Energy Policy 57 (2013) 298–307

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

Carbon footprint evaluation at industrial park level: A hybrid life cycle assessment approach

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HIGHLIGHTS

- A hybrid LCA model was employed to calculate industrial park carbon footprint.
- A case study on SETDZ is done.
- Life cycle carbon footprint of SETDZ is 15.29 Mt.
- Upstream and onsite carbon footprints account for 55.40% and 44.57%, respectively.
- Chemical industry and machinery manufacturing sectors are the two largest sectors.

ARTICLE INFO

Article history:
Received 2 December 2011
Accepted 31 January 2013
Available online 9 March 2013

Keywords:
Carbon footprint
Hybrid LCA
Industrial park

ABSTRACT

Industrial parks have become the effective strategies for government to promote sustainable economic development due to the following advantages: shared infrastructure and concentrated industrial activities within planned areas. However, due to intensive energy consumption and dependence on fossil fuels, industrial parks have become the main areas for greenhouse gas emissions. Therefore, it is critical to quantify their carbon footprints so that appropriate emission reduction policies can be raised. The objective of this paper is to seek an appropriate method on evaluating the carbon footprint of one industrial park. The tiered hybrid LCA method was selected due to its advantages over other methods. Shenyang Economic and Technological Development Zone (SETDZ), a typical comprehensive industrial park in China, was chosen as a case study park. The results show that the total life cycle carbon footprint of SETDZ was 15.29 Mt, including 6.81 Mt onsite (direct) carbon footprint, 8.47 Mt upstream carbon footprint, and only 3201 t downstream carbon footprint. Analysis from industrial sector perspectives shows that chemical industry and manufacture of general purpose machinery and special purposes machinery sector were the two largest sectors for life cycle carbon footprint. Such a sector analysis may be useful for investigation of appropriate emission reduction policies.

1. Introduction

Industrial parks are effective strategies for governments at all levels to help encourage sustainable industrial growth due to the advantages that the problems of zoning can be minimized by properly grouping various types of industrial activities, and costs of infrastructure and utilities can be reduced by concentrating activities in planned areas (Geng et al., 2007). In addition, complementary industries and services provided by industrial parks can entail diversified effects on the surrounding region and finally stimulate regional development (Geng and Zhao, 2009). Thus, to develop industrial parks has become a key strategy for various countries to encourage their industrial development. However, industrial park development is facing several challenges, such as resource depletion, environmental emission, and more recently, climate change, due to its great energy consumption and CO_2 emission (Geng and Cote, 2004). Such challenges are even more critical in China due to unprecedented industrial park growth. Currently, there are over 6800 industrial parks across the whole country, with different types, such as sector-integrated industrial parks (commonly referred to those economic and technological development zones), sector-specific industrial parks

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0301-4215/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.01.057

(such as chemical parks or metallurgical parks with very specific industrial sectors only), and venous industrial parks (such as resource recovery parks where environmental technology companies and firms making "green products" coexist) (Geng et al., 2008, 2009).

It is well known that both industry and energy sectors are the main sources of GHG emissions, especially in China (Zhao et al., 2010; Liu et al., 2012). In 2007, total energy consumption from industrial sector accounted for 71.6% of the national energy consumption, and the proportion of CO_2 emissions from industrial sector was 82.6%, indicating that industry should be the focus of China's energy-saving and carbon-reduction efforts (Xie et al., 2010a, 2010b). In order to respond to climate change, the Chinese government has announced that China is going to reduce the intensity of carbon dioxide emissions per unit of GDP in 2020 by 40–45 percent compared with the level of 2005, and to increase the share of non-fossil fuels in primary energy consumption to approximately 15% by 2020 (Geng, 2011; Geng and Sarkis, 2012). For the sake of achieving this target, National Development and Reform Commission (NDRC, a ministry leveled agency in charge of all planning issues) initiated its first national low carbon development demonstration projects in August 2010, in which five provinces (Liaoning, Hubei, Yunnan, Guangdong and Shaanxi) and eight cities (Chongqing, Baoding, Tianjin, Nanchang, Hangzhou, Xiamen, Guiyang and Shenzhen) were chosen for provincial or municipal level demonstration (Liu et al., 2012). However, such an effort has not targeted industrial parks, one of the most important sources of greenhouse gas emissions. The only national initiative encouraging industrial parks to respond to climate change is the national notice on incorporating low carbon development principles into national eco-industrial park (EIP) development, released by Ministry of Environmental Protection (MEP) in December 2009 (Ministry of Environmental Protection, 2009). This notice is not a legal document and does not have any compulsory authority. It simply stipulates that all the national EIP projects should optimize their energy structure (increase the use of renewable/clean energy) and reduce total energy consumption (energy efficiency/energy saving efforts), without providing a quantitative indicator on greenhouse gas emission reduction.

