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Carbon Footprint and Urban Planning

Incorporating Methodologies to Assess the Influence of the Urban Master Plan on the Carbon Footprint of the City

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Abbreviations

AFV	Alternative fuel vehicle
AV	Average
CF	Carbon footprint
CI	Chemicals, plastics and rubber industry
COP	Conference of parties
CV	Coefficient of variation
EF	Emission factor
EI	Electrical, electronic and machinery industry
EU	European Union
FI	Food, beverages and tobacco industry
FMI	Furniture and other manufacturing industries
GHG	Greenhouse gas emissions
ICE	Internal combustion engine
MAX	Maximum value
MI	Metal products industry
MIN	Minimum value
NI	Industry of non-metallic mineral products
OECD	Organisation for Economic Co-operation and Development
PI	Printing industry and production of paper
TI	Textile and leather industry
TCI	Timber and cork industry
UMP	Urban master plan

Chapter 1
Introduction: Importance of Urban Planning and Carbon Footprint

Environmental conditions not only change naturally across days, seasons and years as a consequence of natural temperature rainfall regimes. Human provoked greenhouse gases (GHG) traps are the responsible of make the planet warmer and much of the world's urban growth is now characterized by poorly management, unstructured expansion and conventional motorisation. The most important anthropogenic (human-caused) greenhouse gases released into the atmosphere include CO_2, CH_4, N_2O, and several other fluorine-containing halogenated substances. Although the direct greenhouse gases CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have dramatically increased their atmospheric concentrations.

Recent 2015 annual Conference of Parties COP 21 (Paris, France)[1] has revealed the world global concern about this extreme climate changes in the near future if no action is taken today. The agreements reached in that Conference are also a reference of the commitments undertaken by all the nations. There are many relevant issues included in that agreement but, perhaps, in relation to the carbon footprint and its consequences, the most important are focused on strengthen policies based on emission reductions or offsetting.

The nations have developed a lot of plans to reduce and control the greenhouse gas emissions but, as reflected in the COP agreement, the efforts made have not been able to control the temperature increase. A new paradigm has to be developed in order to reduce and control GHG emissions, focusing, not only on the most pollutant activities, but also on the common economic and individual activities.

[1]The main objective of the annual Conference of Parties (COP) is to review the Convention's implementation. The first COP took place in Berlin in 1995 and significant meetings since then have included COP3 where the Kyoto Protocol was adopted, COP11 where the Montreal Action Plan was produced, COP15 in Copenhagen where an agreement to success Kyoto Protocol was unfortunately not realized and COP17 in Durban where the Green Climate Fund was created. http://www.cop21paris.org/about/cop21/.

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The most pollutant activities have been deeply controlled since the Kyoto protocol agreement and the climate change has not been reduced as COP 21 text states.

Regarding to the most pollutant activities, on 13 October 2003, Directive 2003/87/EC of the European Parliament and Council established a greenhouse gas emission allowance trading scheme within the European Union, creating a framework for the cost-effective abatement of such emissions. As a result of this regulatory framework, legislative actions have been taken requiring the permits or licenses authorizing the development of certain activities (energy sector installations, iron and steel production and processing, mineral mining and the paper and board fabrication), and those activities' GHG emissions need to be obligatorily monitored.

Nevertheless, there are many other economic activities that are not included within the GHG Emissions Allowance Trading Scheme and whose GHG emissions are not required to be measured or captured.

Those activities outside of the GHG Emissions Allowance Trading Scheme are usually included among the diffuse GHG emission sources, which accounted for 59.4 % of total GHG emissions in the EU in 2010 (De las Heras et al. 2011). The numbers provided suggest that measures designed to reduce diffuse GHG emissions would be welcome.

Currently, diffuse emissions reductions primarily depend on voluntary commitments from those responsible for GHG emissions, but these individuals are not always easy to identify. This fact makes the management of diffuse GHG emissions even more difficult, because emission responsibility cannot be clearly ascribed.

The aforementioned diffuse GHG emissions have to be controlled if COP 21 agreements want to be achieved so specific regulatory rules and tools have to be proposed. Literature has probed the relevance of this kind of emissions and its potential to be controlled and reduced: many authors have studied GHG emissions or the carbon footprint of industrial (Domer et al. 2011; Lee 2011; Liu 2014; Pang et al. 2014; Stylos and Koroneos 2014) or energy activities (Howard et al. 2011; Zhang et al. 2014). Authors have studied the carbon footprint of specific industrial complexes (Dong et al. 2013), the entire industrial sector (Liu 2014) and cities or regions that encompass industrial activities (Carney et al. 2009; Kennedy et al. 2009; Lin et al. 2013).

In spite of the number and the quality of studies performed on this topic, most studies do not support the implementation of preventive measurements because they are primarily descriptive and lack of a predictive function. Moreover, most of the aforementioned research works address carbon footprint calculations using an input-output balance model or a consumption-based approach related to existing facilities and infrastructure, which only allow for corrective rather than preventive measures. Corrective measures based on existing infrastructure and facilities are not as easy or cheap to implement as preventive ones. Efficiency and sustainability criteria can be more easily adopted in the design stage than in the operational stage.

Most of the economic activities causing the GHG emissions are managed in the municipal level so municipalities can adopt a relevant role in promoting plans directly centered on managing GHG diffuse emissions. These programs can be concreted through two types of measures: firstly, through corrective measures based on existing and working cities and secondly, through preventive measures based on urban master plans as it is the main document that shows a community as it is and recommends how it should be in the future.

See, for example, the case of Malmö, the Swedish city, which has experienced a successful transformation from industrial city in crisis to a modern, environmentally aware and forward-looking city. Malmö's urban master plan is a strategy for a new era, looking to a long-term vision for development and shows how planning can contribute to its implementation in the 2030s (Greengard 2015).

Corrective measures have been analyzed in many works addressing GHG emissions or with carbon footprint calculations through consumption-based or input-output approaches (Dhakal 2009; Jones and Kammen 2011; Lin et al. 2013; Minx et al. 2013; Petsch et al. 2011; Puliafito and Allende 2007; Ramaswami et al. 2008; Sovacool and Brown 2010; Weber and Matthews 2008). These works include GHG emissions produced by the individual daily activities, including variables hardly considered by urban planning decisions (daily trips, drinking water, gas or electricity consumption as well as wastewater and waste management). Nonetheless, corrective measures can be provided through these types of approaches because they include GHG emissions currently being produced.

Land-use planning is the general term used for a branch of urban planning encompassing diverse disciplines with the aim to order and regulate each land use in an various (efficient and ethical) ways, thus preventing land-use conflicts. Governments use urban planning to manage the development of land within their jurisdictions, planning for the needs of the community and, at the same time, safeguarding natural resources. To this end, the clear definition is the systematic assessment of land and water potential alternatives for land use, and economic and social conditions in order to select and adopt the best land-use options (Kaiser et al. 1995). Often a land-use plan provides a vision for the future possibilities of development in neighborhoods, districts, cities, or any defined planning area.

Despite confusing nomenclature (the terms land-use planning, regional planning, urban planning, and urban design are often used interchangeably, and will depend on the country, state, city, and even the project in question), the essential function of land-use planning remains the same whatever term is applied. In this work the term urban planning will be used.

Urban planning has a decisive influence on global GHG emissions (Engel et al. 2012) and diffuse emissions (Carter et al. 2015; Zanon and Verones 2013; Zubelzu and Hernandez 2014). China's New National Urbanisation Plan for 2014–2020 places urban policy at the heart of Chinese decision making and signals a strong shift towards an alternative urban pathway, highlighting the need to address urban sprawl, congestion and worsening pollution, with a focus on reforms to urban planning, urban finance and municipal governance (World Bank Group 2014). Nonetheless, there are few studies focused on analyzing GHG emissions from this early stage view perspective. Urban planning initiatives affect GHG emissions because they define the land occupation model, including territories capable of being developed as urban lands, also establish their uses (residential, industrial, retail or public) and characteristics (type of industrial uses allowed and banned) as well as the intensity which those uses are executed and the required infrastructure (road network, water supply, waste and wastewater management and electricity and gas supply). The way that urban dwellers choose their infrastructure (including efficient transport, green buildings, and cleaner energy supply), technology, consumption and lifestyle determines the global GHG emissions (Dhakal 2010).

The main advantage of managing GHG emissions through urban planning comes from the ability to avoid, and not to correct, GHG emissions through activities from the design stage. Urban planning guidelines allow for the easy and cheap implementation of preventive measures related to urban design variables that previous literature usually have looked within consumption-based approaches: Dong et al. (2013) referred to industrial developments, Kim and Kim (2013) to residential intensity, Ho et al. (2013) to urban design, Wu et al. (2013) to eco-efficient cities or even La Roche (2010) to constructive alternatives. Moreover, in the context of urban planning design, data related to infrastructure design are susceptible to be used to make predictions about GHG inventories, which also becomes an advantage.

Urban planning also regulates how cities work and contributes to explore the economic, political, social and cultural activities that are likely to be implemented within the region limits, prescribing an allowable intensity for those activities, and also defines required infrastructure for proposed urban developments. Urban planning outlines where polluting industries included in the GHG emissions allowance trading scheme will be placed, and describes the industrial areas whose activities are not included in the scheme can be executed. Urban planning foresees industrial activities in the earliest design stages. It allows the incorporation of GHG emissions sustainability criteria by defining preventive measures focused on emission sources that cannot otherwise be easily managed by responsible industrial activities defined in the urban planning scope (i.e., wastewater management carbon footprint).

Preventive mitigation measures for GHG emissions can be easily developed under the framework of an urban master plan because they are typically related to infrastructure or urban planning sustainability design criteria. A further problem that emerged from the literature review is the relationship between carbon footprint and infrastructure management: Sovacool and Brown (2010) assessed 12 large cities, whereas Dong et al. (2013) looked at a specific Chinese industrial complex, Kim and Kim (2013) reviewed household intensity, Ho et al. (2013) analyzed urban design models, Wu et al. (2013) studied ecoefficient cities and Yu et al. (2007) and Blanco et al. (2012) identified building solutions.

Urban planning provides an optimal tool, not only to calculate, but also to manage the carbon footprint of urban planning developments, and although many works have addressed carbon footprint calculations and corrective emissions measures, there are few concrete procedures that incorporate carbon footprint calculations from the urban planning process point of view.

But urban planning does not only allows managing the carbon footprint of the developments and so the GHG diffuse emissions, but also allows managing the balance between GHG emissions and offsetting stated in COP 21 agreement text. Urban master plans define the land occupation model which implies defining the lands that are susceptible to be developed as urban areas but also territories (undevelopable lands) not to be included in those developments and preserved of the urbanization processes. These territories can act as carbon sinks depending on the land use and extension.

Concerning to these undevelopable lands, urban master plans (UMPs) can adopt a passive strategy only taking them into account and trying to offset the emissions of Greenhouse gases of the planned developments through the potential of this type of land to capture CO_2. But it would be a lost opportunity to maximize the opportunity to ensure the pursued compensation of GHG emissions, because UMPs could regulate the uses susceptible to be executed on each territory under its jurisdiction or influence area.

So that, urban planning and especially UMPs can contribute to achieving the objectives of COP 21 by the management of most of the economic activities susceptible to generate GHG emissions. In this book it is explained a methodology to include the carbon footprint calculations under the urban planning procedures. The objective is to develop the techniques to determine the carbon footprint for the common managed land uses (residential, industrial commercial and public facilities) and also to propose a set of carbon footprint sustainability metrics focused on analyzing and comparing the carbon footprint of different urban planning development approaches.

In each of the five chapters in which the book has been divided, the authors attempt to clarify a number of basic issues: The first chapter exposes an introduction and a general framework of the problem and the current status. The second chapter analyzes the land-use/urban planning context and its relationship with the carbon footprint calculation. It includes the theoretical framework to face the carbon footprint calculation from the urban planning perspective. The third chapter, entitled “Carbon footprint calculation”, defines the specific methodology developed to compute the carbon footprint of the urban master plans, identifying concrete GHG emission sources and developing specific methodologies to quantify and include them in the carbon footprint calculation.

The fourth chapter tackles the study of specific examples and case studies about carbon footprint calculation. The authors have selected a set of municipalities and the methodology have been applied, assessing the carbon footprint of the most relevant land-uses: residential, industrial, commercial and public facilities.

Finally, chapter fifth is focused on the author’s conclusions and all the references used are detailed.

Chapter 2
Theoretical Framework

Traditionally, urban-planner has strong limitations when trying to mitigate the GHG emissions because urban planning tools were not thought from the point of view of sustainability. So many questions appear in this sense, but the answers were not yet available. There was not a clear concept over how urban planning could act as a response of several activities and their relationship with sustainability in the city, in energy supply and GHG emissions respectively and the vulnerability of cities to climate change.

This chapter seeks a framework for the suitable way to join the structure of urban planning with sustainability point of view, taking into account the main phases and main sectors of planning where to include emissions. This main phases should be a first diagnosis (How much is emitted), definition of measures to achieve objectives (How much is necessary to reduce) and also stablishing sets of indicators for evaluation (How to achieve and control the reductions).

The EEA report, “European Union CO_2 emissions: different accounting perspectives”, details the concepts and methodologies behind three accounting perspectives: territorial, production and consumption-based (EAA, 2103).

The territorial perspective considers emissions that are released to the atmosphere within a country’s borders and jurisdiction. This perspective corresponds to the legally enshrined practice used by sovereign states under international conventions (i.e. UN Framework Convention on Climate Change). The EEA report explains how the production perspective offers different insights, showing emissions resulting from the economic activities of citizens and companies. The third method (consumption-based) explained provides a consumption approach and considers emissions associated with goods and services, attributing their emissions to where they are consumed, regardless of where production of these goods and services result in emissions.

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The methodology exposed in the present book mainly covers the territorial and production perspectives. These both are the most complete approaches and the only ones that allow implementing preventive measures. Conversely, the consumption-based approach only allows considering corrective measures. It becomes one of the most relevant advantages of calculating the carbon footprint at the urban planning stage because a large amount of GHG emissions can be prevented. For example, Dickinson (2007) calculated the carbon footprint of New York City, resulting that total 2013 GHG emissions in New York City were 48.02 million metric tons of carbon dioxide equivalent ($MtCO_{2e}$):

- Direct emissions from on-site fossil fuel combustion or fugitive emissions from within the city's boundary (scope 1): 29,104,659 tCO_{2e}.
- Indirect emissions from energy generated in one location, but used in another, such as electricity and direct steam (scope 2): 16,888,770 tCO_{2e}.
- Indirect emissions that occur outside the city's boundary as a result of activities within the city's boundary, e.g. emissions from exported solid waste (scope 3): 2,026,141 tCO_{2e}.

As it will be discussed later in this book, the proposed methodology will be focused on GHG emissions sources considered in the three aforementioned scopes which also reinforces its validity.

On the other hand, plants absorb carbon dioxide from the atmosphere as they grow, and this captured CO_2 is stored throughout lifetime of the plants. Once they die, the biomass becomes a part of the food chain and eventually enters the soil as soil carbon. If the biomass is incinerated, the carbon is reemitted into the atmosphere and is free to move in the carbon cycle. Soils can also store carbon dioxide, depending on how the soil is used and managed.

This natural way of storing carbon in plants and soils has been called carbon sequestration. It is a biological sequestration that takes emissions out (offset) of the atmosphere and it is also known as greenhouse gas sink. Emissions and sequestration of GHG are greatly sensible to land-use changes. About two-thirds of the world's carbon emissions is sequestered in rocks and sediments, in the standing forests, forest under-storey plants, leafs and forest debris, and in forest soils. For example, carbon dioxide is exchanged between plants and atmosphere allowing that croplands become in grassland, as new areas are cultivated and become cropland or forests when they grow. Using biological feedstocks, such as wood or energy crops, for electricity generation, input to processes that create liquid fuels, or building materials can lead to sequestration or emissions.

Urban greens are integral component of urban ecosystem, contributing towards quality of life and sustainable urban development and carbon sequestration. Currently terrestrial carbon uptake offsets roughly one third of global anthropogenic greenhouse gas emissions (Tripathi and Bedi 2014). Urban green areas play an integral role by sequestering carbon for achieving low carbon society as green spaces within the city limits acting as carbon sinks.

2.1 General Methodology

Urban energy consumption is shaped not only by local geography and economic development, but also by the history and culture of individual cities. The framework of the study presented in this book is focused in urban master plans, with the main objective of planning the land and all the uses for the entire municipal territory (general planning instruments), including the manner and style of buildings, design of public places, etc. A typical master plan addresses the following aspects:

- Transportation and traffic.
- Facilities.
- Parks and open spaces.
- Neighborhoods and housing.
- Economic development land use.

This category of plans usually distinguish the land occupation model including the delimitation of urban, urbanizable and undevelopable (non-urbanizable) lands; dividing urbanizable lands in homogenous areas to be developed and defining all their uses. Planning also includes the design of the urban infrastructure (transport, electricity, drinking water supply as well as waste and wastewater treatment). The major land use recommendations presented are the result from analysis of both, environmental and physical conditions. The planner's vision for future growth is included too with a map of future land which summarizes the recommendations about open space distribution, residential areas, industrial, commercial and civic, institutional and mixed-use areas.

Among the aforementioned variables, the land occupation model evidently affects the resultant GHG emissions inventory, by identifying the urban growth boundaries and those lands susceptible to be developable (urbanizable land) and, complementarily, undevelopable areas (non-urbanizable land). GHG emissions will result from programmed urbanizable land, whereas non-urbanizable land will provide the potential capability of GHG emissions capture. The land occupation model also divides those urbanizable lands into homogenous areas defined by their localization, geographical boundaries, land use category (industrial, household, commercial or public facilities) that are allowed and banned, the intensity by which these uses will be executed (built area), the development standards and the infrastructure designed necessities. The delimited homogenous areas allow the identification of responsibility in emissions, because they perfectly fit the GHG emissions responsible agent definition from the British Standard Institution (2008); therefore, carbon footprint accounting has to be based on the definition of these homogenous areas.

