

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 establishing sets of indicators for evaluation (How to achieve and control the reductions).

The EEA report, “European Union CO₂ 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.

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.

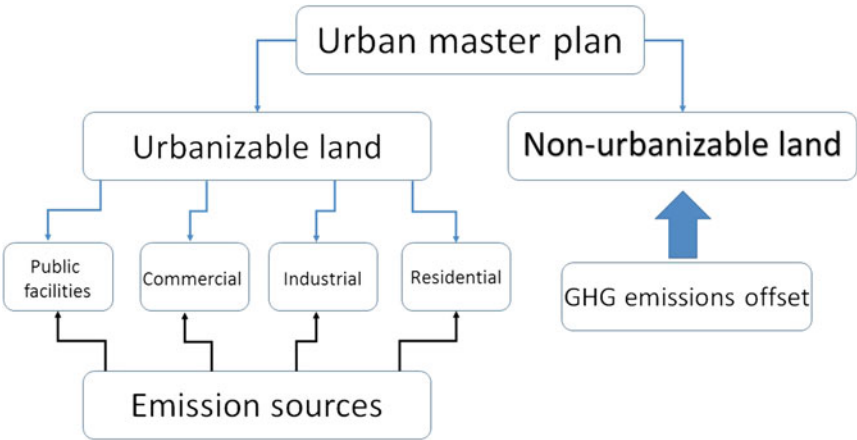


Fig. 2.1 Theoretical GHG emissions framework

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 CO₂ 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 CO₂ 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).

$$CF(\text{kgCO}_{2\text{eq}}) = \sum C_i \times EF_i \quad (2.1)$$

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).

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

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:

$$CF_w \left(\text{kgCO}_{2\text{eq}}/\text{m}_b^2 \right) = EF_w \left(\text{kgCO}_{2\text{eq}}/\text{m}^3 \right) \times C_w \left(\text{m}^3/\text{m}_b^2 \right) \quad (2.3)$$

$$CF_w \left(\text{kgCO}_{2\text{eq}}/\text{m}_b^2 \right) = EI_w \left(\text{kWh}/\text{m}^3 \right) \times C_w \left(\text{m}^3/\text{m}_b^2 \right) \times EF_e \left(\text{kgCO}_{2\text{eq}}/\text{kWh} \right) \quad (2.3')$$

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:

$$CF_{ww} \left(\text{kgCO}_{2\text{eq}}/\text{m}_b^2 \right) = EF_{ww} \left(\text{kgCO}_{2\text{eq}}/\text{m}^3 \right) \times G_{ww} \left(\text{m}^3/\text{m}_b^2 \right) \quad (2.4)$$

$$CF_{ww} \left(\text{kgCO}_{2\text{eq}}/\text{m}_b^2 \right) = EI_{ww} \left(\text{kWh}/\text{m}^3 \right) \times G_{ww} \left(\text{m}^3/\text{m}_b^2 \right) \times EF_e \left(\text{kgCO}_{2\text{eq}}/\text{kWh} \right) \quad (2.4')$$

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.

$$CF_e \left(\text{kgCO}_{2\text{eq}}/\text{m}_e^2 \right) = C_e \left(\text{kWh}/\text{m}_e^2 \right) \times EF_e \left(\text{kgCO}_{2\text{eq}}/\text{kWh} \right) \quad (2.5)$$

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.

$$CF_g \left(\text{kgCO}_{2\text{eq}}/\text{m}_g^2 \right) = C_g \left(\text{kWh}/\text{m}_g^2 \right) \times EF_g \left(\text{kgCO}_{2\text{eq}}/\text{kWh} \right) \quad (2.6)$$

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.

$$CF_{wt}(\text{kgCO}_{2eq}/\text{m}_b^2) = G_{wt}(\text{t}/\text{m}_b^2) \times EF_{wt}(\text{kgCO}_{2eq}/\text{t}) \quad (2.7)$$

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.

$$CF_{wt}(\text{kgCO}_{2eq}/\text{m}_b^2) = EI_{wt}(\text{kWh}/\text{t}) \times G_{wt}(\text{t}/\text{m}_b^2) \times EF_e(\text{kgCO}_{2eq}/\text{kWh}) \quad (2.8)$$

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.

$$CF_t(\text{kgCO}_{2eq}/\text{m}_b^2) = G_t(\text{km}/\text{m}_b^2) \times EF_v(\text{kgCO}_{2eq}/\text{km}) \quad (2.9)$$

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.

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

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_i) 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.

$$G_i(\text{km}/\text{m}_b^2) = \sum N_{ij} \times d_{ij} \quad (2.11)$$

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.

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

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

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

Several authors advocate for considering the alternative fuel vehicles¹ 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.

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

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.

$$CF = EF_e [(C_w \times EF_w) + (G_{ww} \times EF_{ww}) + C_e] + (C_g \times EF_g) + (G_t \times EF_t) + (C_{ws} \times EF_{ws}) \quad (2.16)$$

¹An 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 ($\text{tCO}_{2\text{eq}}/\text{year}$)
1.2. GHG emissions by planned household ($\text{tCO}_{2\text{eq}}/\text{m}_p^2 \text{ year}$)
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 ($\text{tCO}_{2\text{eq}}/\text{m}^2$)
3.2. Global GHG emissions through the urbanizable planned area ($\text{tCO}_{2\text{eq}}/\text{m}^2$)
3.3. Global GHG emissions through the built planned area ($\text{tCO}_{2\text{eq}}/\text{m}^2$)
3.4. Global GHG emissions through the non-urbanizable land area ($\text{tCO}_{2\text{eq}}/\text{m}^2$)
4. The indicators of sustainability in related GHG capture potential
4.1. Balance of GHG emissions (emissions-capture) ($\text{tCO}_{2\text{eq}}$)
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).

$$\text{CP}_i (\text{kgCO}_{2\text{eq}}) = \sum \text{CP}_i (\text{kgCO}_{2\text{eq}}/\text{m}^2) \times \text{Si} (\text{m}^2) \quad (2.17)$$

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.

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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