears the risks of shifting production patterns to other technology areas where public attention is comparatively low. In addition, focussing on coltan alone would give incentives for shifting illegitimate activities to other profitable minerals.

Secondly, Central Africa including the DRC and Mozambique is now the largest supplier of coltan/tantalum on world markets. Our short analysis of the DRC reaffirms that major actors in the region cooperate in their efforts to profit from mining and trading coltan. The conflict structure is dominated by rent-seeking activities of a number of actors over all stages of the supply chain until it enters official markets, not just by fighting over mining licences. The involvement of DRC officials, the ability to earn incomes higher than average as well as the desperate situation of the local population, triggered by high world market demand and no transparency requirements, favor a rather

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perverse stability of such situation. Any certification scheme thus should take into account the ability of all actors involved to mix legal mining products with others along the first stages of the supply chain.

Thirdly, the involvement of China, other Asian countries and production located there lead to increasing complexity while transparency is poor. The large number of small producers for a number of tantalum products such as K-salt and tantalum powder makes it fairly difficult to establish a certification scheme. Moreover, it adds a paradox of "having more shadow due to selected light" to certification schemes: if likeminded producers manage to establish a sustainable supply chain management for a number of goods (however difficult this may be!), other value chains will benefit. Such paradox results from economics: a splitted demand results in a splitted price and splitted awareness, i.e. higher prices for those concerned and lower prices for those who do not care. Probably, the conflict situation wouldn't change much!

For these reasons, any certification scheme is faced with a number of challenges. It differs significantly from e.g. the Kimberley Process for the certification of diamonds, because

1. The number of actors involved upstream and their ability to mix illegitimate sources with legal ones during the first stages of the supply chain are huge;
2. The production chain downstream is much more complex and entirely globalized, with Chinese companies being in the largest position;
3. Tantalum is not an end-product in itself, many companies are unaware yet whether it is a component in one of their products, and consumers have difficulties to realize it either.

A common interest for comprehensive solutions however may stem from the critical need for such metals both in high-tech industries as well as in most countries. Australian mining company Talison is ready to re-enter the market as soon as current uncertainties will be reduced. At the heart of any solution should be the insight that markets need transparency and appropriate prices—both to be safeguarded by proper institutions—to function properly. Illicit trade, intransparency and corruption are to be seen as major risks for business. Market failures are likely to have substantial costs. Chinese companies, and in particular state-owned enterprises, will have to accept their responsibility to perform supply chain due diligence. Some pillars for solutions are as follows.

Certification along supply chains and regional governance interact. Given the manifold actors in the early steps of mining and trading coltan, regional governance in eastern DRC is of crucial importance. Mitchell and Garrett (2010) claim that general conditions and social sector reforms (SSR) in Eastern DRC are an urgent precondition for any other activity. In addition,

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an effective mining law that could be implemented with international support until the actual resource conflict is solved should be considered.[19] However, this will take time. Sustainable resource management actions (SRM, Bringezu and Bleischwitz 2009) may thus co-evolve with such broader reforms, driven by international corporate efforts and consumers' concerns. SRM should include approaches to promote transparency, accountability and trade formalization, which should be co-ordinated with complementary efforts of local governments (e.g. capacity building initiatives) and of the international community (e.g. implementation of due diligence and supply chain assurance and certification schemes). Certification of negotiants, comptoirs, international traders, smelters, capacitor manufacturers and producers should aim at 100 % verification of all their operations.

A two track approach of pilots on the region and capacitor-based certification may yield results. Since capacitor manufacturers consume roughly half of the tantalum world wide and have a strong position in the supply chain, more attention should be focussed here. Compliance with certification schemes and data disclosure in their business reports are a key; third party audits, as suggested by OECD (2010), will improve reliability. The initiatives GeSI and EICC are useful in that direction (see Annex). Public offerings at regional stock exchanges may be options for the future. In particular it would help in the establishment of an international comprehensive monitoring mechanism and any enforcement.

Internationally coordinated approaches to promote legal mineral trade are at stake. Table in the Annex reports relevant initiatives. It provides a brief description of the main characteristics, the actors involved and possible weaknesses. International initiatives like the Extractive Industry Transparency Initiative (EITI) emphasize the need for more accountability within the mining country and at the export stage, where the financing flow is generated. These initiatives are attempts to disclose information provided by administrative schemes in order to enhance the accountability of the actors involved. They should enable lining up with complementary efforts led by the local governments and the international community. For that reason, international law should also promote accountability against corruption and in favour of sustainability; a proposal for an international agreement has been made (Bleischwitz et al. 2009). Following a suggestion made by Collier and Venables (2010: 15), the anti-bribery legislation that the OECD now requires of its membership could be a requirement of WTO membership—a compliance issue for China and elsewhere.

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[19] Satellite fotos in military quality of the conflict areas can be useful in that regard. Garrett and Lintzer (2010) give arguments why the national government should further retire from extraction activities. Discussing the role of the UN as well as legal frameworks is beyond the scope of this paper.

Consolidation and coordination of the different initiatives should be a next step. This will probably faciliteted through ICGLR (see annex). In this respect, a regional resource fund where money of different donors and actors involved (public and private) can converge, could help ensuring better coordination among different actions, better allocation of funds and better division of the tasks.

As regards to prices and taxation, most researchers share the impression that the current systems neither capture negative externalities nor do they promote regional sustainable development. A general assessment and review of the tax system with emphasis on simplification, transparency and accountability as well as raw material taxation at the extraction point would not only generate revenues for such a regional resource fund but also give incentives for value adding activities in the region (Garrett et al. 2010). However tax competition with neighbouring countries (e.g. Rwanda) should be minimized via agreements—the EU offers a lot of such model tax agreements. Such taxation allows for establishing an appropriate legal order and could give more social security to mining workers and along the regional supply chain. Ensuring that the profit from the mining sector trickles down to the local population with value creating activities will require an independent and accountable management of such fund. Further analysis may also shed light on implications for any sustainable growth to contest the theory of a resource curse in this region (Collier and Goderis 2007; Gylfason 2009; World Bank 2008).

International economics and conflict analysis will also have to develop governance mechanisms to turn illicit trade in minerals into opportunities for sustainable development. This will not only require harmonized data and monitoring, but also enforcement systems and capacity building initiatives for the main stakeholders. In that regard, the current barriers and deficits might be removed by international incentives for re-use and recycling: material stewardship is an encouraging concept where capacitor producers currently are key business actors. They should be part of a future international covenant for the recycling of critical metals that involves in particular electronics industry (Wilts and Bleischwitz 2011). Aim in this context is to increase industrial recycling, to collect more consumer goods and to establish recycling facilities internationally. Such covenant is well in line with high prices for primary resources as well as with fair trade.

This is, of course, an agenda that goes beyond the scope of our case study. Having said this however the authors also wish to express the view that bans are a less desirable option because they would result in further economic hardship for the Congolese people. Putting the raw material conflict issue in the framework of sustainable resource management and international governance for trade in natural resources probably is a better way forward.

Annex: International Initiatives and Coverage of the Value Chain of Coltan

Initiative	Action description	Actors responsible	Part of supply chain	Synergies with other actions	Risks
UN-EU partnership on extractive industries and conflict	Aims at ensuring inclusion of conflict prevention and sensitivity in NRM programs. It provides a framework and technical assistance useful to EU and UN agencies to plan and design intervention strategies where extractive industries are driving factors of the conflict	EU and UN	UN and the EU, extractive industries, governments	EITI, capacity building/technical assistance	contribution of other key parties is needed in order to achieve a peaceful outcome in a coordinated and constructive manner
EITI, EITI++	disclosure of public revenues/expenses	Governments and companies	Local companies (comptoires/mining companies)	Capacity building programmes, initiatives supporting transparency in the value chain(certification/chain of custody assurance)	It covers only one part of a broader resource management process. Problems in implementation due to the fragmentation of state organizations
OECD/UN due diligence	Due diligence framework and practical guidance on how to manage risks	Up/down-stream operators	Up/down-stream operators	Promotes the use of schemes for traceability (iTSCi), EITI	Too burdensome requirements, might push companies from OECD countries out of the sector
Capacity building of governments (e.g. Promines DRC)	Strengthening capacity of key institutions to manage mineral sector, improving condition for investment and socio-economic benefits	Local institutions, international donors	Local institutions, business environment	Attends to gaps in EITI, supports the creation of traceability systems	Difficult implementation environment in the region (e.g. situation in DRC), limited resources for too wide scope

Certified Trading Chains (CTC)	Ensure chain of custody for producers and buyers (verification of origin and trade volume analysis, independent audits); on-the-ground assessment of mining conditions	BRG and the local ministry of mines (DRC, Rwanda)	Mining production and trade (focus on companies' concessions—LSM)	Capacity building programmes, fingerprinting process	Capacity building needed, multiple stakeholders involved can hamper the process
iTSCi	Ensure traceability of minerals (phase I-introduction of due diligence procedures, written documentation, independent audits; phase II- "bag and tag system" of traceability)	Initiative of the tin smelting industry	Suppliers and exporters of minerals (in particular ASM)	Possible interaction with Capacity building programmes, EICC/GeSi, OECD/UN due diligence guidelines. Could be integrated in CTC as traceability scheme.	Security of mining sites, commercial visibility, need to publish data for awareness raising
Analytical Fingerprint (AFP)	Independent mineral traceability tool	Up to now: BRG	Mining and trade	Forms part of CTC certification scheme; can be linked to iTCSi	Complex and costly implementation, stakeholders facilitation and institutional support needed
GeSI/EICC	Global e-Sustainability Initiative and Electronic Industry Citizenship Coalition offer a tool and support for certification of smelters	Initiative of electronics industry	Smelters	Link with mineral certification schemes (iTSCi and CTC)	Complexity of ITC supply chain
ICGLR certification scheme	International Conference of the Great Lakes Region, Regional certificate of origin scheme, harmonization, promotion of dialogue	ICGLR	Local producers/ traders	Complementarity with other point of origin certification schemes (CTC, iTSCi)	Ownership issues

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Initiative	Action description	Actors responsible	Part of supply chain	Synergies with other actions	Risks
Bans	mining/export of the mineral is prevented	Governments/ international community	Extraction phase or exports from the producing country	May be symbolic part of broader action	Bringing further economic hardship for people, costly and difficult to enforce
Dodd Frank act	Legal obligation on US companies reporting to SEC to declare use of "conflict minerals"	SEC, SEC reporting companies	SEC reporting companies	Due diligence guidelines and iTSCi	Compliance issues, questionable impact on Congolese people.
Starec plan	Rehabilitation and regulation of mining. Establishments of marketplaces (centres de negoce) in key mining areas	Government of DRC, artisanal miners and their associations	Traders, merchants, diggers, mineral and state authorities		Challenge on how to manage security

Source: Authors'elaboration of different sources

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Chapter 12
Certified Trading Chains in Mineral Production

Gudrun Franken, Jürgen Vasters, Ulrike Dorner, Philip Schütte, Dirk Küster, and Uwe Näher

12.1 Governance Systems for Assuring Standards

Different approaches of governance systems to ensure the compliance of process and production methods, including the social and environmental aspects, have been developed (cf. Levin 2008a). They have different motivations and objectives as well as different liabilities. The strongest governance systems are government regulations, if enforced accordingly. Authorized by a democratic system, they should reflect a national perspective towards management e.g. of natural resources. Regulation and enforcement are in the responsibility and supervision of government institutions. Apart from their national focus they are also influenced by and obliged to international treaties, conventions and standards e.g. on trade, labour and environment.

Much less binding are business codes. Introduced mainly by companies and their associations they are a voluntary approach. However, oriented towards increasing reputation and developing a competitive advantage they can develop and adhere rapidly to changes required, e.g. due to reputational risks.

Criticism on the accountability and independent assurance of business codes, lack of enforcement of government regulations and also the demand for additional standards by consumers have led to certification initiatives (cf. Levin 2008b). These have been developed in several sectors, many of them addressing the management of natural resources (e.g. coffee, wood). Key elements of certification initiatives are governance by multiple stakeholder groups, independent assurance systems and that they are driven mainly by consumer demand. As a result, most of the initiatives comprise a labelling system to distinguish the certified production from the rest of the market (e.g. fair-trade label).

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Certification, thus, can be an instrument to foster compliance to standards especially in an environment where national governance is weak and where business codes alone would not suffice to yield acceptance of the customer.

12.2 Certification of Mineral Resources

In the mineral sector, several certification initiatives have emerged (contribution of Bleischwitz et al. in Part IV). All of them are addressing or driven by problems related to the sector of artisanal and small scale mining, a sector known to struggle with poverty, compliance to ethical standards as well as with a lack of governance. Therefore, the initiative for Certified Trading Chains (CTC), which is presented here, is also in close dialogue with the CASM (Communities and Small-Scale Mining) network. Most prominent is the debate on conflict resources, such as the so called “blood diamonds” which led to the Kimberley certification scheme for diamonds, or the relation of mining to the conflict in the eastern Democratic Republic of Congo (DRC).

All of the current initiatives aim at products, certified for origin or ethical standards, that can be traced down the value chain to the customer. Thus they address high value minerals such as diamonds, gem stones and gold that directly reach the customer e.g. as jewels and are not entering industrial production, where they are subject to processing and mixing and would form only a very small part of the manufactured product.

The drivers of these initiatives have been mainly two factors: Firstly, mineral resources have been associated with conflicts (diamonds). However, the illegal exploitation of mineral resources is rather the symptom than the cause of a conflict (United Nations Security Council 2002; Garrett et al. 2010) and vice versa, conflicts are fuelling illegal exploitation. Secondly, the improved market access and poverty alleviation in artisanal and small scale mining (ASM). These initiatives especially imply fair pricing systems as well as improving the livelihood of workers and communities (gem stones, gold).

Prominent initiatives are:

For the certification of origin:

- the Kimberley Process Certification Scheme (KPCS) for diamonds

For the certification of ethical production:

- Council for Responsible Jewellery Practices (CRJP)
- The Alliance for Responsible Mining (ARM) has partnered with the Fairtrade Labelling Organizations International (FLO) on a joint fair trade standard for artisanal and small-scale mining for gold and associated metals.
- The diamond development initiative (DDI),

and others.

The CTC initiative as laid out here, combines the two objectives of certification of origin as well as ethical production. It is the first initiative—in contrast to the ones mentioned above—being developed for metal ores from artisanal production entering industrial production.

However, certification can only be regarded as the second best option and would be superfluous in case of total conformity with national and international laws, regulations and standards. Law enforcement and institutional capacity are often weak in the mineral sector of many developing countries; CTC tries transitionally to fill the gaps between the ideal world and the reality of sectoral governance.

12.3 Certified Trading Chains: Background and Objectives

In 2002, the United Nations' Panel of Experts on the Illegal Exploitation of Natural Resources and Other Forms of Wealth of the Democratic Republic of the Congo presented their findings to the Security Council on the Illegal Exploitation of Natural Resources in the Democratic Republic of Congo (United Nations Security Council 2002). The Panel had found that the plunder of natural resources and other forms of wealth of the DRC were associated to the conflict in the region. In 2005, the Panel of Experts proposed that enhanced traceability systems should be developed for all important natural resources of the Democratic Republic of the Congo (United Nations Security Council 2005).

Taking up the call for transparency in mineral production, the Federal Institute for Geosciences and Natural Resources (BGR) started two research projects in 2006. The first research project aimed to test the feasibility of 'fingerprinting' coltan samples based on the mineralogical and chemical characteristics of specific ore concentrates (Melcher et al. 2008). In the second initiative, a chain of custody assurance systems was developed, based on the establishment of transparent, traceable and ethical trading chains (Wagner et al. 2007). This concept of Certified Trading Chains (CTC) found entry to the preparatory discussions for the G8 summit in Heiligendamm, Germany, in 2007. The summit protocol stressed the need for action in the ASM sector and acknowledged the potential of certification systems to increase "transparency and good governance in the extraction and processing of mineral raw materials … to reduce environmental impacts, support compliance with minimum social standards, and resolutely counter illegal resource extraction" (article 85). It also expressed support for "a pilot study… concerning the feasibility of a designed certification system for selected raw materials" (article 86) (G8 Summit 2007). To this end, the German government has taken the initiative to support such a pilot project for implementation in Rwanda.

CTC in mineral production are instruments to implement ethical standards and transparency in mineral production, and thereby improve responsibility in the minerals sector by introducing a concept of voluntary self-commitment among the partners within the value chain. Since highly mechanized and large-scale mining (LSM) operations commonly operate within acceptable corporate social responsibility standards, the approach explicitly focuses on artisanal mining organisations, and small-scale companies which use artisanal labour in developing countries.

Export bans on high quality and low volume commodities are costly and difficult to enforce. In contrast, certification can be oriented at the same goals, whilst allowing companies to continue mining or buying minerals from the region on the basis that they have demonstrated to achieve their social and environmental responsibilities, as required by the certification system. In this way, responsible buyers can use their buying power to institute positive change by remaining engaged in the mineral supply chains, rather than disengaging. By ensuring traceability along the trading chain, the CTC scheme serves as an instrument

- to ensure that the trade of certain mineral resources is conducted legally and does not support belligerent groups in the region and
- to assure that process and production methods at the mine site adhere to minimum social and ecological standards.

Key elements of the CTC concept are:

- a focus on high-value stanniferous metals (tin, tungsten, tantalum) and gold,
- it is tailored to be applicable in artisanal mining,
- it includes certification of specific mine sites and respective trading chains (up to the industrial consumer (e.g. smelter, powder producer),
- it introduces minimum standards (mostly based on OECD) on corporate social responsibility and on origin by voluntary certification adapted to the local context,
- an independent third-party audit is obligatory.

Figure 12.1 shows the respective CTC scheme on a national level. On the one hand, CTC aim to increase the contribution of the minerals sector to poverty reduction and the political stabilisation of developing nations. On the other hand, they aim to improve supply security for the processing industry and foster responsibility in industrialised economies, thus, strongly implicating the dual objectives of producer and consumer benefits. The proper implementation of certification will support areas of good governance, where mineral resources are produced and traded legally and transparently and in ways, which protect workers, communities, and the environment. Certification will also support transformation and formalization of informal mining. Formalisation, at least at a minimum level, is a precondition for achieving transparent records of production and trade, to improve governance and to reduce conflicts associated with the mining sector.

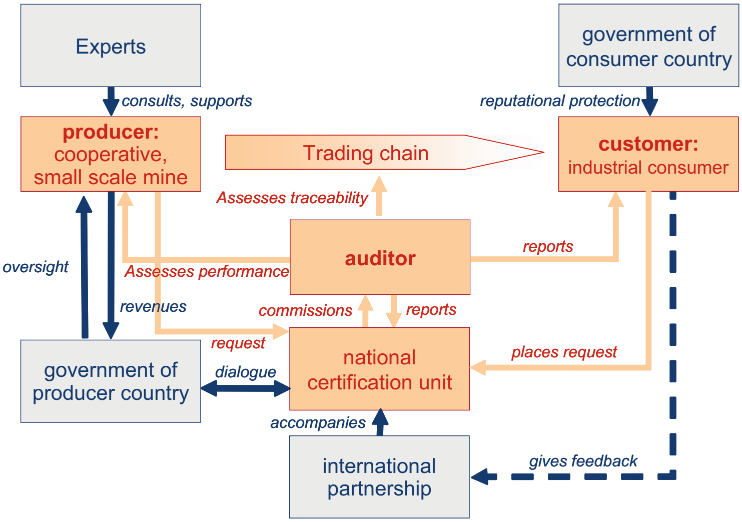

Fig. 12.1 Conceptual flowchart of CTC

12.4 The CTC Principles and Standards

On the basis of an on-the-ground assessment in Rwanda, a set of standards was drafted based on a number of international 'integrity instruments' as well as national law. Each standard was derived from the specific provisions in the Organisation for Economic Cooperation and Development's (OECD) Guidelines for Multinational Enterprises (2000) and Risk Awareness Tool for Multinational Enterprises in Weak Governance Zones (2006), as well as from some of the International Finance Corporation's Performance Standards and the Voluntary Principles on Security and Human Rights. Also recommendations from the Mining Certification and Evaluation Project (MCEP 2006) have been incorporated.

The set of standards was drafted with the focus on transparency along the trading chain including certification of origin as well as assuring corporate social and environmental responsibility. Certification of origin, on the one hand, is based on documentation and plausibility checks related to production, trade and export as well as—in case of doubt—the additional checking instrument of the analytical fingerprint for certain minerals.

After consultation on the content of this standard set at the 8th annual conference of the World Bank's CASM initiative in Brasilia, Brazil, October 2008, five basic principles (Table 12.1) were established each referring to a thematic cluster and two additional standards were added, one referring to gender issues and the other on handling influx migration.

A further step in the CTC consultation process was the workshop on the revised standard held at the conference of Fatal Transaction and the Bonn International Centre for Conversion (BICC) "Digging for Peace—Private Companies and

Table 12.1 Principles and standards of CTC

Principle	Standard
1. Origin and volumes of produced and traded goods as well as company payments to host government are transparent.	1.1 Origin and production volume of minerals from the pilot mine site throughout the trading chain are traceable.
	1.2 Meet fiscal obligations required by host government law.
	1.3 Publish all payments made to government according to internationally accepted standards.
	1.4 Actively oppose bribery and fraudulent payments
2. The company does not use child labour and ensures fair remuneration and work conditions as well as continual improvement of health and safety measures for all employees.	2.1 Maintain salary or payment levels equal to or greater than those in comparable enterprises within Rwanda.
	2.2 Ensure that no child labourers (age under 16) work on company sites.
	2.3 Support workers' organizations and collective bargaining.
	2.4 Provide essential protective and production services to support the work of artisanal miners.
	2.5 Ensure occupational health and insurance in all company operations.
	2.6 Provide training for employees and contractors on safety, health and effective use of on-site facilities.
3. The company ensures security on company sites whilst respecting human rights.	3.1 Provide sufficient and adequately trained security forces.
	3.2 Undertake security risk assessments
4. The company consults communities in which it operates and contributes to their social, economic and institutional development taking into account gender sensitive aspects.	4.1 Interact regularly with communities and local governments to address grievances and other common concerns.
	4.2 Support local enterprises to supply company operations.
	4.3 Implement integrated development programs in nearby communities for livelihood security, social and physical infrastructure and capacity building.
	4.4 Obtain free, prior and informed consent before acquiring land or property.
	4.5 Understand the situation and perspectives of the women in the company's area of influence and design and implement company's operations in a gender sensitive way.
	4.6 Carry out an assessment on human migratory streams created by company operations and develop an influx migration action plan.

(continued)

Table 12.1 (continued)

Principle	Standard
5. The company seeks continual improvement of its environmental performance	5.1 Carry out an environment impact assessment as the basis for developing an environmental management and protection plan and strategy.
	5.2 Properly treat or dispose of hazardous material and waste from its site(s).
	5.3 Make provisions for the full cost of rehabilitation upon closure.

Emerging Economies in Zones of Conflict" in Bonn, November 2008. The workshop enhanced the dialogue with the civil society on the content of CTC. In March 2009, the implementation workshop with national stakeholders in Kigali, Rwanda, started the national CTC implementation. The standards were related to Rwandan legislation as well as revised and adopted specifically for Rwandan conditions.

12.5 CTC in Practice

The pilot project on CTC in Rwanda was started within the framework of a technical cooperation programme to strengthen the competitiveness of the Rwandan mineral sector by developing best practice and enhancing transparency. It was implemented in cooperation with the former Rwanda Geology and Mines Authority (OGMR) (today Rwanda Natural Resources Authority with its Geology and Mines Division (GMD)) and private mining and processing companies.

Rwanda supports the desire to establish Certified Trading Chains (CTC) through the strengthening and supervision of the mining sector in the country. In order to implement socio-economic and environmental best practice in its mining industry, Rwanda is setting and will later enforce good standards in its mining sector to guarantee a sustainable market for its minerals. Preliminary findings suggest that high value metals produced in and exported from Rwanda including tantalum (coltan), tin, and tungsten offer a leverage to handle poverty alleviation, conflict prevention, as well as supply security.

First steps were bilateral consultations with the Rwandan government and other national stakeholders, especially from the industry. A workshop with the stakeholders from government institutions and the mining industry started the implementation in March 2009. Altogether five mining companies, local producers of cassiterite, wolframite and tantalite concentrates who cooperate with or engage ASM, volunteered to join the initiative: Natural Resource Development (NRD), Gatumba Mining Corporation (GMC), Eurotrade Ltd., Wolfram Mining and Processing (WMP) and Pyramids. An independent auditor, who could be paid in future by the requesting producer or industrial consumer, conducted a base line assessment of the companies, their concessions and trading chains to develop

Fig. 12.2 The trading chain

indicators for the certification scheme, to assess the actual status and to give recommendations for improvement (Mutemerie 2009; Fig 12.2). For each standard, a set of indicators for verification, adapted to the situation of mining in Rwanda, has been developed. The audit revealed company performances were different, companies showed strengths or weaknesses in different areas. For example, whereas one company had developed excellent community relations, other companies had taken very limited action in that respect. This revealed opportunities for an exchange of good practices within mining sector in Rwanda.

To address the weaknesses of compliance, the consultancy supported the companies on how to establish respective policies and improvement. These include recommendations on documentation and management systems, on health and safety issues as well as gender and corruption policies and environmental performance. Official audits at the end of 2010 documented progress and formed the basis for a decision on certification. The Rwanda Bureau of Standards (RBS) developed a national process for the certificate based on the current CTC experience. Three out of five companies achieved compliance with the standards and thus, respective CTC certificates in March 2011. As a next step, technical cooperation between BGR and the Congolese Ministry of Mines with the aim of introducing a certification system for coltan, cassiterite, wolframite and gold started in October 2009. The cooperation combines the pilot implementation of certification (with a focus on transparency of origin) at selected mining sites in South Kivu with the capacity building of sector institutions so that they can fulfil their mining oversight function. National and local workshops have paved the way for implementation. For the province of South Kivu four pilot companies with seven mining areas have been selected. Access to mine sites, security and involvement of armed groups are major factors that render certification in this area a challenging task. Nevertheless, it is expected to be one step to support the development of legal and official mining and trade.

12.6 Outlook: Regional and International Integration

In November 2006, the eleven member states[1] of the International Conference on the Great Lakes Region (ICGLR) signed the Protocol against the Illegal Exploitation of Natural Resources, which includes the aim of implementing a mechanism for the certification of natural resources in its Article 11. By implementing the exemplary pilot project in Rwanda and serving as a basis for a certification scheme in the DRC, the CTC system aims for regional stability and peace building, as envisaged by ICGLR. The results of the CTC approach in Rwanda were presented during the ICGLR meetings in April and September 2009 and in April 2010 as a Rwandan contribution to the development of a regional certification mechanism. Since then, the ICGLR has developed a scheme for a regional certification mechanism which was adopted at the end of 2011.

The issue of certification of mineral production and trade is not only a national or regional effort. Support is also coming from the EU Special Representative for the Great Lakes who initiated a Joint Action Plan to curb illegal exploitation of and trade in natural resources in Eastern DRC. As part of this initiative, the OECD has initiated a working group to promote responsible investment through enhanced due diligence in the mining sector on the basis of the OECD Risk Awareness Tool for Multinational Enterprises in Weak Governance Zones and the OECD Guidelines for Multinational Enterprises. A consultation process was started, also including actors (companies and institutions) that participated in the CTC pilot project. At the end of 2010 the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas was published.

Relevant other initiatives in the sector provide feedback and lessons learned such as the Kimberley Process for diamonds, the ARM for the development of a fair trade gold standard or the diamond development initiative. Ongoing other emerging initiatives in this sector show that the issue of responsible mining and certification might develop beyond the current relevance for limited commodities (diamond, jewellery, gold) as well as beyond the large-scale mining sector and increase its relevance along the trading chain.

However, achievements will strongly depend on the continued interest of industries and consumers to call for sustainable and responsible production in the mineral sector. In addition, credibility and effectiveness are key elements for a certification scheme to be successful.

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[1] Member states: Angola, Burundi, Central Africa Republic, Congo, Democratic Republic of Congo, Kenya, Uganda, Rwanda, Sudan, Tanzania, Zambia.

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Chapter 13
Peace and Security by Resources Self-Subsistence Strategies

Susanne Hartard

13.1 Characteristics of Resources Competition and Conflicts

Rising competition and conflicts on resources have a follow-up in resource security actions of many countries in the last years. Resource security has become top priority by many states worldwide, especially in industrialized countries with a high dependency on resources import and resource-rich countries dealing with export contracts on scarce minerals and fossil energy (BMU 2008).

There are multiple reasons for national resource security actions: The experience of increasing volatility of commodity prices on international stock markets is harming high-technology industry especially emerging Green markets like the PV, cell-phones, TV-screens, wind turbines and LED-lamps (contribution of Zepf et al. in Part IV). Rising prices of precious metals and scarce minerals do not express real physical scarceness in all cases, have frequently a political background like unequal resource deposits, trade policy, fast growing new technologies, monopole structures in the mining sector and speculation on the stock market.