Therefore, among the characteristics of the homogenous areas defined by urban planning instruments, it can be assumed that the development standards do not have influence on the GHG emissions and the proposed boundaries only are affected by land use and intensity, because both determine the GHG emissions as a result of the type and the amount of GHG emissions sources consumption. Therefore, the discussion about GHG emission sources is focused on those infrastructures that supply energy or through which GHG emissions sources are consumed. In urban planning instruments, drinking water, wastewater management, electricity, gas, communications, transport and waste management infrastructures have to be taken into account. Thus, if the negligible character of GHG emissions from the communications infrastructure is assumed, then GHG emissions measuring in urban planning instruments must be focused on drinking water supply, wastewater management, electricity and gas supply, transport and waste management infrastructures.

Only one clarification more is needed to complete the theoretical framework: it is the discussion about the green belts (land designated as not for building), which are usually considered within the category of urban infrastructures or public facilities. Green areas are susceptible to generate GHG emissions from maintenance operations and infrastructure (water, public lighting, and wastewater), but it can be assumed that these GHG emissions can be compensated using GHG trap potential of plants. This assumption can be accepted in the urban planning scope due to the defined sustainable design rules for green areas that ensure their neutral character. Furthermore, UMPs can regulate the green zones design in order to provide potential GHG offset, so those categories of green areas should be taken into account to manage the carbon footprint at the early urban planning stage. A complete and regularly updated inventory could help to quantify the potential contribution of this urban initiative.

Summarizing the previous discussion, Fig. 2.1 outlines the theoretical methodological approach framework for estimating and reporting GHG emissions from household land-use by applying urban planning instruments.

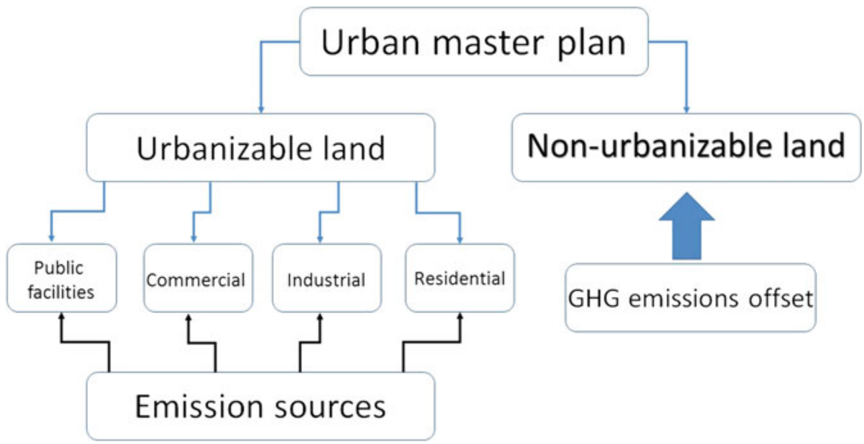

Fig. 2.1 Theoretical GHG emissions framework

2.2 Calculation Method

The carbon footprint has been historically defined as the total sets of GHG emissions caused directly and indirectly by human activities (organization, event, product or individual) through diverse emissions sources. Equivalent tons of carbon dioxide is the unit that have been used to express it, including each equivalence between CO_2 and any other greenhouse gas for the 100th year prevalence (I.P.C.C. 2007).

Given the difficulty of measuring embodied energy, most quantitative studies estimate CO_2 emissions associated with consumption of energy for electricity supply, heat and transportation, waste, material production, etc. within a territorial boundary.

Both, energy consumption and linked emissions, have to be estimated, because the ability to distinguish between the energy and carbon intensity of different sectors can help local authorities analyze trade-offs between policies to reduce energy consumption and policies to reduce the carbon intensity of each energy source.

An emission factor (EF) is defined as the average emission rate of a given GHG for a given source, relative to units of activity. So GHG emissions determination (CF: carbon footprint) from each source is performed by multiplying the appropriate emission factor (EF_i) by the expected consumption (the magnitude of human activity resulting in emissions or the removals taking place during a given period of time) of each source (C_i), as stated in Eq. 2.1 (Eggleston et al. 2006).

$$\mathrm{CF}\left(\mathrm{kgCO_{2eq}}\right) = \sum \mathrm{C_i} \times \mathrm{EF_i} \tag{2.1}$$

If consumptions and emission factors in Eq. 2.1 are specified for each identified source, the mathematical relation to determine GHG emissions expressed in Eq. 2.1 changes as follows (Eq. 2.2).

$$\mathrm{CF} = \mathrm{f}\left[\mathrm{g_w(C_w);\ g_{ww}(G_{ww});\ g_s(G_s);\ g_p\left(C_p\right);\ g_g\left(C_g\right);\ g_{ws}(G_{ws});\ g_t(C_t);\ EF_e, EF_g, EF_v}\right] \tag{2.2}$$

In Eq. 2.2, the value C refers to the consumption, G represents the generation value, and EF refers to emission factor, whereas subscript w refers to water supply, ww to wastewater, e to electricity, g to gas, ws to waste and t to transport. Therefore, only *f* and the different *g*-functions (that allow for assessing the GHG emissions from each considered source) are not yet defined.

A previous work (Zubelzu and Hernández 2014) has involved another variable to fit Eq. 2.2. The aim of this fitting is to quantify the uncertainty in determining the carbon footprint and it is stood at 5 % of the total carbon footprint. The decision of considering this variable depends on each particular case, but it would be advisable if there is no reliable information about sources or their emission factors available.

Once the general approach has been exposed in Eqs. 2.1 and 2.2, the specific rules to determinate the carbon footprint of each analyzed source have to be defined. Thus, specific methodologies to assess the carbon footprint of the aforementioned urban infrastructures (drinking water, wastewater, electricity, gas, transport and waste) will be exposed in the following sections.

2.2.1 Drinking Water Facilities

Water distribution systems account for the supply and treatment of drinking water from source to final consumption. Drinking water, also known as potable water or improved drinking water, is water safe enough for drinking and food preparation

Drinking water utilities can also reduce energy use by promoting the efficient use of water, which reduces the energy needed to treat and distribute water.

The carbon footprint of the drinking water supply can be calculated as follows:

$$\mathrm{CF_w}\left(\mathrm{kgCO_{2eq}/m_b^2}\right) = \mathrm{EF_w}\left(\mathrm{kgCO_{2eq}/m^3}\right) \times \mathrm{C_w}\left(\mathrm{m^3/m_b^2}\right) \tag{2.3}$$

$$\mathrm{CF_w}\left(\mathrm{kgCO_{2eq}/m_b^2}\right) = \mathrm{EI_w}\left(\mathrm{kWh/m^3}\right) \times C_\mathrm{w}\left(\mathrm{m^3/m_b^2}\right) \times \mathrm{EF_e}\left(\mathrm{kgCO_{2eq}/kWh}\right) \tag{2.3$'$}$$

where CF_w represents the carbon footprint of the drinking water supply, EF_W is the emission factor of drinking water supply, EI_w is the energy intensity of the drinking water supply, C_w represents the drinking water consumption and EF_e is the electricity generation mix emission factor.

Carbon footprint calculations have been related to built area (m_b^2) to achieve the greatest applicability and representativeness because gross area would not represent construction density.

2.2.2 Wastewater Management Infrastructure

Wastewater infrastructure is a term used to describe the network for collection, treatment, and disposal of sewage and stormwater in a community, including pipes, sewage treatment plants, outfalls, etc.

The expression to link carbon footprint and wastewater management is shown in Eq. 2.4:

$$\mathrm{CF_{ww}}\left(\mathrm{kgCO_{2eq}/m_b^2}\right) = \mathrm{EF_{ww}}\left(\mathrm{kgCO_{2eq}/m^3}\right) \times \mathrm{G_{ww}}\left(\mathrm{m^3/m_b^2}\right) \tag{2.4}$$

$$CF_{ww}\left(kgCO_{2eq}/m_b^2\right) = EI_{ww}\left(kWh/m^3\right) \times G_{ww}\left(m^3/m_b^2\right) \times EF_e\left(kgCO_{2eq}/kWh\right) \tag{2.4'}$$

where CF_{ww} represents the wastewater carbon footprint, EF_{ww} is the emission factor referred to this concept, EI_{ww} is the energy intensity of wastewater management, G_{ww} represents the wastewater generation and EF_e refers the electricity generation mix emission factor.

2.2.3 Electricity Supply Infrastructure

All electricity generation and supply systems have a carbon footprint, that is, at some points during their construction and operation carbon dioxide is emitted.

The carbon footprint of the two following infrastructures (electricity and gas) can be directly rated by applying an emission factor to a consumption figure, because they are directly related to energy sources.

Thus, the carbon footprint from electricity consumption can be directly calculated by multiplying the electricity generation mix emission factor (EF_e) by electricity consumption (C_e), as shown in Eq. 2.5.

$$CF_e\left(kgCO_{2eq}/m_e^2\right) = C_e\left(kWh/m_e^2\right) \times EF_e\left(kgCO_{2eq}/kWh\right) \tag{2.5}$$

2.2.4 Gas Supply Infrastructure

The carbon footprint of gas consumption is obtained by applying the gas emission factor (EF_g) to gas consumption (C_g), as shown in Eq. 2.6.

$$CF_g\left(kgCO_{2eq}/m_b^2\right) = C_g\left(kWh/m_b^2\right) \times EF_e\left(kgCO_{2eq}/kWh\right) \tag{2.6}$$

2.2.5 Waste Management Infrastructure

Total emissions from solid waste disposal on land, waste incineration and any other waste management activity. Any GHG emissions from fossil-based products (incineration or decomposition) and GHG from organic waste handling and decay are not included.

The carbon footprint of waste management has been defined using a specific emission factor for waste management (EF_{wt}) and a waste generation rate (G_{wt}), as shown in Eq. 2.7.

$$CF_{wt}\left(kgCO_{2eq}/m_b^2\right) = G_{wt}\left(t/m_b^2\right) \times EF_{wt}\left(kgCO_{2eq}/t\right) \tag{2.7}$$

The expression to calculate the carbon footprint of waste management can also be proposed through an energy intensity factor of treating each ton of waste (EI_{wt}) as exposed in Eq. 2.8.

$$CF_{wt}\left(kgCO_{2eq}/m_b^2\right) = EI_{wt}(kWh/t) \times G_{wt}\left(t/m_b^2\right) \times EF_e\left(kgCO_{2eq}/kWh\right) \tag{2.8}$$

2.2.6 *Transport Infrastructure*

Rapid growth in transportation GHG emissions is unavoidable in most developing countries, but transport plays a crucial role in urban development by providing access for people to the main key services: education, markets, employment, recreation, health care and others. The coordination of land-use and transport planning is an improving measure in some countries and cities, with strengthened urban institutions. More than two-thirds of the Organization for Economic Co-operation and Development (OECD) cities now have a municipal work group dedicated to coordinate programs of public investment in urban infrastructure.

Transportation planning generates great opportunities to achieve a more sustainable social development that would benefit both, the city and its inhabitants. Several problems necessitate new directions in transport planning: the coming fuel shortage, climate change, health problems, space constraints and so forth.

The estimation of the total quantity of transportation GHG emissions is based on effective predictive models commonly used in the design of transport infrastructure from urban planning context. In general terms, transportation results are easier to understand than results for buildings and industry because they are not affected by regional differences in climate. It has not been necessary to resort to empirical data due to the lack of reliable information and because predictive models frequently used in urban planning context provide accurate results.

Therefore, the approach to calculate the carbon footprint of transport is shown in Eq. 2.9.

$$CF_t\left(kgCO_{2eq}/m_b^2\right) = G_t\left(km/m_b^2\right) \times EF_v\left(kgCO_{2eq}/km\right) \tag{2.9}$$

where EF_v represents a vehicle emission factor and G_t is the distance traveled during trips (due to industrial activity). EF_v must be defined based on the vehicle fleet composition and subsequent specific emission factors, as it is shown in Eq. 2.10.

$$EF_v = (r_h \times EF_h) + r_l \times \left[(r_d \times EF_d) + \left(r_p \times EF_p\right)\right] \quad (2.10)$$

where r_h, r_l, r_d and r_p represent the fleet fuel consumption into the following categories: heavy duty, light duty vehicles, gasoline consumption for on-road transportation and diesel consumption for on-road transportation rates respectively; while EF_h, EF_d and EF_p are the respective emission factors.

Finally, distance traveled figure (G_t) in Eq. 2.9 depends on the number of trips between the analyzed area i and each possible destination j, always within the corresponding influence area (N_{ij}) and along the possible routes of interconnection between them (d_{ij}), as shown in Eq. 2.11.

$$G_t\left(km/m_b^2\right) = \sum N_{ij} \times d_{ij} \quad (2.11)$$

Here, the transportation distances (d_{ij}) have been measured in maps, while the number of trips generated in the evaluated area and bound for all potential destinations (N_{ij}) have been estimated using a gravitational model commonly used in calculations of the carbon footprint of transport (Zubelzu et al. 2011; Zubelzu et al. 2014).

Therefore, it has been assumed that the number of trips (N_{ij}) can be explained according to personal, business or leisure purposes. The expression to calculate the attraction capacity for each city is shown in Eq. 2.12.

$$N_{ij} = (r_g) \times \left[\left(r_p \times \; p_j/\sum p_j\right) + \left(r_c \times \; c_j/\sum c_j\right) + \left(r_s \times \; s_j/\sum s_j\right)\right] \times \left(1/d_{ij}^a\right) \quad (2.12)$$

In Eq. 2.12, N_{ij} represents the product of the multiplication of three variables:

- The generation component (r_g) specific to each land use and/or activity.
- The potential attraction from each possible destination inside the influencing area, which depends on the population of each possible destination as well as the number of companies and stores able to do business with other company within the analyzed area. In Eq. 2.12 p_j, c_j and s_j represent the population and the number of companies and stores in the area; and r_p, r_c and r_s are the percentages of travels justified by each purpose categories: personal, business or leisure, respectively.
- An impedance factor, which is inversely proportional to the distance (d_{ij}) between the evaluated area and each potential destination.

Some comments have to be remarked concerning to the methodology to assess the carbon footprint of transport. Firstly, depending of specific locations and transport infrastructure available, it might be appropriate to consider the alternative choice of public transport instead to the use of private vehicle. In this case, the carbon footprint of these alternatives can be calculated using the following three equations.

$$CF_{bus} = G_{bus}\left(km/m_b^2\right) \times EF_{bus}\left(kgCO_{2eq}/km\right) \tag{2.13}$$

$$CF_{train} = G_{train}\left(km/m_b^2\right) \times EF_{train}\left(kgCO_{2eq}/km\right) \tag{2.14}$$

$$CF_{train} = G_{train}\left(km/m_b^2\right) \times EI_{train}(kWh/km) \times EE_{train}\left(kgCO_{2eq}/kWh\right) \tag{2.14'}$$

Several authors advocate for considering the alternative fuel vehicles[1] especially electric vehicles as an alternative to conventional internal combustion engine (ICE) propulsion systems. In this case, and considering also the possibility of using public transport infrastructure, Eqs. 2.9 and 2.10 should be completed with these elements as Eq. 2.15 shows.

$$\begin{aligned} CF_T\left(kgCO_{2eq}\right) = G_T \times (\%_V \times [(\%_{DS} \times EF_{DS}) + (\%_{PT} \times EF_{PT})] + (1 - \%_V) \times [(\%_R \times IE_R \\ \times EF_E) + ((1 - \%_R) \times EF_B)]) \end{aligned} \tag{2.15}$$

where CF_T represents the Greenhouse gas emissions from transport, G_T the total generation of trips and $\%_V$, $\%_{DS}$, $\%_{PT}$, $\%_R$ the percentage share of trips among private vehicle, diesel, petrol and railway, respectively. Finally, EF_{DS}, EF_{PT}, EF_E and EF_B represent the emission factors of diesel, petrol, electricity generation mix and bus respectively while IE_R refers to the energy intensity of travelling by railway.

Equation 2.15 should be particularized according to certain uses of the lands, because, for example, personal motivation does not explain, probably, not to travel between the industrial zones.

2.2.7 *Carbon Footprint Accounting Resume*

As Eq. 2.16 shows, GHG emissions from each type of source can be easily isolated by unifying and grouping the terms in Eqs. 2.3–2.9.

$$\begin{aligned} CF = \; & EF_e[(C_w \times EF_w) + (G_{ww} \times EF_{ww}) + C_e] + \left(C_g \times EF_g\right) + (G_t \times EF_t) \\ & + (C_{ws} \times EF_{ws}) \end{aligned} \tag{2.16}$$

[1]An alternative fuel vehicle (AFV) is a vehicle that runs on a fuel other than traditional petroleum fuels (petrol or diesel fuel); and also refers to any technology of powertrains that does not involve petroleum (e.g. electric car, hybrid electric vehicles, solar powered).

Equation 2.16 reveals a general calculation model that can be applied regardless of the specific area that can be studied and afterwards particularized to the extended set of infrastructure regarded as necessary. Therefore, the model firstly described in Eq. 2.9 can be universally recognized and applied to any region.

