Energy Policy 83 (2015) 57–68

Contents lists available at ScienceDirect

Energy Policy

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

Urban planning and industry in Spain: A novel methodology for calculating industrial carbon footprints

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HIGHLIGHTS

- Model to calculate industrial carbon footprint in urban planning stage is proposed.
- Specific industrial activities planned have a strong effect on carbon footprint.
- Gas and electricity are the most relevant sources for the most pollutant industries.
- Transport is relevant source for the less pollutant industries.
- Municipalities can decisively influence on industrial carbon footprint.

ARTICLE INFO

Article history:
Received 9 February 2015
Received in revised form
17 March 2015
Accepted 26 March 2015
Available online 9 April 2015

Keywords:
Climate change
Greenhouse gas
Carbon footprint
Urban planning
Urban infrastructure
Industrial activities

ABSTRACT

In this paper we present a methodology for calculating the carbon footprint of the industrial sector during the urban planning stage in order to clearly develop and implement preventive measures. The methodology created focuses on industrial urban planning procedures and takes into account urban infrastructure in the characterization of GHG emissions. It allows for the implementation of preventive measures based on sustainability design criteria. The methodology was derived for specific industrial activity categories and was tested on a group of municipalities in a province south of Madrid, Spain. The results indicate that the average carbon footprint of industrial activities varies between 137.36 $kgCO_{2eq}/m_e^2$ and 607.25 $kgCO_{2eq}/m_e^2$ depending on the activity. Gas and electricity are the most important emissions sources for the most polluting industrial activities (chemical and nonmetal mineral products), while transportation is the most important source for every other activity. Municipalities can have a decisive influence on the industrial carbon footprint because, except for waste management and two industrial activities related to electricity, the majority of reductions can be achieved through urban planning decision variables.

1. Introduction

On 13 October 2003, Directive 2003/87/EC of the European Parliament and Council established a greenhouse gas (GHG) emission allowance trading scheme within the European Union (EU), creating a framework for the cost-effective reduction of such emissions. As a result of this regulatory framework, permits issued by selected authorities were required for several activities (energy sector installations, iron and steel production and processing, mineral mining and the paper and board fabrication), and those activities' GHG emissions were to be monitored. Nevertheless, there are many industrial activities that are not included within the GHG Emissions Allowance Trading Scheme and whose GHG emissions are not required to be measured or compensated.

Those industrial 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). This figure suggests 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

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http://dx.doi.org/10.1016/j.enpol.2015.03.025
0301-4215/

emissions at the state level even more difficult because emission responsibility cannot be clearly ascribed.

We accept the influence of certain industrial activities on diffuse GHG emissions and their abatement potential (Lin et al., 2010). Many authors have studied GHG emissions or the carbon footprint of industrial (Domer et al., 2013; Lee, 2011; Liu, in press; Pang et al., 2014, Stylos and Koroneos, 2014) or energy activities (Howard et al., 2011; Zhang et al., in press). Authors have studied the carbon footprint of specific industrial complexes (Dong et al., 2013), the entire industrial sector (Liu, in press) 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 a predictive function. Moreover, most of the aforementioned 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. Thus, if preventive measures based on predictions are optimal, urban planning becomes a relevant tool to guarantee the establishment of these measures.

Urban planning has a decisive influence on general GHG emissions (Engel et al., 2012) and diffuse emissions (Carter et al., 2015; Zubelzu and Hernández, 2014). Urban planning regulates activities that are likely to be implemented within the region, prescribes an allowable intensity for those activities, and 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 industrial zones where activities not included in the Scheme can be executed. Urban planning foresees industrial activities in the earliest design stages. It allows for 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 measures for GHG emissions can be easily developed under the framework of an urban master plan because they typically relate to infrastructure or urban planning sustainability design criteria. Several studies have analyzed the relationship between carbon footprint and infrastructure management. Sovacool and Brown (2010) assessed 12 large cities, 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 Silva et al. (2012) identified building solutions.

Urban planning provides an optimal tool not only to calculate but also to manage the carbon footprint of industrial developments, and although many works have addressed carbon footprint calculations and corrective emissions measures, there are few concrete procedures that incorporate carbon footprint calculations within the urban planning process. Thus, the main objective of this paper is to develop a methodology to calculate the carbon footprint of future industrial urban developments for use during the urban planning process. The following sub-objectives have also been proposed:

- To characterize industrial GHG emission sources in an urban planning context.
- To analyze carbon footprint components and determine the relevance of every source in order to prescribe preventive measures.
- To analyze the relationship between carbon footprint and urban design parameters.

2. Methodology

To achieve the above objectives, we identified and characterized urban planning design variables that can influence GHG emission sources. We utilized a land occupation model to ascribe the entire municipal region area to the following urban planning land categories: urban, urbanizable or non-urbanizable. Keeping in mind that desirable preventive functions cannot be implemented wholesale throughout urban lands and are not applicable to lands designated undevelopable, we apply the proposed methodology only to urbanizable lands.

Urban master plans divide urbanizable lands into homogenous areas, or zones, to be developed for specific uses (industrial, household, retail or public facilities) and at specific intensities (built area m_e^2 on total gross area m_g^2). These zones fit the definition of an area responsible for GHG emissions given by the British Standards Institution (2008) perfectly, so carbon footprint calculations can easily be based on them. Urban master plans specify the types of industrial activities able to be developed in each zone, which allows us to apply the proposed methodology to specific industrial activities rather than to the industrial sector in general. However, this opportunity highlights the lack of international, or even national, standardization of industrial activity categories, their variability over time and the scarcity of necessary information for certain industrial activities. Consequently, we have defined the following industrial activity categories for our study, which roughly coincide with international categories:

- Food, beverage and tobacco industry (FI).
- Textile and leather industry (TI)
- Timber and cork industry (TCI).
- Paper making and printing industry (PI).
- Chemical, plastic and rubber industry (CI).
- Nonmetal mineral products industry (NI).
- Metal products industry (MI).
- Electric, electronic and machinery industry (EI).
- Furniture and other manufacturing industries (FMI).

The aforementioned categories include every type of industrial activity and coincide with use regulations in urban master plans, which allows us to apply the developed methodology to all industrial activities considered in those plans.

The accurate determination of each category's carbon footprint depends on the specific GHG emissions sources within those categories. This requires the identification of GHG emissions sources managed in urban planning. The following list denotes the types of infrastructure that must be defined for each industry in Spanish urban master plans and that are generally taken into account in other countries' urban master plans. The list encapsulates all urban infrastructures that are likely to produce GHG emissions (the carbon footprint of communications infrastructure can be considered negligible), and thus serves as a good basis for predictive carbon footprint calculations:

- Potable water infrastructure.
- Wastewater management infrastructure.
- Electricity supply infrastructure.
- Gas supply infrastructure.
- Waste management infrastructure.
- Transport infrastructure.