Rich countries, more often poor in arable land or irrigation water, have started to work on their future food security by additional investments in arable land in developing countries. That means investors from Saudi-Arabia, Qatar, India, China, Europe and US have started buying arable land in developing countries like African nations. The land is intended to use for future food supply of the investing country, critically discussed as land-grabbing in the public (BMZ 2012). These land investments are estimated on 200 Mio. ha arable land, thereof 130 Mio. ha are on the African continent (BMZ 2012). The impacts are losses on unclear and common arable land property and the risk, that developing countries will produce

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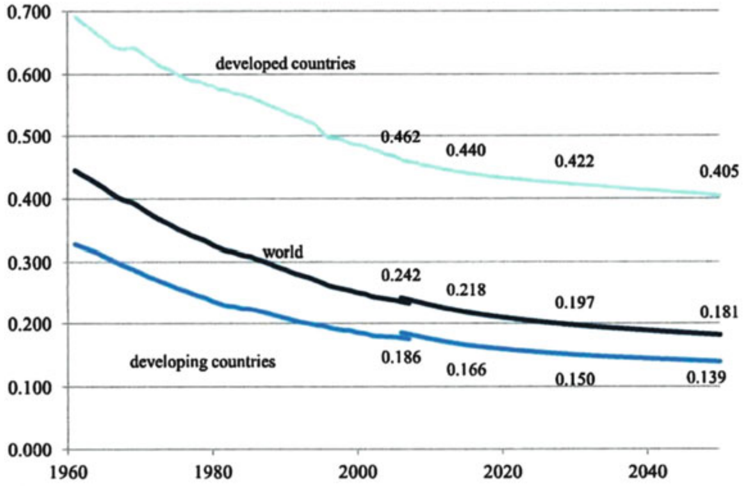

Fig. 13.1 Arable land per capita (ha in use per person) 1960–2040. *Source*: FAO (2012)

export crops instead of ensuring the nutrition of their own countries population (see Fig. 13.1).

The Committee on World Food Security in 2012 has endorsed the "Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security" to promote secure tenure rights and equitable access to land, fisheries and forests. According to FAO it can be presumed that the global demand on food and fodder will increase by 70 % until 2050 (FAO 2011) that time beside general competition on land-use climate induced migration will strengthen the problem.

Oil and natural gas conflicts and crises are creeping conflicts all around the world started 40 years ago with the OPEC oil crisis in 1973, when OPEC reduced the oil export as a political weapon (contribution of Ipsen in Part II). The risks of the approaching end of fossil energy era will probably induce more aggressive behavior of heads of governments. Oil has already been declared to be a "geopolitical weapon" in Venezuela in 2005. The dependency on natural gas import from Russia lead to several crises and a so called "gas war" between Russia and Ukraine and other gas importing countries. The follow-up strategies make European countries actually reduce their dependency (see Fig. 13.2) on oil and gas imports.

They work on alternatives for diversification of their natural gas supply and common investment in future pipelines, own exploitation and a general switch to renewable energy policy. Even if new euphoria on fracking technologies, petroleum sand mining in Canada have blocked the critical knowledge on the end of fossil energy era, new conflicts appear in the "ice melting" North Pole region on the access to crude oil and natural gas reserves to be exploited in the future. Continental shelf frontiers of Russia, Norway, Canada and Denmark, especially the Lomonossow-ridge, have been proven by the Law of the Sea Convention of the

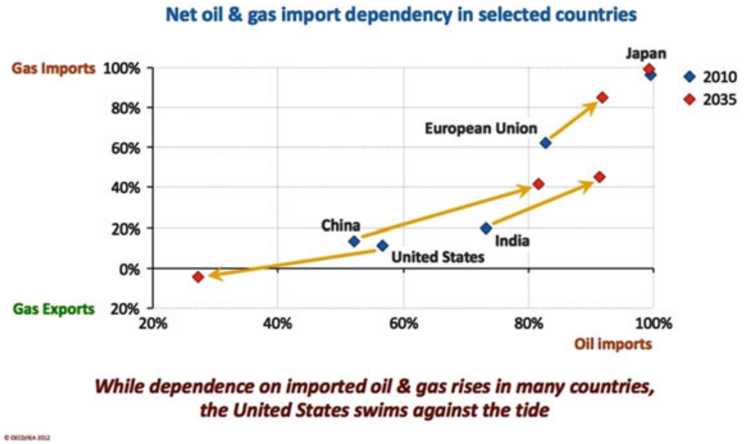

Fig. 13.2 Future risks by oil and gas dependency of selected countries. *Source*: OECD/IEA (2012)

United Nations. The UN–Commission on the Limits of the Continental Shelf in New York has jurisdiction for the subject matter.

According to the U.S. Geological Survey (2008) around 30 % of undiscovered natural gas reserves and 13 % of undiscovered crude oil reserves are estimated to be available in the North Pole area, 84 % of this is estimated to be offshore resources. The Arctic Council has a rising importance to prohibit future conflicts on the Arctic region. The actual development in the US towards energy independency has its origin in the expansion of shale gas production by hydraulic fracturing in the last years (see Fig. 13.3), a technology which is highly controversial discussed.

Resources related competitions and conflicts can be characterized respective the involved resources and kind of conflict (see Table 13.1). The running out oil era increases land use conflicts by needs to substitute crude oil based products like gasoline and Diesel, plastic, pharmacy, fertilizers and packages. Animal husbandry of industrial countries causes an expansion of feed exports like soybean from developing and emerging countries and shifts subsistence cultivation towards an unsustainable export economy. Palm oil and sugar cane plantations in Indonesia, Brazil and other neighbor countries actually push aside the food production for alimentation of native population.

Public international law and councils get an increasing importance to control the access to new deep sea resources mining areas like the polymetallic nodules exploration areas controlled by the International Seabed Authority. The conflicts on nature conservation on seabeds and nodule exploration in the deep sea is not solved by a final international regulation, actually research is been focused on the reserves available.

A big challenge is the price volatility and price peaks of several scarce and strategic minerals (contribution of chapter 2 in Part I). Recent research studies showed that there are several reasons for price volatility; physical scarcity is often

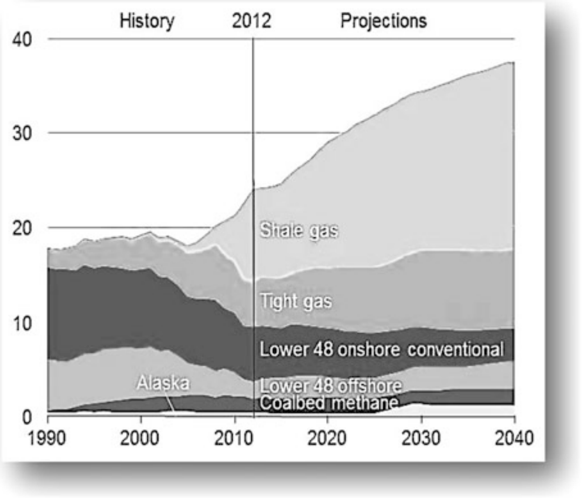

Fig. 13.3 Natural gas production by source 1990–2040. *Source*: U.S. Energy Information Administration, Natural Gas Annual 2012, DOEIEIA-0131(2012) (Washington DC, December 2013). http://www.eia.gov/forecasts/aeo/images/fig_mt-44.png

Table 13.1 The characterization of cross-national resources competitions and conflicts

Kind of competition or conflict	Resource
Arable land use competition	Food-feed-fuel-energy crops-fibers
"Lost ecosystem and C-sinks" in mining areas, urban sealing: roads, settlement areas	Coal mining, metal mining, land-use of golf parks, sand and limestone mining (Germany)
"Conflict resources"	Legal and illegal resources incomes are used to finance civil wars and stabilize corruption economies: diamonds, coltan, gold, tinstone, copper in Central African countries: Kongo, Angola, Sierra Leone, Nigeria and others
Access rights (polar regions, deep sea)	(North pole region onshore and offshore), Arctic resources: natural gas, crude oil, iron, copper, nickel, coal, gold, diamonds Deep ocean resources: black and white smokers and metal nodules manganese, copper, nickel, cobalt, methanhydrates, lead, zinc, iron, silver, gold, indium, gallium, germanium
Water conflicts	Access, fishery rights, pollution, river management of neighbor countries Middle East, fishing rights in oceans
Blocking gas pipes oil embargos export restrictions	Blocking gas taps from Russia, oil crises (OPEC), restricted exports of rare earths from China, unequal resource deposits on oil, gas, scarce minerals and related trade barriers
Resources price peaks and speculation physical and market scarcity	Speculation, demand of emerging markets, real scarcity (electricity, fuel, lithium, indium, copper, phosphorus, food f.e. corn price induced the tortilla crisis)

Source: Authors' own compilation

not the background reason. Gandenberger/Glöser et al. (2012) stated that capital and resources markets are interdependent and price increase cannot be led back on real raw material price increase or capital market development. Especially the rising prices and price volatility of raw materials for the JCT and renewable energy industry are worrying responsible authorities. Reasons for rising prices are the high demand of emerging countries (China), new technologies sudden high demand (screens, E-mobility, solar cells, wind power plants), global market recessions and speculation.

The following examples explain reasons for recent price peaks and an increasing price volatility in close relation to the authors contribution in Part I. It is noted that unsecure resource markets, indistinct future demands and unclear access to resources have the follow-up higher price volatility.

A German survey on the reasons of actual resources price peaks (DERA 2013b) showed that there have been earlier price peaks for several mineral resources and there can be several reasons for prices increase, not only real scarcity. The following examples show the dimension of fluctuation straining the manufacturing trade for some selected minerals:

- The *copper price* has risen by a high demand of China up to 8.684 US$[1]/t in 2008 and after the global market downturn in 2008 fall to 3.071 US$/t even gone up to 9.867 US$/t in 2009/2010 and keeping on a high level (DERA 2013b).
- Irrespective of the *phosphate price* peak in 1975 due to growing world population and rising food and fertilizer demand for agriculture with rising production capacities and as a follow-up of the oil crisis in 1973 (DERA 2013a) the phosphate price has been on a long-term stabile level of 50 $/t rock phosphate. The food market crisis in 2007/2008 caused immense changes and impacts, causing a factor 10 price increase up to 425 $/t rock phosphate (BGR 2013). Phosphate fertilizer price rose by factor 5 from 2006 to 2008 reasons of the food crisis was climate change and land-use public discussion and an increased cereals price (Rawashdeh & Maxwell 2001 in BGR 2013). A close correlation between food market price, rock-phosphate and phosphate fertilizer price can be determined. Additionally the phosphate price is influenced by local prices that means local Subsahara-Africa fertilizer sales can be six-times more expensive than the global world market price due to inefficient trade, higher transport costs and taxes and deliveries (Cheminocs & IFDC 2007 in BGR 2013).
- The price increase of *Lithium* has been induced by the increasing demand of the battery industry beginning after 2003, but also by higher energy and transport costs. The result is a price increase from 170 US$/kg indium (2003) up to 795 US US$/kg (2007) (Fraunhofer ISI, IZT 2009) and is around 610–650 US$/kg in 2013 (Minor Metals Trade Association 2013).

To prohibit competition situations and price shocks means to change resource strategies supply chain policy. Important keywords are resource diversification,

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[1] All dollar-data in this article are current dollars.

substitution if possible, reduction of dissipative losses on the recycling path and general integration of a high rate of secondary material in production.

The following chapter will focus on future options to reduce the risk of rising prices, dependencies and price volatility. The future vision of energy self-supply and autarky seems to be much more tangible than to serve material demands by a local market. Minerals today are exploited on a global market due to the worldwide spread deposits for minerals. Only a growing secondary raw material market can reduce dependencies from mineral imports with increasing prices.

13.2 Energy Security by Renewable Energy Self-Supply and Autarky

The renewable energy transformation in Germany is based partially on the strategy of decentralization and local energy supply. But the future dimension of decentral energy supply plants and feasibility of regional autarky and energy autonomy (Scheer 2006) is still controversial discussed.

Energy autarky concepts in Germany are discussed in connection with renewable energy supply and changing energy supply systems of energy transformation. Villages, regions, companies and even states (for example Bavaria with a high radiant intensity in Germany) set up the political aim to be energy autarkic in the future. The market research institute trend:research in Germany has noticed 240 energy autarkic municipalities in Germany (based on a balance) in 2011 with an estimated increase to 480 in 2020 (Schulte 2013). Actually German cities and villages re-establish the local authority control over energy supply. They invest in renewable energy plants, repurchase the local grid and participate in energy supply offers by public utilities (investment, production, marketing, supply).

In a recent published report by order of Umweltbundesamt (2013) on the question of decentralized renewable energy supply structures is concluded that "island energy autarchy solutions" will not serve energy transformation as a whole in Germany (Peter 2013). Decentralized energy systems cannot serve sufficient the high demand of industry in any industrial region and big city and storage costs are partially too high. A sustainable strategy is noticed to be "connected regions". Self-supporting local autarkic energy supply is highly linked to rural areas. Biomass-based renewable energy concepts depend on land-use for energy crop production and biogas input material supply, rural areas can offer. Rural regions have also the advantage of suitable areas for renewable energy power plant sites with storage requirements (biogas, wood-ship).

But apart from biomass concepts in regions also cities force renewable-energy strategies to raise their independency from fossil energy imports. Suitable city areas for wind power plants or biomass plants are much more difficult to find, but city roof areas (production halls, private houses) have still not been used sufficiently. Cities have the advantage of a compacted energy demand which opens options for joint combined heat and power concepts in concentrated settlement areas and industrial parks.

The changes of the German Renewable Energy Law (EEG 2012, 2014) in the last years had the aim to strengthen self-supply structures of PV electricity in private houses and companies. Investments in PV-plants today include a concept of maximum electricity self-supply to reach the highest return on invest in existing feed-in-tariff and subsidies structures.

According to the changing climate, weather and seasons in Germany the challenge is to balance load profiles of different users with the volatile supply dependent on daily sun hours, wind intensity and seasonal changes.

The energy load profile autarky has actually been supported in German renewable energy policy by funding energy storage systems for private house owners since 2013. Actual private house PV plants reach an autarky level (AL) of 60 % without an electricity storage system and reach 75–100 % autarky level with an integrated electricity storage system like a battery. The autarky level expresses the internal consumed energy (EIC) in relation to the grid energy consumption (ECGrid) all over a year $\mathrm{AL}(\%) = \frac{\mathrm{EIC}}{\mathrm{EIC}+\mathrm{ECGrid}}$.

A high autarky level will increase the independency from electric supplier prices and reduce electricity costs of the PV plant owner. Additionally, the German renewable energy law supports a rising internal consumption (EIC) of own produced PV electricity (EIP) by differentiation of the feed-in tariffs (balance autarky) which is independent from the daily demand but balanced in the yearly account, $\mathrm{EICR}(\%) = \frac{\mathrm{EIC}}{\mathrm{EIP}}$. Technically, energy autarchy today is feasible in private houses, but especially the needed additional storage capacity (heat, electricity) heightens the construction costs of new houses. From the national economic perspective decentralized connected renewable energy supply concepts for settlements areas and refurbishment of old buildings might offer a more cost-effective solution.

Renewable energy autarky concepts can be typed in different kinds (see Table 13.2). Isolated energy application autarky is normally chosen in selected cases for example for an apartment building energy supply to demonstrate independency, houses in outdoor areas, leisure areas or as a concept for a whole small island.

An actual research project funded by German ministries BMU und BMBF is the small island Pellworm in the North Sea, actually growing as a Smart Region Pellworm. Pellworm is an example of a renewable electricity surplus island, producing three times more electricity than the island total demand. Because of volatility of demand and supply actually Pellworm has to be connected to the public grid by a sea-cable. A research project started in 2013 will test components to have a 100 % electricity self-supply by combining technical elements: smart meter, central storage systems at the hybrid power plant (solar, wind, biogas) with lithium-ion batteries and redox-flow-batteries, decentralized storage systems in households and additional electricity storage heating (BINE, Energyload 2013). Rural areas will serve a high potential of energy self-supply in form of decentralized systems.

Table 13.2 Renewable energy autarky concepts

Load profile autarky (PV)	PV cell with battery storage system, buffer storage for heating system, connection to public grid for security reasons
Balance autarky	Renewable energy is fed partially in public grid to balance volatility
Island autarky	Isolated energy application autarky for houses and islands no connection to public grid, outdoor area, leisure residence, island (single solutions)
Energy exporting village/county energy exporting company	Renewable surplus electricity (balance) and heat of combined heat and power plants, heat, steam, electricity offers to neighbor companies or public buildings (energy symbiosis)
Energy surplus house	36–200 kWh/m^2 and year energy surplus (balanced) “plusenergy“houses
Local energy supply networks	Cooperatives: Local heat networks, PV and wind-parks, energy and waste-to-energy symbiosis in industrial parks
Virtual energy autarky	PV-cells on roofs of a total village (solar cadaster calculations), potential wind power calculation on priority areas of a state, village

Source: Authors’ own compilation

There is the potential in many rural areas and villages to become a net-export community for renewable electricity. They have additional local added value by serving cities with electricity and heat. The early started bio-energy villages Morbach (Hunsrück), Kalbe (Milde) and Jühnde (Lower Saxony) in Germany show, that an electricity energy surplus production is possible.

Virtual calculations of the electricity potential on base of available roof space in villages for PV plants show normally an electricity surplus. An example is the Zero-emission-village St. Wendel in the state of Saarland. Using all appropriate roofs 380.000 MWh electricity could be provided, the actual demand of private households was about 137.000 MWh (2011), that means a factor three higher PV electricity potential than the private household demand (St. Wendel Wirtschaftsförderung 2011) This example seems to be portable to many village situations and especially industry roofs seem to be not used to capacity for PV cell or solar heat production purposes.

The future needs smart investment models like company/municipality/citizen co-operations to facilitate a higher solar production rate and use the mentioned potentials. Summing up, it can be expected that a sustainable mix of renewable energy supply has chances of local autarky only in rural areas. Rural villages and districts have also the potential of energy export to urban areas. A whole renewable energy concept in Germany needs a mix of decentralized and central supplies like offshore wind power plants. Renewable heat supply is much more bound to district and local systems.

13.3 Local Responsibility for Energy Security by Cooperatives and Private Investments

In Part II has been discussed the limits of private investments in expensive electricity and heat storage technologies. That is the reason that single company or single house concepts are not always an economic solution for a future renewable energy supply.

A rising amount of cooperatives (see Fig. 13.4) have been established in renewable energy supply to run wind-parks, solar parks and local heat nets. The idea behind cooperative investment is a rising awareness and responsibility of citizen for local energy supply, a rising positive image of renewable energy in German population and clear revenues for member investments in cooperatives. The membership can be limited to a residency of the cooperative region and exclude foreign influence and investments. Local banks trust in local transparent cooperative structures and bank loans are much easier to realize than in many private cases.

The risk for a participation in cooperatives investment is very low. Investments get on average return on invest of 4–6 % of the capital, investment security is higher than in the financial-crisis shaken classic financing by a bank. In general German Renewable Energy investments done by cooperatives have reached an investment level of 1.2 billion EURO invested in projects until 2013. 90 % of the members of co-operatives are private persons, in total there are 130.000 members in energy co-operatives in 2013 in Germany. The renewable energy plants run by co-operatives produce in total 580 Mio. kWh electricity per year (DGRV, BSW, AEE 2013). PV, CHP, solar and geothermal heat co-operatives are not automatically bound to rural areas. They will have an important function in future urban renewable energy supply.

The most investments of German citizen have been done to build wind-power and solar parks. The focal point of energy transition has been laid on electricity supply in the beginning years, disregarding that room heat and warm water have a much higher demand in private households energy consumption (440 billion kWh room heat, 75 billion kWh warm water in total German households in 2011) lighting (12 billion kWh), electric devices (57 billion kWh) and cooking/ironing/drying (40 billion kWh) (Statistisches Bundesamt 2012).

Private ownerships and investments in energy cooperatives for renewable energy plants are a good option to reduce risk of energy supply and decrease dependency from central suppliers. A survey of University of Lüneburg and trendresearch (2013) shows, that citizen are the “economic leaders” of energy transition in Germany. Half of renewable energy plant capacity (except offshore wind power) is owned by citizen. German citizen own 51 % of total onshore wind power plants and 48 % of total photovoltaic plants (48 %). The results underline the positive image of renewable energy investments for citizen.

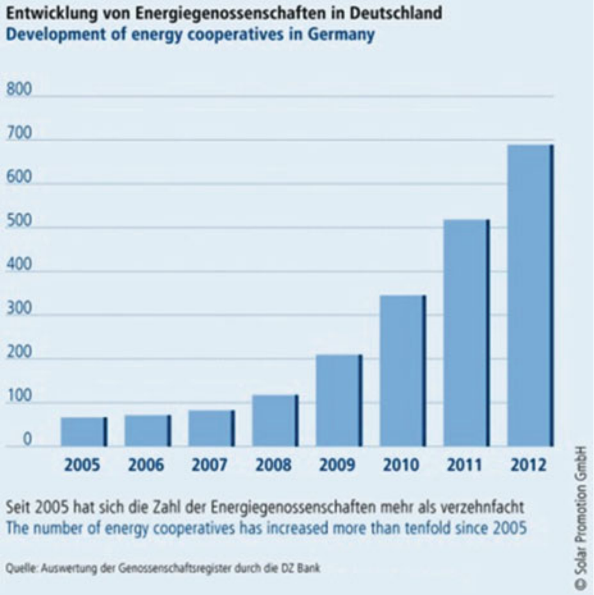

Fig. 13.4 Growth of number energy cooperatives in Germany from 2005 to 2012. *Source*: DZ Bank (2013): Evaluation of the German Register of Cooperatives

An additional option of future local heat supply are "neighbor heat nets" of companies based on contracts. Especially in industrial parks of with a high percentage of primary industry there are experiential options of matching energy intensive industries (smelter, metallurgic processes) with heat demanding production sectors (drying food, pellets). An energy export to a neighbor company makes sense, if all options of reduction of heat losses and internal heat recovery are utilized. Single contracts between heat exporters and heat demanding company will open new chances becoming more independent from fossil based price risks. These kind of co-operation of companies is discussed internationally as energy symbiosis, the total potential in German industrial production structures still cannot be estimated but has to been looked at in future research.

A best practice model for heat net development is Denmark with a 40 year experience in district heating. After the oil crisis in 1973, the Danish government pushed continuous investments in district heating systems. That time, the district heat was fossil based. Renewable energy supply was hardly possible in heat nets and only in the beginning stages. Today the remaining fossil based heat supplies like natural gas are gradually substituted by renewable energy sources (see Fig. 13.5).

In 2011, Danish district heat systems have reached an input of renewable heat from energy and waste of more than 50 % (Danish Energy Agency, DBDH 2013). About 80 % of district heat in Denmark is co-produced with electricity, reaching a high level of efficiency (Danish Energy Agency 2013). The experience in Denmark,

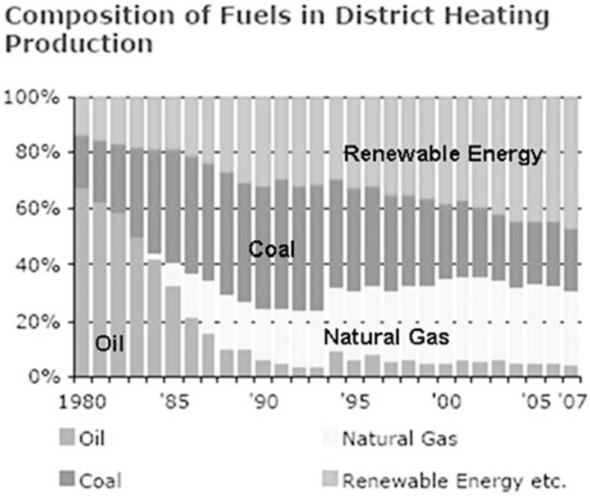

Fig. 13.5 Increasing renewable energy supply (biomass, solar) of district heating in Denmark. *Source*: Elleriis, Jan (2009) presentation on Copenhagen Energy Summit

which has 63 % household supply by district heat nets (Danish Energy Agency DBDH 2013) is an excellent example for a sustainable heat supply systems which contribute for energy safety all over the country. Denmark is also the leading European country with most experience with solar based heat nets. The Danish Government has set a target for solar district heating to reach 1.4 TWh-thermal in 2020 (8 Mio. m^2 solar collector area), meeting 10 % of Denmark's district heating demand.

The examples from Germany and Denmark show the regional potential to reduce the risk of energy supply by a rising awareness and responsibility of citizen and regional stakeholders. Future energy security will be a diverse supply mix from different sources. There is no single solution on a secure renewable energy supply. Regional cultural history, existing ecosystems with a different primary production potential, existing land-use structures and the energy customers (population density, branches) influence the future energy supply concepts in each area. Energy Cooperatives offer economic advantages for investments in renewable energy plants, they can additionally support the connection between energy supply and demand. Efficiency concepts for the autarky of one-family houses might be counterproductive for district heating concepts, no longer needed in sparsely populated areas. Federal structures also have the limit, that house owners cannot be forced to participate in a local heat net. A municipality can influence settlement criteria in a building area or greenfield industrial sites by decisions on the infrastructure offered (heat net, combined heat and power plant, solar oriented positioning of the roofs. But the compulsory connection and usage of green heat and green electricity is not enforceable for community aims in any area.

The aim of the final chapter was to demonstrate future options how energy security can be strengthened by many types of local decentralized energy supply. In Germany there are technical solutions for electricity and heat autarky, which are especially reasonable in rural areas. Houses energy autarky might not be always the best solution from the economical side and has to be balanced in communication with district plans for future renewable energy supply. Central energy exporting areas in Germany will be offshore wind-power plants in the North and Baltic sea in a dimension of needed investments, still discussed. Also bioenergy villages will offer their PV electricity surplus to neighbor cities. Energy security requires additionally a smart inter-connection of regions to balance volatility in demand and supply and adjust the system to changing weather conditions. Smart grid and meters and new communication structures are inevitable to meet all requirements of an economic feasible, transparent and sustainable system.

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Chapter 14
Responsible Material Flow Management: The Case of Waste Management in Developing Countries

Johann Fellner

14.1 Introduction

The goals of waste management are twofold: Firstly the protection of human beings and the environment, and secondly the conservation of resources with a growing importance (contributions of Schebek et al. in Part IV and Zepf et al. in Part VI). Under the principles of sustainability, these goals should be reached in a way that does not impair the well-being of future generations. Thus, waste management practice should not export waste related problems in space and in time, requiring e.g. after care free landfills.

In most countries with affluent economies goal number one has been reached by sophisticated technical solutions. Hence these countries are focusing on goal number two by introducing extended recycling strategies and schemes, meaning in essence that waste is increasingly redirected from landfills to recycling or thermal utilization plants (see Fig. 14.1).

The main question that arises: Are these concepts and technologies developed and applied in affluent economies also appropriate to solve the waste problems in developing countries, where people can not spend more than 10 € per capita and year on waste management?

The goal of this manuscript is to investigate on a general and superficial level, how differences in the economic development determine waste management strategies, concepts and measures in three different regions. In particular the waste management systems of the cities Vienna, Damascus, and Dhaka (see Fig. 14.2) have been investigated.

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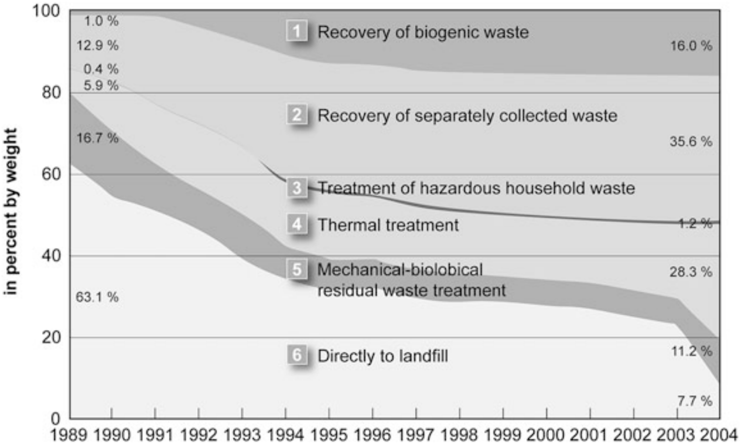


Fig. 14.1 Disposal and recovery of municipal solid waste (MSW) in Austria from 1989–2004 (EPA 2009)

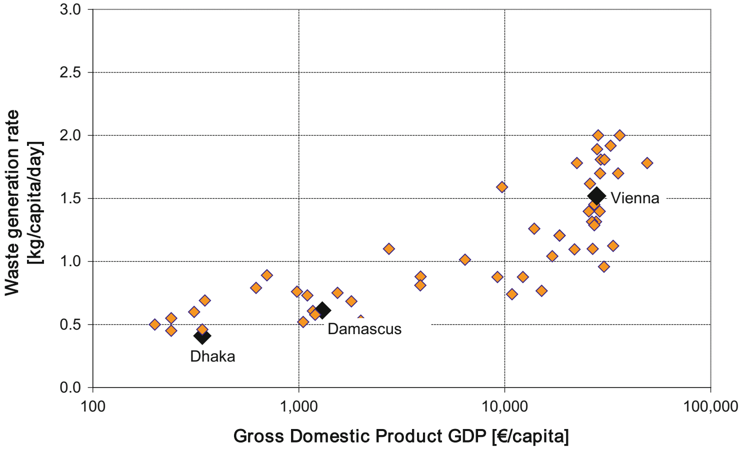


Fig. 14.2 Waste generation rate versus gross domestic product (*Source*: data from World Bank 1999; METAP 2000; OECD 2005)

14.2 Methodology

Based on the methodology of Material Flow Analysis (MFA), as introduced by Baccini & Brunner (1991), the municipal solid waste management (MSWM) of three cities Vienna, Damascus and Dhaka are investigated and evaluated regarding the fulfilment of the goals of waste management. The investigations are based on the following system, considering wastes from households and small enterprises, only (Fig. 14.3).