It is necessary to clarify that terms in Eq. 2.16 have been organized in three different groups of variables according to the source of energy (electricity, gas and fossil fuels) because the GHG emissions caused by waste management come mainly from process of degradation of residues and not of direct energy consumption processes). The organization of the variables around the sources of energy in Eq. 2.9 reveals that greenhouse gases are more sensitive to electricity consumption due to the amount of factors (water, wastewater, waste and electricity) that affects GHG emissions account through this source. Otherwise, three different types of variables can be identified in Eq. 2.16:

- The variables relating to consumption or generation data (C_w, G_{ww}, G_{ws}, C_e, C_g) that directly depend on consumer habits, although the municipal councils, companies or public institutions usually tend to promote actions aimed at reducing them.
- Emission factors depending on technologies that are not controllable by municipal councils or UMPs (EF_e, EF_g, EF_v).
- Variables directly operated by the municipal councils through UMPs, including energy costs (EC_w, EC_{ww}, EF_{ws}) and the length of generated trips (G_t).

2.3 Indicators of Sustainability for the Carbon Footprint

Indicators of sustainability for the carbon footprint are oriented towards measuring the carbon footprint sustainability of an urban planning development, allowing the spatial and temporal comparison between different urban planning developments.

The here proposed set of indicators has been designed with the purpose of measuring the carbon footprint to promote oriented to sustainability measures of an urban planning development in the broadest sense. Therefore, it has been defined the set of indicators related to the following topics:

- The overall amount of GHG emissions,
- The composition of GHG emissions by sources of GHG emissions linked to variables of urban design and
- GHG emissions linked to the capture potential of land.

Each category mentioned includes several specific indicators that have been summarized and grouped in different categories in Table 2.1.

The set of indicators proposed includes measures relating to the emissions of greenhouse gases in both, absolute and relative terms, linked to the emission

Table 2.1 Set of GHG sustainability indicators proposed

1. The indicators of global GHG emissions
1.1. Global GHG emissions by municipality (tCO_{2eq}/year)
1.2. GHG emissions by planned household (tCO_{2eq}/m_b^2 year)
2. GHG sustainability indicators related to GHG emissions sources
2.1. The composition of global emissions of Greenhouse gases by sources of GHG emissions (%)
2.2. GHG emissions composition by transport modes (%)
2.3. Proportional length of travel within the urban development (%; km)
3. GHG sustainability indicators related to urban planning design variables
3.1. Global GHG emissions in the whole area of the municipality (tCO_{2eq}/m^2)
3.2. Global GHG emissions through the urbanizable planned area (tCO_{2eq}/m^2)
3.3. Global GHG emissions through the built planned area (tCO_{2eq}/m^2)
3.4. Global GHG emissions through the non-urbanizable land area (tCO_{2eq}/m^2)
4. The indicators of sustainability in related GHG capture potential
4.1. Balance of GHG emissions (emissions-capture) (tCO_{2eq})
4.2. Non-urbanizable land area required to capture the GHG emissions of one unit of planned urbanizable land area (m^2/m^2)
4.3. Non-urbanizable land area required to capture the GHG emissions of an area unit of land space planned (m^2/m^2)

sources, variables of design of urban planning and the capacity of undevelopable lands to capture GHG emissions. So, the four categories of indicators referred must cover the most relevant topics needed in order to analyze the sustainability of a GHG urban development.

The first two categories of indicators included in Table 2.1 can be calculated with the information required to calculate the GHG emissions. On the contrary, the third category requires further collection of information on the area covered by each category of land use in each municipality studied.

The model of land occupation is decisive to for spatially allocating the GHG emissions, not only accounting through planned urban developments, but also through undevelopable lands because certain land uses are able to capture emissions. This ability to capture relies on the specific use of the land and crops in the territory, because each one offers different capture rates. The theoretical ability to capture (CP) can be expressed as follows (Eq. 2.17).

$$\mathrm{CP_t}\left(\mathrm{kgCO_{2eq}}\right) = \sum \mathrm{CP_i}\left(\mathrm{kgCO_{2eq}}/\mathrm{m}^2\right) \times \mathrm{Si}\left(\mathrm{m}^2\right) \tag{2.17}$$

Although several relevant works referred to the GHG capture potential from specific plant species, there is a lack of information about this capture potential from land use. This variable is more easily taken into account in the analysis of the capability of undevelopable lands to capture GHG emissions. Thus, available species and crops capture potentials have to be transformed (implementation of bush, trees and crops planting densities) into the land use GHG capture potential, playing an important role in reducing greenhouse gas emissions.

The information provided by the last group of indicators has become very relevant after the COP21 agreement. This group provides information about the ability to capture emissions which constitutes one of the key points of the aforementioned agreement.

Chapter 3
Carbon Footprint Calculation

"Only measurable is manageable". Following that simple rule, mensuration of greenhouse gas intensiveness of different products, bodies, and processes is expressed as their carbon footprints.

The calculation of carbon footprint using Eqs. 2.3–2.9 requires gathering information about consumption and generation data, as well as the emission factors.

Regarding to consumption and generation data, the implementation of the proposed methodology becomes a complex task. Including all possible emissions would require addressing the problem of data collection because, by contrast with consumption-based approaches, each *CI* and G_i cannot be empirically quantified because urban developments have not been built yet and this situation force to resort to statistics on historical quantities and then extrapolate these figures to urban planned development.

On the other hand, the emission factors depend mostly on the information available at the point of calculation of the carbon footprint. Only the emission factor of private vehicles has to be defined resorting to statistics in order to define the percentage distribution in categories of vehicles.

3.1 Generation and Consumption Data

The calculation of the carbon footprint using Eqs. 2.3–2.9 requires the collection of data relating, on the one hand, to drinking water (C_w), gas (C_g), and electricity (C_e) consumptions and, on the other hand, in waste (G_{ww}) and wastewater (G_{wt}) generation.

Data can be collected through direct onsite real-time measurements, or through estimations based on models. In general, for products, organizations and events,

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emissions are calculated using specific data on consumption of fuels, energy, and other inputs leading to CO_2 emissions.

Studies will often have to cope with the shortage of reliable information, the lack of standardization of the specific land-use categories or even the lack of corresponding periods of time with reliable information.

The answer to those questions will likely lie in the official statistics and/or scientific studies which will provide information on the consumption and generation data. Recourse to these type of data will also involves using statistical techniques to ensure the significance of the conclusions.

It has been necessary to resort several official statistical institutes (Instituto Nacional de Estadística in Spain, Eurostat in Europe, United States Census Bureau in the United States or the Office for National Statistics in the United Kingdom), to government information published (Spanish Ministry of Energy, US Department of Energy (DOE), Spanish Ministry of Environment, United States Environmental Protection Agency, Environment Agency and Department for Environment, Food and Rural Affairs (DEFRA) in the United Kingdom, by instance), to companies which publish energy reports (Spanish Instituto para la Diversificación y Ahorro Energético or Green House Office in Australia or Red Eléctrica Española).

3.2 Emission Factors

Once generation and consumption data have been identified, the next step is to determine the emission factor for each analyzed source. Some of the required emission factors are well known and many public institutions reports detailed informs about them.

For example, Table 3.1 provides an overview of the emission factors affecting the generation mix of electricity for all nations in the EU.

Also, the emission factor for the combustion of gas comes from a stoichiometric ratio and amounts to 0.20 $kgCO_{2eq}$/kWh according to Eggleston et al. (2006).

However, many other emission factors will have to be calculated resorting to official statistics and/or scientific studies as will be taught in the following chapters of the book.

3.3 Carbon Footprint as Sustainability Indicator

Carbon footprint is commonly used as a metric of climate change impact evaluation and as one of the main focus of many sustainability policies promoted by companies and authorities Most of the information required for indicators of sustainability in the carbon footprint has been necessarily collected to calculate the carbon footprint. There is, however, a lack of relevant information about the capture potential of land uses.

Table 3.1 Electricity generation mix emission factor in the European Union (Zubelzu et al. 2015)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
UE (28)	0.19	0.19	0.19	0.19	0.20	0.19	0.19	0.18	0.19	0.19
Belgium	0.14	0.15	0.15	0.15	0.14	0.15	0.14	0.15	0.14	0.14
Bulgaria	0.20	0.20	0.20	0.20	0.25	0.23	0.22	0.22	0.24	0.24
Czech Republic	0.26	0.26	0.26	0.25	0.26	0.26	0.24	0.24	0.24	0.24
Denmark	0.30	0.29	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Germany	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Estonia	0.44	0.44	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42
Ireland	0.28	0.27	0.28	0.26	0.26	0.25	0.24	0.26	0.24	0.24
Greece	0.32	0.32	0.36	0.36	0.36	0.35	0.36	0.36	0.35	0.35
Spain	0.18	0.19	0.22	0.21	0.22	0.20	0.19	0.16	0.17	0.17
France	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03
Croatia	0.18	0.14	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Italy	0.24	0.24	0.24	0.24	0.24	0.24	0.22	0.22	0.22	0.22
Cyprus	0.29	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28
Latvia	0.11	0.08	0.08	0.11	0.11	0.10	0.09	0.12	0.13	0.13
Lithuania	0.04	0.04	0.06	0.06	0.05	0.05	0.05	0.16	0.15	0.15
Luxembourg	0.16	0.17	0.18	0.18	0.18	0.17	0.19	0.15	0.14	0.14
Hungary	0.21	0.21	0.19	0.20	0.20	0.19	0.18	0.18	0.18	0.18
Malta	0.26	0.26	0.35	0.35	0.35	0.35	0.36	0.35	0.36	0.36
Netherlands	0.31	0.30	0.33	0.32	0.32	0.31	0.30	0.31	0.31	0.31
Austria	0.14	0.13	0.13	0.13	0.13	0.13	0.11	0.13	0.14	0.14
Poland	0.36	0.36	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Portugal	0.21	0.24	0.27	0.22	0.22	0.22	0.21	0.16	0.18	0.18
Romania	0.23	0.22	0.20	0.22	0.22	0.20	0.19	0.17	0.20	0.20
Slovenia	0.16	0.14	0.15	0.15	0.16	0.14	0.14	0.14	0.14	0.14
Slovakia	0.11	0.11	0.13	0.24	0.23	0.16	0.19	0.23	0.18	0.18
Finland	0.22	0.21	0.17	0.21	0.20	0.18	0.18	0.21	0.19	0.19
Sweden	0.34	0.34	0.34	0.37	0.37	0.34	0.32	0.32	0.31	0.31
United Kingdom	0.24	0.24	0.24	0.25	0.25	0.25	0.23	0.24	0.23	0.23
Iceland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Land-use policy decisions are in continuous movement, provoked by individual landowners and land planning managers with a great influence in political, demographic and economic and social preferences. Policymakers can directly affect the uses of land, determining an area as protected, or local authorities can set aside portions of a town for industrial use and create a set of tax benefits for incoming companies to attract there. Sustainability factors have played a secondary sad role in those land decisions.

Measured in tons of carbon dioxide equivalent, carbon capture include investments in afforestation, renewable energy, and improving efficiency in energy consumption.

There are a lot of studies that deal with the GHG emissions capture potential of specific plant species but there are not so many studies that address the potential offset of land uses. Transforming the potential of capture of plant species into land uses is not easy and requires assuming certain simplifications as the planting density and the lack of complicated plant associations, but these choices can affect the GHG equilibrium. In a direct way, through measures dedicated to preserve or restore carbon in standing vegetation (like green areas or forests) and soils, and indirectly, by promoting land-use policies that affect fossil fuel emissions by influencing energy consumption for transportation and in buildings.

Chapter 4
Assessing the Carbon Footprint of Urban Master Plan

In the following sections an example of the methodological approach for assessing the carbon footprint of an UMP is developed. A set of municipalities with similar characteristics have been selected with a view to limiting the scope, and the carbon footprint has been calculated for the urban planning major land uses: residential, industrial, commercial and public services.

4.1 Case Study

The proposed methodology has been developed using empirical data from the Spanish province of Madrid and focuses on a set of 33 medium-sized municipalities located on the border of Madrid and Toledo. The selected municipalities depend heavily on Toledo, Madrid and their surrounding industrial belts to their daily business. This area has been selected due to its relationship with Madrid and Toledo, as well as its similarity to the majority of industrial zones in Spain and many other countries with industrial areas surrounding large, tertiary cities. Figure 4.1 illustrates the location of the judged area and Table 4.1 indicates the municipalities considered in this study.

The urban planning design figures for the municipalities analyzed were collected from Comunidad de Madrid (2015).

Table 4.2 displays the main indicators of the compilation of figures.

The figures for the coefficient of variation in Table 4.2 rates certain degree of variability among the municipalities that have been selected. However, the percentiles and the skewness figures indicate that the greater part of the municipalities are medium or small sized, while there are a few ones that stand out. These municipalities stand out for their gross building area and their amount of planned household units, to the extent that they have been identified as outliers (Fig. 4.2).

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Fig. 4.1 Area location

Table 4.1 Municipalities

Estremera	Ciempozuelos	Moraleja de En medio
Fuentidueña de Tajo	Aranjuez	Serranillos del Valle
Valdaracete	Valdemoro	Batres
Villarejo de Salvanés	Torrejón de Velasco	Arroyomolinos
Villamanrique del Tajo	Pinto	El Álamo
Belmonte del Tajo	Parla	Navalcarnero
Valdelaguna	Humanes de Madrid	Villamanta
Colmenar de Oreja	Torrejón de la Calzada	Aldea del Fresno
Chinchón	Griñón	Villa del Prado
Villaconejos	Cubas de la Sagra	Cadalso de los Vidrios
Titulcia	Casarrubuelos	Cenicientos

4.2 Residential

The first urban planning land use category is the residential one. A residential area is a land use in which housing predominates. Housing may vary significantly between, and through, residential areas. These include single-family housing, multi-family residential, or even mobile homes. Specific definition strongly depends on each local rule but it can be defined in a combined (mainly commercial or public facilities) mode, because residential land use designations implies to accommodate a wide range of commercial, retail, service and office uses areas.

Table 4.2 Summary of the results of urban planning design figures of the municipalities analyzed

		Total surface (ha)	Urbanizable area (ha)	Gross building area (ha)	Household units	Non-urbanizable area (ha)
Mean		5,038.66	190.53	91.49	3,581.23	4,367.53
Median		4,784.83	80.84	29.70	1,240.00	2,955.40
Std. Deviation		4,014.42	316.68	220.73	5,301.78	3,815.85
Variance		1.61×10^{11}	1.00×10^{9}	4.87×10^{8}	2.81×10^{7}	1.46×10^{11}
Coefficient of variation		0.80	1.66	2.41	1,48	0.87
Skewness		1.61	3.61	4.88	2,28	1.49
Kurtosis		3.52	15.61	25.42	5,04	2.43
Minimum		533.07	1.27	0.25	25,00	301.40
Maximum		18,902.41	1,656.37	1,228.79	22.305,00	16,672.33
Percentiles	25	2,079.37	28.23	13.61	444,00	1,287.07
	75	6,430.00	215.84	69.19	3.789,00	6,397.77

4.2.1 Data Collection

The following sections include a definition about the way that the required data have been collected. Although each specific study will require a data research according to information available, in these sections the reader could find figures susceptible to be used extensively or maybe a clue to bound its search.

4.2.1.1 Consumption and Generation Data

As indicated in the following tables, the data set necessary to calculate the carbon footprint of the residential use has been obtained from historical annual official statistics.

The annual water consumption data for each residential unit (Instituto de Estadística de la Comunidad de Madrid 2014a) is presented in Table 4.3.

The data in Table 4.4 reveal the re-used and treated wastewater averaged volumes for each residential unit (Instituto de Estadística de la Comunidad de Madrid 2014a) in Madrid.

Table 4.5 shows the electricity consumption for residential units (Instituto para la Diversificación y Ahorro Energético 2013).

The residential unit annual consumption of gas (Table 4.6) has been collected from the Spanish Ministry of Energy (Ministerio de Industria, Energía y Turismo 2014).

To calculate the GHG emissions from waste management, it is necessary the waste generation data from residential units, whose results are shown in Table 4.7 (Instituto Nacional de Estadística 2014c).

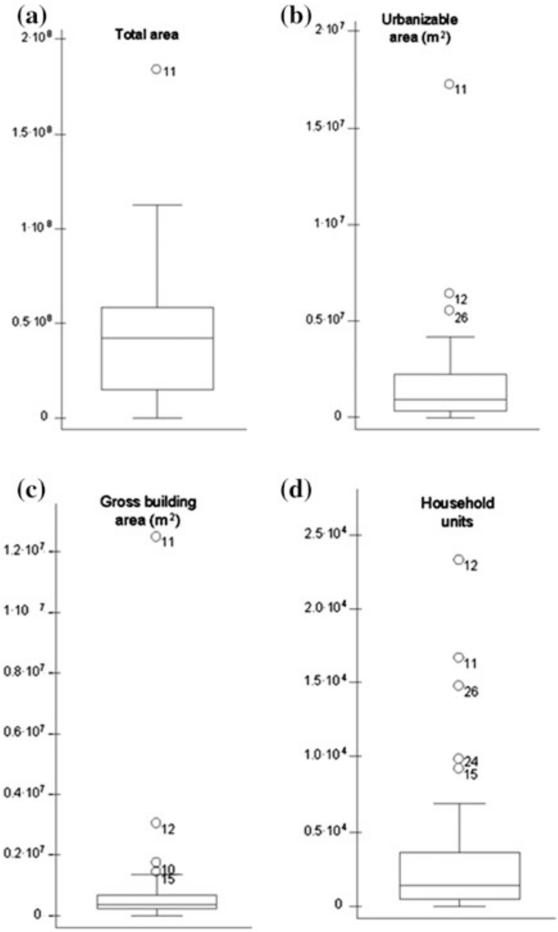

Fig. 4.2 Box plot diagram with urban planning figures of the municipalities analyzed

Table 4.3 Consumption of water (m^3/year) of average household in Madrid (2006–2011)

2006	2007	2008	2009	2010	2011
147.02	145.89	139.03	138.26	133.11	132.83

Table 4.4 Treated and re-used wastewater volume (m^3/year) of average household in Madrid (2006–2011)

	2006	2007	2008	2009	2010	2011
Treated wastewater	320.98	239.00	240.44	219.31	238.16	249.51
Re-used wastewater	2.07	3.03	2.94	2.90	2.92	3.84

Table 4.5 Electricity consumption (kWh/year) of average household in Madrid (2006–2011)

2006	2007	2008	2009	2010	2011
4,281.27	4,189.94	4,147.69	4,183.86	4,400.04	4,388.56

Table 4.6 Gas consumption (kWh/year) of average household in Madrid (2006–2011)

2006	2007	2008	2009	2010	2011
8,546.26	8,961.84	9,233.45	7,237.32	7,995.14	8,963.08

Table 4.7 Waste generation rates (kg/year) of average household in Madrid (2006–2011)

2006	2007	2008	2009	2010	2011
1,830.89	1,755.61	1,576.11	1,483.81	1,115.48	1,042.36

It has been adopted a 2.24 travels/residence rate for r_g in working days and 10 % of this rate for non-working days, according to the data from Comunidad de Madrid (2005). Distances between cities (d_{ij}) were measured directly on maps, and the annual population density, companies and shops were collected from official statistics (Instituto de Estadística de la Comunidad de Madrid 2014b; Servicio de Estadística de Castilla La Mancha 2014).

