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Life cycle analysis of greenhouse gas emissions for fluorescent lamps in mainland China

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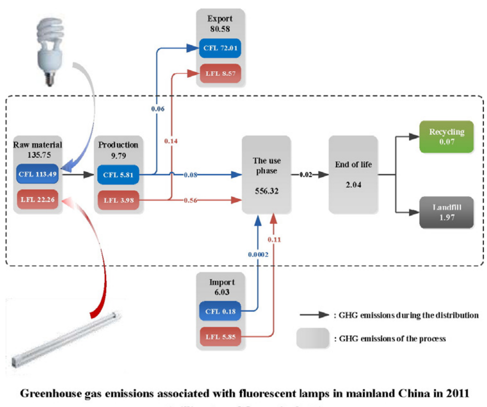
HIGHLIGHTS

- GHG emissions of compact with linear fluorescent lamps were compared.
- GHG emissions of fluorescent lamps at the national level of China were qualified.
- More than half of GHG emissions were embodied in the exported fluorescent lamps.

GRAPHICAL ABSTRACT



Greenhouse gas emissions associated with fluorescent lamps in mainland China in 2011 (million tons CO_2-equivalents).

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ABSTRACT

China is the world's largest emitter of carbon dioxide, and it is also one of the largest fluorescent lamp consuming and producing country in the world. However, there are few studies evaluating greenhouse gas (GHG) emissions of fluorescent lamps in China. This analysis compared GHG emissions of compact fluorescent lamps with linear fluorescent lamps using life cycle assessment method in China's national conditions. The GHG emissions of fluorescent lamps from their manufacture to the final disposal phase on the national level of China were also quantified. The results indicate that the use phase dominates the GHG emissions for both lamps. Linear fluorescent lamp is a better source of light compared to compact fluorescent lamp with respect to GHG emissions. The analysis found that in 2011, China generated around 710.90 million tons CO_2-eq associated with fluorescent lamps. The raw material production and use phases accounted for major GHG emissions. More than half of GHG emissions during the domestic production were embodied in the exported lamps in recent years. This urges the government to take necessary measures that lead to more environmental friendly production, consumption and trade patterns.

1. Introduction

Climate change has been an urgent and serious global problem, and it is mainly caused by the greenhouse gas (GHG), especially carbon

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dioxide (CO_2). As a result of the associated greenhouse effect, the global temperature increased by 0.85 °C on average from 1880 to 2012 (Zhang and Wang, 2015). At the Paris climate conference in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal (European Commission, 2015). The agreement sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2 °C. It is estimated that lighting consumes about 19% of the global electricity production, of which about 62% is consumed by fluorescent lamps (FLs) (IEA, 2006). Electricity production can generate tremendous GHG mainly due to fossil fuel combustion, therefore the amount of GHG emissions associated with FLs is considerable. In addition, with the phasing out of incandescent lamps in several countries, such as China (NDRC, 2011), America, the European Union, Australia (Ramroth, 2008; Waide, 2009) and so on, the popularity of FLs is rising. So it is increasingly necessary to investigate GHG emissions related to FLs.

In 2007, China surpassed the U.S. as the largest emitter of carbon dioxide in the world (Gregg et al., 2008), mainly because of rapid economic development and high industrial energy consumption. Global carbon dioxide emissions from fossil fuel combustion and industrial processes (cement and metal production) increased to 35.3 billion tons in 2013, out of which 10.3 billion tons came from China, accounting for 29% (Olivier et al., 2014). China has been facing increasing international pressure to reduce carbon emissions. It is urgent and vital to accelerate the pace of GHG emission reduction in China to the success of global efforts in addressing climate change.

In 2009, China announced the goal of controlling GHG emissions, i.e. carbon dioxide emission intensity in 2020 decreasing by 40%–45% than that in 2005 (Xinhuashe, 2009). China in 2014, for the first time proposed that it intended to achieve the peaking of CO_2 emissions around 2030 and to make the best efforts to peak early and intended to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. China also proposed that by 2030, carbon dioxide emissions per unit of GDP reduced by 60%–65% compared with that in 2005. China's commitment related to carbon emissions will bring huge pressure to the transformation of domestic energy structure and industrial restructuring. In addition, China is one of the largest FL consuming and producing countries in the world. In 2011, domestic production of compact fluorescent lamps (CFLs) in China accounted for over 80% of the world's production (Xin et al., 2012). There is an increasing need to analyze GHG emissions of FLs in China.