Based on the results of the material flow analysis, the performance of each waste management system with respect to the overall objectives of waste management

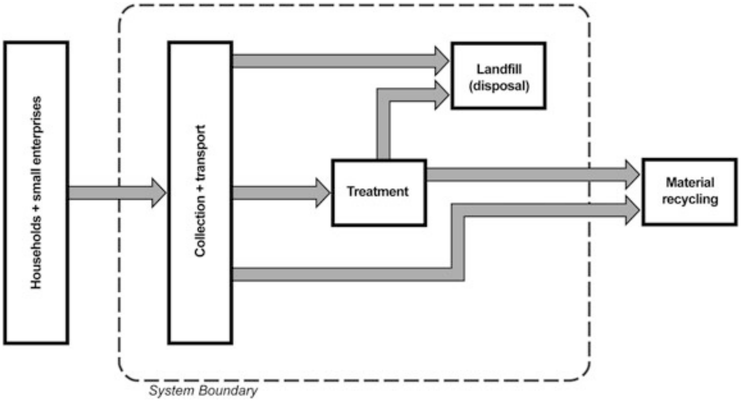


Fig. 14.3 System definition—Municipal Solid Waste Management

(protection of human beings and environment, conservation of resources, and sustainability) is evaluated. Since sufficient data for detailed cost benefits analysis are missing, in particular for the regions of lower economic capacity, the assessments are focused on the following main indicators:

Human health related indicators:

- Percentage of the population having direct contact with waste (scavengers and habitants of residential areas without waste collection service)
- Emissions of dioxin and furan (expressed as Toxic Equivalent TEQ)

Environmental protection related indicators:

- Greenhouse gas emissions (expressed as CO_2-Equivalents)
- Nitrogen emissions to the hydrosphere
- Long term emissions from landfills or disposal sites (final storage quality)

Resource conservation related indicators:

- Rate of material recycling
- Rate of waste landfilled
- Required landfill space (volume)

Economic indicator:

- The ratio of overall expenses for solid waste management to the Gross Domestic Product (GDP) of the region

Based on the status quo of the waste management systems, different scenarios such as

1. Full coverage of waste collection service
2. Upgrading of existing disposal practice to sanitary landfilling

3. Mechanical biological pre-treatment of collected waste
4. Incineration of collected waste
5. Implementation of separate waste collection

are analyzed in the view of their impacts on costs and on reaching waste management objectives using the simplified environmental indicators as listed above. In the scenarios 2–5 the waste collection rate of the status quo is assumed. Finally, preliminary suggestions are given regarding strategies for waste management in countries with a low GDP in the range of 200–2,000 €/capita and year.

14.3 Results

Status quo of waste management systems

City of Vienna

In the city of Vienna (Austria) the household waste generation rate amounts to 540 kg per capita in 2002. Many waste fractions are collected separately (21 different fractions). The subsequent considerations are focused on the main waste streams (see Fig. 14.4). In the considered year over 50 % of the household waste generated was treated in waste incineration plants, around 40 % was recycled (including 10 % composting) and 10 % was directly landfilled without any pre-treatment. The overall expenses for waste management in Vienna were around 200 €/to waste (or 106 €/capita/year). This equals almost 0.40 % of the Gross

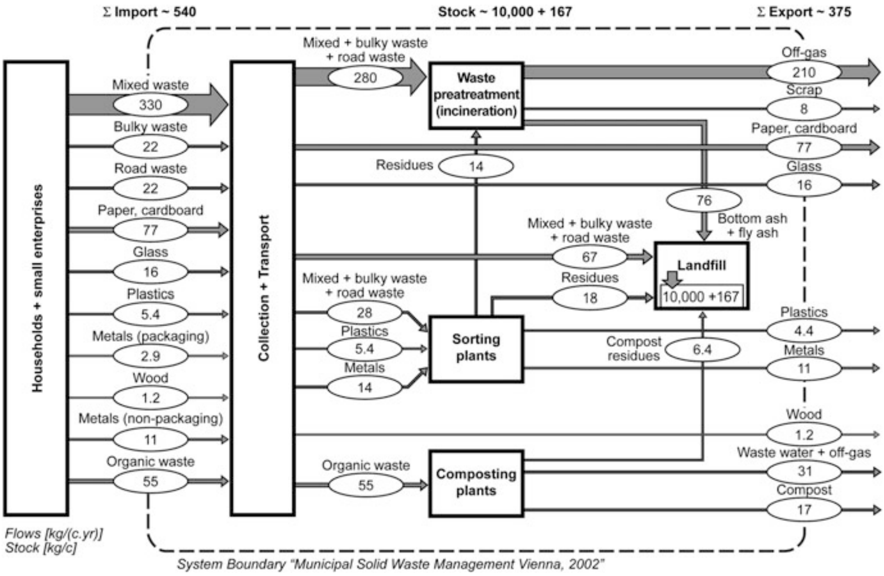
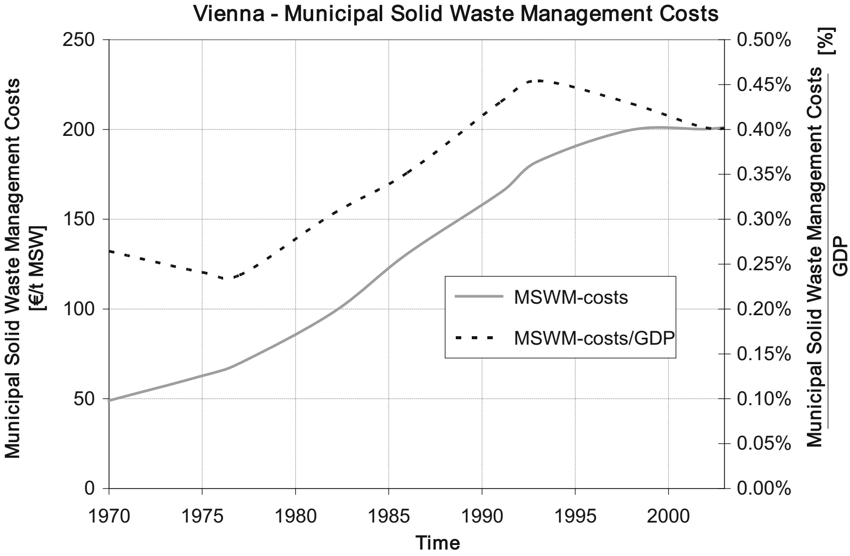


Fig. 14.4 Municipal Solid Waste Management—Vienna (2002) (*Source*: MA48 2002)



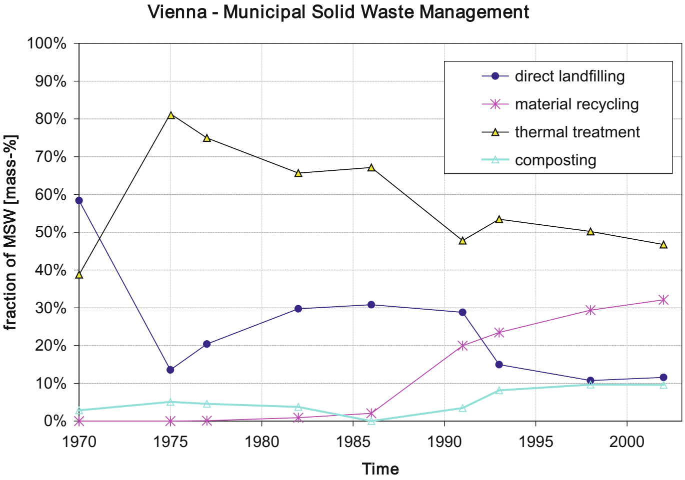


Fig. 14.5 Development of MSWM in Vienna since 1970—specific costs of MSWM (*upper figure*) and share of waste treatment options (*lower figure*) (*Source*: MA48 2002; MA5)

Domestic Product (27,300 €/capita). Around 60 % of the budget is required for collection; the rest is spent on treatment (29 %) and disposal of waste and residues (12 %). During the last 30 years the costs for collection, treatment and landfilling of waste rose by factor 4 (from 50 €/t to 200 €/t). However, if the corresponding increase in GDP is taken into account, the increase since 1970 amounts to only 60 % (from 0.26 % of the GDP in 1970 to 0.40 % in 2002, see Fig. 14.5).

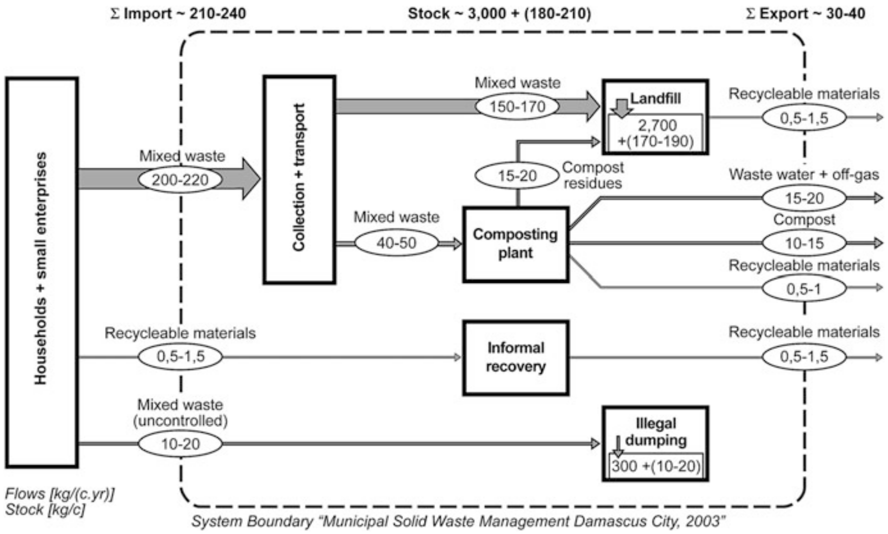


Fig. 14.6 Municipal Solid Waste Management—Damascus (2003)

14.4 City of Damascus

In Damascus (around two million inhabitants) household waste is not separated but collected together in one bin. In 2003 the waste generation rate per capita amounts to 230 kg/year (Alboukhari 2004). More than 90 % of the inhabitants are served by regular waste collection managed by the municipality. The remaining inhabitants (up to 150,000) live in shantytowns of the city without waste collection service. In addition to the formal sector organized by the municipality, an informal sector of waste collection and waste recovery exists, operated by thousands of scavengers (Fig. 14.6).

14.5 Dhaka City

In Dhaka city (~10 million inhabitants) less than 50 % of the population is served by a formal waste collection system. The annual household waste generation rate per capita is between 110 and 150 kg (Zurbrugg et al. 2005). Waste recovery and recycling are performed by an informal sector of more than 100,000 scavengers (Sinha 1993) (Fig. 14.7).

An overview of the solid waste management practices in three cities is given in Table 14.1. The expenses for MSWM per capita and year vary from less than 1 € up to 100 €. Relating the figures to the local GDP, the expenses for MSWM range from 0.18 % of GDP in Dhaka City to 0.40 % in Vienna. In the regions of lower economic capacity more than 80 % of the SWM budget is spent on collection and

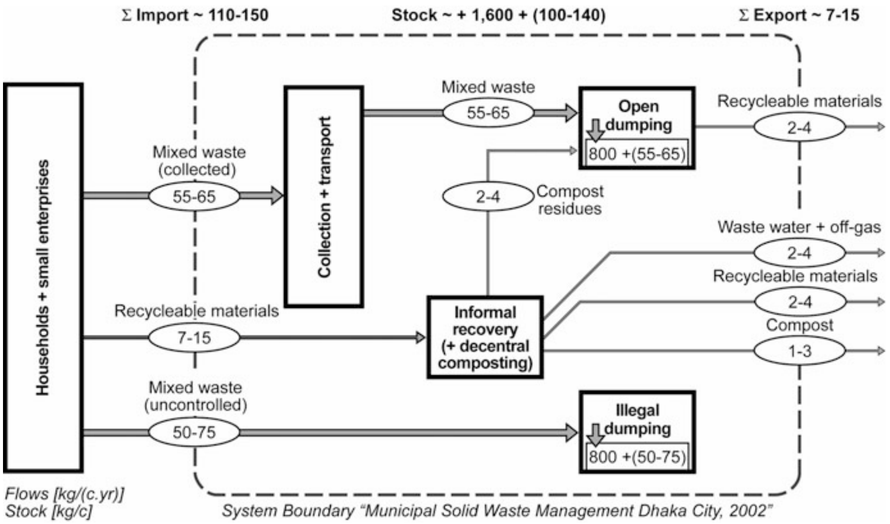


Fig. 14.7 Municipal Solid Waste Management—Dhaka City (2002)

transport (Brunner and Fellner 2006). It is therefore comprehensible that decentralized waste treatment, which requires less transportation, is seen as an approach to reduce collection costs and help to control the municipal budget for waste management. However, on the other hand specific treatment costs in small facilities that adhere to the same emission control standards are considerably higher than in large plants.

Analyzing the data of Table 14.1 it becomes obvious, that the major factor determining the level of development of waste management is the economic capacity of a region. Other factors such as public awareness of environmental problems, acceptance, environmental laws, cultural conditions, and so on, are either going hand in hand with the economic potential or are generally of smaller importance. Based on the information about the GDP of a region, the "state" of the waste management system can be largely assessed.

14.6 Assessment of the Investigated Scenarios

All investigated scenarios are analysed in view of their impacts on costs and on reaching the waste management objectives, whereby the fulfilment is evaluated by single environmental indicators. All assumptions regarding the costs of the different MSWM practices are summarized in Brunner and Fellner (2006). "Environmental" consequences of various MSWM scenarios, expressed as percentage of the status quo, are given in Fig. 14.8. The reduction potential on Greenhouse gas emissions is directly influencing climate change induced world-wide impacts (contribution of Nordås and Gleditsch in Part I)

Table 14.1 Comparison of the status quo of Municipal Solid Waste Management in Vienna, Damascus and Dhaka (cf. Brunner and Fellner 2007)

	Unit	Vienna (2002)	Damascus (2003)	Dhaka (2002)
Capita	[Mill.]	1.56	2	10
MSW generation	[t/a]	850,000	450,000	1,400,000
MSW/capita	[kg/capita/a]	545	225	140
MSW/capita/day	[kg/capita/day]	1.5	0.6	0.4
Total Costs	[Mill. Euro/a]	169	7.5	6.6
Costs per tonne MSW collected	[€/t]	200	18	10
Costs per capita	[€/capita/a]	106	3.8	0.7
Gross Domestic Product (GDP)	[€/capita]	27,300[a]	1,360[a]	370[a]
Costs MSWM/GDP	[%]	0.40	0.28	0.18
Selected Indicators for the Assessment of Solid Waste Management Systems				
Percentage of population having direct contact with waste	[% of total population]	< 0,01	5–10	40–50
Dioxin/furan emissions	[µg TEQ/capita/year]	0.1	30	130
N-emissions	[g N/capita/a]	7	41	170
Greenhouse gas emissions[b] (CO_2-equivalent)	[kg CO_2/capita/a]	27	98	92
Material recycling rate[c]	[%]	25	7	6
Landfill volume required	[m^3/capita/a]	0.14	0.23	0.21
Disposal rate	[kg/capita/a]	167	185	129
Final storage quality		no	no[d]	no

[a] IMF (2009)

[b] Methane emissions from landfills calculated according to IPCC (2002)

[c] Including compost

[d] Final storage quality could most likely be reached in Damascus due to the prevailing arid climate "without" leachate generation from landfills in the long term

The hygienic hazard for the population having direct contact with waste can only be reduced by the introduction of a complete collection service. Other investigated scenarios, such as the improvement of waste disposal sites to sanitary landfilling or biological or thermal waste treatment, will mainly have a direct impact on the environment (e.g., N-emissions to hydrosphere, greenhouse gas emissions or land use for waste disposal), with likely indirect effects on human health. Additionally, the environmental benefits of the scenarios 2–6 are strongly limited by the waste collection rate achieved.

In Damascus separate collection of paper, glass, plastics and metals can potentially increase the conservation of resources with a simultaneous reduction of the expenditures on waste management. However, the income of thousands of scavengers would be cut by this measure if not integrated into a formal collection scheme. The same strategy (separate collection) would not be beneficial in Dhaka City, since

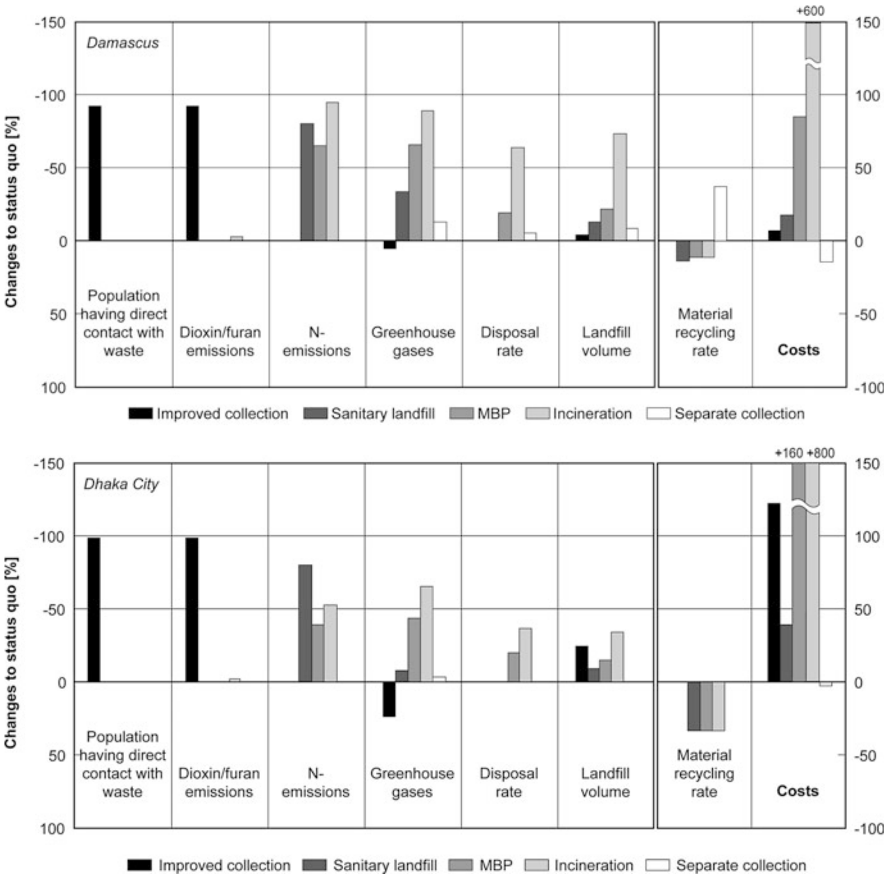


Fig. 14.8 Changes of goal oriented parameters for different scenarios of Municipal Solid Waste Management in Damascus und Dhaka City

the recovery of recyclable materials, performed by the informal sector, already occurs at a high rate, which can hardly be improved by a formal separate collection system.

Conclusions

The main objectives of solid waste management are twofold: (1) protection of human health and environment in a sustainable manner and (2) conservation of resources. Goal number one has been reached in most countries with a high GDP. Hence, these countries focus on goal number two by introducing extended recycling strategies and expensive pre-treatment technologies. In regions of lower economic development (e.g., Syria and Bangladesh) current

(continued)

practices of solid waste management still do not meet the primary objective: the protection of human health. Thus, waste management in these regions must focus on different issues than in affluent countries. Most important is the introduction of a complete collection service, since this is the most effective way to protect human health. In case of sufficient (internal) financial resources for waste management, this key measure is to be supplemented by upgrading the current disposal practice to sanitary landfilling. This measure will reduce the costs of environmental impacts effectively. Other measures investigated are either too expensive (e.g., mechanical-biological or thermal waste treatment), difficult to implement or hard to accept by local stakeholders (e.g., separate waste collection would cut the income of scavengers). Before emphasis is given to reach the goal of resources conservation, the main objective of waste management, that is to protect human health and the environment, has to be fulfilled. In general it can be concluded that appropriate waste solutions are regionally specific and largely dependent on the economic development of a region.

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Part V

Water Conflict Prevention by Water Resource Management

Chapter 15
Water Gap: The Overuse of Fresh Water

Thomas Kluge

According to the United Nations report on the status of the achievement of the objectives set in the Millennium Development Goals, there are between 900 million and 1 billion people with no access to clean drinking water worldwide (around 750 million of them are in rural areas). The situation is even worse when considering sewage. Around 2.5 billion people do not have basic sanitary facilities, and given the population growth, this figure will hardly change. Approximately 1.5 million people die yearly as a result of water-borne diseases (Heymann et al. 2010: 4).

The present discussion within the UN of current and future gaps in water supply systems is based on certain assumptions: a growing population; increasing nutritional needs; and no improvement in either water governance or water use efficiency (contribution of Zimmermann et al in Part V). Based on these premises, a gap in the water supply system equivalent to 2.8 km^3 is estimated, with the largest part of the gap expected in India, China, South East Asia and Africa. According to this analysis, in 20 years half of currently available fresh water will be missing (IFC 2009: 16).

The alarming situation on the future water gap of resource water cannot be viewed in isolation. It is connected to other issues such as agricultural production, food security, energy security, economic growth, poverty reduction, loss of biodiversity and the adjustment to the consequences of climate changes (Schewe et al. 2014; Wada et al. 2013). In short, water is in competition with other goods such as agriculture, drinking water, industry and energy.

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15.1 Governance of Ground Water

70 % of the global fresh water resources are used for agricultural purposes. In many developing and emerging countries the water use for agriculture is even over 90 %. The second largest user is the industrial and energy sector with a combined share of 20 %. Private households account for just 10 % of worldwide water use. However, the share of water use varies considerably from sector to sector in relation to the development level and prosperity of individual countries (Heymann et al. 2010: 5).

Agriculture is by far the biggest user of water, and therefore, the main reason that many river basins—for example, the Indus, the Tigris, and the Yellow Rivers—are overused. The result of such overuse is that the entire river systems run dry during the times of vegetation when the plants need the most water, and no longer flow into the ocean, as shown in the illustrations found in atlases (Pearce 2007: 120ff.).

In many areas of the world the overuse of river systems leads to a systematic exploitation of groundwater. This is found in particular in those areas where metropolitan concentrations create an increasing demand for potable and industrial quality water that cannot be covered by surface water alone. The great metropolitan agglomerations of Latin America, such as Mexico City, Rio de Janeiro, Lima, as well as those of Asia, such as Peking, Shanghai, Hong Kong etc., are all characterized by such problems. These megalopolises extend their supply systems into their hinterlands, thus, spawning conflicts over the water use with surrounding areas (Flörke et al. 2013; Hoff et al. 2014). In this way, the solution of the problem is simply displaced in space and time, in that distant surface water resources (space) and deep groundwater streams with geological time frames for recovery (time) are incorporated into metropolitan water supply systems.

Deep groundwater streams are also used for agricultural irrigation. As a result conflicts arise in the catchment areas of mega-cities concerning the water to be used for agricultural, drinking needs and industry/energy. The economic limitations placed on the surrounding areas (curtailing of agriculture and other regional economic activities) are as a rule not addressed (that is, there are no regional plans for compensation or transfer).

As far as the groundwater itself is concerned poor regulation of groundwater abstraction rights and rates of recharging is the rule, where, on the contrary, the goal should be to abstract no more water than can be replenished either over, on the average, a decade or in 30 years (UNESCO 2009: 127f.). An average of 30 years is, in fact, a sensible hydrological recharging rate with respect to large bodies of groundwater. However, it is often the shorter precipitation and recharging periods (5–7 years) which lead non-linearly to so-called ‘jump-effects’ (sudden changes, especially drops, in groundwater levels), which are ecologically very problematic and unsustainable (for example, the exhaustion of groundwater during vegetation; cf. Kluge 2000: 136ff.).

The practice of withdrawing groundwater without an appropriate monitoring system leads to uncontrolled drops in groundwater levels. This process of unregulated drops in groundwater levels is intensified in many areas of the world

(India, Jordan, South East Asia and Latin America) by the subsidization of energy prices, in particular, the price of oil for diesel water pumps in order to maintain agricultural production (Pearce 2007). In the USA, irrigation is dependent on farming, in fact, threatened because banks are refusing to provide loans for energy costs if harvest incomes seem too risky (Friebe 2009: 14).

Entire regions around the world are being drip-fed with deep groundwater (fossil water). This water, millions of years old, should be regarded as a non-renewable resource, for its renewabilty rate is, if such water is renewable at all, measured in geological time frames. The northern edge of Africa with the Sahara as hinterland, the Middle East (Libya, Saudi Arabia), as well as Iran, Pakistan, India and Northeast China are all areas where the irreversible exploitation of fossil water is taking place. These ancient waters, used for agriculture, are evaporated and lost. The irreversibility of the lost of fossil waters demands that a line be drawn: waters must be managed according to proposed use and their substitution or renewal rates; and non-renewable resources should be as much as possible exempted from use or used only for the most pressing needs (for example, exclusively for drinking water) (Foster/Loucks 2006: 13f.; UNESCO 2009: 160f.).

The loss of groundwater also affects the ecological function of geological bodies of water, wetlands and lakes. Wetlands are not only natural purification stations for water but they also safeguard local and regional climate and ecosystem-services such as fish and fiber for building materials, as well as food, in particular the fruit-bearing trees that grow along shore areas. Wetlands also have an important compensation function: they guarantee dry weather flow during droughts and thus function as a buffer. In addition, wetlands safeguard biodiversity, for example, when particular habitats must draw on groundwater supplies through the capillary fringe. At present, entire lakes and wetland areas are drying out, paradigm cases being Lake Chad, the Aral Sea and the Dead Sea (MEA 2005; Anderson et al. 2008: 25f.).

The logic of this process, caused by farming needs and the drinking water needs of settlement areas, is the existence of a systematic competition over the use between urban areas and agriculture. The usual result is the loss of wetlands and lakes, the drying up of rivers in arid and semi-arid regions, and the extensive sinking of groundwater levels.

The technologies for tapping into groundwater (drill technologies and hydrological exploration methods) have progressed much faster than corresponding necessary governance systems (including groundwater monitoring), much to the detriment of groundwater reserves. The systematic exploitation of groundwater in many parts of the world is on the rise. That is all the more the reason to hold to the basic principle that non-renewable resources (such as fossil groundwater) should be used extremely carefully and efficiently. In fact, it is extremly necessary to organize the society in such a way that water needs are covered by the increasingly efficient use of renewable resources. One particularly promising way of increasing such efficiency lies in water re-use, a method of recycling water that has a long tradition in certain industrial sectors (UNESCO 2009: 120f.).

Currently, unregulated anarchy rules in many parts of the world with respect to the use of deep groundwater, a situation that many national governments welcome in fact. It is not only a problem of subsidies for oil drilling. In India, Iran, Mongolia and in the northeast of China groundwater is being extracted as a result of the Green Revolution. The finiteness of groundwater often displays itself in the regions mentioned when pumping processes shift the saltwater/freshwater relationship; as a result the dwindling freshwater resources become salted.

The designation of groundwater water basins and the (state) regulation of groundwater tapping in the line with the rules of sustainability (for example, the creation of calibrated groundwater models) require powerful water-control institutions. And these institutions must have the necessary specialist knowledge needed for establishing and monitoring groundwater recharging rates (monitor programs).