4.2.1.2 Emission Factors

It have been used both, official and scientific studies, to assess a value for EC_w. Table 4.8 reports the results from the most relevant previous works in literature.

Attempting to these works it has been adopted the mean value of the results in Table 4.8, amounting to 2.10 kWh/m^3.

Table 4.8 Energy cost of drinking water supply (kWh/m^3)

<table>
<tr><th colspan="2">Work</th><th>Lower limit</th><th>Average</th><th>Upper limit</th></tr>
<tr><td colspan="2">Global Water Research Coalition (Instituto para la Diversificación y Ahorro Energético 2010)</td><td>0.40</td><td></td><td>1.00</td></tr>
<tr><td colspan="2">California Energy Commission (2005)</td><td>0.21</td><td>–</td><td>8.25</td></tr>
<tr><td rowspan="3">Sala (2007)</td><td>Surface-water catchment</td><td>0.0002</td><td>–</td><td>1.74</td></tr>
<tr><td>Groundwater catchment</td><td>0.37</td><td>–</td><td>1.32</td></tr>
<tr><td>Desalination</td><td>4.94</td><td>–</td><td>5.41</td></tr>
<tr><td colspan="2">Cabrera et al. (2010)</td><td>0.13</td><td></td><td>0.31</td></tr>
<tr><td colspan="2">Hardy and Garrido (2010)</td><td>0.23</td><td>1.02</td><td>6.99</td></tr>
<tr><td colspan="2">Qi and Ni-Bing (2013)</td><td></td><td>1.29</td><td></td></tr>
</table>

Table 4.9 Energy cost of wastewater treating and re-use (kWh/m^3)

Author/s	Wastewater treatment (kWh/m^3)			Re-use of wastewater (kWh/m^3)		
	Lower limit	Average	Upper limit	Lower limit	Average	Upper limit
California Energy Commission (2005)	0.29	–	1.33	0.11		0.32
Cabrera et al. (2010)	0.36		0.80	0.20		0.43
Hardy and Garrido (2010)	0.41	0.58	0.72	0.32	0.57	0.85
Qi and Ni-Bing (2013)		0.97				

Table 4.10 Spanish emission factor (kgCO_{2eq}/kWh) for electricity generation mix (EF_e)

2006	2007	2008	2009	2010	2011
0.44	0.45	0.38	0.35	0.27	0.34

Scientific studies summarized in Table 4.9 allow to determine the energy cost of wastewater management.

Also, it has been necessary to use an averaged value of the figures summarized in Table 4.4 of 0.66 and 0.40 kWh/m^3 linked to the treatment and re-use of wastewater, respectively.

The data in Table 4.10 show the emission factor of power generation mix in Spain from the years 2006 to 2011 (Red Eléctrica Española 2011, 2012, 2013, 2014a, b).

It has been defined an emission factor for waste management. In this case the information source has been the aggregated data of waste generation and related GHG emissions published by the Spanish National Emissions Inventory (Oficina Española de Cambio Climático 2014). The results are shown in Table 4.11.

The emission factor for vehicles (EF_v) calculation needs information coming from different sources. In the first place, official statistics of vehicle fleet compositions (Dirección General de Tráfico 2014) in Spain during the 2006–2011 period are resorted to determine r_d and r_p. emmision factors published by Transport Research Laboratory (GHG Protocol 2005), which amount to 0.22 kgCO_{2eq}/km for a medium petrol car (EF_p) and 0.12 kgCO_{2eq}/km for a diesel vehicle (EF_d). Thus, EF_{vl} (Table 4.12) has been calculated using the combination of emission factors for each fuel and the proportions of each type of fuel from the vehicle fleet composition.

Table 4.11 Waste management emission factor (kgCO_{2eq}/t)

2006	2007	2008	2009	2010	2011
370.23	387.54	385.37	442.07	434.21	428.29

Table 4.12 Emission factor (EF_{vl}) for light vehicles (2006–2011)

2006	2007	2008	2009	2010	2011
0.175	0.173	0.171	0.169	0.168	0.167

Table 4.13 Emission factor (EF_v) for vehicles (2006–2011)

2006	2007	2008	2009	2010	2011
0.213	0.211	0.209	0.231	0.205	0.204

Meanwhile, the emission rate for heavy duty vehicles amounts to 0.622 $kgCO_{2eq}$/km (EF_h), corresponding to the average between heavy and light duty trucks emission factors published by the United States Environmental Protection Agency (GHG Protocol, 2005).

Finally, it is necessary to collect the percentages of light duty vehicles. Empirical traffic counts on roads between 2006 and 2011 are a perfect source of data (Comunidad de Madrid 2011, 2012), representing the following percentages 91.39, 91.47, 91.51, 91.73, 91.84 and 91.71, respectively. Thus, these percentages has been applied to the aforementioned emission factors (EF_{vh} and EF_{vl}) in order to calculate EF_v (Table 4.13).

4.2.1.3 Carbon Footprint Sustainability Indicators

The last category of indicators requires assessing the potential capacity of non-urbanizable land to capture GHG emissions. Although literature has widely studied the capture potential of specific plant species, there is an important lack of information about the capture potential capacity of land uses. This information is more easily manageable at the land planning stage. Therefore, it has been necessary to transform the potential capture of certain plant species to land uses, through the application of densities, proving the figures listed in Table 4.14, including the bibliographic source also.

4.2.1.4 Carbon Footprint Calculation

Finally, the results for GHG_w (Table 4.15) are obtained by replacing the calculated energy cost of drinking water supply in Eq. 2.3 and the data from Tables 4.5 and 4.6.

Many authors have analyzed the relationship between the carbon footprint and water supply infrastructures. Significant, the study by Shrestha et al. (2011) proved the influence of drinking water policy decisions on the resulting carbon footprint linked to this source. Qi and Ni-Bing (2013) established that the difference in carbon footprint from drinking water between extreme infrastructure design characteristics was 1.47 %.

Table 4.14 CO_2 capture potential rates of non-urbanizable land uses and crops

Land use	Capture potential (tCO_2/ha)	Source
Poplar	18.66	Own elaboration based on data from CITA (2008)
Conifer	19.24	Own elaboration based on data from García et al. (2010)
Conifer and other non-conifer species	15.87	Own elaboration based on data from García et al. (2010)
Irrigated arable crops	36.75	Own elaboration based on data from Martínez-Val (2008)
Dry crops	13.45	Own elaboration based on data from Carvajal (2011)
Bushes	4.50	Own elaboration based on data from García et al. (2010)
Bush with conifer	1.55	Own elaboration based on data from García et al. (2010)
Bush with other non-conifer	2.38	Own elaboration based on data from García et al. (2010)
Cry olive trees	6.59	Own elaboration based on data from Domenech et al. (2011)
Other non-conifer	12.50	Own elaboration based on data from García et al. (2010)
Grass	8.82	Own elaboration based on data from Martínez-Val (2008)
Grass-bush	5.94	Own elaboration based on data from García et al. (2010) and Martínez-Val (2008)
Irrigated vineyard	19.11	Own elaboration based on data from Carvajal (2011)
Dry vineyard	6.26	Own elaboration based on data from Carvajal (2011)
Dry crops with other non-conifer	19.70	Own elaboration based on data from García et al. (2010) and Carvajal (2011)
Irrigated fruit trees	21.92	Own elaboration based on data from Carvajal (2011)
Dry fruit trees	6.30	Own elaboration based on data from Domenech et al. (2011)
Horticultural crops	12.58	Own elaboration based on data from Carvajal (2011)
Vineyard with olive trees	13.19	Own elaboration based on data from CITA (2008)
Irrigated olive trees	20.12	Own elaboration based on data from CITA (2008)
Bush with conifer and non-conifer	1.55	Own elaboration based on data from García et al. (2010)

(continued)

Table 4.14 (continued)

Land use	Capture potential (tCO_2/ha)	Source
Conifer with eucalyptus trees	31.26	Own elaboration based on data from García et al. (2010)
Olive trees with conifer	12.91	Own elaboration based on data from García et al. (2010) and Domenech et al. (2011)
Grass with non-conifer	3.54	Own elaboration based on data from García et al. (2010)
Grass-bush with non-conifer	5.45	Own elaboration based on data from García et al. (2010)
Dry crops bush with conifer and non-conifer	21.25	Own elaboration based on data from García et al. (2010) and Carvajal et al. (2011)
Vineyard with fruit trees	6.28	Own elaboration based on data from Carvajal (2011) and Domenech et al. (2011)
Natural pasture	6.33	Own elaboration based on data from CITA (2008)
Eucalyptus	43.t8	Own elaboration based on data from Norverto (2003)

Table 4.15 GHG emissions from the water supply ($kgCO_{2eq}$/year) of average household in Madrid (2006–2011)

2006	2007	2008	2009	2010	2011
137.29	138.70	112.58	101.78	75.59	94.99

The results of the carbon footprint of the wastewater management are shown in Table 4.16.

Then, the results for GHG emissions from electricity are shown in Table 4.17.

Data presented in Table 4.17 are considerably higher than the results from drinking water or wastewater in Tables 4.2 and 4.5, which reveals the importance

Table 4.16 GHG emissions from wastewater treatment and re-use ($kgCO_{2eq}$/year) of average household in Madrid (2006–2011)

	2006	2007	2008	2009	2010	2011
Treated wastewater	95.00	72.01	61.71	51.17	42.86	56.55
Re-used wastewater	0.37	0.55	0.45	0.41	0.31	0.52
Total	95.37	72.56	62.16	51.58	43.17	57.07

Table 4.17 GHG emissions from electricity ($kgCO_{2eq}$/year) of average household in Madrid (2006–2011)

2006	2007	2008	2009	2010	2011
1,900.88	1,893.85	1,596.86	1,464.35	1,188.01	1,492.11

Table 4.18 GHG emissions from the gas consumption (kgCO_{2eq}/year) of average household in Madrid (2006–2011)

2006	2007	2008	2009	2010	2011
1,727.26	1,811.25	1,866.14	1,462.71	1,615.87	1,811.50

Table 4.19 GHG emissions from waste treatment (kgCO_{2eq}/year) of average household in Madrid (2006–2011)

2006	2007	2008	2009	2010	2011
677.85	680.37	607.39	655.95	484.35	446.44

of electricity consumption in overall GHG emissions. Several studies have examined the relationship between the urban carbon footprint and the electricity generation mix emission factor (Zubelzu et al. 2015; Álvarez et al. 2015).

The carbon footprint of gas supply are shown in Table 4.18.

The results in Table 4.18 are on the same order of magnitude as the results from electricity in Table 4.17 which allows concluding that both variables affect in a similar order.

Finally, to calculate the GHG emissions linked to waste management, that multiplies the emission factors summarized in Table 4.10 by the waste generation rates in Table 4.11. The results are shown in Table 4.19.

The reader will also find relevant literature about waste management and carbon footprint in the following references: Romero et al. (2010), who found a rate of 341 kgCO_{2eq}/t for the city of Barcelona waste treatment, or by Mühle et al. (2010) who calculated, in Germany and the United Kingdom, the waste treatment emissions amounting to 103 and 284.4 kgCO_{2eq}/t, respectively.

Several statistical variables have been exposed in Table 4.20, relating to the carbon footprint of transport. It should be noted that, while the other sources can be reasonably assumed to be constant among municipalities, it is not possible to assume that regarding to the traveled distances as this metric differs among them. Thus, the data presented in Table 4.20 show the averaged values (AV), the coefficient of variation (CV), maximum (MAX) and minimum (MIN) GHG emissions values for each year analyzed (period 2006–2011).

Table 4.20 Summary of transport GHG emissions (kgCO_{2eq}/year) of average household (2006–2011) in each analyzed city

	2006	2007	2008	2009	2010	2011
AV	1,930.05	1,900.72	1,860.77	1,908.37	1,845.58	1,891.55
CV	0.65	0.65	0.65	0.67	0.70	0.68
MIN	243.14	239.67	238.61	238.42	231.00	235.01
MAX	4,521.34	4,461.87	4,442.11	5,206.78	5,225.15	5,240.84

The average values presented in Table 4.20 are indicative of the most relevant source, except for 2008, ranked in the first position. It has been probed that the greatest influence on GHG emissions comes from traffic relationships and the resultant traveled distances, rather than from the fleet vehicle composition or from the percentage of heavy vehicles, given the variation magnitudes of these variables observed in this work. This fact allows to conclude that measures based on traffic management (reducing distances or developing lands closer to trips attractive cities, for example) are more effective than generic measures related to the vehicle fleet composition.

This fact makes relevant the urban planning role to manage the amount of GHG emissions from transport use, because the aforementioned management oriented measures could be implemented through urban planning decisions.

The literature has proposed (Sovacool and Brown 2010) the promotion of battery electric vehicles and other "zero emissions" vehicles as a help to reduce the carbon footprint of transport. However, urban planners could only facilitate this option through improving the recharging infrastructure. This is a classic chicken and egg problem, and several drawbacks should be carefully study: the impact of increasing the number of electric vehicles sold on the electricity generation mix emission factor (Huo et al. 2009; Álvarez et al. 2015). It is also important to consider the consequent variation in emissions of carbon dioxide due to the consumer's interval for recharging the battery and its influence in the electric infrastructure needed, which would result a key factor in the growing of the electric vehicle fleet.

4.2.2 GHG Emissions Resume

The complete GHG results for each analyzed city and year are included in Table 4.21.

Establishing the comparison frame built with those data, presented in Table 4.21, a range between 9,383.47 and 3,905.17 kgCO_{2eq}/year. The largest values in Table 4.21 appears from 2008 and they are not from a specific source, but from a combination of the second highest values in the GHG emissions from gas,

Table 4.21 Summary of GHG emissions (kgCO_{2eq}/year) of average household

	2006	2007	2008	2009	2010	2011
AV	6,792.14	6,822.32	6,411.20	5,913.79	5,499.39	6,077.34
CV	0.18	0.18	0.19	0.21	0.23	0.21
MIN	5,105.23	5,161.27	4,790.74	4,259.87	3,905.17	4,433.01
MAX	9,383.43	9,383.47	9,015.74	8,854.31	8,446.89	9,287.75
IL	6,777.76	6,80812	6,407.19	5,921.83	5,517.41	6,104.36
SL	6,806.52	6,836.52	6,435.18	5,950.95	5,546.64	6,134.02

electricity and transport. Conversely, the lowest values in 2010 are linked to the smallest emissions from transport and, especially, from electricity.

Several studies have addressed the carbon footprint calculation, but most of them have used a consumption-based approach. These approaches include not only the sources studied in this work, but the sources from all daily habits. The results are hardly conditioned by the local variables, such as the electricity generation mix emission factor, so the comparison of results should be treated with caution. However, the reader can find several studies similar to the ones presented here in the following literature:

- Lin et al. (2013) and Ramaswami et al. (2008) calculated the carbon footprint for 12 large cities varying the results between 0.996 and 4.3 tCO_{2eq}/year for each individual.
- Minx et al. (2013) also studied the carbon footprint through a consumption-based approach for 434 cities in the United Kingdom, assessing an average of 12.5 tCO_{2eq}/year for each individual.
- Petsch et al. (2011) and Jones and Kammen (2011) obtained, in several regions of the United States and with a consumption-based approach, 19.5 and 20 tCO_{2eq}/year for each individual, respectively.
- Other studies, with less scientific impact, but also very relevant, such as Carney et al. (2009).

It is possible to analyze the percentage that each source represents on the overall GHG emissions, considering the average of all the cities studied (see the data presented in Table 4.22).

The data in Table 4.22 showed that traffic was the most relevant source, with electricity and gas alternate occupying the second position depending on the specific annual consumption data, whereas waste, water supply and wastewater are, in that order, the less relevant sources. In spite of the aggregated data detailed in Table 4.22, traffic is not the most relevant source in all cities, as it is shown in Table 4.23.