Under such a circumstance, it is critical to conduct carbon footprint analysis at the industrial park level so that the raised methodology and policy implications can be shared by more industrial park managers. Consequently, the objective of this paper is to present an innovative method on carbon footprint analysis at the industrial park level. A case study approach is employed to illustrate this method's feasibility and applicability. The whole paper is organized as below. After this introduction section, we provide our research methodology, including an overview of carbon footprint related studies identifying relevant research literatures and setting the stage for this study, as well as data collection process. We then present the case study results and provide policy implications. Finally, we draw research conclusions, identify limitations and future research directions.

2. Methodology

2.1. Selection of carbon footprint analysis methods

Carbon footprint has become a widely used term and concept in the public debate on responsibility and abatement action against the threat of global climate change. It is a measure of the exclusive total amount of carbon dioxide emission that is directly and indirectly caused by an activity or is accumulated over the life stages of a product, including activities of individuals, populations, governments, companies, organizations, processes, industrial sectors etc. (Wiedmann and Minx, 2008). Academically, carbon footprint has been applied to measure the total CO_2 emission at different levels, such as nations (Hertwich and Peters, 2009; Sun et al., 2010), cities (Sovacool and Brown, 2010; Xi et al., 2011), households (Weber and Matthews, 2008; Druckman and Jackson, 2009), organizations (Eva et al., 2009), corporations (Huang et al., 2009; Cagiao et al., 2011). However, there are few studies focusing on the industrial park level due to its complex features and data availability.

From methodology point of view, many carbon footprint calculators (Kessel et al., 2008; Padgett et al., 2008; Andrews, 2009; Kenny and Gray, 2009) and international standards (WRI and WBCSD, 2004; IPCC, 2006; ISO, 2006; BSI, 2008) have been published by different organizations. In general, carbon footprint analysis methods can be categorized into three types, namely, IPCC method, process analysis-based life cycle analysis (LCA) method, and input–output analysis (IOA) method. Each of them has certain advantages and disadvantages. IPCC method provides detailed calculation formulae and principles for various emission sources, but it is only suitable for closed system and onsite emission, and cannot be used for calculating indirect emission (Geng et al., 2010a, 2010b). LCA method is a bottom-up method and can provide more specific information to decision-makers. However, it is more time-and-labor consuming since it requires a large amount of detailed data. It suffers from a systematic truncation error due to the delineation of system boundary and the omission of contributions outside this boundary (Suh et al., 2004). IOA method is a more comprehensive top-down approach and has a potential to solve the major drawback of LCA method (Crawford, 2008). It mainly uses public data from input–output table and can reduce both time and manpower once the model is in place. However, the suitability of IOA to assess micro systems such as products or processes is limited as it assumes homogeneity of prices, outputs and their carbon emissions at the sector level. Although sectors can be disaggregated for further analysis, bringing it closer to a micro system, this possibility is limited, at least on a larger scale (Wiedmann and Minx, 2008; Suh and Huppes, 2002). Consequently, a hybrid LCA method that integrates both LCA and IOA is more appropriate for industrial parks, in which both the whole industrial system and the individual companies can be analyzed. It can preserve robustness of IOA model and at the same time provide accuracy of LCA, thus increasing completeness, flexibility, and reliability of estimates (Pandey et al., 2011).

Hybrid LCA method can be further categorized into three types, namely, tiered hybrid LCA, input–output-based hybrid analysis, and integrated hybrid analysis (Suh et al., 2004; Suh and Huppes, 2005). Considering the unique nature of industrial parks (manufacturing based industrial clusters with a great amount of material and energy consumption), tiered hybrid LCA is selected for this study. The reason is that it allows a detailed process analysis on the direct and downstream requirements (e.g., construction, use, maintenance, and end-of-life) and some important lower order upstream requirements of the production system through LCA while the remaining higher order requirements (e.g., materials extraction and manufacturing of raw materials) are covered by input–output analysis.

Fig. 1 demonstrates how to conduct tiered hybrid LCA analysis at the industrial park level. There are three types of carbon footprints for the life cycle analysis of one industrial park: upstream carbon footprint, onsite carbon footprint, and downstream carbon footprint. The upstream carbon footprint includes purchased electricity and heat carbon footprint, material carbon footprint, and depreciation carbon footprint. Onsite carbon footprint includes direct energy consumption carbon footprint, and