15.2 River Diversion as a Means to Compensate for Inter-regional Conflicts of Use

The policies of large countries, however, are moving in a different direction, with an attempt being made to compensate for bottlenecks caused by the overuse of rivers and groundwater by introducing technological solutions aimed at expanding the supply of water. China has pushed this approach the farthest. Using large-scale river diversion China wants to put an end to the shortage of water in the North China Plain by diverting water from the water rich South to the dry North. After its completion by the middle of this century, this project will transfer nearly 45 cubic kilometers of water from the Yangtze to the Yellow River. This equals the entire current water flow of the Yellow River. The diversion consists of three sections: the eastern section will bring water from estuary regions to Shandong Province and Tianjin City; the middle section will bring water from the Danjiangkou Reservoir to Beijing and the surrounding area; finally, the western part will move water from source areas directly into the upper flow of the Yellow River.

In addition to the immense impact of this project, including massive resettlement and the ecological loss of wetlands and their important compensation areas and buffer zones, it also raises the general question as to whether food production would not be better ensured through intensive agriculture in the South, especially considering the large part of the diverted water to the North is lost to evaporation during plant production in the North's desert-like climate. The assessment of a virtual water trade would show a positive balance, given the immense costs of such a water transfer project (Jöst et al. 2006; DeSalle et al. 2008).

Another example is Egypt. The country has increasing problems guaranteeing a secure supply of food due to insufficient quantities of Nile water given the fact of settlement pressures and population growth in the Nile Delta. As a result Egypt wants to construct a canal through the second largest wetlands area in the world, the

Sudd (in Sudan). Cutting through the White Nile's large wetland in Sudan would bring 5 km^3 more water per year (by saving water from evaporation as a result of the increased runoff flow in the marsh). However, three times the amount of water saved in this way (15 km^3) evaporates every year from the surface of the Lake Nasser Reservoir. Aside from this, Egypt uses a huge amount of fossil water in the desert west of the Nile in order to supply farms and new cities (Peterson 2008: 2f.).

Large-scale water transfers are also planned in other regions of the world. For example, India's "River Interlinking Project" would transfer water from the Ganges and the Brahmaputra, which contain large amounts of monsoon water, to the dry South (Khalid 2004: 554f.). Spain continues to consider redirecting water from the Ebro to the dry southern areas of Murcia and Almeria (Breuer 2007). And Russia is taking another look at old Soviet plans to transfer water from the big Siberian rivers to the cotton-growing areas of Central Asia. Such plans would cost enormous sums of money—official estimates in India reach 200 billion dollars, while in Spain the cost of such water transfer projects would be even higher than building desalination plants (Schepers 2005: 6). In addition, one must consider the damage to the rivers from which the water is taken. These large-scale technological systems are supply-side approaches, mainly aiming at an increase in the supply of water to the areas suffering from a water shortage. They are a reaction to the overuse of regional rivers and groundwater.

Worldwide there has been developed a kind of culture of dehydration, not only in semi-arid areas but in tropical zones as well, as a result of the intensive use of rivers and the unregulated use of groundwater due to dense settlement and increased agricultural production. The Dead Sea, for example, as well as the Aral Sea, has broken up into several parts.

The proposed rescue plan for the Dead Sea, the Two Seas Canal (connecting the Red and the Dead Seas), proposes to pump water from the Red Sea to the Dead Sea in order to use the pressure gradient of the Dead Sea (which lies 400 m under sea level) to desalinate part of the seawater (by means of reverse osmosis processes). This could then be used as drinking water in Jordan and Israel, thus reducing water extraction from the Jordan River (the rest of the seawater would then flow into the Dead Sea without desalination). What strikes one about this supply-side solution is, once again, the large-scale use of technology to expand supply. One looks in vain here for considerations of how the demand-side might be steered in one direction rather than another, and what is required to work in a river basin with only or mainly renewable quantities of water, so that the Jordan River can still be guaranteed an ecological runoff over the long term and the Dead Sea was provided with a new equilibrium (Kluge 2014).

Initial cost/benefit analyzes indicate that a more economical and ecologically sustainable rescue of the Jordan River (and the Dead Sea) is possible through an integrated steering of demand (Tielbörger 2010). Given their high construction, maintenance and renovation costs, their ecological and social consequences, and the emergence of new potentials for conflicts over use that follow in their paths, it may be doubted that such high-tech alternatives are at all sustainable.

15.3 Further Driving Forces Behind Water Shortages

Examples of the continuous receding of wetlands and lake areas are perhaps not so immediately noticeable in Western Europe (Succow/Jeschke 1990).[1] On the other hand, if one takes a look at a distribution map of the trade in virtual water, one sees that Germany is a large net importer of virtual water. Water, for example, that guarantees our level of nutrition (meat and milk products) by ensuring the growth of feed plants (soy, etc.), comes from Argentina and Brazil (where virgin forests are sacrificed for the sake of cultivated land) (Sonnenberg et al. 2009: 7f.; Liebrich 2009: 1).

Further 'driving forces' restricting the availability of water are, in addition to overuse of groundwater and surface water, and the lack of integrated management, include:

- Population growth,
- Climate change,
- The coupling of energy and water,
- And changed eating habits.

Especially in youthful societies, with high rates of growth and correspondingly high levels of urban population concentration (for example, Sao Paulo; southern African; India; countries in Central Asia such as Kazakhstan, Tajikistan; Mongolia; North China; etc.), there are, in addition to high levels of water use due to agriculture, also many pollution problems due to industrial activities (India, China). All of the areas are mentioned zones with intense population dynamics which also display a high degree of overlap either with already existing water stress zones or with areas marked by increasing shortages of water.

If we include the areas with decreasing rainfall due to climate change, we see a large overlap with the areas of increasing water shortages. Climate change causes an intensification of the hydrological cycle, which can, in turn, intensify water circulation. We have already seen an increase in precipitation in the Polar Regions and in the permafrost areas. Precipitation is, on the other hand, decreasing in hunger areas such as the African Savannah, as well as in southern Africa, northeast China and South and East Asia.

In addition, it should be noted that we can observe a shift in the precipitation-runoff relationship due to the intensification of glacier melting. This results in an increased flood risk in spring (for example, in the runoff system of the Alps) and a higher probability of dry drainage during the period between summer and fall (BMU 2007: 15f.). This will lead to even less precipitation in certain regions of the world (IPCC 2007).

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[1] A look at the history of the environment shows, however, that Germany can certainly be classified as a good example of the systematic destruction of wetlands (as a result of such programs as so-called soil drainage or river regulation/straightening, among others)

15.4 Competition Between Water and Energy[2]

The European discussion of an energy turnaround is centered on the goal of a sustainable reduction of greenhouse gases (CO_2 equivalent). Such a reduction can only be reached by developing an energy supply system that differs from the one currently in place in three aspects:

- Energy saving (for example, optimizing energy use in buildings and processes; energy efficient automobiles and appliances; climate-friendly behavior).
- Efficient and low-emission energy conversion (for example, reduction of energy loss in power and heat production, above all through cogeneration of heat and power).
- Greater use of renewable energy through the use of these forms of energy in all areas of energy use: heat, power, transportation and process power.

As for the use of renewable energy sources (bio fuels), currently it is above all a matter of the biodiesel and bioethanol production, both of which has increased dramatically

Irrigation of agricultural areas is already responsible for 75 % of freshwater use. The cultivation of plants for biofuels is radically increasing the global demand for water. If the biofuel trend continues unabated then by 2050 the same amount of water will be used for the cultivation of energy crops as for food production. China and India may serve here as examples. In both countries, the number of farms growing corn and sugar cane for the production of biodiesel and ethanol continues to rise. Both countries are already faced with regional and seasonal water shortages, and in some parts of both countries, the difficulties in encountered providing water could be intensified and the cultivation of foods such as grains and vegetables endangered. According to IMWI[3] a liter of ethanol extracted from Chinese corn requires 2,400 l of irrigation water. In India the balance sheet looks even worse: almost 3,500 l water is needed to grow enough sugar cane for a liter of ethanol. It is foreseeable that such intensive use of water for the production of biofuels will lead to competition between food supplies and energy prices and to a rise in food prices as well.

In addition, the cultivation of biofuels has considerable ecological consequences, such as soil erosion and loss of biodiversity. Because of the agro-industrial farming methods employed, energy crop farms are prime agents in soil depletion, and the resulting lack of nutrients leads to soil erosion and progressive desertification. Often unsuitable soils are subjected to monocultivation (after they have been cleared, such soils are no longer capable of continuous cultivation without intensive soil improvement). Soil loss leads inevitably to a decline in available agricultural

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[2] These issues on water and energy, water and food have gained importance and are referred to as "water, energy and food security nexus" and this so-called nexus-concept is subject on International Conferences (The Federal Government 2011, 2013).

[3] International Water Management Institute

land and thus to food shortages (de Fraiture et al. 2008: 2f.; UNESO 2009: 135f.; IWMI 2009: 1; Lindhauer 2008: 3).

Another question concerns the climate neutrality of biofuels. From the biofuel industry, one often hears the claim that the use of biofuels is climate neutral. The starting point of this argument is that during the burning of fuel from plants only the exact amount of CO_2 is emitted as was incorporated during the growth. This argument ignores entirely the manner in which the fuel is produced. Neither the production of the pesticide and fertilizer used, nor the energy costs of transport, the agricultural machines used, and the processing of the plants into ethanol or diesel are taken into account. During all these stages und processes, large amounts of fossil fuels are lost. In addition, the clearing of rain forests and the draining of wetlands in order to plant energy crops leads to the release of large quantities of CO_2 (Umwelt Institut München e.V. 2007: 4f.; Müller et al. 2008: 86).

Another aspect of coupling water and energy is hydroelectric power. When rivers are dammed to produce hydroelectric power (for example, the Euphrates and the Tigris in Eastern Turkey) this means that the water needed for the production of power which flows up to the dam (hydrostatic difference) is not available for other uses such as irrigation (Pearce 2007).

A further consequence is that the dam causes the water flow up to the dam to be equalized and slowed, and this happens below the dam as well. In fact, the technology of large dam building is often justified with the argument of better management of flood waves (in addition to the production of power). Real floods with their large amounts of water can be tamed by the dams, it is claimed. However, at best the crest of the flood waves can be somewhat tempered. At the same time, the presence of erosive material which continually causes damage to the dam walls raises the question of the economic feasibility of such systems.

Another problem, questioning the economic feasibility of dam systems can be seen in the example of the Mekong River. The equalizing of the Mekong's flow as it passes through several dam levels upstream (in Chinese territory) causes an interruption of its connection to important lateral waters, especially key wetlands areas. When the Mekong's flood waters are high enough it is normally linked to the Tonlesap, a lake and wetlands area, that is a central hatchery for the Mekong's abundance of fish. Thus the Chinese dams threaten a protein rich nutritional source for millions of people who live off the Mekong (IRN 2009: 4f.; Rosenberg et al. 2010: 1f.; McCully 2001: 5f.).

Reservoir lakes, especially those near a dam, collect erosion and bedload, and this leads to a threat to the stability of the dam wall over the long run due to the permanent silting of the reservoir. The shift in precipitation due to climate change is causing more and more heavy rain events which, in some regions, cause a flooding of dams. Worldwide, overflow structures are being constructed to prevent the undermining of the dam walls during flooding.

Hydroelectric power thus changes the flow behavior of river systems. The stability of the dam walls is then a question of time. Here the lesson is clear: the less the mania for gigantic projects is at play, the greater is the chance of being able to deal with possible risks (Imhof/Lanza 2010: 2f.; McCully 2007: 7f.).

Still another aspect of coupling water and energy is the desalination of seawater. If the energy needed is readily available then one can produce freshwater almost without limit. However, energy represents a real limit. Robust thermal desalination following the distillation principle is very energy intensive. Modern reverse-osmosis plants use considerably less energy but need more maintenance, for example, the chemical pretreatment of the water and the replacement of membranes. Seawater desalination, being a very expensive and energy-intensive way of providing freshwater, seems questionable when used to grow grain and animal feed plants, as is the case in Saudi Arabia, for example, (UNESCO 2009: 145; El-Manharawy/Hafez 2003: 165f.).

15.5 Competition Between Water and Food

Population growth and economic growth, especially in the so-called emerging market countries (the BRIC states), result in an increased demand for food, especially for meat products. Higher incomes and an increasing urbanization have a marked influence on diet, with a greater consumption of meat products being the result. Due to their economic development, China and India, for example, both now have middle classes with more income and with nutritional habits that have correspondingly changed. Though one sees a greater switch to meat eating in China than in India, the latter has experienced a very large increase in milk consumption, especially cheese and yoghurt (China has also seen an increase in the consumption of milk products). More milk, cheese and meat leads, of course, to a higher consumption of plants for animal feed, which translates, in turn, into an increase in water consumption. Viewed globally, and taking 2000 as the starting point, the production of meat and milk products will have doubled by 2050, with the production of meat rising to 465 million tons and that of milk growing to 1,043 million tons. As a result, already existing glaring environmental problems will be exacerbated even further (Schlatzer 2008: 6; Swiaczny/Schulz 2009: 137f.) (see also Fig. 15.1).

Already 35 % of global grain production is used for animal feed, while probably 1.1 billion people are undernourished worldwide. This means that the demand for water will increase sharply over the next decade as a result of efforts to allay the hunger of 1.1 billion people. It is, therefore foreseeable that the freshwater demand for food production alone will have doubled by 2030 (UNEP 2005).

15.6 A Look at the Future of Agriculture

The answer to the water shortage facing the world lies above all in learning to manage renewable water resources in such a manner that one can get by on them. Water management must be integrated with land use in such a way that it is no

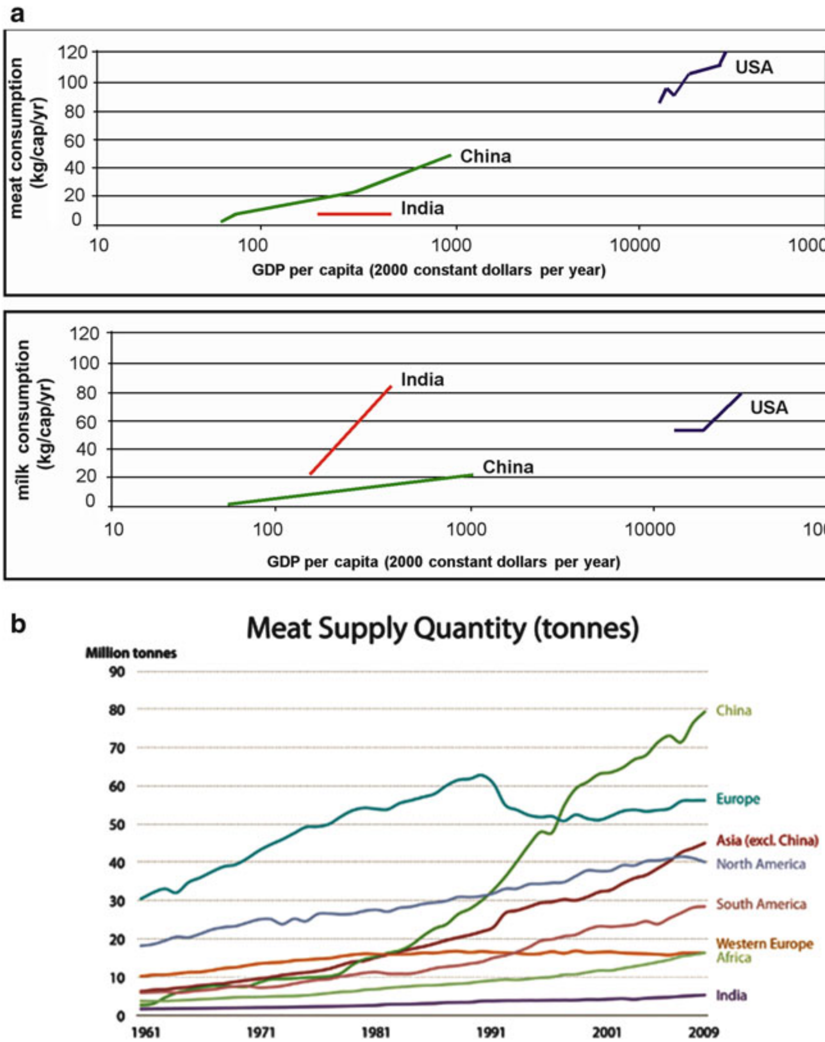

Fig. 15.1 Changes in nutritional habits: Trends in milk and meat consumption (1961–2000) (**a**) *Source*: FAO (2012), (**b**) *Source*: na.unep.net/geas/articleImages/Oct-12-figure-4.png

longer the case, as was during the Green Revolution, that the only thing that counts is increases in yields per hectare. More importantly, the yield per given amount of water must be optimized. This means additional investment, for example, in evaporation reduction by drip irrigation or roofing (plastic covering or glasshouses) or the use of less water consuming plants. In high precipitation areas an integration gain (that is, the possibility of multiple harvests per year) can be achieved by rain fed agriculture. However, the expansion of irrigated areas will not bring any increase in yields because, so far, the area gained by irrigation has been matched by the area lost due to salinization of already irrigated land. For this reason, despite increases in irrigated land, we have seen stagnation. Although, irrigated land composes only 20 % of land devoted to food production worldwide, this land accounts for 40 % of global food production (Giordano et al. 2007: 8f.; Inocencio et al. 2003: 4f.; Neubert 2002: 2f.; Lotze-Campen 2006: 2; Heymann et al. 2010: 9f.; Mauser 2007: 221).

Another point, one that was neglected in the past at great cost, is the collection of rain water in cisterns (for example, ground catchment techniques and roof runoffs with rain barrels). Small dams and so-called water banking are also worthy of mention. Water banking can mean, for example, that during monsoons when there is only a short period of heavy rainfall, the rainwater can be collected in a kind of sandbank (covered with clay as protection against evaporation) and then used during dry periods for drinking water or as water for animals or for gardening. To use water banking extensively in a river basin area demands a form of integrated water resource management (IWRM) in order to prevent those living downstream from coming up empty while those upstream follow a reasonable water use program (contribution of Zimmermann et al. on IWRM in Namibia in Part V). Well planned, water banking offers a tremendous opportunity, above all in those regions which, due to climate change, experience compressed (shorter and more intensive) precipitation periods (Inocencio et al. 2003: 4f.; Steenbergen/Tuinhof 2009).

15.7 Water Reuse and Urban Growth

We should not forget that urbanization is increasing steadily. So far, every second world citizen lives in an agglomeration area, and the trend will continue (for example, the population in Africa is expected to double between 2000 and 2030, according to UN reports). To supply these centers with watr, a double paradigm change is necessary, one that deals both with a lack of sustainable management and an overuse of water resources (Heymann et al. 2010: 5).

We do not need a constant expansion of the supply of water to deal with water shortages; rather what is required is a steering of demand according to the criteria of a rational allocation: who needs water, for how long and for what purpose. When such allocation plans are in place, especially those ensuring a sensible balance between the resources water and land, then one can speak of integrated water resource management (IWRM). If, for example, on the water side a resource mix consists of water banking and rainwater harvesting, with a limited extraction of surface groundwater, then, in order to ensure a balance between water and land use, forms of farming must guarantee a high utilization efficiency of these resources. In fact, the water side of the equation has for years been experiencing new technological developments which could revolutionize water use. The most promising approach involves waste water management, and is based on the reuse of materials and water—another paradigm change (Heymann et al. 2010: 16f.).

Waste water is no longer seen as a waste material to be disposed of, but as a valuable material. The advantages of this view of things are:

1. the reduction of emissions to soil and water bodies;
2. the recycling of valuable materials

Something similar has long been a standard technological practice in industry, when one thinks of operational and technical production processes as well as cooling water circuits.

When reusing waste water, it is particularly important to be able to recycle nitrate and phosphate for use as essential plant nutrients. If earlier "waste water disposal" methods, employing chemical and energy intensive methods, aimed precisely at destroying these nutrients (de-nitrification and de-phosphorization), now the beneficial aspects of these ingredients are stressed. This also means exploiting the energy potential of waste water. Using anaerobic technology, possibly with the addition of household biological waste, the waste water is first treated anaerobically in order to extract methane gas, and then bacteria and viruses are filtered out using membrane technology, while preserving the nutrients.

Taking North European and North American households as a basis, we can distinguish between *gray* water and *black* water. Black water includes toilet drain with feces and urine: it contains the potential for methane gas recovery, as well as that of nitrates and phosphates. Gray water comes from showers and bathtubs, household waster water, sinks and washing machines. The decoupling of *gray water alone* from the normal waste water stream (after purification and recycling it can be used as toilet water) means a fresh water reduction of about 40 %, and represents a considerable gain in energy as well by exploiting the potential heat found in gray water.

In Germany, a minimum of 1.4 (maximum 5.3) KW per hour and cubic meter is needed to pump water from wells and then process, transport and distribute it. According to Eurostat, the figures are 5.6 KW per hour and cubic meter for surface water and 7.2 KW for groundwater. Gray water recycling requires only 0.6 (maximum 0.8) KW per hour and cubic meter. Thus, the production of gray water requires only half as much energy as the conventional water cycle (Kluge/Libbe 2010). The energy saving effects of almost halving the freshwater supply is even more favorable (cf. Cornel et al. 2009; Bieker et al. 2009).

Gray water is the one item in the European water budget which heat contains. Hot water is, at 17 %, the second largest energy consumption item (natural gas, for example, stands at 14 %). Up to 50 % of the heat energy from shower, bathtub and washing machine can be recovered. The closer the heat exchanger is to the source of use, the higher the recovery rate, with the minimum scale size being an apartment building. Gray and black water recycling requires modern technologies in order to be able to use the residual water gained from black water, after freeing it from bacteria and viruses, as irrigation water for crops (or as process water for industry). This represents a revolution in energy and material recycling because there is a double reuse effect. In the gray water system water is returned to the household and energy is derived from the waste water stream, while in the black water system vacuum technology is used to transport waste water to treatment plants, where they are treated with anaerobic methods and membrane filters. Overall one needs only a quarter of the original freshwater for such vacuum transport.

The major gains from these technologies are the huge savings in freshwater, the doubling of energy savings from fermentation and heat extraction, the recycling of nitrates and phosphates (with the latter being in limited supply worldwide), and the the use of residual water as irrigation water. Total calculations show that these modern systems are both more economical and by far more sustainable than conventional water supply and waste water disposal technologies (Felmeden/ Michel 2010).

15.8 The Outlook

By focusing clearly on this way of looking at the world water crisis, which considers its causes and possible solutions together, we can see how much needs to be invested in these areas, especially in knowledge-production for subsistence farmers and for commercial farming. One must be active in both of these areas; and though this will have little impact on water in the short run, it will lead to the development of sustainable cooperation structures in the long term. When one turns to water efficiency in land use, what is needed, in addition to plant protection and fertilizer products, is rainwater harvesting, drip irrigation, water reuse and gray water, all of which are capital intensive. The same goes for the new separation technologies for the water use and for gray and black water circulation circuits. In order to close the gaps described above in water supply systems by building an integrated water resource management system (which would require a strengthening of weak water institutions and the introduction of the technologies already mentioned) extensive investment is needed. Estimates from the World Bank, the UN and Deutsche Bank Research run between 420 to 520 billion Euros per year. We see here that a huge (world) market potentially exists requiring an immense amount of investment (Heymann et al. 2010: 6f.).

The present situation looks, admittedly, quite different. Such huge amounts of capital cannot be raised by the states (or municipalities and regions) concerned alone.

The fact that private capital, as a result of its bad experience with privatization attempts in the water sector (non-profitability), has withdrawn from this industry, makes it more und more clear how important it is, given the foreseeable problems, to set a price for water from which investors can expect to make a profit on their advanced capital (interest, amortization, etc.)

How little this principle is respected can been seen by looking at such places as Egypt, Spain, Syria or India, where agriculture is the main consumer of water resources. When the state subsidizes water prices for the sake of farming, there is no price elasticity (and hence no water savings), and the subsidy functions as a stimulus for over exploitation of resources. This leads as a further consequence to pressures to expand supply. In Europe, it was above all the southern countries which undermined the cost recovery principle in the EU's Water Framework Directive, by insisting on a can-do and not a must-do clause (Rumm et al. 2006; Borchardt et al. 2006).

However, it is important to remember that in many developing countries it is difficult for end users to pay cost recovery prices. At best one can set prices here to cover maintenance and operational costs. Investment costs should be carried by society as a whole, since, if water infrastructures are badly in need of renovation and plants must be rebuilt, it is simply impossible to demand a user-dependent reconstruction (with corresponding prices and fees paid by the end users). Here the money needed must be raised from other sources.

As for cities and large metropolitan agglomerations (with a total population of 2.5 billion people), here the risks are found in settlements (slums) which have no proper sanitation. And with this we return to the starting point of this essay: the issue of sanitation, where nothing much has changed in recent years. Donor countries are spending just 5 % of development aid to achieve the Millennium Development Goals (Orsenna 2010: 310). WHO calculates that every Euro invested in water supply systems and sanitary facilities in developing countries brings a return of between 4 and 12 Euros in savings on economic costs. One might ask then why more is not invested here. The answer probably is that current water prices are set so low that too little return can be expected by investors (Auswärtiges Amt 2010: 1).

The large gap in investment of 500 billion Euros between what is needed and what is actually available could be ameliorated by setting up a World Water Fund, and stocking it with the funds raised with the imposition of CO_2 fees or with so-called development aid. International agreements could form the legal basis of recognition of a human right to water, with such agreements legally guaranteeing access to water internationally. Such agreements could also deal with the stagnating sanitation/waste water issue. Similar human rights, such as the right to food and the right to health, could then be better coordinated with the right to water.

Water for irrigation, waste water management in the form of energy and material recycling, and efficient water use are, in the last analysis, investments wanted by society, and their costs (installation of facilities) must therefore be carried by the state. This kind of infrastructure supports health and development, thus freeing potential for other activities such as work and learning. Costs for maintenance and repair could be, following the cost recovery principle, carried by end users.

A more general point is that the public sector has to be in a position to make decisions concerning long term infrastructure projects, and this will only be possible if it has the planning and financial capability needed. International development cooperation and World Water Funds are more necessary than ever in this connection (Heymann et al. 2010). An international council for sustainable development should take responsibility for oversight and coordination, so that sustainable and efficient solutions can be funded and past mistakes avoided.

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Chapter 16
The Management of Water Resources Under Conditions of Scarcity in Central Northern Namibia

Martin Zimmermann, Marian Brenda, Alexander Jokisch,
and Wilhelm Urban

16.1 Introduction

The amount of water in the hydrological cycle is constant. At the same time, water demand is increasing due to population as well as economic growth (GWP 2000). These circumstances lead to competition and potential conflicts over water resources and a water gap (contribution of Kluge in Part V). A deficient water management or its complete absence is likely to have negative social, economic, and environmental implications. Especially, political and technical dependencies as well as power structures which disadvantage certain population groups have to be mentioned in this context. These issues are of particular importance in developing countries where securing water supply is paramount. This is why management approaches have been developed of which one will be presented in the following. Beside of institutional and political aspects, demand management and technical contributions play a key role when solving these kinds of problems. Before the proposed water supply techniques will be explained in detail, the specific case study and the objectives of the corresponding research project are introduced.

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16.2 Integrated Water Resources Management

An early example of an integrated regulatory approach can be found in the 1930s with the establishment of the Tennessee Valley Authority (Snellen and Schrevel 2004). However, the concept of Integrated Water Resources Management (IWRM) became more popular among engineers, planners, and scientists in the water sector at the beginning of the 1990s (Snellen and Schrevel 2004). This is mainly due to the debate on sustainable development triggered by the United Nations. The Global Water Partnership's (GWP) definition for IWRM is by far the most often cited by water experts:

> *IWRM may be defined as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems* (GWP 2000.)

The concept refers at first to natural resources related to water. Furthermore, it tries to provide a spatial and temporal balancing of several water usages on one hand and resource conservation on the other. Economic sectors, such as agriculture, energy, industry, and households, are inseparably linked to water resources. These usages imply impacts on water resources and the environment. In addition, the four Dublin principles play a crucial role in the development of IWRM and illustrate further dimensions to be integrated. The principles were formulated on the International Conference on Water and the Environment in 1992 (ICWE 1992):

1. Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.
2. Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels.
3. Women play a central part in the provision, management and safeguarding of water.
4. Water has an economic value in all its competing uses and should be recognised as an economic good.

The principles define water as a scarce resource and, thus, as an economic good. Apart from gender-related aspects, participation can also be identified as one of the concept's theoretical core issues (ICWE 1992). All relevant stakeholders are supposed to be integrated into the processes of planning, decision making, and management. Among other aspects, spatial integration was explicitly a part of the European Water Framework Directive of 2000 (Directive 2000/60/EC). It says that a management of water resources, whether surface waters or aquifers, has to be geared to the hydrological catchment boundaries. This implies that in the majority of cases, national and regional administrative borders have to be crossed in order to comply with the directive. Authorities and actors separated so far are, thus, obliged to cooperate with each other. However, the list of aspects to be considered could be extended arbitrarily, for instance, by the integration of different types of water bodies or by the integration of the water supply and the wastewater disposal side.