Table 4.22 Weight of each source (%) on total GHG emissions

	Water supply (%)	Wastewater (%)	Electricity (%)	Gas (%)	Waste (%)	Traffic (%)	Others (%)
2006	2.02	1.40	27.99	25.43	9.98	28.42	4.76
2007	2.03	1.06	27.76	26.55	9.97	27.86	4.76
2008	1.76	0.97	24.91	29.11	9.47	29.02	4.76
2009	1.72	0.87	24.82	24.79	11.12	31.92	4.76
2010	1.38	0.79	21.66	29.46	8.83	33.13	4.76
2011	2.02	1.40	27.99	25.43	9.98	28.42	4.76

Table 4.23 Number of cities where each source is the most relevant in GHG emissions per year

	2006	2007	2008	2009	2010	2011
Electricity	17	17	0	17	0	0
Gas	0	0	17	0	17	17
Transport	14	14	14	14	14	14

Table 4.24 Weight of each source (%) in the total GHG emissions grouped according to EF_e sources

	Electricity (%)	Gas (%)	Fossil fuels (%)	Others (%)
2006	31.41	25.43	28.42	14.74
2007	30.86	26.55	27.86	14.73
2008	27.63	29.11	29.02	14.24
2009	27.42	24.79	31.92	15.88
2010	23.82	29.46	33.13	13.59
2011	27.16	29.92	30.79	12.14

To fulfill the analysis, it have been collapsed the figures according to energy source into the following categories: electricity (drinking water, wastewater and electricity dependent variables), gas, fossil fuels (transport) and others. Respectively weight of each source has been listed in Table 4.24.

4.2.2.1 GHG Sustainability Indicators

In the following sections, including the four categories of carbon footprint sustainability, indicators are explained for each of the 33 analyzed municipalities.

- *Global GHG emissions indicators*

The first set of proposed indicators are related to the overall amount of GHG emissions. Global GHG emissions indicators (Fig. 4.3) show patterns close to the aforementioned urban planning figures (Fig. 4.2), but slightly biased due to the effect that the GHG emissions of transport (not only depends on the urban planning figures but also on the distances travelled and the productive structure of the surrounding municipalities) exert on the total amount of emissions. This effect will be discussed later in this book, but it implies that those municipalities, without the greatest urban development figures, but far from the most important trip attraction points, could generate the highest emissions.

The plots in Fig. 4.3 allow to check that the outliers are still visible in the box plot referred to the GHG emissions in each municipality (box plot a), but not in the box plot that attributes the GHG emissions for each household unit (box plot b). This demonstrates the homogeneity in the distribution of the GHG emissions independently of the specific municipalities.

		Average emissions (tCO$_{2eq}$/year)	Average emissions (kgCO$_{2eq}$/res·year)
Mean		21,641,55	6,624.10
Median		7,575,54	6,100.34
Std. Deviation		31,486,59	1,554.94
Variance		$9{,}91 \cdot 10^8$	$2.42 \cdot 10^6$
Coefficient of variation		1.45	0.23
Skewness		2.13	0.68
Kurtosis		3.87	-0.57
Minimum		232.34	4,598.12
Maximum		118,464.22	9,953.59
Percentiles	25	3,603.20	5,311.11
	75	22,053.17	7,642.42

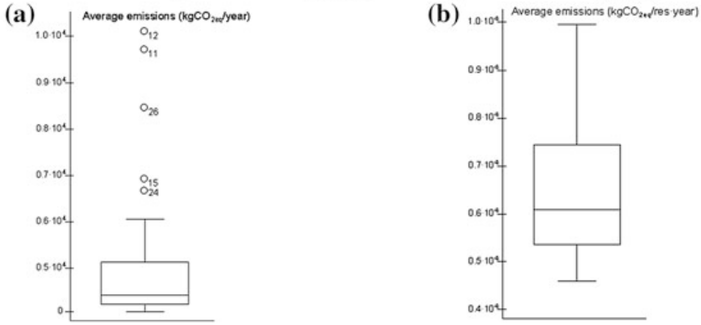

Fig. 4.3 Summarized results of the indicators mentioned in the overall amount of GHG emissions

Lin et al. (2013) and Ramaswami et al. (2008) calculated the carbon footprint of twelve big cities varying their resulting figures between 0.99 and 4.3 tCO$_{2eq}$/yr per person (this results have been obtained by removing the 20.97 % of total results attributable to the sources managed in the present paper). The similarity between the results obtained in the present book, through a predictive methodology, and those from Lin et al. (2013) and Ramaswami et al. (2008), obtained through a consumption-based methodology in this field, gives reliability to our work.

- *GHG sustainability indicators related to GHG emissions sources*

The second category of indicators is related to the composition of the GHG emissions. The first indicator within this category relates to the composition of the global GHG emissions according to each source, whose results for each analyzed year are shown in Fig. 4.4.

The importance of energy sources in the GHG emissions has been reported previously in the literature. Lin et al. (2013) represented the 32.74 % of emissions from energy consumption for Xianmen or Carney et al. (2009), they found that emissions from energy consumption were ranked as the first or the second position, after transport, in the carbon footprint importance for 18 cities in the European Union.

Deepen in GHG emissions from transport, it can be seen that the private vehicle becomes the most important source (Fig. 4.5) not only because it takes the majority of trips, but also by providing the highest rate of GHG emissions for passenger and travelled distance.

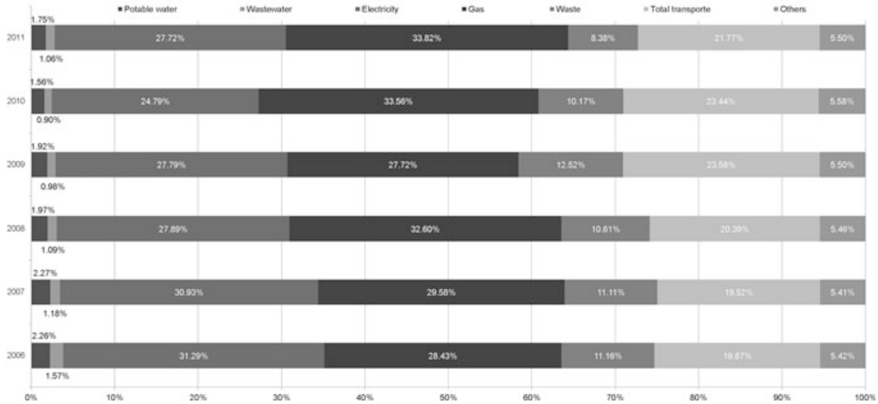

Fig. 4.4 The composition of global emissions of Greenhouse gases according to the emission sources

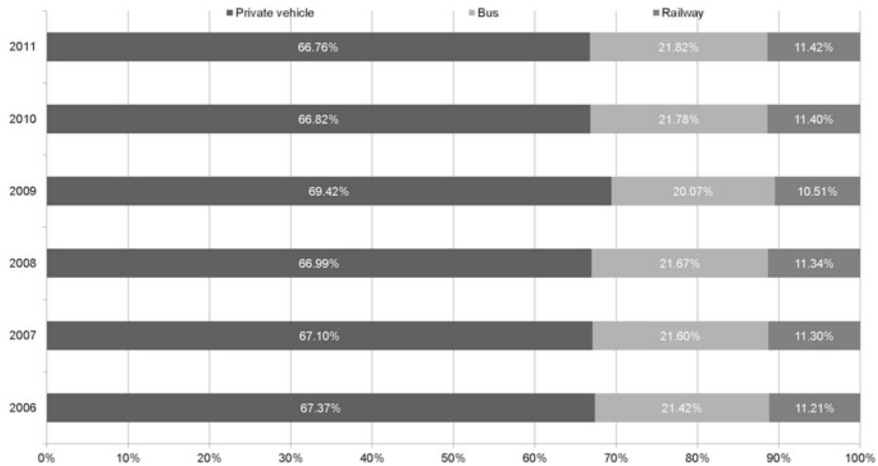

Fig. 4.5 GHG emissions modal share according to transport

Seeing the relevance of the private vehicle in GHG emissions, certain measures can be taken to reduce that role: try to control the traffic congestion through road network design measures, as Sovacool and Brown (2010) noted, or prioritizing public transport solutions through modal transport interchanges, following Cui et al. (2011). The promotion of electric vehicle has also been proposed as a solution to mitigate the GHG emissions, but the use of battery electric vehicles implies increasing the dependence on the electricity mix generation emission factor (Álvarez et al. 2015), so the future seems to be clear, but decisions must be taken carefully.

		Emissions interior journeys (kg CO_{2eq}/year)	Emissions exterior journeys (kg CO_{2eq}/year)
Mean		3,258.70	19,010.79
Median		487.38	5,812.04
Std. Deviation		5,462.81	29,167.46
Variance		$2.98 \cdot 10^7$	$8.51 \cdot 10^8$
Coefficient of variation		1.68	1.53
Skewness		1.75	2.67
Kurtosis		1.66	8.16
Minimum		14.71	451.82
Maximum		18,003.74	135,450.64
Percentiles	25	160.69	2,466.87
	75	2,008.44	27,057.76

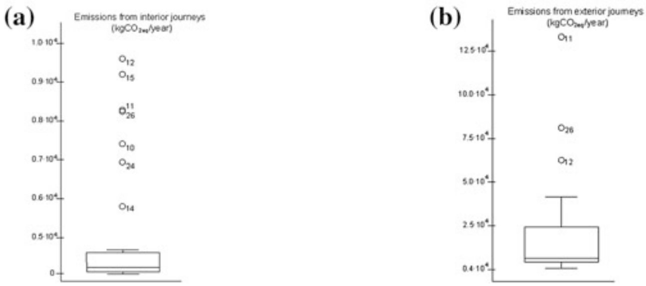

Fig. 4.6 Results of the indicator related to the distribution of the GHG emissions from road transport between interior and exterior trips

Finally, the indicator related to the distribution between distances traveled inside and outside and analyzed urban planning development (Fig. 4.6), allows analyzing the effect that the planned road network produces on the global GHG emissions. The results of this indicator show that the emissions related to the travel emissions affairs are clearly superior to the emissions of the interior ones. This implies that the ability of urban-planners to overcome the GHG emissions of this source is not majorly based on the urban planning design variables that defines only the inside of the road network.

Data in Fig. 4.6 also show the remarkable asymmetry of the data from the interior trips. It is caused by both for the greatest municipalities which generate a great amount of trips (points 11, 12, 14, 15, 24 y 26) and to other municipalities, smaller but far from the main attraction places (points 10 and 14). However, despite the outliers, external routes data are more concentrated, as the coefficient of variation stresses.

- *GHG sustainability indicators related to urban planning design variables*

The third group of indicators links the GHG emissions to the urban planning of design variables. Table 4.25 summarize the results of each indicator included in this category.

The indicators related to the total or to the undevelopable areas in Table 4.25 indicate the greater dispersion due to the difference among the figures of each urban planning development. On the contrary, the results of the indicators related to urbanizable or built areas are more concentrated, which probes the similarity among each urban planning proposal independently of specific locations. Nevertheless, there are certain peculiarities that are better perceived seeing the box plots exposed in Fig. 4.7.

Table 4.25 Results of the indicators that link the GHG emissions (per hectare) with the urban planning design variables

		Emissions/total surface (tCO_{2eq}/ha)	Emissions/urbanizable (tCO_{2eq}/ha)	Emissions/gross building area (tCO_{2eq}/ha)	Emissions/undevelopable (tCO_{2eq}/ha)
Mean		5.57	131.16	342.84	8.73
Median		2.55	126.15	284.45	3.27
Std. Deviation		6.74	55.91	208.01	12.03
Variance		4.55×10^4	3.13×10^3	4.33×10^4	1.45×10^5
Coefficient of variation		1.21	0.43	0.61	1.38
Skewness		1.64	0.49	1.97	1.87
Kurtosis		2.01	−0.35	4.48	3.03
Minimum		48.56	42.04	90.21	52.97
Maximum		24.87	270.42	1,032.88	46.32
Percentiles	25	0.86	76.36	224.06	0.89
	75	8.01	172.44	392.41	9.63

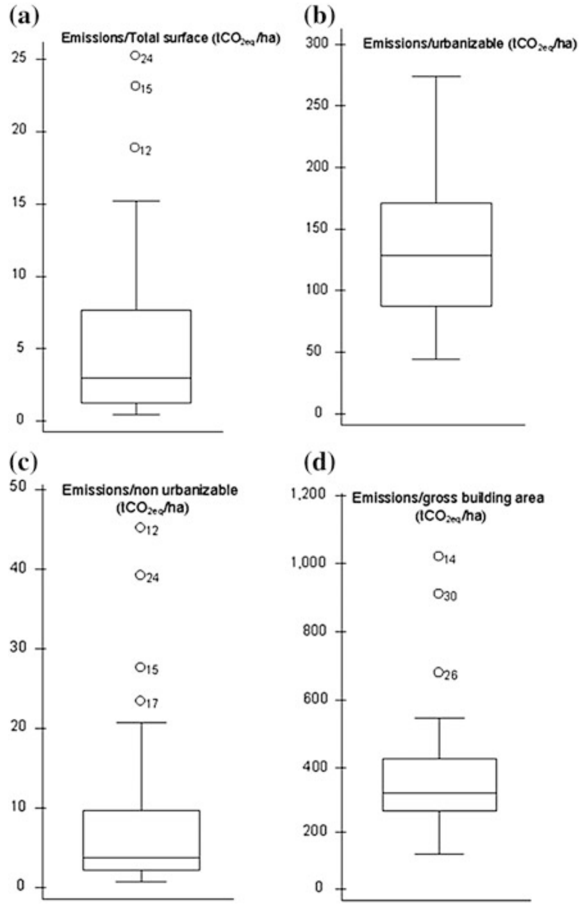

Fig. 4.7 Box plots of indicators that link the GHG emissions with the urban planning design variables

The box plots in Fig. 4.7 allow probing that the skewness in the first indicator (GHG emissions on the total area, Fig. 4.7a) is caused by a set of municipalities whose emissions are attributable to the size of the urban planning development figures. Conversely, data tend to appear more homogenous when results are linked to urbanizable area, due to the similar rates of this factor on total land areas studied (Fig. 4.7b). The box plot in Fig. 4.7c schematizes the indicator referred to the gross building area. These figures allow to point out that the resulting carbon footprint could be caused by different sources. In fact, the municipality numbered 30 occupies the penultimate position according to its urbanizable land area, but it is very far from the most attractive points, which explains why it is outlined.

Delving into this argument, Fig. 4.8 shows the traveled distances and the results of the indicators related to the urban planning variables (box plots), splitting the data between the municipalities where transport is the most relevant source.

		Traveled distances (km)	
		Transport	Other
Mean		89.06	39.15
Median		88.20	33.55
Std. Deviation		12.71	16.58
Variance		161.61	274.80
Skewness		-0.35	2.29
Kurtosis		-1.08	5.95
Minimum		70.57	24.59
Maximum		105.44	95.77
Percentiles	25	76.74	29.57
	75	100.30	42.01

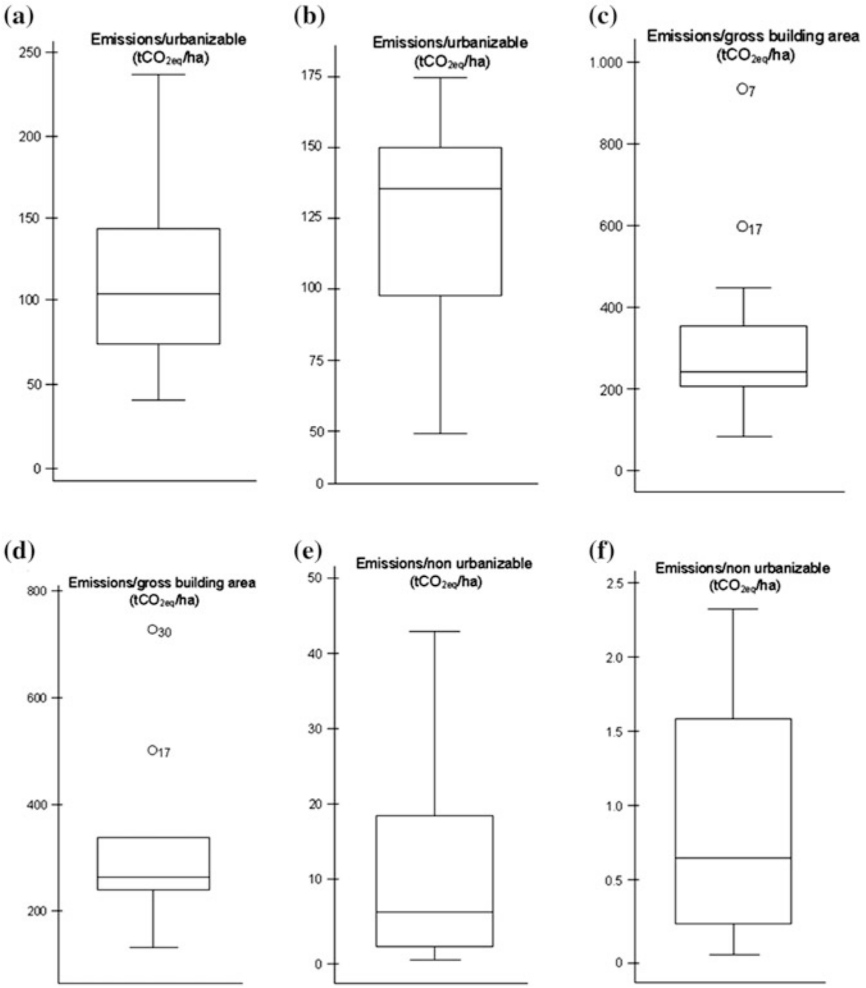

Fig. 4.8 Results of distances and indicators referred to urban planning design variables according to the main GHG emissions source (transport or any other)

The distances travelled are considerably higher in those municipalities where transport is the most relevant source (see Fig. 4.8a, c and e). Although these municipalities do not have to be characterized for their big urban planning proposals, they are usually located far from the main trip attraction points. The consequences of those characteristics are reflected in the metrics related, not only to the built gross area, but also to the urbanizable and non-urbanizable land as the box plots highlights in Fig. 4.8.

- *GHG sustainability indicators related to the capture potential*

The last group of the proposed indicators relates to the potential carbon capture of the non-urbanizable land resulting from planning sustainability design solutions. The first indicator within these groups is referred to the difference between the GHG emissions and the capture potential. Table 4.26 collects the results for this indicator, distinguishing between deficit and surplus municipalities.

