Land Use Policy 48 (2015) 223–235

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Methodology to calculate the carbon footprint of household land use in the urban planning stage

Sergio Zubelzu[a,*], Roberto Álvarez[b], Adolfo Hernández[c]

[a] Department of Statistics and Operational Research II (Decision Analysis), Complutense University of Madrid, School of Economics & Business, Somosaguas Campus, 28223, Pozuelo de Alarcón (Madrid), Spain
[b] Department of Industrial Engineering, Polytechnic School, Antonio de Nebrija University Pirineos, 55, 28040 Madrid, Spain
[c] Department of Statistics and Operational Research II (Decision Analysis), Complutense University of Madrid, Faculty of Commerce and Tourism, Avenida de Islas Filipinas, 3, 28003 Madrid, Spain

ARTICLE INFO

Article history:
Received 19 February 2015
Received in revised form 21 May 2015
Accepted 3 June 2015

Keywords:
Climate change
Greenhouse gas
Urban planning
Urban infrastructures

ABSTRACT

The growing concerns of climate change require implementing measures to quantify, to monitor and to minimize greenhouse gas (GHG) emissions. Nonetheless, most of the measures available are not easy to define or execute because they rely on current emissions and have a corrective character. To address this issue, a methodology to characterize GHG emissions that allows implementing preventive measures is proposed in this paper. The methodology is related to household urban planning procedures and considers urban infrastructures to characterize GHG emissions and to execute preventive measures based on sustainability design criteria. The methodology has been tested by applying it to a set of medium-sized municipalities with average GHG emissions from 6,822.32 $kgCO_{2eq}$/year to 5,913.79 $kgCO_{2eq}$/year for every residential unit. The results indicate that the greatest pollutant source is transport, especially in the issuance of street network design, followed by gas and electricity consumption. The average undevelopable land area required for the complete GHG emissions capture amounts to 3.42 m^2 of undevelopable land for every m^2 of urbanizable land and 9.02 m^2 of undevelopable land for every m^2 of built land.

1. Introduction

Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 established a scheme for greenhouse gas (GHG) emissions allowance trading within the European Union (EU), creating a framework for greenhouse gas emission allowance trading for the cost-effective reduction of such emissions. As a result of this regulatory framework, several activities (installations operating in the energy sector, iron and steel production and processing, the mineral industry and the paper and board industry) were forced to obtain an appropriate permit issued by the competent authorities. Their emissions have to be characterized, measured and compensated. But there are many industrial activities outside of the regulatory framework whose GHG emissions do not have to be measured or compensated. Those industrial activities not affected by the GHG emissions allowance trading scheme are included among the GHG emissions diffuse sources, and they have acquired significant relevance within the European Union, amounting to 59.4% of the total GHG emissions in the EU in 2010 (De las Heras et al., 2011).

In spite of this magnitude, there are few notable plans directly centered on managing GHG diffuse emissions because of the difficulties in quantifying and monitoring GHG emissions and identifying those responsible for the emissions.

In the context of a program's execution complexity, 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 planning master plans.

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 from all individual daily activities, including variables hardly considered by urban

* Corresponding author. Fax: +34 91 394 29 20.
E-mail addresses: szubelzu@ucm.es (S. Zubelzu), ralvarez@nebrija.es (R. Álvarez), a.hernandez@emp.ucm.es (A. Hernández).

http://dx.doi.org/10.1016/j.landusepol.2015.06.005
0264-8377/

planning decisions (daily journeys, 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.

Conversely, although urban planning exerts a relevant influence on GHG emissions (Carter et al., 2015; Zanon and Verones, 2013), especially on diffuse emissions, there are few studies focused on analyzing GHG emissions from this activity. Urban planning affects GHG emissions because it defines the land occupation model, including territories capable of being developed as urban lands, establishes their uses (residential, industrial, retail or public) and characteristics (type of industrial uses allowed and banned), the intensity in which those uses are executed and required infrastructures (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 in the design stage. Urban planning allows for the easy and cheap implementation of preventive measures related to urban design variables that the literature usually considers 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 being used to make predictions about GHG emissions, which also becomes an advantage.