Hence, it can be assumed that the observed broad consensus over the mentioned aspects is only due to the wide scope of interpretation of these notions. This is why some experts make serious allegations against the concept of IWRM (e.g. Biswas 2004). Mainly, the lack of operational suggestions is criticised. It is not clear by which means the goals of an IWRM can be pursued. In addition, the criteria for the assessment of a sustainable management process remain vague. Furthermore, when looking at recent research projects in the field of IWRM (UFZ 2009), it often seems that topics, such as participation and social sustainability, are not adequately dealt with (Zimmermann 2010a). Yet in the context of water projects in developing countries, the issues mentioned are crucial for the success and viability of proposed institutional or technological transitions. In general, it has to be questioned if universal solutions are appropriate for specific problems. In the following, the framework conditions of the case study will be presented.

16.3 Central Northern Namibia

The Namibian part of the Cuvelai basin is located in central northern Namibia (Fig. 16.1). Almost 1 million people or 50 % of the Namibian population live in this area (Kluge et al. 2008), which comprises only about 7 % of the country's area. This part of Namibia is almost exclusively inhabited by the largest ethnic group, the Owambo. Oshakati is the major city in the region with a population of roughly 45,000 people (Zimmermann 2010b).

Central northern Namibia is characterized by high precipitation variability (50–990 mm per year, including consecutive droughts and floods) and seasonal

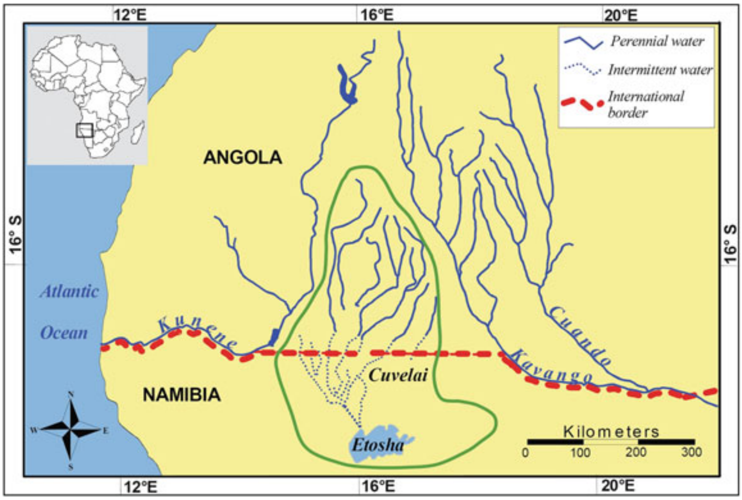

Fig. 16.1 The Cuvelai-System's catchment area (map created by Steffen Niemann)

alternations of a dry period during winter (from May until October) and heavy rainfall during summer (from November until April). Up to 96 % of the precipitation occurs in the rainy season (Namibia Meteorological Service).

Especially the lack of perennial rivers and the salinity of groundwater aquifers are a challenge for the regional water supply which is fed by the Namibian-Angolan border river Kunene. The system consists of a 150 km long open canal and a pipeline scheme with an overall length of about 2,000 km (Zimmermann and Urban 2009). The water is withdrawn at Calueque dam on Angolan territory. Four treatment plants driven by the Namibian water supply utility NamWater (Namibia Water Corporation Ltd.) accomplish the treatment of the raw water in order to achieve drinking water quality.

Apart from the large-scale supply scheme, natural and traditional water resources are used by the rural population. The Cuvelai basin is named after a system of ephemeral and intermittent rivers which seasonally drain the rainwater runoff of southern Angola into the region. Water from these so-called Oshanas is retained by excavation dams which are called Omatale or earth dams by locals. Hand-dug wells (so-called Oshikweyo) are another important traditional source of water (Niemann 2000). They are connected with shallow aquifers and filled with water mainly during the rainy season. During and shortly after this period, the water quality is acceptable in terms of chemical parameters. However, the salinity increases in the dry season due to evaporation. Apart from that, the contamination with algae and faeces is generally a serious problem of unprotected wells. Furthermore, it is said that groundwater levels are dropping.

Social and economical factors exacerbate the situation. A population growth of approximately 3 % and migration into the urban centres of the region will probably enhance the demand for water (Kluge and Moser 2008). This is due to the fact that urban dwellers feature different patterns of water utilisation compared to the rural population. Apart from that, the hygienic conditions are deteriorating due to insufficient waste and wastewater disposal strategies especially in informal peri-urban areas. At the same time, it is expected that the withdrawal of Kunene water on Angolan territory will grow due to socio-economic developments. These activities comprise for instance hydropower or irrigated agriculture. Although usable quantities of water have been laid down in a bilateral agreement between Angola and Namibia, the situation poses the risk of potential conflicts.

The rural water supply is mostly provided by private taps but approximately 20 % of the households in rural areas use public water points. Here, the majority of the population is unemployed and lives on subsistence agriculture (Deffner et al. 2008). Many practise crop and livestock farming or produce traditional drinks (such as Oshikundu or Otombo). Problems can be seen in the high livestock density, overgrazing, soil degradation, and deforestation. In addition, exogenous factors and systemic shocks such as climate change have to be considered including an increasing precipitation variability, a decreasing or at least fluctuating runoff of the Kunene River, and more frequent floods as well as droughts. On the whole, the regional water demand exceeds the local natural resources. This strong water-related hydrological and technological dependency is a debilitating factor for the sustainability of the water supply system. This is why an integrated management approach is necessary.

16.4 Proposed Water Supply Techniques

Within the research project “CuveWaters—Integrated Water Resources Management (IWRM) in the Cuvelai-Etosha Basin (Central Northern Namibia)” several small and medium-scale water supply techniques are developed, tested, and assessed in terms of their contribution to an IWRM in order to achieve a sustainable use of water resources. The project’s further main objectives are to reduce the dependency on the water of the Kunene River by developing endogenous water resources and to examine the social as well as technological feasibility of the adapted techniques. The central idea is to test and establish a multi-resource-mix of diverse water supply and sanitation techniques. The rational use of water is promoted within a demand oriented approach. This means that different water qualities are supposed to be used for different purposes. The usages range from drinking water to irrigation and water for livestock. These tasks are accompanied by capacity development and participation of all relevant stakeholders, including the water users. By an increased water supply security, livelihoods are improved and poverty is mitigated which also stimulates the regional economic development.

CuveWaters is funded by the German Ministry of Education and Research (BMBF). Project partners are the Institute for Social-Ecological Research (ISOE) in Frankfurt/Main and the Chair of Water Supply and Groundwater Protection as well as the Chair of Wastewater Technology (both at the Institute IWAR) of the Darmstadt University of Technology. Namibian cooperation partners are the Desert Research Foundation of Namibia (DRFN), the Namibian Ministry of Agriculture, Water, and Forestry (MAWF), and branch offices of the GIZ (German Society for Technical Cooperation) and the BGR (German Federal Institute for Geosciences and Natural Resources) in Namibia. The integration of different institutions on the one hand and social, ecological, and engineering methods on the other allows for the development and implementation of adapted concepts for problem solving. In doing so, the balance among participatory and technological aspects of the project is guaranteed. In terms of the water supply side, several adaptable decentral techniques for rural areas are investigated and tested, namely rainwater harvesting, decentral groundwater desalination, and subsurface water storage. These preselected and proposed technical solutions for the pilot phase will be explained in the following.

16.4.1 Rainwater Harvesting

Rainwater is hardly collected in the region by technical means despite an annual mean of 472 mm (Sturm et al. 2009). Precipitation can be harvested from roofs or other relatively impermeable surfaces. Generally, high runoff coefficients are preferred due to higher yields and less losses. Regarding the roof catchments, corrugated iron roofs with runoff coefficients of 0.8 to 0.85 (Gould/Nissen-Petersen

2003) are more effective than thatched roofs. Latter can not be recommended for high-quality rainwater collection, since they discolour the water and make it less palatable and attractive for human consumption. The rainwater is, then, channelled to a tank using gutters and downpipes which are usually made out of PVC or sheet metal as these materials are available but also most durable (DTU 2002). For the construction of ground catchments, compacted soil, plastic sheeting, or concrete can be used. Concrete lined surfaces feature relatively high runoff coefficients of 0.73 to 0.76 (Prinz 1996; Gould/Nissen-Petersen 2003) and are thus preferred over other options for the pilot phase.

The most cost-intensive part of a rainwater harvesting (RWH) system is the reservoir. The storages have to be constructed on-site and adapted to local conditions. Hence, attention has to be paid to the availability of construction materials and workforce. Furthermore, selected designs have to be cost-effective and robust. Four pilot plants for RHW were constructed in the jointly selected village of Epyeshona (Okatana Constituency, Oshana Region) from October 2009 until February 2010. The village community chose households during several workshops as sites for three roof catchment facilities with catchment areas between 87 and 100 m^2. Differing materials were applied for the tanks of these systems: polyethylene, ferro-cement, and concrete bricks (Fig. 16.2). The reservoirs have a capacity of 30 m^3 each and are built above ground. A potential yield of up to 40 m^3 can be achieved annually with the given mean rainfall of 472 mm/a, but this is a matter of current research in the pilot phase. Although the harvested rainwater is of relatively good quality (DTU 2000; Holländer 2002), it is mainly used for micro-scale irrigation (Fig. 16.3). The gardens have a size of approximately 150 m^2 each. The water can also be used for domestic purposes and is furthermore of good quality, especially compared to traditional sources.

A 120 m^3 cistern was constructed for another pilot plant with a concrete-lined ground catchment which supplies six households. The reservoir is built below ground and made of concrete bricks and ferro-cement. The catchment area has a size of 480 m^2 and can achieve a yield of up to 170 m^3. As in the case of the roof catchment systems, these numbers have to be confirmed in the pilot phase. The institutional setting of this facility was developed by the users themselves in participatory workshops. The collected water is mainly supposed to be used for horticulture. Hence, community gardening plots were created close to the tanks with a current total size of approximately 900 m^2. Furthermore, the users were trained in basic gardening techniques. All in all, up to 24 technicians from the village received capacity building measures to build, operate, and maintain the described RWH systems. At the moment, actual system performances in terms of water quality and quantity, technology, utilisation, and institutionalisation are monitored.

People in remote areas without access to the piped water supply scheme use water from hand-dug wells for domestic purposes and livestock watering. This water becomes brackish due to hydrogeological conditions and evaporation during the dry season. Moreover, many wells are contaminated with algae, faeces, and parasites since they are unprotected. Hence, decentralised and robust techniques for

Fig. 16.2 Trained technicians during the construction of the concrete brick tank for rainwater in the village of Epyeshona

Fig. 16.3 Gardening plot beside the ferro-cement tank in the village of Epyeshona Decentral groundwater desalination

groundwater desalination are proposed. Pilot plants were installed in two jointly selected villages of the Omusati Region. The facilities are completely solar-driven due to the lack of conventional sources of energy such as electricity, oil, or gas. Furthermore, the region features a solar radiation of more than 6 kWh/(m^2*d) and a mean sunshine duration of 8 to 9 h/d (Mendelsohn et al. 2003).

Two pilot plants were constructed in the village of Amarika (500 inhabitants, Otamanzi Constituency): a membrane distillation plant of the Fraunhofer Institute for Solar Energy Systems (ISE, Freiburg) and a reverse osmosis (RO) plant of the proaqua company (Mainz). The salinity in Amarika is approximately 23,000 mg TDS/l which is nearly as much as seawater.[1] Both systems produced in the year 2011 in average 3.4 m^3/d of drinking water. The RO plant runs with a chemical-free scale remover and disinfection. Together, both plants are using 21 m^3/d of raw water. The brine of the desalination process is mainly reinjected into deeper groundwater layers, where the salinity is higher than the salinity of the brine. The installed power of photovoltaic panels in Amarika is 19.8 kWp (67.8 kWh/d).

In addition, a chemical-free evaporation plant of the Terrawater company (Kiel) with an average production in 2011 of 1.4 m^3/d was put into operation in the village of Akutsima (500 inhabitants, Okahao Constituency). Furthermore, a multi-stage-desalination plant of the Solar-Institute Jülich/IBEU with a capacity of 500 l/d was installed, which needs no electrical power. Together, both plants require 18 m^3/d of raw water. The salinity amounts to approximately 5,000 mg TDS/l. The brine is completely evaporated in ponds since the soil is nearly impermeable.

The pilot plants are operated by trained local caretakers since July 2010. They are supported by a service provider (Aqua Services & Engineering, Windhoek) who regularly checks and maintains the facilities. In addition, the systems are monitored by the German manufacturers via remote data transmission. Institutional arrangements are again developed in participatory workshops with the users to raise their understanding and responsibility.

16.4.2 Subsurface Water Storage

The technique of Subsurface Water Storage (SWS) is intended to store the natural runoff from the above mentioned Oshanas of the Cuvelai-Etosha-Basin. While in the rainy season (from November until April) the region is experiencing floods, it can happen that the whole area suffers from droughts in the dry season. Especially in the 1960s and 1970s, it has been tried to store Oshana water for utilisation in the dry winter season in pump storage dams and excavation dams. Major problems of

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[1] TDS stands for Total Dissolved Solids and is a measure for the total content of organic and inorganic substances in molecular, ionized, and colloidal suspended form in a liquid. Salinity is the sum of all dissolved ions in the water. Seawater has a salinity of 33,000 to 35,000 mg TDS/l. According to the WHO (2006), the taste of fresh water can be judged as good at values below 600 mg TDS/l. Water with more than 6,000 mg TDS/l is not suitable for livestock watering.

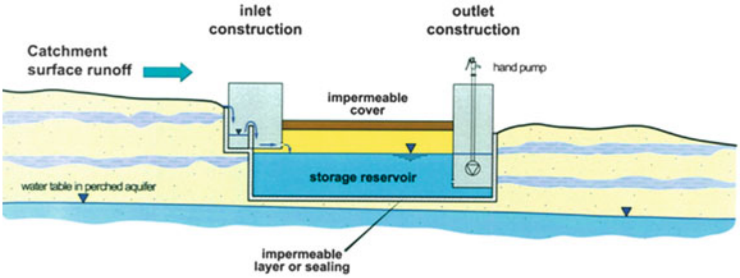

Fig. 16.4 Two closed ponds, one subsurface tank and the greenhouse after completion of construction

these techniques are the high evaporation rate in northern Namibia (2,700 mm/a) and the declining quality of the water stored. Instead of using open reservoirs, closed subsurface storages are proposed to avoid these disadvantages (Fig. 16.4). Flood water runoff will be channelled by a gravitational canal or pumps through an inlet construction into the reservoir. Stored water can then be withdrawn by hand pumps for instance. However, it is assumed that the provided water will be of medium quality and thus is intended to be used for small-scale irrigation and livestock watering. In the village Iipopo two ponds, one subsurface tank, a greenhouse and irrigation schemes were constructed in September 2011. Start of operation was March 2012 when the floodwater came. The combined capacity of the tank and ponds is 400 m^3, the irrigation area (greenhouse and open garden) is 1,176 m^2.

SWS is mainly considered for the storage of flood water in areas without suitable aquifers. The technique does not interfere with saline or fresh water aquifers since it is independent from local groundwater. Furthermore, the components of SWS are supposed to be constructed from local or at least easily available materials. Within the project, it is planned to clarify methodical and technical questions as well as the conditions of operation and maintenance since a general state of the art for SWS is not documented yet.

Conclusions

In the Namibian CuveWaters project a multi-resource mix of diverse water supply and sanitation techniques is successfully tested on a small and medium scale level. Developing endogenous water resources increases the security of water supply and is improving the livelihoods of the rural population and thus fostering regional economic activities. The IWRM approach proposed and especially its adapted decentral water supply techniques can make crucial contributions in this context in a dry region with 472 mm annual rainfall.

Techniques like small rainwater reservoirs and cisterns (120 m^3) and subsurface water storage (400 m^3) tanks from run-off surface water are usable for small-scale irrigation, horticulture and lifestock watering purposes. They

(continued)

are especially suitable for areas without suitable aquifers for water storage and water applications without needed drinking water quality.

Groundwater desalination is the regional adapted solution to get a higher water quality. Solar-driven membrane distillation and reverse osmosis plants, evaporation plants and multi-stage desalination plants offer adapted techniques in less developed areas without electricity.

The proposed techniques are decentral and adapted to the natural and social conditions. Only locally available construction materials have been used such as in the case of rainwater harvesting. In addition, this option is very robust and requires low maintenance. Moreover, the specific problems of the region have been addressed with appropriate treatment processes such as in the case of groundwater desalination. These systems are furthermore completely self-sufficient due to the exclusive use of solar energy. Finally, the utilisation of all proposed techniques enables a constant water availability in quality and quantity all over the year. In doing so, the population's resilience potential is increased. At the same time their vulnerability against exogenous shocks is reduced. Severe droughts, for instance, can be survived unscathed due to stored water.

The discourse on IWRM leaves many questions regarding operational aspects unanswered. However, there is a broad consensus that sustainable development and participation are core elements of IWRM. This is not only accomplished by integrating theories and methods of social, natural, and engineering sciences but also of practical and traditional knowledge of the actors involved, especially the water users. Thereby, knowledge is not only transferred in one direction, from the scientists to the stakeholders, but also in the opposite direction. The participation of users ranged from joint decisions on technical questions to the layout of institutional frameworks as in the case of the rainwater harvesting systems. Here, participation does not only mean taking part and providing information but also taking decisions and responsibilities. This has been achieved by participatory workshops which guaranteed the social and cultural embedding of the techniques. Not only the future users and inhabitants have been involved but also regional and local actors and institutions such as Local Water Committees, Regional Councils, Community Development Committees, and traditional authorities. By considering local needs and conditions of human beings and nature, the proposed IWRM approach is able to deliver solutions that are adapted, appropriate, and problem-oriented.

Eurocentric blueprints of water supply regimes cannot be transferred to developing countries without any reflection. Traditional concepts of large-scale systems are not necessarily appropriate for all parts of the world. The proposed approach of a multi-resource-mix, i. e. the combined diversification of sources and development of endogenous potentials, could be a promising

(continued)

alternative. The fact is that water is indeed available in the presented case study region, yet, it is only from various sources and of differing qualities. Adapting to these conditions means applying sophisticated treatment processes only for the production of potable water. Aside from that, water of moderate quality can be used for irrigation, livestock watering, or other domestic purposes. In doing so, the dependency on an external resource can be mitigated and self-sufficiency can be enhanced. This way of utilisation seems to be an adequate approach for addressing the core problem identified which is the dependency on the water of the Kunene River. This also implies that harmful competition for water resources and causes for potential conflicts are reduced.

At present, CuveWaters is in the project's second phase. The majority of pilot plants has already been installed and is currently tested in terms of their performance, manageability, and suitability for daily use. The socio-technological monitoring and evaluation will be continued until 2012. Beside of technical and ecological aspects, institutionalisation, acceptance of the users, and security are of paramount importance. In the subsequent third phase of the project, a region-wide introduction and implementation of those techniques is proposed which have proven to be sustainable and viable after evaluating the pilot phase. Thus, it is hoped that appropriate decentral water supply techniques can make successful contributions to cope with conditions of scarcity.

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Part VI
Resource Aspects in Renewable Energy Technologies

Chapter 17
Sustainable Land Use: Food Production or Fuels

Anna Hennecke and Nils Rettenmaier

17.1 Introduction

Climate change and concerns of energy security are the main drivers for the promotion of renewable energy carriers. One of the main pillars of the strategy to mitigate climate change and save non-renewable energy carriers is the use of biomass[1] for energy. Bioenergy can be obtained from wood and silvicultural residues, dedicated energy crops and agricultural residues as well as from organic waste. Already today, biomass is contributing about 15 % to the global energy consumption, however, most of it is traditional non-commercial firewood and charcoal for heating and cooking.

The focus of this chapter[2], however, is on modern bioenergy, i.e. a commercial use of biomass which is deliberately grown for energy purposes. Today, the modern bioenergy carriers most commonly used for heat and power generation and for transport are biodiesel (e.g. from rapeseed), bioethanol (e.g. from maize and sugarcane) and pure plant oils (e.g. from oil palm). Strong incentives have been put in place to increase the use of bioenergy both in the transport as well as in the energy sector, mainly in the form of mandatory targets (cf. US Congress 2007; EU 2009).

In addition, the demand for industrial crops for biochemicals and biomaterials is slowly but steadily increasing. All in all, these non-food biomass uses are already

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[1] Biomass means material of biological origin excluding material embedded in geological formations and transformed to fossil.

[2] This chapter was compiled in march 2011.

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putting pressure on global agricultural land (cf. Bringezu et al. 2009) (contribution of Hartard in Part IV with available land per capita). At the same time, global population growth and changing human diets due to economic development lead to an additional demand for agricultural land for food and feed production. The result is an increased competition for land for the production of food and feed as well as biomaterials and bioenergy, which might even aggravate in the decades to come, jeopardise food security (cf. Eickhout et al. 2007) and give rise to conflicts. In 2008, when food prices soared, biofuels were blamed for causing hunger and disturbing markets as well as for the expansion of agricultural land at the cost of (semi-)natural ecosystems. In this context the question arises: *How can the resource land be used in a sustainable manner—for food production and/or fuel production?* This chapter approaches this question in three parts. It will start by giving an overview of global land use. The second part deals with reasons for increasing pressure on land. The third part will discuss the impact of a particular land use (biofuels production) on two important aspects of sustainability: global greenhouse gas (GHG) emissions and food security and how these are addressed in policy making.

17.2 Land: Availability of a Limited Resource

17.2.1 Current Land Use for Bioenergy

Currently, some 40 % of the global land surface is used for agricultural production. The majority of this land, about two thirds, is pasture for grazing cattle and one third is dedicated to crop production (Fig. 17.1). Not more than 1.7 % of this crop land was used for dedicated energy crops in 2007 on a global level (cf. UNEP 2009: 63). However, this share is higher in some countries. For example, in Germany around 15 % of total arable land is dedicated to bioenergy. Rapeseed for biodiesel and pure plant oil accounts for half of this area (cf. FNR 2010).

A closer look reveals that the focus of global bioenergy production is on three regions: US, Brazil and Europe. In these three regions the major part of liquid biofuels is produced (Fig. 17.2). The US produces 43 % of global liquid biofuels, mainly bioethanol from corn. Brazil is second with 32 %, mainly bioethanol from sugarcane and Europe is third with 15 %, producing mainly biodiesel from rapeseed. (cf. UNEP (2009): 34).

17.2.2 Future Land Availability for Bioenergy

During the last couple of years the global production of bioethanol for transport fuel has tripled from 17 billion litres in 2000 to more than 52 billion litres in 2007 (cf. UNEP 2009: 33). Biodiesel production expanded eleven-fold from

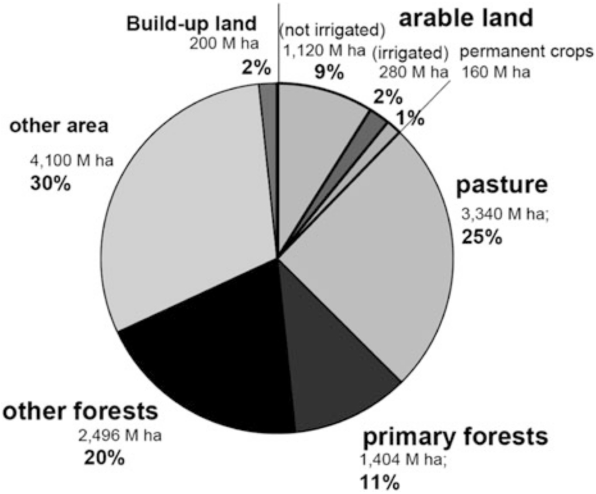


Fig. 17.1 Current global land use structure. Figure adopted from. *Source*: Fehrenbach (Fehrenbach et al. 2008): 47

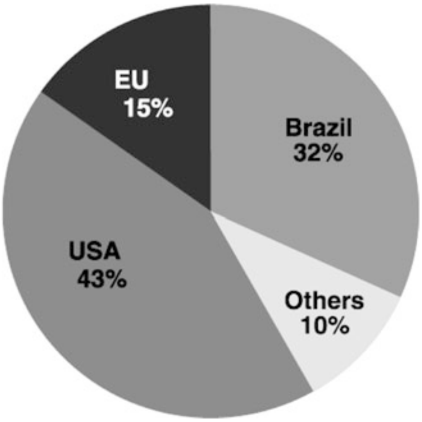
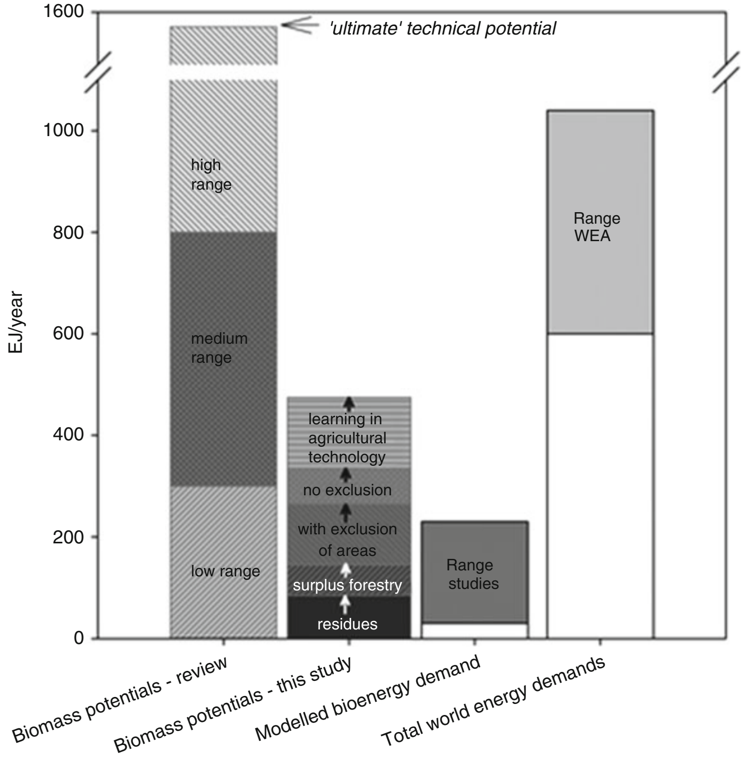


Fig. 17.2 Proportion of global production of liquid biofuels in 2007. *Source*: UNEP (2009): 34

less than 1 billion to almost 11 billion litres. In the light of increasing competition for agricultural land between the production of food, feed, fiber and fuel (sometimes referred to as the 4 F's) the question arises how much land will be available for bioenergy purposes in the future, both in Europe and at global level. Reliable knowledge of the bioenergy potentials is essential for both policy and industry in order to achieve the challenging policy targets in the renewable energy sector.

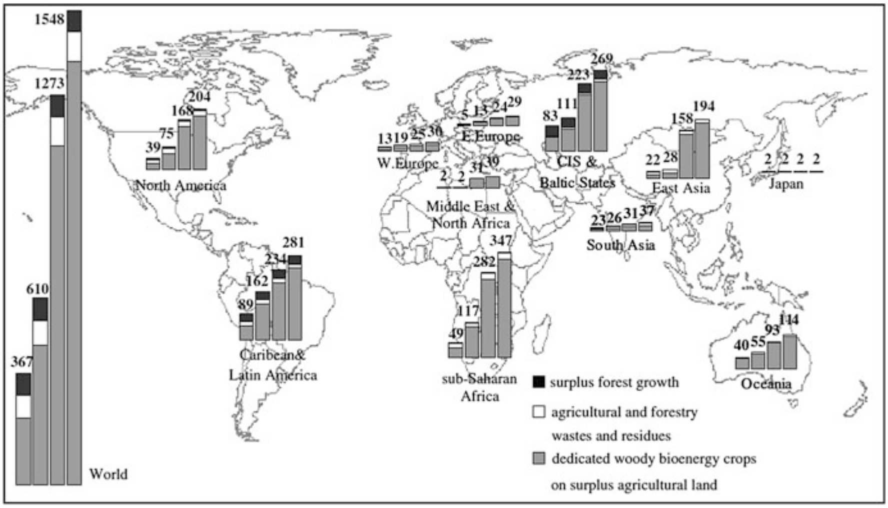


Notes: Biomass potentials covered by Dornburg et al.'s review (1st bar from the left), with the lignocellulosic biomass supply potentials from the analysis carried out in Dornburg et al.'s study (2nd bar), the modelled primary bioenergy demands included in this study (3rd bar) and the estimate range for the total global primary energy demand from the World Energy Assessment (4th bar), all by the year 2050.