Results in Table 4.26 highlights that most of the municipalities own a potential capture surplus (it has to be noticed at this point that figures in Table 4.4 do not take into account either GHG emissions currently produced or the GHG emissions of any other planned land use). Some of the deficit municipalities are outlined in Fig. 4.2 (municipalities numbered 12, 15 and 24), while the other deficit ones are those municipalities where the non-urbanizable lands do not provide a relevant capture potential (mainly due to the majority presence of bush or grassland land uses).

To manage the analysis of the indicators related to the capture potential, Fig. 4.9 shows the results of the indicators that measure the required area of non-urbanizable land to capture the GHG emissions of each basic unit of area of urbanizable or gross built lands.

Table 4.26 Results of the GHG emissions balance indicator for deficit and surplus municipalities

		Deficit municipalities (tCO_2)	Surplus municipalities (tCO_2)
Number		7	24
Mean		−21,701.30	57,490.71
Median		−4,604.98	48,659.70
Std. Deviation		29,464.66	50,176.15
Variance		8.68×10^8	2.52×10^9
Skewness		−1.95	2.23
Kurtosis		3.94	6.87
Minimum		−83,569.82	3,926.70
Maximum		−1,941.34	22,904.55
Percentiles	25	−4,604.98	48,659.70
	75	−3,879.88	74,832.33

		Non-urbanizable/urbanizable	Non urbanizable/built
Mean		10.55	27.74
Median		9.20	24.75
Std. Deviation		5.00	17.42
Variance		25.03	303.30
Coefficient of variation		0.47	0.63
Skewness		0.34	1.66
Kurtosis		-0.58	3.30
Minimum		2.44	3.64
Maximum		21.25	81.16
Percentiles	25	6.24	16.58
	75	13.93	32.77

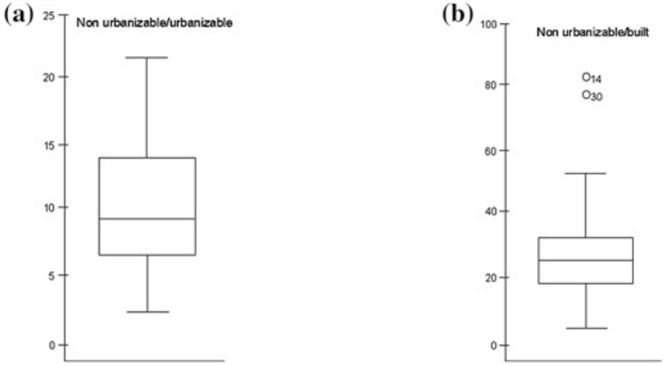

Fig. 4.9 Results of the indicators that link the required area of non-urbanizable land to capture the GHG emissions of each unit area of urbanizable or built lands

The highest rates are linked, as it was expected, to the built area (Fig. 4.9b). This indicator determines a greater variability and certain positive skewness caused by municipalities both with high GHG emissions and with low capture potential from the non-urbanizable land (bush or grassland land uses).

Results in Fig. 4.9 also show that the capture potential allows compensating the GHG emissions of certain municipalities with the higher pollutant concentration. This happens, i.e. in the municipality numbered 11, whose GHG emissions are very relevant (see Figs. 4.2 and 4.3) but whose high capture potential level allows neutralizing its GHG emissions. This fact highlights the ability of the municipal authorities as design managers to act, not only on the urban developments, but also on the undevelopable lands to manage the GHG emissions. Thus, promoting high capturing land uses (intensive agricultural or forestry crops) on the undevelopable lands, the municipal authorities can help to capture the GHG emissions produced in the urban planning developments. They can also act as a sustainability administrator, guiding the project managers to include surfaces for these kinds of land uses when and how each UMP's stages are considered, in order to optimize the compensation, complete or partial, of the GHG emissions.

4.3 Industrial

Industrial classifications are intended to accommodate a wide range of industrial activities including: manufacturing, processing, warehousing, wholesaling and limited commercial and office uses. Relating to the analysis of industrial activities in carbon emissions, the following categories have been considered:

- Food, beverages and tobacco industry (FI).
- Textile and leather industry (TI)
- Timber and cork industry (TCI).
- Printing industry and production of paper (PI).
- Chemicals, Plastics and Rubber Industry (CI).
- Industry of non-metallic mineral products (NI).
- Metal products industry (MI).
- Electrical, electronic and machinery industry (EI).
- Furniture and other manufacturing industries (FMI).

Conversely, there are not annual figures about consumption and generation data available for each aforementioned industrial category. The authors have resorted to resume studies and not to yearly official statistics.

4.3.1 Data Collection

As it was stated previously, related to residential land use, the information included in the following sections is specific for the exposed example.

4.3.1.1 Consumption and Generation Data

The major source of information regarding water consumption and wastewater production were the Spanish Survey of Water Use in the Industrial Sector in 2006 (Instituto Nacional de Estadística, 2009) and the Spanish Water Use in Manufacturing Industry 2007–2010 (Instituto Nacional de Estadística, 2013) documents.

Waste generation data came from the Spanish Survey on Waste Generation in the Industrial Sector (Instituto Nacional de Estadística, 2014a).

Data on gas and electricity consumption were collected from the Spanish Energy Consumption Survey (Instituto Nacional de Estadística, 2014b). In the case of residential uses, the absence of data required to work with the average data presented in Table 4.27.

Table 4.27 Average annual values for drinking water (C_w), gas (C_g) and electricity (C_e) consumptions and waste (G_{wt}) and wastewater (G_{ww}) productions

	C_w (m^3/m_b^2 year)	G_{ww} (m^3/m_b^2 year)	G_{wt} (kg/m_b^2 year)	C_e (kWh/m_b^2 year)	C_g (kWh/m_b^2 year)
FI	8.32	5.62	134.87	177.89	165.62
TI	2.66	2.19	8.64	52.48	46.14
TCI	0.92	0.33	32.50	120.42	146.56
PI	10.53	8.01	106.15	129.40	191.13
CI	44.64	28.84	238.98	596.03	762.46
NI	8.12	3.66	354.00	375.86	845.29
MI	4.30	3.27	139.77	204.44	126.42
EI	2.73	1.30	63.64	185.42	87.59
FI	2.17	0.84	9.88	27.76	4.66

For trip generation (G_t), it has been directly measured the distances (d_{ij}) between each analyzed city in Table 2.1 and each potential destination city inside its influencing area on a map.

Identifying the influencing area has been a difficult task, because each area is generally measured based on the probability of trips made by inhabitants; as a result, it has been assumed that the influencing area covers cities up to 70 km from each generation point. The capacity of a city to attract trips beyond this distance can be considered negligible because distance appears in the denominator in Eq. 2.8.

The second required variable to determine trip generation is the number of trips between the analyzed city and each potential destination (N_{ij}), which requires the determination of r_g and e_i. Trip generation rates (r_g) were obtained from Martin and McGuckin (1998). The rates published by these authors are not linked to a concrete set of activities, but to the manner in which generic industrial activities are executed. The authors distinguish between general light industrial, general heavy industrial, industrial park and manufacturing and warehousing activities. Therefore, it have been also considered the average rate between the industrial categories defined and the maximum (general light industry or industrial park uses) and minimum (general heavy industry) activity values.

It should be noted that, while the data reported by Martin and McGuckin (1998) refer to industrial gross area, calculations in the present work has been linked to built area to represent and apply better the author's methodology to other industrial developments. For this reason, figures presented in Martin and McGuckin (1998) have been multiplied by a common industrial edificability index in Madrid that accounts for up to $0.62\,m_e^2/m_g^2$ (Ayuntamiento de Madrid, 2005).

Therefore the calculated average for the distances traveled (Gt) from analyzed cities (km/m_b^2 year) amounts to 1.69.

4.3.1.2 Emission Factors

There is no difference between the emission factors obtained related to the residential land use in previous point (Sect. 4.2.1.2) and the emissions factors required for the industrial land use.

In the case study has been assumed that there are no differences in the provision of electricity, gas or water between residential and industrial land uses within a municipality. This hypothesis should be tested in each case, because there may be several differences in certain emission factors, for example due to different electricity supply methods that will affect the electricity generation mix emission factors.

4.3.2 Carbon Footprint Calculation

The carbon footprint of the analyzed industrial sectors was derived by substituting consumption and generation data and emission factors into Eqs. 2.4–2.9. Table 4.28 shows the results of this process, including the average, the lower and upper limits. Table 4.28 also points the percentage difference between the upper and lower limits divided by the average value, which indicates the capacity of each activity's carbon footprint to be modified.

Only few authors have compared the absolute values revealed in Table 4.28. The literature typically presents aggregated data for regions, cities, industrial parks or specific industries derived from consumption- or input-output-based approaches, and these results are not strictly comparable here. For example, Dong et al. (2013) deduced a total carbon footprint of 34.43 $kgCO_{2eq}/m_g^2$ for the gross area of a Chinese industrial complex.

According to the data shown in Table 4.28, chemical industries and furniture and other manufacturing industries are ranked first and last, respectively, by total carbon footprint, where the average value for the latter industry is equal to one-fourth the value of the first one. The range between extreme results

Table 4.28 Carbon footprint average per activity ($kgCO_{2eq}/m_e^2$ year)

	Average carbon footprint
FI	272.23
TI	154.57
TCI	205.28
PI	252.47
CI	607.25
NI	555.91
MI	272.84
EI	228.61
FI	137.36

(1,110.71 and 43.59 $kgCO_{2eq}/m_e^2$) rises to 1,067.12 $kgCO_{2eq}/m_e^2$, which emphasizes the importance of industrial uses identification and definition with the aim of integrate them in the urban planning instruments that supports the determination of carbon footprint.

The ranking of industrial activities summarized in Table 4.28 coincides with findings from Lin et al. (2013), who have observed that the highest carbon footprint in Xianmen came from chemical and non-metallic minerals processing industries. Dong et al. (2013) have also placed the chemical industry in the first position; however, conversely the work here presented, Dong et al. (2013) have based their estimations on industrial production emissions and not on the sources that the authors of the present book have analyzed, they ranked machinery manufacturing in the second position.

When carbon footprint results are broken down into GHG emission sources (Table 4.29), it can be seen that transport becomes the most important emissions source, followed by electricity and gas in all activities except for the most polluting ones (chemical and non-metallic mineral processing activities are associated with high gas and electricity sources). The relevance of the electricity source to the carbon footprint within chemical industries found in the present work coincides with results from Dong et al. (2013).

The aforementioned study conducted by Carney et al. (2009) also faces with the industrial carbon footprint calculation finding that energy consumption alternated between the first and the second, behind transport, position in carbon footprint importance for 18 cities in the European Union. Dong et al. (2013) accounted for 49.16 % of the emissions from electricity and heat, direct energy consumption and waste treatment for an industrial park in China. Lin et al. (2013) found that emissions from energy consumption in Xiamen amounted to 32.74 % of the total carbon footprint.

Table 4.29 Carbon footprint composition by source and industrial activity

	Water (%)	Wastewater (%)	Waste (%)	Electricity (%)	Gas (%)	Transport (%)
Food	2.23	0.48	17.66	22.72	12.30	44.62
Textil	1.26	0.33	1.99	11.80	6.03	78.59
Timber	0.33	0.04	5.64	20.39	14.43	59.17
Paper making and printing	3.05	0.74	14.98	17.82	15.30	48.11
Chemical	5.37	1.10	14.02	34.12	25.38	20.00
Nonmetal mineral products	1.07	0.15	22.69	23.50	30.73	21.85
Metal products	1.15	0.28	18.26	26.43	9.36	44.52
Electric, electronic and machinery	0.87	0.13	9.92	28.20	7.74	53.14
Furniture and other manufacture industries	1.16	0.14	2.56	7.03	0.69	88.43

Table 4.30 Contribution of identified sources to the carbon footprint of each industrial activity

	Electricity (%)	Gas (%)	Fossil fuel (%)
Food	43.08	12.30	25.57
Textil	15.38	6.03	52.03
Timber	26.40	14.43	29.93
Manufacture and printing of paper	36.59	15.30	27.97
Chemical	54.62	25.38	10.94
Non-metallic mineral products	47.42	30.73	11.21
Metal products	46.12	9.36	29.28
Electrical, electronic and machinery	39.12	7.74	32.43
Furniture and other manufacturing industries	10.89	0.69	57.93

Regarding the carbon footprint composition by sources, the variables included in Eq. 2.10 allow us to identify three types of energy sources involved in industrial activities' carbon footprint: electricity, gas and fossil fuels linked to transport. The waste management data derived from Eq. 2.8 can be ignored because GHG emissions from waste management largely come from waste degradation processes and additional energy consumption needs are commonly satisfied with generated biogas instead of electricity or gas). Thus, percent contributions of each identified source to each industrial activity's carbon footprint are shown in Table 4.30.

Electricity is proved to be the largest source of emissions for the majority of the industrial activities analyzed (food, beverages and tobacco, manufacturing and printing of paper; chemical; non-metallic mineral products and electrical, electronic and machinery industries), including the most polluting industries identified in Table 4.10 (chemical and non-metallic mineral products). Conversely, for the two less-polluting industrial activities (textile and leather and furniture and other manufacture industries), fossil fuels associated with transport are the largest source of GHG emissions.

Based on the value derived in Table 4.30, the most energy-intensive (electricity and gas) industrial activities (chemical and non-metal mineral products) are associated with the highest carbon footprint.

Several studies have deal with the relationship between the carbon footprint and the characteristics of the energy supply. For example, Sovacool and Brown (2010), have proposed gas cogeneration systems to mitigate the carbon footprint of industrial sector. However, implementation of this measure is not feasible for all industries, especially for the smaller ones. These authors also proposed low carbon transport technologies promotion (electric vehicles for instance) to directly reduce the carbon footprint; but urban planners could only facilitate this option by supplying recharge infrastructure, and then the impact of electric vehicles on electricity generation mix emission factor (Huo et al. 2009; Shi et al. 2013) would have to be taken into account and the resulting carbon footprint analyzed. There is a deep analysis of the relationship between the electric vehicle promotion and the resulting GHG emissions in Álvarez et al. (2015).

Sovacool and Brown (2010) have noted that carbon footprints reductions regarding to transport could also be achieved by attempting to control traffic congestion through road network design measures or by prioritizing public transport solutions through the provision of public transport infrastructure and facilities or for modal transport interchanges, following Cui et al.'s (2011) conclusions.

The carbon footprint of gas and electricity could be reduced through urban planning instruments following sustainability design criteria, as evidenced Karimpour et al. (2014), Katunsky et al. (2013) and Yu et al. (2007).

Waste management measures are focused on becoming more efficient in waste separation and collection, to the extent that these processes affect waste treatment energy consumption, as Sevigné Itoiz et al. (2013) proved. Urban planning instruments can promote separate collection systems for urban waste to fulfil the objectives stipulated by legislation providing areas to build waste recycling centers.

Regarding to transport, urban planners aims to analyze the transport variable simply by managing industrial activities to be implemented (prohibit traffic generation intensive activities in Table 4.1, for instance). Conversely, the reduction in the carbon footprints through road network design variables is not very relevant because only distances on domestic travels can be managed, and these are negligible. In those analyzed equivalent municipalities whit important commercial relationships with other municipalities, the greater part of carbon footprint emissions comes from trips outside the cities. Average emissions from internal distances traveled in the present study account for approximately 3.54 % of the total, so this figure would be the maximum abatement achievable through urban planning decisions.

4.4 Commercial

Commercial activities category includes a wide range of business that would hardly be standardized. In addition, the collection of data for each commercial category is not an easy task. That is why it is advised to analyze the most relevant commercial categories in order to achieve the numbers required to calculate the carbon footprint.

Those data are referred to the consumption and generation data included in Eqs. 2.3–2.9, since it is the most common managed urban planning variable, calculations have been referred to the built area.

Three types of commercial categories that include the most relevant activities:

- Catering: Preparation and delivery of food and beverages for off-site consumption without provision for on-site pickup or consumption.
- Commerce: establishments where the consumer goes to acquire different products (clothing, jewels, books, drugs… stores).
- Offices: An establishment providing direct, "over-the-counter" services to consumers (e.g., insurance agencies, real estate offices, travel agencies, utility company offices, etc.)

Main commercial land uses are planned in order to receive molls or big commercial retails although specific activities as the aforementioned can also be placed on it.

It has been taken into account and aggregated data have been used due to the impossibility of collecting individualized data for each category.

4.4.1 Data Collection

As it was stated previously, the data in the following sections are only directly applicable for the exposed example. Hence, the reader must take into account that using them could distort its calculations.

4.4.1.1 Consumption and Generation Data

Official statistics have been the source about consumption and generation data for commercial activities extracted from Instituto de Diversificación y Ahorro Energético (2013) and Instituto Nacional de Estadística (2009, 2013, 2014a).

The Table 4.31 shows the calculated average values for the analyzed years.

4.4.1.2 Emission Factors

There is no difference between the emission factors obtained related to the residential land use explained in point (Sect. 4.2.1.2) and the emission factors required for the industrial land use.

It has been assumed, in this case study, that there are no significant differences between providing electricity, gas or water between residential and industrial land uses within a municipality. This assumption must be tested in each case because there can be several differences in certain emission factors, for example due to different electricity supply methods, which could affect the electricity generation mix emission factors.