A few of life cycle assessment (LCA) studies have been performed analyzing environmental impacts of FLs (Bakri et al., 2010; Department for Environment, Food and Rural Affairs, DEFRA, 2009; OSRAM, 2009; Principi and Fioretti, 2014; Quirk, 2009; Tahkamo et al., 2014; Tan et al., 2015; DOE, 2012; Welz et al., 2011). These studies can be divided into two categories: one focused on the comparative of FLs with other luminaires, such as light-emitting diodes (LEDs) and incandescent lamps; the other analyzed environmental performance of FLs. For the first category, Quirk (2009) investigated the full life-cycle costs and benefits of using a 13 W CFL and a 6 W LED to compared with a less efficient 60 W incandescent lamp. The study found that CFL and LED lamp are roughly four times more efficient than incandescent lamps. The OSRAM (2009) evaluated the environmental impacts of a 40 W incandescent, 8 W CFL and 8 W LED lamp. The study concluded that current LED lamps, as of 2009, are comparable to CFLs of life-cycle energy, and both provide significant energy savings compared to incandescent lamps. The previous estimates have found that fluorescent lamps result in a clearly lower environmental impact than incandescent lamps. The use phase is the main contributor to GHG emissions. However, most previous studies were not evaluating GHG emissions of FLs in China's national conditions. For the second category, Bakri et al. (2010) compared the environmental performance of electromagnetic and electronic ballast used for FLs. Tan et al. (2015) evaluated environmental impacts of linear fluorescent lamps (LFLs) and compact fluorescent lamps (CFLs) based on Chinese conditions, yet the GHG emissions are not the key point. In addition, former studies focus solely on the product level, no study has been conducted at the national level.

There are a number of studies regarding the role that Chinese trade plays in global CO_2 emissions (Liu et al., 2015a,b; Su and Ang, 2013; Xie et al., 2015; Yunfeng and Laike, 2010; Zhang et al., 2014). According to Su and Ang (2013), from 2002 to 2007, the carbon emissions embodied in China's exports increased from 764 to 1775 Mt. Xie et al. (2015) implemented a multi-regional input-output framework to evaluate the carbon footprints and embodied carbon flows for eight regions of China. It was found that the construction, electricity/stream supply, and machine manufacturing rank as the top sectors with the largest total carbon emissions. Liu et al. (2015b) found that in China, the transferred carbon emissions embodied in demand–supply chains driven by consumption and export both showed rapid growth during 1997–2007. Above all, input–output analysis is the most common methodology used in these literatures to identify effects of production and estimate the embodied emissions in international trade. Few studies use LCA, the so-called “bottom up” approach. However, LCA has advantages over input–output analysis in the embodied carbon evaluation of single products because it collects production information from the technical details (Xie et al., 2015), and it can get relatively accurate results. Most of the studies focused on the whole nation emissions of China, such as agriculture, equipment manufacturing, however, the role of FLs was small and vague. Furthermore, details of FLs regarding their production, import, export, and waste management are missing.

This study consists of two parts: one part is to compare GHG emissions of CFLs with LFLs in China's national conditions, and all the materials, energy use and pollutant emissions to the environment from each process are analyzed; the other part is to quantify GHG emissions of FLs from their manufacture to the final disposal phase on the national level of China. The amount of GHG emissions related to the exported FLs is provided as well. The goal is to determine the life cycle stages with material and energy inputs that cause the greatest impacts and allow a better understanding of the GHG emission characteristics of FLs. The analysis also helps government understand GHG emissions embodied in exported products and provides a reference to policy makers for the GHG emission reduction.

2. Methodology

Life cycle assessment is scientific methodology that enables researchers to quantify and provide a comprehensive view of the environmental and sustainability impacts of a product across a range of categories for a product over its entire life cycle. The LCA is conducted according to the international standards ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b). EBalance, which is Chinese LCA software, has been used to model different processes in the life cycle of the two lighting technologies. EcoInvent and Chinese Life Cycle Database (CLCD) are used as databases. CLCD is a database based on Chinese conditions, and the data represents the average level of China's manufacturing technology and market. GHG are converted to the measurement of carbon dioxide equivalents (CO_2-eq), using the Intergovernmental Panel on Climate Change (IPCC) 100-year Global Warming Potential (GWP) factors. A cradle to grave approach has been taken up for the study in order to include the raw material production, manufacturing, distribution, use, and end-of-life stages of the lamps.

2.1. Comparison of compact fluorescent lamps with linear fluorescent lamps

The life cycle of the stages is shown in Fig. 1. The lamps selected were a 15 W CFL and a 28 W T5 LFL. Functional unit selected for this study was 62 million lumen–hours of lighting service, which is approximately representative of total light output of the 28 W T5 LFL over its lifetime. And it is equal to 8 times of the CFL to provide light throughout its stated life.

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