Fig. 17.3 Comparison of the range of biomass energy supply potentials. *Source*: (Dornburg et al. 2010)

In recent years, hundreds of biomass resource assessments (or biomass potential studies) have been published. Unfortunately, the results differ largely from each other: biomass energy potentials are found to range between 200 and 500 EJ/year in 2050 (cf. Berndes et al. 2003; Dornburg et al. 2010). Figure 17.3 compares global biomass potentials reported in several studies (1st bar from the left) and the total primary energy demand according to the World Energy Assessment (4th bar). It can be concluded that both ranges are in the same order of magnitude, i.e. that biomass could contribute a remarkable share to the global energy supply.

A recent review of biomass resource assessments reveals a high diversity regarding the choice of the type of potential, the types of biomass, methods and scenario assumptions (cf. Rettenmaier et al. 2010). According to the report, a



Factor	System 1	System 2	System 3	System 4
Animal production system used (pastoral, mixed, landless)	Mixed	Mixed	Landless	Landless
Feed conversion efficiency	High	High	High	High
Level of technology for crop production	Very high	Very high	Very high	Super high
Water supply for agriculture (rain-fed = r.f., irrigated = irri)	r.f.	r.f. and irri.	r.f. and irri.	r.f. and irri.

Fig. 17.4 Technical bioenergy production potential in 2050 based on systems 1–4 (EJ/year the left bar is system 1, the right bar is system 4). *Source*: (Smeets et al. 2007)

comparison of results is complicated due to different terminology and systematisation of categories as well as insufficient documentation of approaches and scenario assumptions.

Scenario assumptions and constraints such as nature protection areas, expected food demand are probably the most important single reason for variation in the results of biomass resource assessments, especially in the case of land availability for dedicated energy crops. Dedicated energy crops make the largest contribution to the biomass potential for energy. At the same time, however, the range of results for energy crops is considerably large, as the development of key parameters of the food and feed production system is highly uncertain, e.g. the rate of improvement in agricultural and livestock management. These parameters play a crucial role for the land availability for non-food purposes.

The effects of these assumptions on the estimated potentials are apparent even within a study. For example, Smeets et al (Smeets et al. 2007) estimated up to 700 % variation in regional bioenergy production potentials (Fig. 17.4). The assumptions underlying these variations concern

(a) the animal production system used—extensive grazing or intensive indoor breeding?
(b) the efficiency in the conversion of biomass to bioenergy

(c) the level of technology for crop production and
(d) the water supply—rainfed agriculture or irrigation when rainfall is not sufficient?

In brief: Until now only a minor share of croplands are used for biofuels (1.7 %). These are concentrated in a few regions—US, Brazil and Europe—in which biofuels make up a larger share of their available cropland. Studies on bioenergy potentials clearly show that the future land availability for food, fibre and fuels will crucially depend on the framework conditions. How much surplus agricultural land will be available for biofuels in the future depends on e.g. if cattle production is intensified, if yields are rising in regions that have not yet experienced the green revolution. Differences in these assumptions gave rise to the large range in the estimated bioenergy potentials in the studies.

17.3 Competing Uses of Land: Food and Biofuels

Having looked at how much land will be potentially available in future, the next section introduces the drivers for an increasing need for agricultural land: Biofuel policies, population growth, changing habits in food consumption and increasing demand for bio-based materials.

17.3.1 Land for Biofuels

Among all modern bioenergy carriers, liquid biofuels for transport are by far the most widespread and most commonly used ones. Biofuel promotion policies are implemented in a number of countries, among others to achieve the goals of GHG mitigation, energy diversification and increased employment in the rural sector.

- Europe: In 2003 the Biofuels Directive (2003/30/EC) was issued targeting a biofuel quota of 5.75 % (cf. EU 2003). In 2009 the Renewable Energy Directive (2009/28/EC) passed parliament (cf. EU 2009) which increases the mandatory target to 20 % for the overall share of energy from renewable sources until 2020 and a 10 % target for energy from renewable sources in transport. A large share of this target is expected to be met by bioenergy.

Europe’s share of the global bioenergy potential is <5 % (see Fig. 17.4). In contrast to that political goals to increase bioenergy use in Europe are high. Therefore Europe will have to rely on imports to meet its bioenergy targets and will increase pressure on land not only inside Europe but worldwide.

- US: Under the Energy Independence and Security Act of 2007 the Renewable Fuels Standard programme was drafted. It requires increasing the volume of renewable fuel to be blended into transportation fuel from about 30 billion litres in 2008 to 130 billion litres by 2022.

The US law was designed primarily to support domestic maize production. The revised law foresees an increasing use of second generation biofuels and sugarcane bioethanol which may also be imported.

- Mexico: A Law for the Promotion and Development of Bioenergy was issued in 2008 (cf. LPDB 2008) considering the use of bioethanol as oxygenating additive in gasoline. As a result of the law's provisions, a program for the introduction of biofuels was drafted.

This law is mainly an answer to the declining Mexican oil reserves and the search for opportunities for the poor domestic rural sector.

These biofuel promotion policies may lead to an increased demand of dedicated energy crops and hence the need for expanding land use for the production of biofuels.

17.3.2 Land for Food and Other Purposes

The biomass demand due to biofuel promotion policies adds to a baseline biomass demand which is expected to increase. Drivers for the demand for biomass and implicitly the demand for land are:

- Growing population.
- Changing food demand and human diets. The consumption of meat and dairy products is increasing in many countries. These products require a larger amount of land per unit nutritional value than plant-based products.
- Rising demand in for industrial crops. Increasingly, chemicals and materials such as bioplastics for packaging are made from biomass.

However, one additional hectare for bioenergy production does not imply that one hectare of cropland is taken out of food production or that one hectare of e.g. rain forest is cleared leading to high GHG emissions. The effects of an increasing use of land for biofuels are discussed in the next sections. Hereby, the focus will be on the effects on global GHG emissions and on food security, two crucial aspects when evaluating the sustainability of land use.

17.4 Land for Biofuels: Effects on GHG Emissions and Food Security

17.4.1 Mitigation or Increase of Global GHG Emissions Through Biofuels?

Biofuels can be a means of reducing global GHG emissions because they take up the GHG emitted in their combustion during the growth of the feedstock. Whereas their combustion is climate neutral, additional GHG are emitted during the establishment of the crop plantation, cultivation, transport of raw materials and the industrial conversion of the crop into the fuel.

A large number of studies have been made to estimate GHG reduction along the life cycle of biofuels as compared to the life cycle of fossil fuels: From early studies on rapeseed oil in the 1990s (cf. Reinhardt 1993) until the 2000s when more and more LCAs on a range of biofuels from different feedstocks were made, for example from sugarcane, oil palm, soy, wheat, corn and Jatropha (Fehrenbach et al. 2008): 9; cf. RFA (2009).

The general picture of these studies was that even when considering the complete production process from cultivation to end use, the use of biofuels can reduce GHG emissions as compared to fossil fuels provided that they are not produced with inefficient production techniques, for example in a worst case scenario for sugarcane bioethanol the on-site energy source is not bagasse but fuel oil.

The underlying assumption of these LCAs was that biofuels were produced from harvest surplus or on idle land. However with rising production of biofuels this assumption became not applicable any more because other areas, for example grasslands in Germany and the formerly unused cerrado in Brazil, needed to be converted into arable land. These land-use changes lead to a change of the carbon stock in vegetation and soils and cause GHG emissions. It became more and more clear that it was not sufficient to only consider the production process from cultivation to end use. The system boundaries were set too narrow and in the following, more and more studies included direct land-use changes in LCAs.

17.4.2 GHG Emissions from Direct Land-Use Changes (dLUC)

The production process of biofuels begins by establishing the energy crop plantation. If (semi-)natural ecosystems such as grassland, forest land or wetland are converted into arable land, the area’s carbon stock in vegetation and soils is changed. Carbon is stored in the vegetation in form of leaves and branches, in form of dead wood on the ground and in roots and humus in soils. If the carbon stock is larger before the establishment of the plantation than thereafter, the difference is released as CO_2 by burning or microbial decomposition of above and below ground carbon. This has a negative influence on the GHG balance.

Emissions from dLUC can make up a significant part of the biofuel carbon footprint. For example, converting savannah in Brazil to cultivate soy for biodiesel leads to GHG emissions around 160 gCO_2eq per MJ bioethanol, which is more than five times higher than the emissions from the production process of bioethanol and about twice the emissions of conventional gasoline which are around 85 gCO_2eq per MJ gasoline (cf. Fehrenbach (Fehrenbach et al. 2008): 82–84).

Regarding the calculation of GHG emissions from dLUC there is a scientific consensus to use the methodologies published in the IPCC Guidelines for national

GHG Inventories. These are also used by the Annex I countries under the Kyoto Protocol to calculate emissions from land-use changes in their annual report of inventories of their national GHG emissions (cf. IPCC 2006). However, also the cultivation of energy crops on existing agricultural land, i.e. without prior land-use change, can cause the conversion of grasslands and forests along with high GHG emissions—these are called indirect land-use changes (iLUC) (cf. Searchinger et al. 2008).

17.4.3 GHG Emissions from Indirect Land-Use Changes

Indirect land-use changes arise if agricultural land so far used for food and feed production, e.g. a maize field, is now used for energy crop cultivation. This can lead to displacement effects. If the demand for maize remains constant, additional maize must be produced on a different area. This area could possibly be acquired by clearing (semi-)natural areas like grasslands and forests. The energy crop plantation thus indirectly contributes to an increase in GHG emissions.

Quantification of indirect land-use change is currently a hot debate in science. The difficulties of quantifying the emissions from iLUC are:

- ILUC can not be attributed individually to a specific biofuel production process, but depend upon the complex mechanisms of agricultural markets and prices of possible substitutes.
- Using one additional hectare for bioenergy production does not imply that one additional hectare of natural area needs to be converted to cropland.
- In some cases, bioenergy production has positive effects on land availability. For example, when co-products of bioenergy production can be used as feed (DDGS, rapeseed cake, sugar beet pulp) they are substituting feed that would need to be cultivated otherwise.

Currently, there are two main approaches to quantify GHG emissions from iLUC: econometric models and deterministic approaches.

Econometric models have originally been developed to simulate the effect of agricultural policies on markets and trades flows. They can be used to estimate market-induced changes in the use of land. In order to calculate GHG emissions, in a second step these models need to be combined with biophysical models that include global data on the carbon stock of different areas and land use options. The results of the studies differ between 18 and 180 g CO_2eq per MJ biofuel (cf. Searchinger et al. 2008; Perrihan et al. 2010) due to differences in scenarios and the model setup.

Deterministic approaches to include iLUC aim at providing an approach that is practicable and applicable for policies. On the basis of historic land use data a hectare based value (13.5 g CO_2eq per hectare per year) is proposed to be added on top of the GHG balance of the biofuels (cf. Fritsche 2010).

With Sheehan (cf. Sheehan 2009) it can be concluded that research on the quantification of iLUC still has a long way to go despite the already complex approaches of econometric modeling. He stresses at the same time that the uncertainties in the quantification of iLUC must not be a reason for disregarding them. This conclusion is shared by policy makers in Europe and the US: as iLUC may be significantly influence GHG emissions it cannot be ignored when setting up policy support for biofuels that aim at reducing GHG.

In brief: Land-use changes involve both direct and indirect effects. Direct land-use changes comprise any change in land use which is directly induced by the cultivation of an energy crop. This can be a conversion of (semi-)natural ecosystems such as grassland, forest land or wetland into new cropland. ILUC occur if agricultural land so far used for food and feed production is now used for energy crop cultivation. Provided that the demand for food and feed is constant, food and feed production is displaced to another area where again unfavourable land-use changes, i.e. the conversion of (semi-)natural ecosystems might occur. This phenomenon is also called leakage effect or displacement.

Both direct and iLUC ultimately lead to changes in the carbon stock of above- and below-ground biomass, soil organic carbon, litter and dead wood. Depending on the previous vegetation and on the crop to be established these changes can be neutral, positive or negative. For example, if fallow/set-aside land is transformed the carbon stock does not change significantly since it remains agricultural land. The carbon stock change is therefore often set at zero. However, if (semi-)natural ecosystems such as grassland, forest land or wetland are converted, high carbon emissions can be caused. In contrast, the use of degraded land may even lead to carbon sequestration.

17.4.4 Policy Approaches to Address Direct and Indirect Land-Use Changes

Politicians in Europe address dLUC in the catalogue of sustainability criteria in the Renewable Energy Directive (2009/28/EC). The directive prohibits the conversion of land with high carbon stock namely forested areas with a canopy cover of more than 30 % and peatlands. Biofuel producers have to prove that they do not source biofuels from these areas in an independent certification system that is accredited by the European Commission or the German government.

It still is an open question how to address iLUC in policy making. The European Commission stated in their report from December 22nd 2010 (EU 2010: 14) that four options will be assessed until mid 2011:

1. take no action for the time being, while continuing to monitor,
2. increase the minimum GHG saving threshold for biofuels,
3. introduce additional sustainability requirements on certain categories of biofuels,
4. attribute a quantity of GHG emissions to biofuels reflecting the estimated indirect land-use impact.

In the US the Environmental Protection Agency (EPA) issued a proposal regarding the inclusion of iLUC. The implementation of this proposal was put on hold by a 5-year moratorium agreed on in the House of Representatives on 24 June 2009. The proposal will be subject to a scientific review in the meantime.

17.4.5 Biofuels and Food Security

The link between biofuels and food security is established through the competition of uses of agricultural products or agricultural land. On the one hand agricultural products can be used to generate energy on the other hand they can be consumed as food. This is true for rapeseed as well as soy, palm oil, corn and sugarcane. As biofuels are a driver on the demand side they may lead to price increases of agricultural products. According to FAO one of the major dimensions of food security is economic access i.e. food security exists when people can afford to purchase food (cf. FAO 1983). Seen from a historical perspective prices for maize, wheat, palm oil and soybeans have been declining since the 1960s. But repeatedly prices peaked, as for example in the mid-1970s and recently in 2007/2008 (cf. Zuurbier and van de Vooren 2008: 227). Food price inflation is socially and politically sensitive because they strongly affect lower income consumers around the world. The following two sections therefore address the questions: How did biofuels contribute to the recent increase in food prices? Which policy approaches are needed to ensure food security in a future with increased biofuel production?

17.4.6 Impact of Biofuels on Food Prices

Significant increases in food prices were noted in 2007/2008. According to FAO the price index for food increased by 57 %, for rice by 75 % and for wheat by 120 % (cf. FAO 2008). Five main causes were identified to play a role in these price increases (cf. Braun 2008; BMZ 2008; Zuurbier and van de Vooren 2008):

- Demand for grains and oilseeds for biofuels: As mentioned, the increased use of agricultural products for biofuels contributed to the price increases. However, studies disagree to which degree they are responsible.
- Weather-induced shortage of supply: Draughts in Australia, one of the world's largest grain producers, have led to crop failures and shortages on the supply side.
- Oil price peaks: High oil prices made agricultural production more costly because expenses for mechanical cultivation, fertilizers, pesticides and transport of inputs and outputs increased.
- Speculation in agricultural markets.

– Decades of lacking investments in agricultural productivity in developing countries: Subsidised and therefore cheaper agricultural products from Europe and the US have led to a decline of prices on local markets in developing countries down to a level with which local production could not compete. As local producer were not able to sell their products, or only sell them at low prices, investments in agriculture went more and more down. Therefore, many African countries that were net food exporters 20 years ago became net food importers today according to the German Federal Ministry of Economic Cooperation and Development (cf. BMZ 2008).

17.5 Policy Approaches to Address Food Security

A number of policy approaches to address food security have been suggested in the context of the biofuel discussion. On one side these suggestions address directly existing biofuel policies and include e.g. a moratorium for further increases of biofuel quotas (cf. BMZ 2008). On the other side they target the agricultural sector in general and stress that in the long-term production capacity needs to be improved and food prices stabilized. Arguing that food crisis are “not a crisis in terms of shortage of food, but a crisis in terms of income shortage (in terms of purchasing power and of investment potential to increase productive capacity)” (Zuurbier and van de Vooren 2008: 245) the International Food Policy Research Institute (IFPRI) suggests specific policies for developing countries and developed countries (cf. Braun 2008):

Regarding developing countries IFPRI suggests first of all reforms of agricultural policies to facilitate smallholder access to land, credits, advisory, seeds and fertilizers to increase production capacity. Second, they stress the importance of investments in agricultural infrastructure like roads, electricity, communications, storage and processing capacity, agricultural technologies and market access for small farmers.

Regarding developed countries IFPRI suggests reforms of trade policies in Europe and the US, i.e. cutting back agricultural subsidies and trade barriers of industrial countries against developing countries. “A level playing field for developing-country farmers will make it more profitable for them to ramp up production in response to higher prices” ((Braun 2008): 2).

Conclusions

Land is a limited resource. The demand for this limited resource will increase due to population growth, changing human diets, demands for biomaterials and—on top of that—policies for the promotion of bioenergy production and use. This chapter has dealt with the question: How can land be used in a

(continued)

sustainable manner—for food production and/or fuel production? More specific: What effect does increasing bioenergy production have on two specific aspects of sustainability: global GHG emissions and food security?

Regarding global GHG emissions the use of land for biofuels can in principle contribute to a mitigation of global GHG emissions. Producing and using biofuels generates less GHG emissions than producing and using their fossil counterparts. This effect, however, is reversed as soon as (semi-) natural ecosystems are converted to cultivate energy crops, because this conversion leads to enormous GHG emissions. While the EU renewable energy directive tackles the issue of dLUC with a certification approach, there still is a "science gap" regarding the issue of iLUC. The scientific community lags behind and can currently not answer the policy needs. Nevertheless, avoiding iLUC will be crucial to reap the GHG benefits of biofuel production.

Regarding food security: A conflict between biofuel production and food security does not arise per se. Studies on land potentials show that in principle there could be enough land available for food, fuels and fibre under the prerequisite that among others agricultural and livestock management are improved and made more efficient. It will therefore be crucial how these framework conditions are shaped. The major part of biomass potentials is not in Europe but in developing countries in Africa, Latin America and Southeast Asia, i.e. countries where food security is most critical. The connection between biofuels and food security arises through increases in prices. If this connection will worsen or improve food security will depend on whether adequate agricultural and trade policies are formulated. Policies that concentrate on cutting agricultural subsidies, on improving agricultural infrastructure in developing countries and on promoting smallholder productivity.

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Chapter 18
Strategic Resources for Emerging Technologies

Volker Zepf, Benjamin Achzet, and Armin Reller

The title of this chapter assembles meaningful, grandiose words which can be seen as the solutions in favor of a better world. At the same time these words are already battered and maybe even have a portentous scent attached to them. So first a reflection about these words is being indicated.

18.1 Introduction and Definition of the Wording Resource and Emerging Technology

Today, the attributes strategic, emerging as well as the words resources and new technologies are used in an inflationary manner. At the same time the meaning of these words does not seem to be exactly clear. Yet an overarching definition is indispensable for a thorough understanding of the issue.

The first difficulty lies in the word *strategic*. It is an expression commonly used by the military and exactly that understanding of 'strategic' suits well for today's more economic oriented view: a consideration which is based on a longer timeframe around a selected topic or material. The length of the timeframe and the width of the topic are however undefined. Maybe the counterpart tactical can help to scale the definition. Tactical is what has to be done now or in the very next future in a restricted and well defined, i.e. manageable, area. Next, the word *resource* has to be dealt with. Nowadays the expression resource is often directly linked to materialistic considerations. Resources in this respect are thought of as commodities or rare metals and maybe money, funds or other financial values. A resource is however a lot more. The word resource is derived from the Latin word

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resurgere which means as much as to revive, to arise or to pour out of something. So there is no direct distinction to any materialistic thing. Moreover the etymological meaning allows and asks for a broader understanding. There is certainly a materialistic side incorporated like the commodity issue just mentioned, but also a non-materialistic side. This side incorporates immaterial features like knowledge or know how, time, education, processes, procedures and the like. These non-materialistic issues are potentials and should not at all be forgotten. They are of great importance, especially for countries lacking some commodities like Germany, France etc. Obviously education builds the basis for knowledge. Together with experience, processes can be established on how to ideally solve a problem which in turn can be thought of as Know How.

Another facet should not be forgotten in this context: the colonialism, where technical Know How, often located in countries with little raw material occurrences, was combined with physical resources, i.e. raw materials, from entirely poor countries. This topic again gets into focus today. Certain behaviorisms suggest that a neo-colonialism is spreading again, especially in African countries. Or that at least a neo-colonialism is impending. So the old global humanitarian problem may become a new one again.

Finally the list of *emerging technologies* is not a globally agreed one. Instead the issue is of discursive character. Before the focus is put on today's emerging technologies, a look back into history may help to get a better idea about the nature of new or emerging technologies.

18.2 The Nexus of Technological Evolution and Resource Use

A first insight in a new or first technology can be attained from the caves of Lascaux and some others in southern France where around the nineteenth century fascinating wall paintings have been discovered. This parietal art has been dated to the Palaeolithic at around 30,000 BC when the technique of painting with modest and ubiquitous raw materials was perfectly mastered. Mainly charcoal or iron and manganese oxides were used to draw the figures which already show first signs of perspective. The paints were made up of pigments extracted from minerals which were found and mined in or near the caves. Research showed that the pigments were used either pure or mixed with talc to distend the valuable pigments (Lascaux 2012).

A further decisive breakthrough is represented by the Neolithic Revolution, maybe not so much on the basis of the invention of new materials but on the knowledge about harvesting. A next step can be assigned to the general era of the Bronze Age, when a new materialistic technology evolved that allowed alloying of copper and tin to fabricate bronze. This technology required as a prerequisite of course the knowledge about the raw materials, their mining, refining and handling.

In the same time another remarkable insight can be derived e.g. from the Nebra Sky Disk, a bronze disk of around 30 cm diameter, dated at around 1600 BC. It was found near the small village of Nebra, Saxony-Anhalt, Germany and shows stellar, lunar and solar relationships and thus an insight in knowledge about astronomy and the annual recurrence of the seasons. The Iron Age then again represents a general new technological era. At about the same time the Greek philosophy evolved contributing new ideas about community and polis. Then follows a nearly 1,000 years lasting time until in the course of the Late Middle Ages the craftsmanship and construction of huge cathedrals can be seen as new technology. Towards the End of the Middle Ages then a new self-conception in the sciences sprawled questioning old concepts by observation and experiments using new instruments like telescopes. The global sciences eventually split to form the nature or philosophical sciences and the natural sciences. In the Occident ideas like the Enlightenment and the French Revolution gave new directions and self-confidence for further research. Scientists like Isaac Newton (1643–1727) then set up a new pace in the natural science.

A decisive breakthrough on the materialistic technical side was eventually initiated by Thomas Newcomen (1663–1729), a trader and preacher. He was born in Dartmouth, Devon near the Dartmoor where tin mining was an early industry. A big problem was the bad weather which often led to flooding of the pits. This reduced the possible depth of mining. Newcomen invented a first steam engine, probably around 1710, destined to pump water out of the flooded pits. This pump was overall successful so that the invention can be regarded as the prime for the Industrial Revolution. The optimization of this steam engine and numerous other inventions set a completely new pace in emerging technologies. Improved steam engines were implemented into the railway system. That, together with the idea of giving people a day off per week to improve efficiency allowed for a first short vacation using the railway for a short trip to the seas. With a modest income new demand, leisure, amusement and lifestyles were developing and people began an everlasting demand for ever more products.

Coal was one of the most important resources which not only was and sometimes still is mined under miserable (humanitarian) conditions. But its use severely impacted and still impacts the environment. Coal, i.e. fossil-carbon compounds formed as products of photosynthetic activities, and stored for millions of years, fuelled the industrialization. Its combustion then produced enormous amounts of CO_2, or you could say the trapped carbon dioxide has been unleashed. Next to the general negative impacts of the mining activities, especially the numerous burning coal fires, mainly in China, which cannot be extinguished, add continuously to all the other CO_2 emissions which are known to contribute to global warming. This major global issue of climate change and thus the need for CO_2 reduction drives several of the most dominant global developments; renewable energy generation being one of the most actual and important one.

Coming back to technological advance, in a next step the invention of the diesel engine and the implementation of mass production, driven by Henry Ford's automobile production of the Tin Lizzy, marked a further milestone in technological improvement. Now the need for power, electricity and fuels grew rapidly, both for the production and the consumer side. Certainly the world wars fuelled production even more and the repair struggles after the wars set a new basis for further technological advance. Cheap transport and the invention of the 20 foot equivalent container (TEU) were fundamental for the globalization. In the advent of globalization Know How could join easily with cheap labor, science with industrial needs, so that an unprecedented technological push occurred which seems to be still ongoing despite partial global economic difficulties.

This short trip through history of technological advance shows that ever more materials were required and that the time in between major breakthroughs initially took considerable time with the gaps becoming shorter. Nikolai Dimitrijewitsch Kondratieff (1892–1938) offered a new explanation for the time beginning at around 1780 until 2000. He stated that economic growth phases are driven by basic innovations and that these are followed by an expansion, stagnation and recession scheme before a new cycle will start. He identified five phases or cycles with 40–60 years duration each. The basic innovations began with the steam engine, followed by railway and steel, chemistry and electrical engineering, petrochemicals and automobiles, and information technology in the fifth phase. These cycles or loops are called *Kondratieff Cycles* or *Theory of the Long Waves*. Today a sixth cycle seems to emerge, whose labeling could be biotechnology and genetics, but also nanotechnology or just human enhancement. For each of these cycles specific materials and technologies were a prerequisite and of utmost importance to achieve a breakthrough in innovation. All innovative phases were accompanied by the invention of completely new materials or a fundamental change in materials use, Know How so to speak.

So in general the number of materials used and needed grew in an exponential shape which is illustrated exemplified in Fig. 18.1 where the elements used for energy pathways were determined in a work done by Augsburg University (Achzet et al. 2011 and update by Zepf et al. 2014).

Initially, from the Stone Age through the beginning of the industrial revolution, the elements or materials like copper, tin and iron usually had a single functional, often mechanical use. From then on, the elements fulfilled several purposes and became *poly-functional* materials.

Not only that an element showed characteristics to serve different uses, the intelligent combination of different elements showed ever more functionalities. Even though or maybe just because of new identified material functionalities a miniaturization could go along, reducing the size of many products.

For most applications this reduction in size was accompanied by an increased efficiency. As new technologies depend more or less on such poly-functional materials and supply is often restricted by near-monopolistic situations, this poses one of the biggest challenges today.

So, coming back to the question of the *emerging technologies* (EmTech) of today, it can be said that there is no unambiguously accepted list of EmTech. In principle a list would be difficult to define and assemble mainly due to the fact that the development of technologies is per se dynamic, so the ‘list’ can only be a

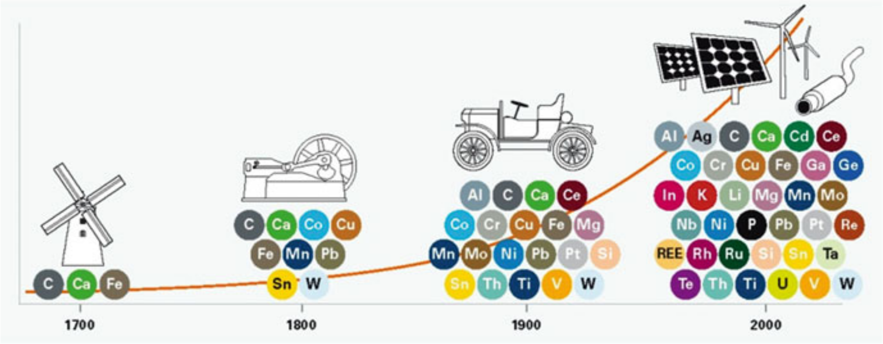


Fig. 18.1 Elements widely used in energy pathways

snapshot. As well there will be different suggestions on what is still emerging and what is already established. As an example an LED lamp may be considered both a (yet) emerging and an established technology at the same time. The search for EmTech on the World Wide Web primarily lists the acronym NBIC (nanotechnology, biotechnology, information technology and cognitive science), a concept hosted by the US National Science Foundation (NSF) called ‘Converging Technologies for Improving Human Performance’ in 2003 (Roco & Bainbridge 2003). Other but similar categorizations have been created e.g. by Garreau (2005) with a system he calls GRIN (Genetics, Robotics, Information Technologies, Nano) or GRAIN (Genetics, Robotics, Artificial Intelligence, Nano) which was adopted by Mulhall (2002).

Even though these approaches cover a wide bandwidth, they lack of some not so obvious technological fields like construction (homes for the growing global population) and the non-materialistic side. Therefore another attempt to summarize the relevant technologies is shown in Fig. 18.2.