Table 4.31 Average annual values for drinking water (C_w), gas (C_g) and electricity (C_e) consumptions and waste (G_{wt}) and wastewater (G_{ww}) productions

	C_w (m^3/m_b^2 year)	G_{ww} (m^3/m_b^2 year)	G_{wt} (kg/m_b^2 year)	C_e (kWh/m_b^2 year)	C_g (kWh/m_b^2 year)
2006	0.329	0.264	7.744	1,035.116	482.403
2007	0.330	0.264	7.672	1,037.114	486.325
2008	0.320	0.256	7.566	1,036.509	485.333
2009	0.319	0.255	7.456	1,038.148	484.236
2010	0.312	0.250	7.552	1,036.337	482.972
2011	0.316	0.252	7.339	1,036.591	483.090

Table 4.32 Carbon footprint ($kgCO_{2eq}/m^2$ year) of drinking water supply for commercial use

2006	2007	2008	2009	2010	2011
0.148	0.152	0.124	0.114	0.086	0.109

4.4.2 Carbon Footprint Calculation

Thus, following a similar scheme of the residential land use analysis, results of each analyzed GHG source will be discussed and finally aggregated figures will be presented. Table 4.32 shows the calculated carbon footprint for the drinking water supply.

The figures of the wastewater management carbon footprint (Table 4.33) are slightly lower than the data in Table 4.32.

The carbon footprint of the energy consumption is greater than the carbon footprint of the water management. Table 4.34 reflects the carbon footprint of the electricity consumption.

Continuing with the carbon footprint of gas, results summarized in Table 4.35 show a lower level than the carbon footprint of the electricity exposed in Table 4.34.

The carbon footprint of traffic of commercial use does not have the importance that this source has in residential or industrial uses as reflected in Table 4.36.

Table 4.33 Carbon footprint ($kgCO_{2eq}/m^2$ year) of wastewater management commercial use

2006	2007	2008	2009	2010	2011
0.007	0.007	0.006	0.005	0.004	0.005

Table 4.34 Carbon footprint ($kgCO_{2eq}/m^2$ year) of electricity consumption of commercial use

2006	2007	2008	2009	2010	2011
455.45	466.70	393.87	363.35	279.81	352.44

Table 4.35 Carbon footprint ($kgCO_{2eq}/m^2$ year) of gas consumption of commercial use

2006	2007	2008	2009	2010	2011
97.50	98.29	98.09	97.87	97.61	97.64

Table 4.36 Carbon footprint ($kgCO_{2eq}/m^2$ year) of transport of commercial use

2006	2007	2008	2009	2010	2011
51.74	53.43	52.20	51.47	52.61	53.02

Table 4.37 Carbon footprint ($kgCO_{2eq}/m^2$ year) of waste management of commercial use

2006	2007	2008	2009	2010	2011
3.834	3.798	3.746	3.691	3.739	3.633

Finally, data presented in Table 4.37 exposes the results of carbon footprint of the waste management.

4.4.3 GHG Emissions Resume

The comparison of the data series reflected in Tables 4.34, 4.35, 4.36, 4.37, 4.38 and 4.39 highlights the result of the carbon footprint of each analyzed source related to the commercial use. Summarizing those numbers, Table 4.38 shows the aggregated carbon footprint of commercial land use.

And Fig. 4.10 reflects the percentage composition of the carbon footprint for each studied year (period 2006 to 2011).

On the contrary, to the carbon footprint of residential and industrial uses, it can be seen that traffic is not the most relevant source in commercial land use. There is a huge different between the carbon footprint of electricity and the others in Fig. 4.10. Do not appear to be significant differences between years and the variability in electricity generation mix emission factor.

The above-mentioned relevance of carbon footprint of electrical supply makes it the most relevance source for each analyzed municipality and probes that the GHG from EF depending sources also become the most important ones, as shown in Table 4.39.

Table 4.38 Carbon footprint ($kgCO_{2eq}/m^2$ year) of commercial land use

2006	2007	2008	2009	2010	2011
608.675	622.376	548.039	516.503	433.866	506.840

Table 4.39 Weight of each source (%) in the total GHG emissions (grouping sources depending on categories)

	Electricity (%)	Gas (%)	Fossil fuels (%)	Other (%)
2006	70.20	26.50	3.01	0.29
2007	70.62	26.04	3.06	0.29
2008	67.01	29.31	3.35	0.33
2009	65.24	30.92	3.50	0.34
2010	59.09	36.31	4.20	0.40
2011	64.51	31.47	3.67	0.35

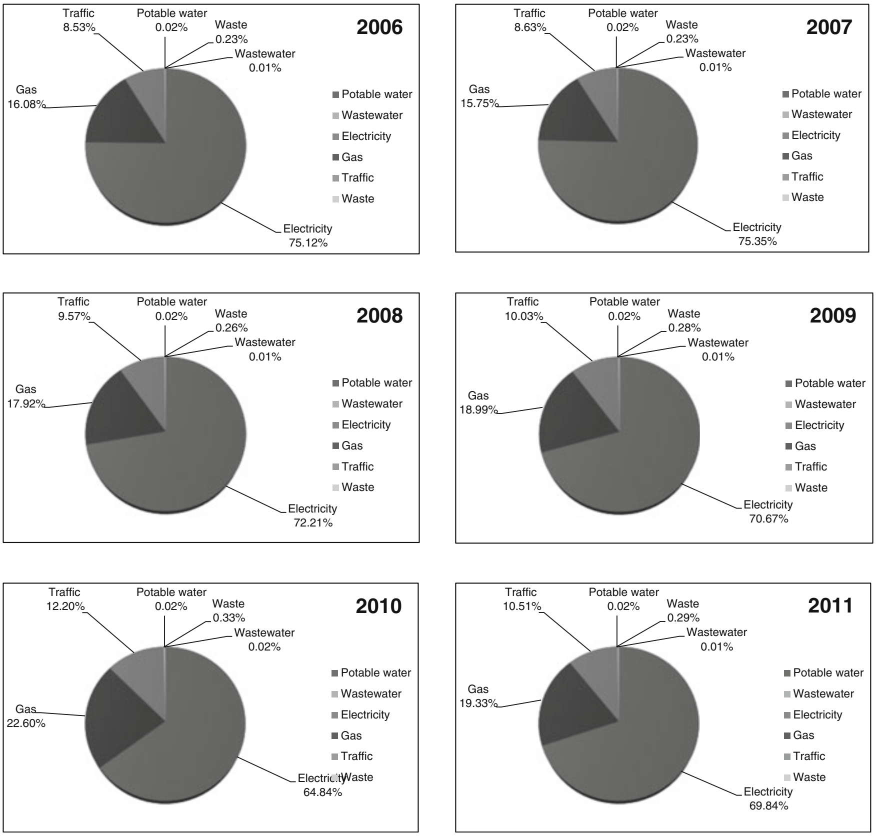

Fig. 4.10 Percentage carbon footprint composition by years

4.5 Public Facilities

Variety in specific activities included in public facilities land use is even greater than in commercial, residential or industrial. A lot of specific activities can be planned under this land use category such as educational, religious, health or institutional buildings, as well as leisure or sport activities or many others.

It greatly hinders the analysis of this use of the land. The optimum situation would entail studying each specific activity or each group of categories susceptible to be executed in this land use.

The most intense energy activities in the framework of this land use (sanitary and educational services) have been analyzed. However, the lack of reliable sources of information for each isolated activity implies the need to consider them all together.

Table 4.40 Averaged annual values for drinking water (C_w), gas (C_g) and electricity (C_e) consumptions and waste (G_{wt}) and wastewater (G_{ww}) productions

	C_w (m^3/m_b^2 year)	G_{ww} (m^3/m_b^2 year)	G_{wt} (kg/m_b^2 year)	C_e (kWh/m_b^2 year)	C_g (kWh/m_b^2 year)
2006	0.329	0.264	7.744	771.011	634.011
2007	0.328	0.262	7.672	772.499	638.450
2008	0.334	0.267	7.665	772.049	631.224
2009	0.318	0.254	7.664	773.269	634.556
2010	0.319	0.255	7.598	771.920	630.221
2011	0.328	0.262	7.662	772.110	639.889

4.5.1 Data Collection

The information exposed in the following paragraphs is specific for public facilities land use and the analyzed zone. Several data (maybe some emission factors) could be used for other examples but the reader must apply them carefully.

4.5.1.1 Consumption and Generation Data

Again, it has been necessary to resort to the statistics reflected in official sources with the aim to quantify the data relating to generation and consumption: Instituto para la Diversificación y el Ahorro Energético (2013) and Instituto Nacional de Estadística (2009, 2013, 2014a). Table 4.40 shows the results of this exercise.

4.5.1.2 Emission Factors

There is no difference between the emission factors account related to the residential land use in point (Sect. 4.2.1.2) and the emission factors required for the industrial land use.

It is assumed, in this example, that there are no relevant differences in providing electricity, gas or water between residential and industrial land uses within a municipality. This assumption should be tested in each study because there could be several differences in certain emission factors, for example due to different electricity supply methods that will affect the electricity generation mix emission factors.

4.5.2 Carbon Footprint Calculation

Therefore, Table 4.41 presents the results of the water supply carbon footprint of the above public facilities activities.

Table 4.41 Carbon footprint ($kgCO_{2eq}/m^2$ year) of drinking water supply of public facilities land use

2006	2007	2008	2009	2010	2011
0.148	0.151	0.129	0.114	0.088	0.114

The carbon footprint of wastewater management is also lower that the carbon footprint of the water supply as Table 4.42 shows.

The electricity supply appears as the most relevant source in this category of land use. The specific results are shown in Table 4.43.

Continuing with energy supply analysis, Table 4.44 displays the carbon footprint of gas. The figures in this table stress lower values than the numbers in Table 4.43 related to the electricity consumption.

The carbon footprint of transport is shown in Table 4.45.

Finally, results of the carbon footprint of waste management are shown in Table 4.46.

Table 4.42 Carbon footprint ($kgCO_{2eq}/m^2$ year) of wastewater management of public facilities land use

2006	2007	2008	2009	2010	2011
0.066	0.066	0.066	0.066	0.066	0.066

Table 4.43 Carbon footprint ($kgCO_{2eq}/m^2$ year) of electricity consumption of public facilities land use

2006	2007	2008	2009	2010	2011
339.58	347.30	293.28	270.12	208.38	262.40

Table 4.44 Carbon footprint ($kgCO_{2eq}/m^2$ year) of gas consumption of public facilities land use

2006	2007	2008	2009	2010	2011
128.27	128.11	128.38	128.08	128.13	128.12

Table 4.45 Carbon footprint ($kgCO_{2eq}/m^2$ year) of transport of public facilities land use

2006	2007	2008	2009	2010	2011
14.56	15.04	14.69	14.49	14.81	14.92

Table 4.46 Carbon footprint ($kgCO_{2eq}/m^2$ year) of waste management of public facilities land use

2006	2007	2008	2009	2010	2011
1.425	1.412	1.429	1.425	1.415	1.438

4.5.3 GHG Emissions Resume

Tables 4.43, 4.44, 4.45, 4.46, 4.47 and 4.48 show the summarized results of the carbon footprint of each analyzed source related to the public facilities land use. The aggregated data for each analyzed year are shown in Table 4.47:

The figures presented in Table 4.47 reflect lower values than the results referred to any other land-use analyzed. Deeping into the composition of the carbon footprint of each year, Fig. 4.11 includes the carbon footprint percentage composition according to years from 2006 to 2011.

Table 4.47 Carbon footprint ($kgCO_{2eq}/m^2$ year) of public facilities land use (period 2006–2001)

2006	2007	2008	2009	2010	2011
483.454	493.197	437.121	414.839	352.020	408.224

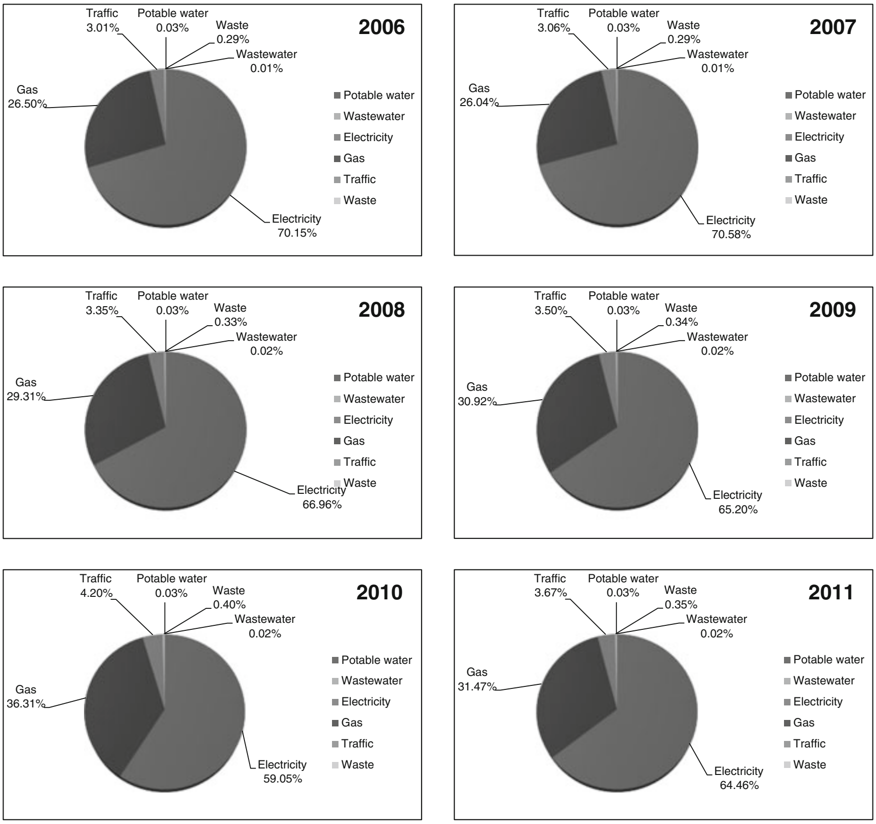

Fig. 4.11 Percentage carbon footprint composition by years

Table 4.48 Weight of each source (%) in the total GHG emissions grouping depending on sources categories

	2006 (%)	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2011 (%)
Drinking water	0.03	0.03	0.03	0.03	0.03	0.03
Wastewater	0.01	0.01	0.02	0.02	0.02	0.02
Electricity	70.15	70.58	66.96	65.20	59.05	64.46
Gas	26.50	26.04	29.31	30.92	36.31	31.47
Transport	3.01	3.06	3.35	3.50	4.20	3.67
Waste	0.29	0.29	0.33	0.34	0.40	0.35

Table 4.49 Weight distribution of each source (%) in the total GHG emissions grouped depending on sources categories

	Electricity (%)	Gas (%)	Fossil fuels (%)	Others (%)
2006	75.16	16.08	8.53	0.23
2007	75.38	15.75	8.63	0.23
2008	72.25	17.92	9.57	0.26
2009	70.70	18.99	10.03	0.28
2010	64.88	22.60	12.20	0.33
2011	69.88	19.33	10.51	0.29

The electricity appears as the most important carbon footprint source as graphics in Fig. 4.11 show. It is also the most important source in each analyzed municipality and, as expected, electricity depending sources are the most relevant on the resulting carbon footprint (Table 4.48).

Conversely to the carbon footprint of residential and industrial uses, it is remarkable that traffic is not the most relevant source in commercial one. It is also noticeable that there exist differences between the values of greenhouse gas emissions produced by electricity defect, when compared with those calculated for other emission sources, as it is reflected in Fig. 4.11. On the other hand it can be seen that it does not appear to exist significance differences between years and the variability in electricity generation mix emission factor.

The mentioned relevance of carbon footprint of the electrical supply makes it is the most relevance source in each analyzed municipality and that the GHG from EF depending sources also become the most important as Table 4.49 shows.

Figures in Table 4.49 show he importance of electricity depending sources in the process shown, placing the gas in second place in the ranking.

Chapter 5
Conclusions and Future Recommendations

Urban areas are major sources of greenhouse gas emissions as the most significant increase of energy consumptions and CO_2 emissions is taking place today in major cities of the world.

Environmental degradation is a major world's challenge. Institutional responsibilities for urban environmental management are often unclear and weak, especially over problems of cross-boundary pollution. Improvements in urban design, dealing with the issues of energy consumptions and GHG emissions, will have a determinant role on mitigating global warming. Thus, it is necessary to focus on the important role of urban design in combating global warming.

Urban master plans become a great tool to manage the carbon footprint and measure the cost-effectiveness for reducing GHG emissions in cities. These instruments are able to regulate the main daily activities and determine the land-use patterns in cities as the two important key factors in reducing GHG by local governments.

In order to reduce GHG emissions, it is necessary to face the magnitude of such emissions. Quantifying the carbon footprint is necessary in order to anticipate at the urban planning stage which strategies can lead to the greatest reductions in GHG emissions, projecting preventive and not corrective measures.

In this book it has been analyzed the land-use context and its relationship with the carbon footprint calculation. It has to be noticed that studying the carbon footprint at the urban planning stage has the disadvantage of the low level of information and definition of the project. Nonetheless, it ought to be irrelevant in view of the aforementioned benefits. There are multiple possible synergies between the urban planning and urban infrastructures design and the carbon footprint calculation in order to achieve the less carbon dependence as possible.

The carbon footprint of the cities and, consequently, of the citizens, is affected by many decisions. And these decisions have a great influence on the emissions of

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residence, commerce and transportation sectors in those neighborhoods, affecting to life quality.

Land-based mitigation policies may provide mechanisms for reducing GHG, translating key decisions at the urban planning stage: land-use model (urbanizable and non urbanizable lands, land uses–residential, industrial, commercial or public facility-), urban infrastructure design (water supply, wastewater and waste management, electricity and heat supply…), transport infrastructures (road or public transport). So, assessing an accurate carbon footprint just form urban planning stage is necessary in order to implement preventive measures related to urban design and through the aforementioned management tools.