Thus, the main objective in the present work is to develop a strategy to calculate GHG emissions related to household urban planning developments in urban planning procedures. Additionally, secondary objectives have also been proposed:

- To identify and to characterize GHG emissions sources susceptible to being considered in household urban planning developments.
- To analyze the GHG emissions composition and the relevance of every source to prioritize preventive measurements.
- To develop a strategy to analyze urban planning sustainability linked to the ability of undevelopable lands to capture GHG emissions.

2. Materials and methods

To achieve the proposed objectives, we first defined the theoretical framework to determine GHG emissions within urban planning. Second, we identified the responsible for GHG emissions calculation, as well as the emission sources and factors. Finally, we developed methodologies to calculate GHG emissions from household urban planning developments and to analyze the capture potential linked to undevelopable lands.

To test the methodology, we applied it to a set of 31 municipalities located in Madrid, by collecting the required information and calculating GHG emissions.

2.1. Theoretical framework

We focused our study on urban planning master plans for the entire municipal territory (general planning instruments). This category of plans usually defines the land occupation model including the delimitation of urban, urbanizable and undevelopable lands; divides urbanizable lands in homogenous areas to be developed and defining uses that may occur in each area and designs the urban infrastructure (transport, electricity, drinking water supply as well as waste and wastewater treatment).

Among the aforementioned variables, the land occupation model affects GHG emissions because it defines the urban growth boundaries and specifies lands susceptible to be development (urbanizable) and, complementarily, undevelopable areas (non-urbanizable). GHG emissions will result from urbanizable land, whereas, undevelopable land will provide the potential capability of GHG emissions capture. The land occupation model also divides urbanizable lands into homogenous areas defined by their localization, geographical boundaries, land uses (industrial, household, retail or public facilities) that are allowed and banned, the intensity with which these uses will be executed (built area), the development standards and the infrastructure necessities. The homogenous areas allow identification of emissions responsibility because they perfectly fit the GHG emissions responsible agent definition from the British Standards Institution (2008); therefore, GHG emissions accounting has to be based on the homogenous areas.

Therefore, among the characteristics of the homogenous areas defined by urban planning instruments, we can assume that the development standards do not influence the GHG emissions and the proposed boundaries only 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, discussion about GHG emissions sources is focused on 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 are taken into account. Thus, if the negligible character of the GHG emissions from the communications infrastructure is assumed, then GHG emissions calculation in urban planning instruments must be focused on drinking water supply, wastewater management, electricity, gas, transport and waste management infrastructures.

Only one clarification is left to be completed: green areas, which are usually considered within the urban infrastructures or public facilities. Green areas are susceptible to generating GHG emissions from maintenance operations and infrastructure (water, public lighting, and wastewater), but we have assumed that these GHG emissions can be compensated with the GHG capture 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 neutral character.

Summarizing the previous discussion, Fig. 1 outlines the theoretical framework to calculate GHG emissions from household land use in urban planning instruments.

2.2. GHG emissions sources and emission factors determination

GHG emissions determination from each source is performed by applying the appropriate emission factor (EF_i) to the expected consumption of every source (C_i), as stated in Eq. (1) (Eggleston et al., 2006).

$$\mathrm{GHG}\left(\frac{\mathrm{kgCO_{2\,eq}}}{\mathrm{res}}\right)=\sum_{i=1}^{i=n}C_i\left(\frac{\mathrm{ud}}{\mathrm{res}}\right)\times \mathrm{EF_i}\left(\frac{\mathrm{kgCO_{2\,eq}}}{\mathrm{ud}}\right) \tag{1}$$

We used the CO_2 equivalent mass unit, including every equivalence between CO_2 and any other greenhouse gas for the 100th year prevalence (IPCC, 2007). If consumptions and emission factors in Eq. (1) are specified for every identified source, the mathematical relation to calculate GHG emissions expressed in Eq. (1) is as