18.3 Emerging Technologies: A Selection

Even though NBIC, GRIN or GRAIN are emerging technologies, the focus should be shifted towards the growing world population with the inherent need for energy (contribution of Schebeck et al. in Part 4, Hagelüken in Part 3 and Jägermann in Part 6). Energy production is still based on fossil fuels and thus tied to CO_2 emissions which are identified as factors of global warming. So there is a need for energy saving wherever possible combined with renewable energy production as much as possible. As the renewable energy production is a decentralized system compared to the classic energy production complex with big power plants, new grids are required which can carry the electrical load over long distances, be it by means of supra-technology or via High Voltage Direct Current (HVDC) Systems. So these technologies will push the need for several additional and new materials.

Emerging Technologies – sortings

sorting based on hierarchy of needs and daily life requirements

Environment	***Construction***	***(Daily) Life***	***Mobility***	***Information & Communi-cation technology***	***Energy***	***Energy Storage***
• Catalysis • Lighting	• Buildings • Steel • Glass • Infrastructure (road, rail …) • Superalloys	• Medicine & Pharmacy • Desalination • Water purification • Refrigeration • Heating / Cooling	• Electrovehicles • Hybrid Vehicles • Increased efficiency (optimization of existing technology) • Weight reduction • Traffic Control	• Displays • Communi-cation network / infrastructure (urban & rural) • Mobile communi-cation • RFID	• Renewable Energies: Wind, Solar, Hydro, Biomass, Geothermal • Fission (?) • Grid ***Smart Grid*** • Hardware • Software (Control)	• (Traction) Batteries • Grid Stabilization • Grid Quality • Island Application • 4-C-market
N **B** I C	**N** **B** **I** C	**N** **B** I **C**	**N** B I C	**N** B **I** **C**	**N** **B** I C	**N** **B** **I** C

‘Classic’ nominations		
NBIC (NSF 2003)	**GRIN** (Garreau 2005)	**GRAIN** (Mulhall 2002)
• Nanotechnology • Biotechnology • Information Technology • Cognitives Science	• Genetics • Robotics • Information Technologies • Nano	• Genetics • Robotics • Artificial Intelligence • Nanotechnology

Note: the table shows different coloms detailing emerging technology fields. These may be further pushed by either N - Nanotechnology, B - Biotechnology (Genetics), I - Information Technology, C - Cognitive Sciences. A bold letter states more, grey letters indicate less tendency as push factor. This list has been assembled by Chair of Resource Strategy, Augsburg University.

Fig. 18.2 Overview on emerging technologies

As not all areas can be covered herein, a selection of EmTech is explained in more detail. Obviously this list cannot be complete and the descriptions themselves are not entirely embracing, but they should give a picture of the vastness of the issue(s).

Lighting—Incandescent lamps, using a tungsten filament, were identified as wasting too much energy, so that several countries worldwide put sales prohibitions in place, e.g. ecodesign directive 2005/32/EC and Commission Regulation (EC) No 244/2009. As well toxic ingredients like mercury are banned. So the need for energy saving lamps which are free of toxicity steered the development from compact fluorescent lamps and mercury-free lamps to Light Emitting Diodes (LED). The LED production and sales are gaining momentum at present. For these diodes especially the phosphors, i.e. luminophores or luminescent substances, are crucial for the achievement of the desired light and color. The first LEDs at around 1970 managed to radiate yellow and red light using gallium-arsenic-phosphors. Today aluminum, indium, but decisively gallium, europium (Eu^{2+}) and cerium (Ce^{3+}) are indispensable for LED manufacturing. Terbium as well is widely used. As a substitute for europium and cerium, maybe manganese (Mn^{2+} or $^{4+}$) shows potential (Jüstel 2011). In common fluorescent lamps (tubes) the phosphors used are mainly three-band phosphors, which are on the inside of the glass covers. They contain mainly the rare earth elements yttrium, europium, terbium, lanthanum and cerium in specific combinations and concentrations. Except maybe lanthanum and cerium the supply of rare earth elements is presently and at least in the near future critical, if not endangered. As China has set export restrictions and tariffs on rare earths due to own demand and environmental problems during the mining and processing phase (Chinese Ministry of Commerce 2010). More details about the Chinese actions and behavior in this issue have been elaborated by Zepf (2013). Another LED system emitting blue light depends on the use of indium-gallium nitride (InGaN or GaN) which again are materials with critical supply situations. Without modern lighting technology however, the global energy saving goals cannot be met. Substitutions for these elements are presently not available; maybe the organic LEDs (OLED) will prove as potential substitution.

The *Information and Communication Technology* (*ICT*) is mainly based on semiconducting materials and a high diversity of about 60 elements which are fabricated in these systems (Donner 2011). These 60 elements serve different functions; e.g. as casing, logic board, display etc. All these functions incorporate a special elemental composition and the fast dynamics in the ICT arena makes a prediction of the elements needed both in quantity, quality and time nearly impossible. A general idea of the vast use however can be attained. According to UNEP the composition of a cell phone is comprised of about 50 % plastics—mainly the casing—15 % for both copper and glass, 4 % both for cobalt or lithium (battery) and carbon and the remaining 12 % are other elements like nickel, iron, zinc, tantalum, cadmium or lead (Cell phone composition 2006). Similar data have been assembled by Huisman (2004). The noble metals gold, silver and palladium are contained as well. Hagelüken (2011) states an average of 250 mg silver (Au), 24 mg gold (Au), 9 mg palladium (Pd) and about 9 g of copper (Cu) per mobile phone. Compared to the 1.6 billion mobile phones sold in 2010 approximately 400 t Ag, 38 t Au, 14 t Pd and 14.000 t Cu (Hagelüken 2011) were built into these phones within 1 year. This of course represents a (future) recycling potential. For comparison, the annual production of these elements were in 2010: 22.200 t Ag, 2,500 t Au, 197 t Pd and 16 Mio. t Cu (USGS 2011). So for Pd at least the quantities used for the mobile phone production are remarkable.

Back to ICT in general, main boards contain chips made mainly out of silicone, silver and copper; whereas capacitors and high performance transistors contain tantalum and niobium, but also aluminium, barium titanium and others. Coltan is the main ore from which tantalum is mined. The biggest mining activities presently are in the eastern—southeastern part of the Democratic Republic of Congo, near the border to Ruanda. Illegal mining activities are said to have contributed to the civil war parties so that today a legal mining activity is pursued. USGS shows that the biggest tantalum producers are Brazil, Democratic Republic of Congo and Rwanda. The central African countries produce nearly half of the global production (USGS 2011, USGS 2014). The German Federal Institute for Geosciences and Natural Resources (BGR) initiated an analysis method for proofing respectively fingerprinting the source of Coltan to attain a kind of a certificate for 'clean' raw materials which were not produced by child labor or did not promote civil wars and war lords (BGR 2010).

Energy storage or batteries for the 4-C market (camera, computer, cellular phone, and cordless tools) represent the biggest market for accumulators. The most important technologies in this field are based on lithium-ion (Li-Ion), nickel-metal-hydride (NiMH) and to a decreasing amount nickel-cadmium (NiCd) technology.

The Li-Ion technology is leading the market with about 90 % share as Li-Ion provides the highest energy density (Hanning 2009). The materials used are of course lithium but also cobalt as cathode material and a carbon based anode material. Cobalt is problematic because about half of the annual global production comes from the Democratic Republic of the Congo (USGS 2014) where severe negative environmental and social conditions persist. Cobalt can be replaced by manganese and nickel to further enhance efficiency (Whittingham 2004). More recent research mentions a lithium-phosphor based cathode.

For NiMH next to nickel also lanthanum, one of the rare earth elements is used. Fortunately lanthanum is one of the most abundant REE but even lanthanum got into the maelstroms of finance-political difficulties resulting in volatile commodity prices.

In the NiCd arena cadmium poses a problem as cadmium has toxic characteristics which led to a ban in several countries around the globe, e.g. the EU directive on the restrictions of the use of certain hazardous substances in electrical and electronic equipment (EU RoHS directive 2011/65/EU).

The short term energy storage is also getting momentum. Several capacitor technologies have been developed to satisfy the market demands. Especially tantalum based capacitors demonstrate high performance characteristics (Jayalakshmi 2008). But again, tantalum is coated with a problematic mining situation as described above.

Storage for traction batteries in electric vehicles is a further growing market. Next to the capacitors for the short-term energy storage, mainly electrochemical storage systems are appropriate for the automotive sector. High temperature batteries (Natrium-Nickel-Chloride - NaNiCl), Li-Ion, NiMH, NiCd, lead acid batteries or Hydrogen Storage Systems are possible solutions. Li-ion technology is again the best available option at present, due to the specific energy density and cycle stability, so that the demand for lithium is expected to grow significantly. With an estimate of 100 million light vehicles to be produced annually by 2020, 3 % are expected to be full electric cars, 2 % plug-in hybrids and 15 % full hybrids, this sums up to a lithium demand of more than 60.000 tons per year (Achzet 2010), compared to about 30,000 t in 2010. The question here however remains, i.e. if the estimate for 2020 is realistic at all.

Loudspeakers in mobile phones and ICT usually use rare earth elements based *permanent magnets* containing neodymium, praseodymium, iron and boron. Here the availability of neodymium and to a lesser extent praseodymium is critical—due to a quasi-monopolistic production situation in China.

Displays are based on the same technologies as LCD computer monitors or modern LED TVs. In liquid crystal displays indium-tin-oxide (ITO) layers are used as a transparent electrode in polarization filters as they function both as a transparent layer and offer electrical conductivity at the same time. One potential competitor for future indium demand is the solar industry producing thin film solar cells on copper-indium-selenide (CIS) and copper-indium-gallium-selenide (CIGS) basis.

The biggest producer of indium in 2010 was China with estimated 300 t followed by the Republic of Korea producing 80 t and Japan with 70 t. The world total is estimated at 574 t (USGS 2011). When reserve data were published in 2008, the range of indium was around 20 years of production; today no more reserve data are published so that a strategic supply decision is nearly impossible. So indium seems to be a perfect solution for both applications but supply constraints already push substitutions. A possible substitute for the main application in ITO electrodes could be fluorine-tin-oxide (FTO) (Ziemann & Schebek 2010), antimony and some others (USGS 2011).

IBM introduced processor chips based on hafnium to obtain higher performance (IBM 2007). Again hafnium is a rare element with at least no supply in excess. Interestingly there are no more reliable new informations attainable on the future use of Hf in the chip industry.

In 2008, the global share of *renewable energies* was 7 % and is predicted to increase to 14 % in 2035 (IEA 2010). This in turn means that renewable energies will have to bring a considerable bigger share on the energy production. As neither solar nor wind energy are capable to provide the base load; and biomass, geothermal and hydro power cannot provide enough energy alone on a global meso- to macro-scale, a multitude of energy systems is necessary within a complex network to assure a stable energy supply.

The materials side asks for special steels with high corrosive resistance especially in case of hydro and geothermal energy production. The installation of biomass energy production facilities is of minor criticality whereas the fertilizers needed to achieve quantitative sufficient biomass for energy production are in direct competition with global food production.

In the *solar energy* several principle technologies are available. On one side there is the photovoltaic (PV) field which directly produces electrical energy and on the other side there are big power plants like concentrated solar power plants (CSP). A third area is represented by small thermal solar systems usually used on a micro- i.e. household scale. All of the available technologies are based on different elemental compositions with different efficiencies. The bulk share of PV is based on silicone thick film solar cells which show an efficiency of around 16–20 %. Thinfilm panels based on amorphous silicon achieve between 5 % energy conversion efficiency, Copper-Indium-Selenide (CIS) and Copper-Indium-Gallium-Diselenide (CIGS) panels vary from 10 to 12 %, Cadmium-Telluride (CdTe) panels achieve about 10–16 %, Gallium Arsenide (GaAs) panels up to 40 % (Fölsch 2009; Bayerisches Staatsministerium WIVT 2010). Interesting is as well the relative global share of these individual PV-systems: Si-based thick film systems account for about 88 %, CdTe contribute 5.5 %, CIS-systems about 2.5 % (Hering 2012). For all of these technologies research is underway to increase efficiency. Compared to efficiency levels of about 90 % for hydro energy, this research indeed seems necessary. And the material quantities needed to provide sufficient energy with solar power are expected to be huge; comparative research is still required.

As has been said, the list could be extended way longer; so the number of 60 elements can be explained. Important to note is, that these elements are not always needed in big quantities, but often like spice (metals) which allow some functional characteristics in the first place. The issue however gets obvious when a map of the world is drawn which shows the sources of these elements. In principle they are mined all over the world, usually fabricated in the far-east regions and sold mainly in western countries but increasingly also in the far-east regions. So the geography of the elements tells a story that all this development is only possible with cheap transport to gather even tiniest quantities from outposts and bring them together into a small powerful gadget. These lifestyle and production products are indispensable from daily life, at least as merchandising tries to imply.

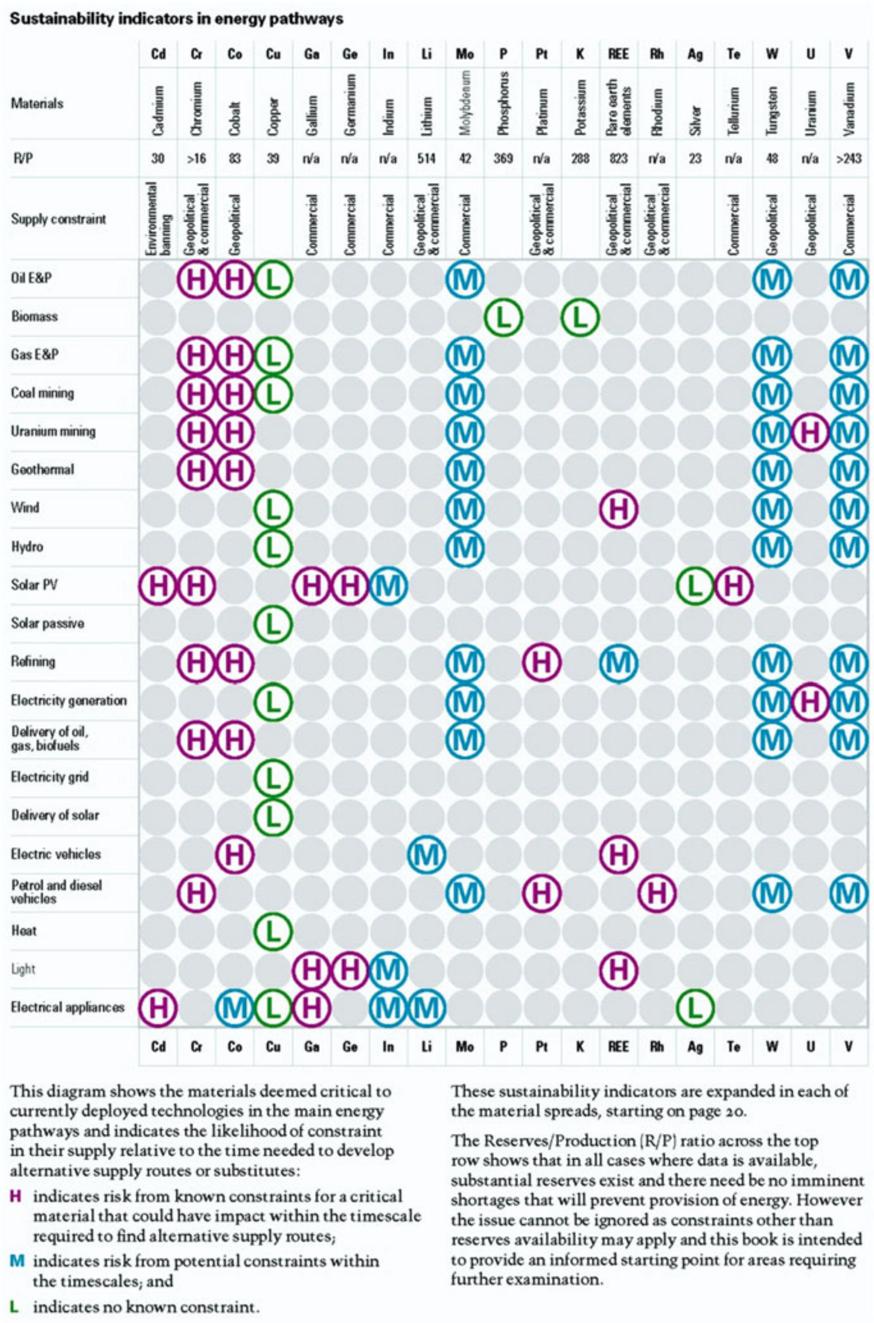
The realization of long term decisions for recycling or substitution in order to reduce potential material risks is very difficult to implement, mainly due to the extreme dynamics in this area and the dependency on poly-functional materials with an unsecure supply and demand situation. From a resource strategic point of use, there is no question as to the necessity of recycling or not. Of course recycling and even before that re-use and re-manufacturing are necessary and relevant options. However, nowadays the economic or financial aspect usually outruns the resource aspects; if a recycling does not provide financial profit, the option is out of question.

18.4 Summary

This short description of just some technologies shows that several elements are indispensable and can only be substituted by elements who themselves are critical materials and where supply is as well not guaranteed. The list should have also shown the fact that not a single technology can be extracted and viewed separately. The real problem only is revealed when all possible competitors and factors next to the pure availability are taken into consideration. Even when quantitative data is difficult to gather, the qualitative idea should give enough momentum for early action. Within the Energy Sustainability Challenge, hosted by BP, Augsburg University assembled a list of critical elements for energy pathways which are deemed as emerging or at least important technologies. Figure 18.3 shows the allocation of 19 elements to various energy pathways and highlights three grades of criticality: L—meaning no immediate action is necessary, M-indicating caution as action may be imminent and H—showing action is absolutely necessary to secure supply.

It should have become obvious that a discourse about the topic and further research is needed. Yet the message should be that for emerging technologies, no matter how advanced they are or how effective and efficient, the materials side could be a show stopper both on short, mid and long term.

Shortage and supply risks are given, but it is essential to have a reliable answer to the question, if such a shortage situation actually is present or probable. Several seemingly critical raw materials are indeed not that endangered by supply shortages as is implied by media and headlines. A closer look is often appropriate. If shortages



Sustainability indicators in energy pathways

	Cd	Cr	Co	Cu	Ga	Ge	In	Li	Mo	P	Pt	K	REE	Rh	Ag	Te	W	U	V
Materials	Cadmium	Chromium	Cobalt	Copper	Gallium	Germanium	Indium	Lithium	Molybdenum	Phosphorus	Platinum	Potassium	Rare earth elements	Rhodium	Silver	Tellurium	Tungsten	Uranium	Vanadium
R/P	30	>16	83	39	n/a	n/a	n/a	514	42	369	n/a	288	823	n/a	23	n/a	48	n/a	>243
Supply constraint	Environmental banning	Geopolitical & commercial	Geopolitical		Commercial	Commercial	Commercial	Geopolitical & commercial	Commercial		Geopolitical & commercial		Geopolitical & commercial	Geopolitical & commercial		Commercial	Geopolitical	Geopolitical	Commercial
Oil E&P		H	H	L					M								M		M
Biomass										L		L							
Gas E&P		H	H	L					M								M		M
Coal mining		H	H	L					M								M		M
Uranium mining		H	H						M								M	H	M
Geothermal		H	H						M								M		M
Wind				L					M				H				M		M
Hydro				L					M								M		M
Solar PV	H	H			H	H	M								L	H			
Solar passive				L															
Refining		H	H						M		H		M				M		M
Electricity generation				L					M								M	H	M
Delivery of oil, gas, biofuels		H	H						M								M		M
Electricity grid				L															
Delivery of solar				L															
Electric vehicles			H					M					H						
Petrol and diesel vehicles		H							M		H			H			M		M
Heat				L															
Light					H	H	M						H						
Electrical appliances	H		M	L	H		M	M							L				
	Cd	Cr	Co	Cu	Ga	Ge	In	Li	Mo	P	Pt	K	REE	Rh	Ag	Te	W	U	V

This diagram shows the materials deemed critical to currently deployed technologies in the main energy pathways and indicates the likelihood of constraint in their supply relative to the time needed to develop alternative supply routes or substitutes:

H indicates risk from known constraints for a critical material that could have impact within the timescale required to find alternative supply routes;

M indicates risk from potential constraints within the timescales; and

L indicates no known constraint.

These sustainability indicators are expanded in each of the material spreads, starting on page 20.

The Reserves/Production (R/P) ratio across the top row shows that in all cases where data is available, substantial reserves exist and there need be no imminent shortages that will prevent provision of energy. However the issue cannot be ignored as constraints other than reserves availability may apply and this book is intended to provide an informed starting point for areas requiring further examination.

Fig. 18.3 Sustainability indicators in energy pathways should be prone, then solutions show up of course in the classic re-phases (re-use, re-manufacture and re-cycle) and in substitutions; and in the thinking of functionalities rather than single technologies. Thinking in functionalities like solar energy leaves a wider application field than reducing the options down to e.g. CdTe-PV as the only possible technology. If here, Cd would be prohibited due to its toxic characteristics, the CdTe-PV would be dead and the search for substitutions in a timely manner very difficult. An early opening of the options and the use of alternatives on a systemic level seems appropriate. To stay with the example, there are sufficient other PV systems on Si or CIGS basis available. The same is true for wind turbines, where rare earth elements based systems are only an alternative to classical asynchronous drive systems.

On the other hand, the inventions made by EmTech may as well render technologies of today or other EmTech nearly instantaneously obsolete. Nanotechnology for example could lead to the ideal situation of fewer (material) quantities needed for the manufacturing of a product and probably of enhanced efficiency as well. It cannot be estimated, which elements will be of strategic or tactical importance within the next 5, 10 or 50 years as the advance of NBIC, GRIN or any other EmTech cannot be judged reliably.

What can be said is that the general quest for maximizing performance should be shifted in favor of a technological design, tailored and optimized according to at least some criticality factors. Keep alternative solutions open for some time to attain experience of the success and feasibility of the new technology. Maybe it is a sound solution to follow two or more technological roads in order to reduce stress on a single raw material and of course, the prerequisite for any decision is to get a reliable data base. Recent data uncertainty should give enough incentive to change that situation.

Finally the initial thoughts about resources should be called in mind again: Know How, education, research and all the non-materialistic features can and should play a more decisive role than just the gamble on best short term commodity prices. Only a wise use of all resources together and doing this by incorporating socio-cultural (moral), ecological and economic considerations, seems to be the most advantageous and promote successful emerging technology.

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Chapter 19

Perspectives on Photovoltaic Energy Conversion: Dependency on Material Choices

Wolfram Jaegermann

19.1 Introduction

The perspectives on Photovoltaic Energy Conversion are promising. Although there is dependency on material choices, technology dynamics and technical evolution new generations of PV modules will offer an increase in material efficiency and give future answers on sustainable material choices and alternatives.

Unfortunately, the given resources of In and Te as main constituents of compound semiconductor thin film solar cells are generally considered to be not available in the needed amounts to secure a several TW production of electric power. The estimates of the overall amount to In and Te reserves are hard to quantify as they are only gained as byproducts e. g. of Cu and Zn mining.

The estimated resources will only allow to provide a good percentage of the overall electrical power needed. The limited availability of In and Te will not lead to restrictions in the extension of thin film solar cells for the next decades (contribution of Hagelüken in Part III and Zepf et al. in Part IV). But it will not be possible to guarantee the complete primary energy needs of the world using only CdTe and/or CIGS thin film solar cells even with the introduction of recycling technologies. For this reason new absorber materials would be needed for the development of novel thin film PV converters.

The costs to be expected for different future solar cell systems are highest for the solar cell materials under investigation now and are lowest for many new materials, which may provide alternative solutions as absorber material but have hardly been investigated yet. There is the need for a better understanding of fundamental issues of thin film solar cells to improve the performance of the established thin film solar cells of Si, CdTe, and CIGS. This argument is even more true for new absorber

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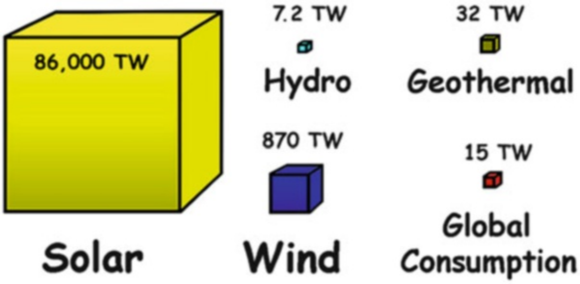


Fig. 19.1 Estimated yearly energy supply of the most important renewable energy sources compared to the yearly global consumption *Source*: Wikipedia World energy resources and consumption 2011

materials which may complement or substitute the established materials in the long run as will be discussed below.

As is shown in Fig. 19.1, which compares the projected energy supply of the most important renewable energy sources to the global energy demand per year (for 2004), it is immediately evident that harnessing solar radiation provides the most promising solution. The amount of solar energy which reaches the earth is by several magnitudes more than sufficient to provide a sustainable source of energy for mankind. The application of solar energy will also avoid any sacrifice to the global energy budget as the equilibrium of radiation to and from the earth would not be modified by human interference. With the given radiation 1 h of solar radiation on Earth provides nearly the world's total annual energy needs. On the other hand solar radiation is a rather diluted and discontinuous energy source which in many applications necessitates concentration and storage efforts.

19.2 Technology and Cost Issues of Solar Cells: The Generation Concept of Solar Cells

In principle, very many different light absorbing materials and device structures may be applied to convert light into electricity. However, so far only a very limited number of solar cells have been developed to technological maturity as will be presented in more detail below. In addition, novel concepts have been suggested and are also intensively investigated today, but are still off any practical realizations, as will also be discussed later.

Therefore, Solar Cells may be classified according to their technological maturity in accordance to their presently given market share and future cost expectation. Only crystalline Si, thin film solar cells based on two compound semiconductors (CdTe, CIGS), and thin film Si must be taken into account for terrestrial applications of today (MRS Bulletin 2008; MRS Bulletin 2007; MRS Bulletin 2005; Luque and Hegedus 2010). Other types of solar cells have not yet reached a status which allows their terrestrial application. As for all industrial products the costs of solar cells also depend on the cumulative production volume. The given cost development and future expectations for different solar cells are shown in Fig. 19.2 as function

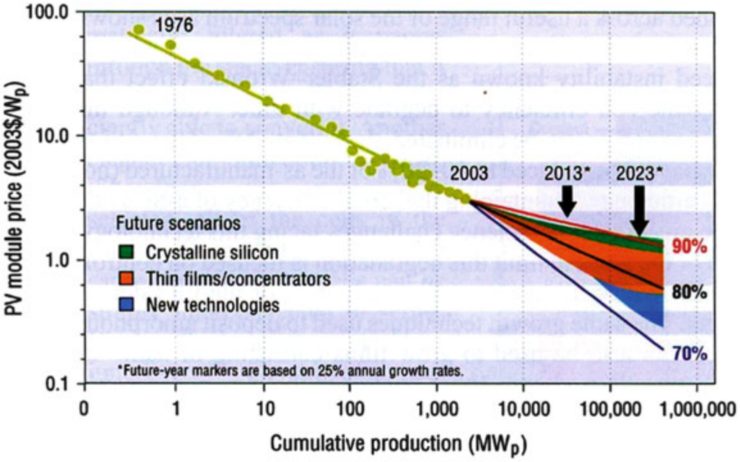
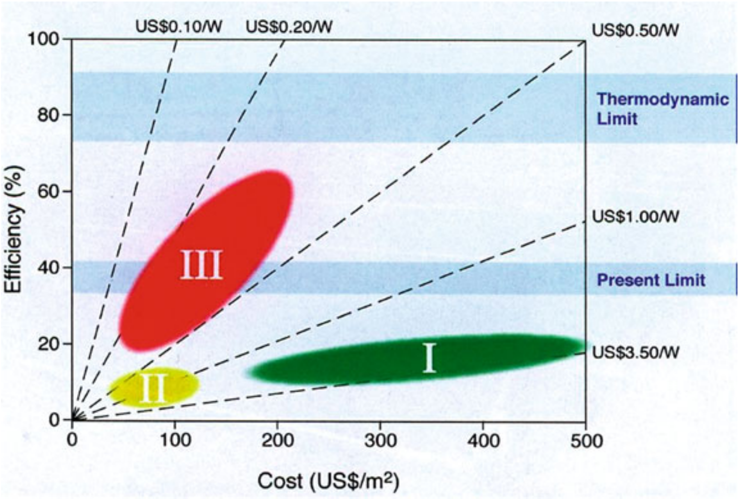


Fig. 19.2 Cost developments and projections of solar cells in dependence of cumulative production as given for different cell technologies: Crystalline Si cells, thin film solar cells and new technologies. The maturity is given by percentage levels. *Source*: MRS Bulletin 2008

of cumulative production. Also indicated are defined levels of production costs reached at different years (MRS Bulletin 2008). The expectations for further cost reduction of course strongly depend on the learning curves to be estimated for different technologies which are assumed to be lower for a already reached higher maturity: Therefore Si cells will probably follow learning curves with lower cost reduction because of higher maturity level as thin film solar cells or new technologies.