The methodology exposed in the present book strongly depends on the specific location of the urban development to be analyzed. To the extent that the analyzed land development has not been built when it is analyzed, and also because available data for carbon footprint calculation are scarce. The required information, mainly related to consumption and generation data, has to be obtained from official statistics or scientific sources as it has been mentioned. Urban planners are now always placed in an annalistic position to extrapolate them to the particular conditions. The reader must take cautions with the data collection treatment and its interpretation, because these processes will have a heavy influence on the results and consequently on the measures to be implemented.

Once the information required is available, the exposed methodology allows an easy carbon footprint calculation as well as the powerful sensitivity analysis of the measures susceptible to be taken. In the examples exposed in the book, the results clearly highlights the nature one of each carbon footprint composition for all analyzed land uses.

Complementarily, a set of carbon footprint sustainability indicators has been proposed in order to compare the resulting carbon footprint among different urban developments. The indicators presented in the book provide a broad view of the carbon footprint relationship with most of the relevant urban planning design variables.

The methodology presented in this book does only represents a little step in a better world global challenge: to maintain high quality of life in the cities while ensuring low GHG emissions. Any step forward to be taken is relevant although the greatest one is the formal commitment of applying the knowledge available to prevent the climate change.

We strongly believe that the science has to be able to provide solutions to climate change and land-use planning and planning control ensuring quality of life for generations. Our actions will play a vital role in the success implementing future low carbon cities, preparing for the risks particularly during the formulation of urban master plans.

References

Álvarez R, Zubelzu S, Díaz G, López A (2015) Analysis of low carbon super credit policy efficiency in European Union Greenhouse gas emissions. Energy 82:996–1010

Blanco Silva F, Lopez Diaz A, Zubelzu Minguez S (2012) Renovation of windows in the building of the Faculty of Political Sciences of the University of Santiago de Compostela (Spain). Energ Environ Study J Environ Prot Ecol 13(2):802–810

British Standards Institution (2008) Guide to PAS 2050: How to assess the carbon footprint of goods and services. Department for Environment Food and Rural Affairs, London

Cabrera E, Pardo MA, Cabrera E, Cobacho R (2010) Agua y Energía en España. Un reto complejo y fascinante. Ingeniería del Agua 17(3):235–246

California Energy Comission (2005) California's water-energy relationship. Final staff report. CEC 700–2005–011 SF. California Energy Comisión, Sacramento

Carney S, Green N, Wood R, Read R (2009) Greenhouse Gas Emissions Inventories for Eighteen European Regions, EU CO2 80/50 Project Stage 1: Inventory Formation. The Greenhouse Gas Regional Inventory Protocol (GRIP), Manchester

Carter JG, Cavan G, Connelly A, Guy S, Handley J, Kazmierczak A (2015) Climate change and the city: building capacity for urban adaptation. Prog Plann 95:1–66

Carvajal M (2011) Investigación sobre la absorción de CO2 por los cultivos más representativos. LessCO2 initiative, Murcia

CITA (2008) Estudio sobre la funcionalidad de la vegetación leñosa de Aragón como sumidero de CO2: existencias y potencialidad (estimación cuantitativa y predicciones de fijación). Informe final diciembre 2008. Centro de Investigación y Tecnología Agroalimentaria de Aragón, Zaragoza

Comunidad de Madrid (2011) Estudio de Tráfico. IMD 2010. Dirección General de Carreteras, Comunidad de Madrid, Madrid

Comunidad de Madrid (2012) Estudio de Tráfico. IMD 2011. Dirección General de Carreteras, Comunidad de Madrid, Madrid

Comunidad de Madrid (2014) Visor de Planeamiento Urbanístico. Madrid: Consejería de Medio Ambiente y Ordenación del Territorio Comunidad de Madrid. http://www.madrid.org/cartografia/planea/planeamiento/html/visor.htm

Cui S, Meng F, Wang W, Lin J (2011) GHG accounting for public transport in Xiamen City, China. Carbon Manage 2:383–395

De las Heras A, Domenech C, Carles E (2011) Análisis de Datos de Emisiones de CO2 en España. Entidades sujetas a la Directiva Europea 2003/87/CE. Período 2011 y context Global. Fundación Emrpesa y Clima, Barcelona. http://www.empresaclima.org/images/Publicaciones/Libros_enteros/analisis_d_es_co2_espa%F1a_periodo_2011_y_c_global.pdf

de Madrid A (2005) Las Áreas Industriales del Plan General de Madrid, Área de Gobierno de Urbanismo. Vivienda e Infraestructuras, Madrid

S. Zubelzu and R. Álvarez Fernández, *Carbon Footprint and Urban Planning*,
SpringerBriefs in Applied Sciences and Technology,
DOI 10.1007/978-3-319-31050-3

de Madrid C (2005) Encuesta domiciliaria de movilidad en 2004 en la Comunidad de Madrid. Documento de Síntesis. Consorcio de Transportes de la Comunidad de Madrid, Madrid
Dhakal S (2009) Urban energy use and carbon emissions from cities in China and policy implications. Energy policy 37:4208–4219
Dhakal S (2010) GHG emissions from urbanization and opportunities for urban carbon mitigation. Curr Opin Environ Sustain 2(4):277–283
Dirección General de Tráfico (2014) Fleet Vehicle Composition Surveys. Dirección General de Tráfico, Ministerio de Fomento, Madrid. http://www.dgt.es/es/seguridad-vial/estadisticas-e-indicadores/parque-vehiculos/
Domenech J, Martínez M, Fernández M (2011) La agricultura y el CO2. Cuadernos de campo 47(3):4–11
Domer A, Finn DP, Ward P, Cullen J (2013) Carbon footprint analysis in plastics manufacturing. J Cleaner Prod 51:133–141
Dong HJ, Geng Y, Xi FM, Fujita T (2013) Carbon footprint evaluation at industrial park level: a hybrid life cycle assessment approach. Energy Policy 57:298–307
Dickinson J (ed) (2007) Inventory of New York City greenhouse gas emissions. DIANE Publishing
EEA (2013) EEA Technical report No 20/2013 European Union CO2 emissions: different accounting perspectives
Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds) (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme, Hayama
Engel D, Petsch S, Hagen H, Guhathakurta S (2012) Neighborhood relation diagrams for local comparison of carbon footprints in urban planning. Inf Visual 11:124–135
García R, Pérez MA, Pérez JR (2010) Inventario de Sumideros de carbono de Extremadura. Consejería de Industria. Energía y Medio Ambiente Junta de Extremadura, Mérida
GHG Protocol (2005) GHG emissions from transport or mobile sources. GHG Protocol—Mobile Guide (03/21/05) v1.3. GHG Protocol, Whasington. http://www.ghgprotocol.org/files/ghgp/tools/co2-mobile.pdf
Gressgård R (2015) The whole city or the city as a whole? Social Transformations in Scandinavian Cities: Nordic Perspectives on Urban Marginalisation and Social Sustainability 199
Hardy L, Garrido A (2010) Análisis y evaluación de las relaciones entre el agua y la energía en España. Papeles de agua virtual nº 6. Fundación Botín, Madrid
Ho CS, Matsuoka Y, Simson J, Gomi K (2013) Low carbon urban development strategy in Malaysia-The case of Iskandar Malaysia development corridor. Habitat Int 37:43–51
Howard RW, Santoro R, Ingraffea A (2011) Methane and the greenhouse-gas footprint of natural gas from shale formations. Climatic 106:679–690
Huo H, Wu Y, Wang M (2009) Total versus urban: Well-to-wheels assessment of criteria pollutant emissions from various vehicle/fuel systems. Atmos Environ 43(10):1804–1976
Instituto de Estadística de la Comunidad de Madrid (2014a) Encuesta sobre suministro y saneamiento de aguas. Instituto de Estadística de la Comunidad de Madrid, Madrid. http://www.ine.es/jaxi/menu.do?type=pcaxis&path=/t26/p067/p01/a2011&file=pcaxis
Instituto de Estadística de la Comunidad de Madrid (2014b) Censo de población y vivienda 2011. Instituto de Estadística de la Comunidad de Madrid, Madrid. http://www.ine.es/censos2011_datos/cen11_datos_resultados.htm
Instituto Nacional de Estadística (2009) Encuesta sobre el uso del agua en el sector industrial en el año 2006. http://www.ine.es/daco/daco42/ambiente/aguaindu/uso_agua_indu06.pdf
Instituto Nacional de Estadística (2013) Uso del Agua en la Industria Manufacturera 2007-2010. http://www.ine.es/daco/daco42/ambiente/aguaindu/uso_agua_indu0710.pdf
Instituto Nacional de Estadística (2014a) Encuesta sobre generación de residuos en el sector industrial. http://www.ine.es/jaxi/menu.do?type=pcaxis&path=%2Ft26%2Fe068%2Fp01&file=inebase&L=0

Instituto Nacional de Estadística (2014b) Encuesta de Consumos Energéticos. http://www.ine.es/jaxi/menu.do?type=pcaxis&path=%2Ft04%2Fp01&file=inebase&L=0
Instituto Nacional de Estadística (2014c). Encuesta sobre recogida y tratamiento de residuos urbanos. Instituto de Estadística de la Comunidad de Madrid, Madrid. http://www.ine.es/jaxi/menu.do?type=pcaxis&path=%2Ft26%2Fe068%2Fp01&file=inebase&L=0
Instituto para la Diversificación y Ahorro Energético (2010) Estudio de Prospectiva. Consumo Energético en el sector del agua. Fundación OPTI-IDAE, Madrid
Instituto para la Diversificación y Ahorro Energético (2013) Informe Anual de Intensidades Energéticas. Intensidades de Energía Final en el sector Residencial en España. Instituto para la Diversificación y Ahorro Energético (IDEA), Madrid
I.P.C.C (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change (I.P.C.C.), Geneva
Jones CH, Kammen DM (2011) Spatial Distribution of U.S. household carbon footprints reveals suburbanization undermines greenhouse gas benefits of urban population density. J Environ Sci Technol 45:4088–4095
Kaiser EJ, Godschalk DR, Chapin FS (1995) Urban land use planning, vol 4. University of Illinois Press, Urbana, IL
Karimpour M, Belusko M, Xing K, Bruno F (2014) Minimising the life cycle energy of buildings: review and analysis. Building Environ 73:106–114
Katunsky D, Korjenic A, Katunska J, Lopusniak M, Korjenic S, Doroudiani S (2013) Analysis of thermal energy demand and saving in industrial buildings: a case study in Slovakia. Building Environ 67:138–146
Kennedy CA, Ramaswami A, Carney S, Dhakal S (2009) Greenhouse gas emission baselines for global Cities and metropolitan regions. Paper presented at the 5th urban research symposium: cities and climate change—responding to an urgent agenda, Marseille, 28–30 June 2009
Kim T, Kim H (2013) Analysis of the effects of intra-urban spatial structures on carbon footprint of residents in Seoul, Korea. Habitat Int 38:192–198
La Roche P (2010) Assessing green house gas emissions for buildings: analysis of the performance of several carbon counting tools in different climates. Informes de la Construcción 62:61–80
Lee K (2011) Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry. J Cleaner Prod 19(11):1216–1223
Lin JY, Liu Y, Meng FX, Cui SH, Xu LL (2013) Using hybrid method to evaluate carbon footprint of Xiamen City, China. Energy Policy 58:220–227
Liu Y (2014) Dynamic study on the influencing factors of industrial firm's carbon footprint. J Cleaner Prod In press
Martin WW, McGuckin NA (1998) NCHRP Report 365: Travel estimation techniques for urban planning. Transportation Research Board, National Research Council, Whasington DC
Martínez-Val JM (ed) (2008) El futuro del carbón en la política energética española. Fundación para Estudios sobre la Energía, Madrid
Ministerio de Industria, Energía y Turismo (2014) Estadísticas anuales de consumo de gas natural. Ministerio de Industria, Energía y Turismo, Madrid. http://www.minetur.gob.es/energia/balances/Publicaciones/gas-natural-anual/Paginas/gas-natural-2000-2009.aspx
Minx J, Baiocchi G, Wiedmann T, Barrett J, Creutzig F, Feng K, Förster K, Pichler P, Weisz H, Hubacek K (2013) Carbon footprints of cities and other human settlements in the UK. Environ Res Lett 8:035–039
Mühle S, Balsamb I, Cheeseman CR (2010) Comparison of carbon emissions associated with municipal solid waste management in Germany and the UK resources. Conserv Recycl 54:793–801
Norverto CA (2003) La fijación de CO2 en plantaciones forestales y en productos de madera en Argentina. Paper presented at the XII Forestry Congress, Quevec city

Oficina Española de Cambio climático (2014) Inventario de emisiones de gases de efecto invernadero de España e información adicional años 1990-2012. Dirección General Oficina Española de Cambio Climático. Ministerio de Medio ambiente, Medio Rural y Marino, Madrid

Pang M, Pun M, Chow W, Arifin Z, Ishak M (2014) Carbon footprint calculation for thermoformed starch-filled polypropylene biobased materials. J Cleaner Prod 64(1):602–608

Petsch S, Guhathakurta S, Heischbourg L, Müller K, Hagen H (2011) Modeling, monitoring, and visualizing carbon footprints at the urban neighborhood scale. J Urban Technol 18(4):81–96

Puliafito SE, Allende D (2007) Patrones de Emisión de la Contaminación Urbana. Revista Facultad de Ingeniería Universidad de Antioquía 42:38–56

Qi C, Ni-Bing C (2013) Integrated carbón footprint and cost evaluation of a drinking wáter infrastructure system for screening expansión alternatives. J Cleaner Prod 60:170–181

Ramaswami A, Hillman T, Janson B, Reiner M, Thomas G (2008) A demandcentered, hybrid life cycle methodology for city-scale Greenhouse gas emissions. Environ Sci Technol 42: 6455–6461

Red Eléctrica Española (2011) El Sistema Eléctrico Español 2010. Red Eléctrica de España, Madrid

Red Eléctrica Española (2012) El Sistema Eléctrico Español 2011. Red Eléctrica de España, Madrid

Red Eléctrica Española (2013) El Sistema Eléctrico Español 2012. Red Eléctrica de España, Madrid

Red Eléctrica Española (2014) Avance del informe del sistema eléctrico español 2014. Red Eléctrica de España, Madrid

Red Eléctrica Española (2014) El Sistema Eléctrico Español 2013. Red Eléctrica de España, Madrid

Romero A (2010) Las emisiones de GEI en el tratamiento de Residuos Municipales en el Área Metropolitana de Barcelona. IX Jornadas sobre Biometanización de Residuos Sólidos Urbanos, Barcelona

Sala L (2007) Balances energéticos del ciclo de agua y experiencias de reutilización planificada en municipios de la Costa Brava. In: Proceedings of Seminario Agua, Energía y Cambio Climático, Valencia

Sevigné Itoiz E, Gasol CM, Farreny R, Rieradevall J, Gabarrell X (2013) CO2ZW: Carbon footprint tool for municipal solid waste management for policy options in Europe. Inventory of Mediterranean countries. Energy Policy 56:623–632

Servicio de Estadística de Castilla La Mancha (2014) Censo de Población 2011. Servicio de Estadística de Castilla La Mancha, Toledo. http://www.ies.jccm.es/?id=293

Shrestha E, Ahmad S, Johnson W, Batista JR (2011) The carbon footprint of water management policy options. Energy Policy 42:201–212

Sovacool BK, Brown MA (2010) Twelve metropolitan carbon footprints: a preliminary comparative global assessment. Energy Policy 38:4856–4869

Stylos N, Koroneos CJ (2014) Carbon footprint of polycrystalline photovoltaic systems. J Cleaner Prod 64(1):639–645

Tripathi NG, Bedi P (2014) Digital earth for manipulating urban greens towards achieving a low carbon urban society. In: IOP conference series: earth and environmental science (vol 18, no 1, p 012157). IOP Publishing

Weber CL, Matthews HS (2008) Quantifying the global and distributional aspects of American household carbon footprint. Ecol Econ 66(2–3):379–391

World Bank Group (2014) Urban China. Toward Efficient, Inclusive, and Sustainable Urbanization. https://openknowledge.worldbank.org/handle/10986/18865

Wu L, Jiang Q, Yang XM (2013) Carbon footprint incorporation into least-cost planning of eco-city schemes: practices in Coastal China. In: The 18th Biennial conference of international society for ecological modeling. Procedia Environ Sci 13:582–589

Yu JH, Yang CZ, Hu JW, Tian LW (2007) Effects of envelope energy saving strategies on energy consumption in residential building. In: Proceedings of the 5th international symposium on heating, ventilating and air conditioning vols I-II, 849–857

Zanon B, Verones S (2013) Climate change, urban energy and planning practices: Italian experiences of innovation in land management tools. Land Use Policy 32:343–355

Zhang S, Pang B, Zhang Z (2014) Carbon footprint analysis of two different types of hydropower schemes: comparing earth-rockfill dams and concrete gravity dams using hybrid life cycle assessment. J Cleaner Prod In press

Zubelzu S, Hernández A (2014) Methodolgy for household carbon footprint calculation incorporated in urban planning procedures. In: Proceedings of XVIII international congress on project management and engineering, 16–17 July 2014

Zubelzu S, Isidro A, Blanco F, Gutiérrez MA (2011) Los Métodos Gravitacionales como herramienta para el cálculo de las emisiones de gases de efecto invernadero derivadas del tráfico rodado en la planificación urbana. Revista de construcción 26(2):187–207

Zubelzu S, Isidro A, Blanco F, Gutiérrez MA (2014) Calculation model for Greenhouse gases diffuse emissions from transport. Analysis by urban design variables. Revista Facultad Ingeniería Universidad Antioquía 73:200–213

Zubelzu S, Álvarez R, Hernández A (2015) El papel del mix de generación de energía eléctrica y la huella de carbono en las infraestructuras urbanas. In: Proceedings of XIX international congress on project management and engineering, 16–17 July 2015