As another classification scheme it has been suggested to group the different solar cells in different generation of photovoltaic technologies (Fig. 19.3) (Green 2003). This concept considers the different physical device concepts of solar converters. The expected costs of PV will thus depend on the physically possible energy conversion efficiencies and the production cost depending on the device structure and involved manufacturing steps. First (crystalline Si) and second (thin film) generation cells are limited in their conversion efficiencies by the Shockley – Queisser-Limit (Shockley and Queisser 1961) as only part of the solar radiation energy can be converted to electrical power when only one light absorbing material with one definite band gap is utilized (photons of the wrong energy are either not absorbed or loose part of their energy). In the "third generation PV concepts" the Shockley-Queisser Limit shall be surpassed and the thermodynamic limit of energy conversion may be approached by minimizing the thermal loss mechanism of electron hole pairs. The "trick" involved is based on the reduction of loss mechanisms in the conversion of photons of excess energy. Here different processes have been suggested as tandem or multi junction cells, intermediate band cells, hot-carrier cells, multi electron-hole pair formation by impact ionization, as well as photon up-and down conversion (Green 2003).



Notes: I First Generation Crystalline Si PV, II Second Generation Thin Film PV, III Third Generation PV concepts beyond the present Shockley-Queisser-Limit

Fig. 19.3 Generation classification scheme of different PV technologies (generation I–III). *Notes*: I First Generation Crystalline Si PV, II Second Generation Thin Film PV, III Third Generation PV concepts beyond the present Shockley-Queisser-Limit. *Source*: Green 2003

Currently photovoltaic energy converters are mostly based on single-crystalline or multi crystalline Si solar cells. These cells are already under development for a long time and are produced from Si wafers cut from large single crystals or large grain multi-crystalline blocks applying well-known manufacturing steps as established in Si microelectronics. These Si solar cells are classified as “first generation solar cells” and are expected to keep their leading position for the next years despite their principle disadvantages as low absorption coefficient for visible light which leads to rather thick solar cells in the range of several hundred μm and the high energy input needed for their production. These disadvantages are overcompensated by inherent advantages as e. g. the high level of device and production technology and unlimited resources of Si. More details on research needs and efforts for crystalline Si solar cells are given in the next chapter.

However, because of the disadvantages of bulk Si solar cells also thin film solar cells have already been developed for quite a while but have reached a competitive level of production only recently. These thin film solar cells are based on strongly light absorbing thin film semiconductors which are deposited on cheap substrates using low cost deposition techniques. They are classified as “second generation solar cells” with the expected advantage to be more competitive in the long run because of the reduced cost and energy demand in production (for more details of R&D see also next chapter).

Finally, the “Third Generation PV concepts” summarize all new physical PV concepts which have been suggested to surpass the given limitation of the Shockley-Queisser limit. With only one absorber material only the photons with energy above this band gap will be absorbed, the photons of lower energy will be lost. On the other hand the photons of larger energy as the band gap will be absorbed but the high energy electron hole pairs will lose their excess energy due to fast relaxation to the band gap. As a consequence only about 30 % of the initial radiation energy of the sun will be converted at best to electrical energy neglecting other device and materials related loss mechanisms in transport and transfer of charge carriers. As already mentioned above a number of novel device structures have been suggested which at least in part may overcome the inherent energy loss mechanism of only one light absorber. The most well known and elaborate systems are multifunction cells in which n different solar cells of different band gaps are stacked on each other. With such systems the highest conversion efficiencies of PV converters has been reached with values above 40 % in concentrated sunlight e. g. using a stack of epitaxially grown multi layers of Ge, GaAs and GaInP2 (Olson et al. 2003). Recently, the world record has been achieved with 41.1 % conversion efficiency using a Ge/(GaIn)As/(GaIn)P triple junction with current matching (Guter et al. 2009). Other concepts use intermediate defect levels (impurity bands) (Luque/Marti 1997), hot carrier extraction by quantum dot structures (Ross/Nozik 1982) or multi electron formation (impact ionization) (Werner et al 1995) to overcome the efficiency limitations inherent with the energy relaxation of electron-hole pairs. Other concepts involve extra optical layers which combine two low energy photons to a high energy photon (up conversion) or split one high energy photon into two low energy photons (down conversion, Trupke et al. 2002a, b). So far most of the third generation concepts have not proven their applicability for efficient conversion of solar radiation despite the tandem or triple solar cells. In some cases organic solar cells (MRS Bulletin 2005), which uses organic dyes or polymers as absorbing materials, are also designated as third generation concepts. According to the definition given above this is not valid as the energy loss mechanisms due to thermalisations, which is related to non-adjusted energy levels to the solar spectrum, is not overcome by organic absorbers. By contrast, the localized character of the involved energy states in organic semiconductors will lead to a reduction of spectral absorption bandwidth and to reduced charge carrier mobilities. Therefore we will count organic solar cells to second generation thin film solar cells.

19.3 Status and Perspectives of Different Photovoltaic Technologies

Progress of research size solar cell efficiencies, which are directly related to cost issues, are shown in Fig. 19.4. for the most important solar cell technologies of today. As is immediately evident there has been a steady improvement of conversion efficiencies during the last 35 years and a number of cells have reached

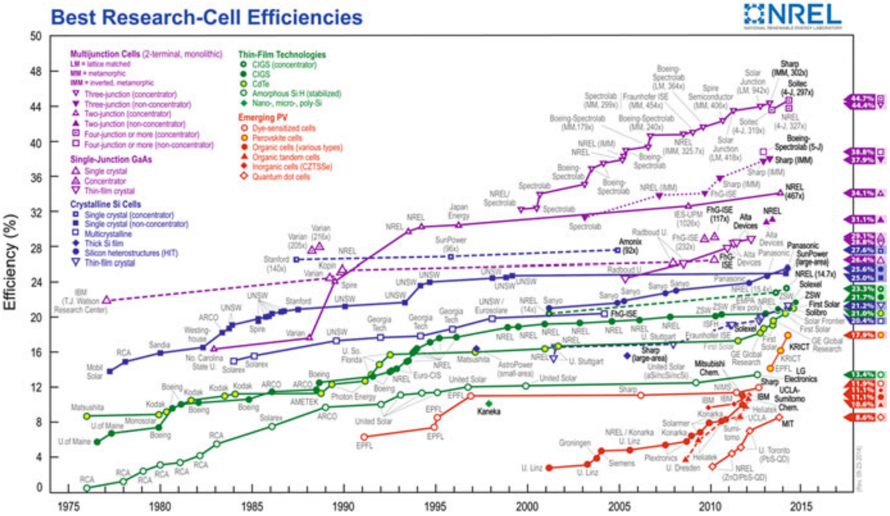


Fig. 19.4 Progress of PV efficiency limits of research-scale devices of different solar cell technologies. *Source*: Data compiled by Lawrence Kazmerski, National Renewable Energy Laboratory (NREL 2014)

conversion yields even above 20 %. This is clearly due to a better understanding of device and materials properties with time as the outcome of improved research efforts. On the other hand there are also a number of cells which do not show any strong improvements for the last years which must be related to missing research support as e. g. for CdTe solar cells. Only recently the efficiency has been raised to values above 20 %. For these cells strong improvements are still possible by a better understanding of device and materials properties in dependence on processing steps. On the other hand for mature cell technologies as crystalline Si, which are already close to their theoretical efficiency limit, cost reductions can only be expected by improved engineering of large scale module production.

Silicon solar cells are the backbone of photovoltaic energy converters with a market share in the range of 80 % worldwide. The share is expected to decrease slowly to a value of about 75 % in 2014 in relation to thin film technologies (EPIA 2010). Despite their classification as first generation technology crystalline Si cells are still the best solutions for very many applications especially on roof-top systems for which a maximum of electrical power is expected for a limited area. A typical crystalline Si solar cell consists of single crystalline or large grain polycrystalline wafers cut from bulk crystals grown from Si melts at high temperatures (melting temperature of Si is 1,410 °C). Additional high temperature steps are needed to prepare Si from SiO_2 (reduction of SiO_2 with C at temperature of around 2,000 °C) and for the subsequent cleaning cycles (Ceccaroli/Lohne 2003). As for the wafer production by cutting bulk crystals or crystalline blocks nearly 50 % of the previously synthesized high purity material is lost again, it is immediately clear that the production of Si solar cells will remain rather expensive from an energetic as well as from a monetary point of view.

19.4 First Generation Technology: Crystalline Si Cells

The schematic structure of Si solar cells is schematically shown in Fig. 19.5. Due to the weak light absorption of Si (it is an indirect semiconductor with rather low absorption coefficients for solar light) the needed thickness of the absorber layer is rather large (typically in the range of 300 μm) and needs to be mostly free of defects and contaminations. As a consequence of the low light absorption large parts of the solar spectrum penetrate deeply into the bulk of the Si solar cells before generating electron-hole pairs. Therefore the non-equilibrium charge carriers must achieve high diffusion lengths before recombination in order to reach the contacts for efficient charge carrier separation. Light induced carriers recombining within the solar cell would not contribute to the generation of electrical power. For this reason the bulk of Si must be prepared in a very controlled manner without any intrinsic or extrinsic defects to avoid recombination centers in the band gap. Thus only very pure "solar grade" Si can be used for the preparation of high quality wafers as basis for efficient Si solar cells. For this reason Si photovoltaic will remain a rather costly and energy consuming solar cell technology with limited perspectives in cost reduction. On the other hand there are no resource limitations for Si and the solar cells in themselves are environmentally harmless. Also the given fundamental and technological knowledge of materials and device properties as well as of the involved processing steps are most advanced for Si because of its prominent role in Si based microelectronics. For this reason Si solar cells have reached a high level of maturity with the given and well known advantages for photovoltaic applications, which will last for a number of additional years.

The Si technology of today leads to PV converter modules with typical costs of 2–3€/Wp which translates to electrical power generation costs in the range of 0.30 €/kWh (IEA (2010), SRA 2007). In 2014 the PV converter module costs have already been reduced to values of ~0.50 €/Wp (pvinsights.com (2014)). Another important parameter is the energy payback time, which is defined as the deployment time of the solar cell to generate the same amount of energy as is used for its production. Of course this number depends on the insolation and thus on geographical area where the solar power plant is erected and the specific technology under consideration. As a good mean number Si will provide energy payback times in the

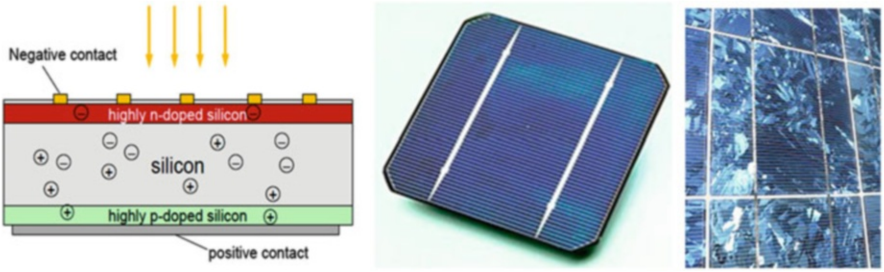


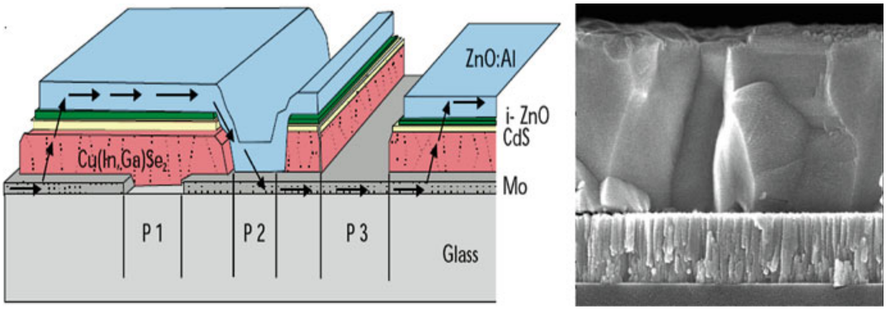
Fig. 19.5 Schematic device structure of a crystalline Si solar cell (*left*, (Luther 2007) and pictures of Si single crystalline Si cells (*center*) and multicrystalline Si cells (*right*)

range of 2 years. In comparison the life time of PV power plants should be very high as no moving parts are involved with proven life times well above 20–30 years. It is expected that with improvements in crystalline Si solar cell technology the above given performance numbers will further improve with time. On the other hand the costs for Si solar modules will decrease following the above given learning curves (Fig. 19.2). Key issues in improving Si PV technology are cheaper and more energy efficient routes to solar grade Si wafers. One promising and intensively investigated route is the direct production of crystalline sheets of Si directly from the melt e. g. by ribbon-growth technologies, which at the end should produce thin film crystalline Si solar cells which are considerably thinner (up to 50 μm) as the given cells. Also improvements in the optical managing of the light will contribute to higher efficiencies without strong increases in cost. With all these improvement it is expected that the cost of crystalline Si solar cells will fall below 0.50 €/Wp within the next few years.

In summary, it can be concluded that Si based PV is an already existing and sustainable solution for electric energy generation from light. The expected technology developments will lead to further cost reduction. However, it seems also to be clear that the expected costs cannot be reduced to the level possible with fossil energy sources we have been adapted to in the last decades. Optimistic assessments lead to overall reductions by a factor of about 5 in the long run, which leads to electrical energy production costs in the range of 0.10 €/kWh. With these numbers one will surpass grid parity soon but may stay above the production costs as presented for other non renewable primary sources which, however, are often calculated without considering their environmental impact.

19.5 Second Generation Technology: Thin Films

Classical Second generation solar cells are PV technologies based on thin films of Si, CdTe and CIGS ($Cu(InGa)Se_2$). All these have demonstrated reasonable module energy efficiencies above 10 % and for CIGS and CdTe research cells values above 20 % have been reached. These cells are characterized by a sequence of layers which are deposited onto cheap substrates with the application of mature thin film deposition techniques (Fig. 19.6). As the absorber layers show high light absorption coefficients as CdTe or the different compositions of the chalcopyrite family (CuIn(Ga)S(Se)) due to their direct energy gap, very thin films in the range of 1 to 2 μm would be sufficient for efficient light capture. In the case of thin film Si usually tandem cells of (amorphous) a-Si or (microcrystalline) μc-Si are applied. With the given principle advantages of thin film technology on cheap substrates thin film solar cells were already discussed for a long time as the most promising devices for an economic competitive energy technology. However, due to severe problems in realizing the expected conversion efficiencies this promise could not be kept for a long time. Due to incomplete knowledge about material's and device properties and processing effects it was not possible to reach the expected device performance for



Notes: showing the monolithic integration of the different cells in the module and cross sectional scanning electron microscopy images of the layer structure

Fig. 19.6 Schematic structure of a thin film solar cell (in this case CIGS). *Notes*: showing the monolithic integration of the different cells in the module and cross sectional scanning electron microscopy images of the layer structure. *Source*: Powalla 2010, Personal Communication

a long time. But this status seems to be overcome in recent years due to increased R&D efforts and a number of thin film technologies enter the market just now with expectations that their share will grow in the next future compared to bulk Si.

Amorphous Si was the most successful thin film technology in the past with a market share of about 6 %. Usually tandem or triple junction structures of different Si based thin film layers are used which can be deposited by plasma or hot wire enhanced Chemical Vapor Deposition techniques (CVD) using Si-H compounds as precursors (Poortmans/Arkhipov 2006). The advantage of a-Si is the increased absorption coefficient of light due to a quasi-direct band gap. On the other hand a large number of defects exist in the band gap which must be passivated by the incorporation of Hydrogen. Because of weak Si-H bonds such solar cells show degradation effects induced by solar radiation which leads to a steady decrease of their efficiency (Staebler-Wronski-effect). As a consequence either μc-Si layers must be included in the absorber layer and/or complicated multilayer structures must be prepared (triple junction structures) which reduces the degradation effect but also increases the complexity and thus the costs of these solar cells. Overall module efficiencies of a-Si up to 10 % after degradation and about 12 % for μc-Si tandem cells have been reached. Typical costs presented for the production of the cells differ considerably in a typical range of 1 €/Wp; the most optimistic number given for the next future has been announced to reach 0.5€/Wp in the last fifth World PV conference (25th EU PVSEC) conference (Oerlikon 2010). In the meantime, however, thin film Si cells are not any more considered to be competitive.

Recently, also the production of thin film solar cells based on compound semiconductors with high absorption coefficients as CdTe and CIGS have reached the production level (Poortmans/Arkhipov 2006; Luque/Hegedus 2010). CdTe has proven to be just now the most promising PV technology regarding the production cost with published numbers below 0.8 €/Wp already given now and expectations of 0.5 €/Wp for the next future (First Solar 2014). As a consequence the relative share of CdTe solar cells is strongly increased with an overall production volume of 1.8 GW. The advantage of the CdTe thin film technology is the easy and fast deposition process which is possible with different but similar techniques which are based on a physical vapor deposition process. The moderate module efficiencies of about 14 % and the best research cell efficiencies of 21 % indicate that there is still room for improvements in the device structure. The same is true for the production and processing technology as thinner cells and modified device structures should lead to better performances from a fundamental point of view but so far cannot be realized because of limitations in the processing technology (Jaegermann et al. 2009). CIGS solar cells show the highest research cell efficiencies reached so far for thin film solar cells with values above 20 %. However, the deposition technology is more complicated which also leads to slower deposition rates. Despite of many companies being in the start-up phase CIGS based solar cell have not yet reached the same production volume as CdTe cells. The most competitive production technology is run by Solar Frontier with module efficiencies close to 14 % (solarfrontier.com (2014)).

As thin film technology the performance of the solar cells and also of the modules is strongly dependent on the interface properties between the different dissimilar layers used in the formation of the solar cell. Abrupt hetero interfaces will not work as differences in the lattice constant will lead to defect levels at the interface. Furthermore, grain boundary effects must also be considered which are hardly investigated so far. This is also true for the control of nucleation and growth of the different films to be deposited on each other which should give rise to optimized morphologies. Finally the doping and defect chemistry in the bulk of the different layers combined to form the solar cell are also not well understood which leads to limitations in the doping levels and thus in the maximum photo voltage reached which is well below the theoretical expectations (Jaegermann et al. 2009). For this reasons the module efficiencies of both compound semiconductor solar cells are still below the values which can be expected from a theoretical point of view, with typical experimental numbers in the range of 11–14 %. The success of thin film technologies in recent years can definitely be related to increased R&D efforts. But despite the evident success, a detailed understanding of the involved materials and device properties depending on preparation and processing steps is still not on the same level as for bulk Si solar cells. There are still a number of processing "tricks" and empirically developed technology issues which are hardly understood and which need further research for reaching the full potential of thin film solar cells. These are interface and contact issues, a better understanding of defect and doping processes, and finally a better control of nucleation and growth of the different materials layers involved. Regarding these limitation in knowledge there are still chances for considerable improvements of thin film solar cells by further R&D efforts. The expectations are electric power production costs well below 0.5€/Wp which would make thin film solar cells economically competitive to C-based fossil fuels as primary energy.

In summary, it is safe to conclude that the established thin film solar cells are on the run to play an important part in solar energy conversion with estimated costs which will be competitive to standard non-renewable primary energy sources in the next future. However, the materials used will most probable—with the exception of thin film Si, which, however, shows the lowest module performances—not be available in the needed amounts to guarantee an entire PV based energy supply. Therefore, alternative thin film solar cells based on new compound semiconductors should be developed as additional or substitutional solutions for thin film PV which require further efforts in R&D.

19.6 Third Generation Technology and Organic Solar Cells

In the original definition of third generation solar cells only such device concepts have been considered which allow to surpass the Shockley-Queisser-Limit (see above). There have been a number of suggestions of such devices presented so far, which in most cases are still very far from any practical application. For this reason these systems will not be addressed in this article any further and interesting readers may refer to the original literature as already given above. Even if practical solutions cannot be expected in short times the presented concepts are very interesting from a basic point of view. There is theoretically justified hope that third generation solar converters may be realized with an improved understanding how to deal complex systems. Therefore, they should be explored with reasonable efforts.

The only third generation system so far which have proven to be successful are tandem or triple cells with highly absorbing compound semiconductors as e. g. epitaxial cells based on lattice matched GaAs and similar 3–5 semiconductor compounds. With such cells the highest conversion efficiencies of PV converters have been reached with. 41.1 % efficiency with a triple cell based on (GaIn)P/(GaIn)As/Ge (Guter et al 2009). The highest value of today is 44.4 % measured with InGaP/GaAs/InGaAs triple junction at 300 suns (Sharp 2012). However, such high performance devices are extremely expensive in their manufacturing and contain elements as Ge, Ga, and In, which are limited in their resources. Therefore such devices will only be of interest for terrestrial use when they can be combined with efficient and cheap light concentrating collectors. However, also thin film solar cells with low cost production technologies may be developed as tandem or triple junction cells, as already shown for thin film Si cells, which also would lead to strongly improved conversion efficiencies. However, in contrast to the epitaxial cells presented above strategies and knowledge must be acquired to produce tandem structures combining lattice mismatched or even dissimilar materials based on cheap thin film deposition technologies. However so far the scientific knowledge does not exist which would allow to combine very many non-epitaxial layers reaching favourable optoelectronic device properties.

Also organic photovoltaic cells (OPV) have still not reached the status of technological maturity. But organic solar cells have reached rather interesting conversion efficiencies in the range of 11 % in very short times, recently (MRS Bulletin 2005; Acc. Chem. Research 2009; Ameri et al 2009) (Service 2011). In organic solar cells devices strongly bound excitons (electrostatically bound electron-hole pairs) are formed after light absorption. These excitons are separated from each other by donor-acceptor interfaces in which either different organic semiconductors (either small molecules or polymers) or organic/inorganic hybrid systems are combined which will only be possible if the energy offset of the involved electron states is large enough to overcome the electrostatic (coulomb) binding energy of the electron-hole pair. These offsets contribute to an inherent OPV specific loss in the photo voltage of organic solar cells in relation to the energy of light absorption. Another inherent disadvantage of organic semiconductors is related to the localized character of the relevant energy states (the HOMO as highest occupied molecular state and the LUMO as lowest unoccupied MO). As a consequence of the weak electronic coupling across the molecular units of the organic units bad transport properties are usually obtained either for the primary formed excitons or the electrons and holes. As a consequence specific device structures must be used to adjust the absorption lengths to the diffusion lengths. On the other hand organic semiconductors exhibit also specific advantages for solar cell applications as their high absorption coefficients and the tunable optical absorption gap. Another often discussed advantage of organic cells is the possible use of low cost organic molecules (dyes) on flexible substrates which also gives rise to a wide variety of possible material's combinations. In addition, there is the chance to use low cost and low temperature deposition technologies outside vacuum which may also involve printing technologies.

As major drawbacks of existing devices so far the lack of stability and the very low efficiencies reached with high area modules. Despite these facts there are many research and development efforts worldwide to further develop OPV as competitive technology expecting at first specific application areas as off-grid, light-weight, and/or transparent solar cells. It is expected that a better understanding of the involved elementary processes and the inherent differences to inorganic semiconductor devices will further improve the performance of organic solar cells. It should be mentioned that the basic research needs for the OPV systems are equivalent to other electronic devices based on organic semiconductors as organic light emitting diodes (OLEDs) or organic electronics as e. g. organic field effect transistors (OFETs). Challenges to be addressed are (1) optical gaps in the red part of the solar spectrum, (2) improved understanding and engineering of interface properties, (3) strongly improved stability, (4) improved transport properties. If these challenges can be met in a satisfactory way OPV but also organic/inorganic composites may contribute to solar energy generation with cost effective, flexible, and easy-to-design solar cells. Recently, perovskite compounds of the composition RMX3 (with R=org. cation, M=Pb, Sn, X=ll, Br. I) have been developed which show very promising conversion efficiencies, approaching 20 %, but still lack stability and contain hazardous metals like Pb (Green et al. 2014). However, to my understanding the real costs of OPV in industrial dimensions cannot be estimated yet in a reliable way as no system has reached a competitive technological maturity so far.

Conclusions on the Perspectives of Photovoltaic Solar Energy Conversion

As discussed above photovoltaic converters have reached different technological maturity for different cell technologies. First generation solar cells as crystalline Si solar cells are already very far in their development and would in principle be able to secure the energy demand of mankind. However, the costs and energy demands of manufacturing Si solar cells are still too expensive to be competitive today without further subsidies. Further improvements of technology are imaginable and are topics of intensive R&D efforts world-wide. But it is expected that Si will not meet the long-term cost goals in a satisfying way. Therefore, if no alternatives will be available in the next close future—with time periods in the range of 50 years—energy will only be available on an increased cost level compared to the familiar and convenient situation based on C-fuels of today. But as no real sustainable alternative does exist so far there is no real alternative given and also Si based solar cells have to be used in increasing shares as primary energy source. To reduce the cost difference to traditional primary energy sources as far as possible a politically motivated and consumer driven implementation of photovoltaic energy power plants must be organized already today mostly based on bulk Si solar cells. Such implementation schemes as e. g. supported by feed-in tariffs have been started in Germany already some years ago and have been proven to be very successful. The involved costs may be considered as a substitution of solar energy implementation which is also well known for many other energy technologies. However, the implementation of a new and at first rather expensive energy technology cannot rely on the economic power, responsibility, and dedication of only one country—namely Germany. The energy crisis and the related climate change are world-wide challenges which must also be solved by international collaboration. Therefore people expect and demand the commitment of all developed countries and of national and international organizations as well as of academia and industry to put more efforts into the implementation of future-proof energy systems as it is already existing with crystalline Si solar cells.

As alternative solution one may hope for future development at first related to second generation solar cells as e. g. represented by thin film solar cells based on CdTe, CIGS and maybe μc-Si/a-Si. These solar cells have proven to be more cost effective and energy effective recently and may be considered as more competitive alternative to the traditional but non-sustainable energy systems of today. Indeed, the recent developments, especially of CdTe solar cells have shown very promising prospects which may be taken as optimistic forecast of future developments in cost reduction. Indeed, with further improvements of technology thin film solar cells will have the chance to be cost competitive to given energy technologies or may even surpass the cost limits of C-based fuels with decreasing reserves. On the other hand, the given

(continued)

limitations in resources discussed already above for the frontrunners of thin film technologies as Te and In(Ga) narrows the expectation that the energy demand of mankind can be secured only based on existing thin film solar cell technologies. The expected amount of energy, which would be available with these restricted elements, will not be able to satisfy the world's energy demands (Wadia et al. 2009). Even if such studies must be taken with care because of uncertain values on known resources, expected demands, percentage of recycling, and improvements in technology the implementation of such studies must be seriously considered and alternative solutions must be sought. As is also evident there are many other inorganic materials which may be considered as alternative absorber layers for photovoltaic thin film devices. Some of them have already been studied some years ago and have proven conversion efficiencies in the range of 10 % as e. g. Cu_2S, but have been stopped in their development because of non-solved degradation phenomena. Others like FeS_2 and Zn_3P_2 or SnS have not reached conversion efficiencies which make them competitive to absorber materials used today.

However, the limitations of novel materials and their PV devices are often due to an inadequate knowledge of materials, device properties, and synthesis and processing procedures. So far many successes in the improvement of given solar cells are due to serendipity effects and are not based on a adequate understanding of the involved physics and materials science and a knowledge-based design and development of these solar cells is not possible as for the archetype Si solar cells. Therefore, additional research efforts are overdue to improve the knowledge needed for given thin film technologies but also to develop novel absorber materials to a competitive status. These novel thin film devices provide realistic chances for marketable photovoltaic energy systems, which may reach a competitive status in rather short times. Even if such optimistic expectation may be too early for organic solar cells and for sure for many of the third generation concepts one may also expect further improvements here if the complex properties of these systems would be better understood. It can definitely be expected that more reliable predictions will be possible for the technological perspectives of these cells in realistic time frames. Most promising to my expectations are tandem and triple cells based on cheap thin film technologies.

From the facts presented above it is clear that different solar cell technologies will exist in parallel being applied with their specific characteristics for different application areas. Bearing in mind how severe the challenge is mankind has to face for a secure, environmentally friendly, affordable, and adequate supply of energy strong additional efforts in the support of research and development are overdue. So far the cumulative expenses spent for research in the field of renewable energy and specifically for solar cell research is far below the expenses spent for other energy technologies.

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Despite this fact the recent success in the improvement of conversion efficiencies and cost reductions proves that the increased efforts in recent years have been rewarding investments. I feel safe to argue that reliable and adequate funding in research and development, but also comparable efforts in photovoltaic implementation schemes as feed-in tariffs to be shouldered in a fair share by all developed countries will provide economically competitive solar cells in short times. With competitive solar energy the chance for blooming landscapes and satisfying living conditions will be within reach for hopefully all people in the world. If, however, the ecologically justifiable number of people is equivalent to a number well exceeding seven billion as expected in the next decades is another matter of discussion.

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