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A study of waste fluorescent lamp generation in mainland China

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ABSTRACT

Fluorescent lamps (FLs) are already widely used, and demand for them can only be expected to increase, because of their energy-saving features. The potential health risk from the toxic mercury they contain, however, is receiving increasing public attention and concern. In this study, future quantities of FL production and consequent waste FL generation in China are predicted using the Extended Logistic Model and Modified Market Supply Method. The distribution of waste FLs generated are also evaluated for different regions in mainland China, for the years 2012, 2015 and 2020, based on anticipated lighting demands. The predicted yearly production of FLs could rise to about 12 billion units in 2020, while the quantity of waste FLs generated from domestic use would be about 6 billion units, yielding about 937,400 tonnes of waste. Guangdong is the top waste-FL-generating province, followed by Jiangsu, Shandong, Zhejiang and Sichuan. The estimated annual quantity in Guangdong could reach 500 million units by 2020, accounting for approximately 8.63% of the total amount generated over all of mainland China. As for the areal densities of waste FL generation, Shanghai is predicted to have the highest—231,400 units per square kilometer, followed by Hunan, Beijing, Sichuan and Zhejiang. The quantity of waste aluminum caps and glass, and the potential mercury emissions, from waste FLs were evaluated as well. The results of this study are expected to help attain a better understanding of the issue of waste FL generation and distribution in mainland China, and to contribute to the development of policies and/or regulations on FL management and waste FL collection and treatment (or disposal) facilities.

1. Introduction

Fluorescent lamps (FLs) are widely used in both homes and public buildings—commercial as well as governmental, because of their energy-saving features and long lifespan compared with traditional incandescent lamps (ILs). Indeed, replacement of traditional inefficient ILs with FLs has been heavily promoted in recent years, as the FLs reduce energy consumption by at least 65% and last up to 10 times longer than the ILs (DOE, 2013). Since 2007, many countries have announced policies aimed at phasing out incandescent lamps; these include Australia, the U.S., Canada, and the European Union countries (Waide, 2010), with Australia leading the way with a plan to phase out incandescent lights completely by 2010 (DOI, 2009; Ramroth, 2008).

China is no exception, as the government announced a national roadmap for gradually phasing out incandescent lamps, on November 1st 2011, prohibiting the importation and sale of ILs step by step, starting on October 1st 2012 (NDRC, 2011). The FL industry has experienced rapid development in the past one and a half decades in China, with the government formally launching the ambitious "green lighting" program responding to the energy shortage. In 1994, China produced about 0.25 billion FLs (CNIS, 2002), and production rose to about 7 billion in 2011 (Ye et al., 2012), more than 28 times what it was in 1994. With the gradual phasing out of ILs and expanded use of FLs, an accelerated obsolescence of FLs and their consequent entry into the solid waste stream is expected over the next several years in China.

A fluorescent lamp contains mercury at the magnitude of milligrams (dos Santos et al., 2010; Rey-Raap and Gallardo, 2012; Sarigiannis et al., 2012; Singhvi et al., 2011); it is the essential component for generating ultraviolet radiation, which is then is converted into visible light by ultraviolet light (UV) excitation of a fluorescent phosphors coating on the glass envelope of the lamp (European Commission, 2013). Mercury, however, is one of the heavy metals of high toxicity and can cause serious damage to various human organs. Once released into the atmosphere, mercury can remain there for a long time, and be transported over long distances, before being deposited on the ground via precipitation (Dastoor and Larocque, 2004; Morel et al., 1998). Mercury

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compounds can bioaccumulate, and can easily be enriched as they move through the food chain (Morel et al., 1998). While the toxicity of mercury depends on the form of its compounds and the method of intake, many physiological functions can be adversely affected, including the nervous system, the immune system, the reproductive system, the motor system, the renal system and the cardiovascular system (Clarkson and Magos, 2006; Zahir et al., 2005).

Because of the great public health challenges caused by mercury, the expanding use of FLs has caused increasing public concern over the potential risk of mercury exposure from waste FLs breakage and disposal. In response, the Chinese government announced a national roadmap for gradually reducing the mercury content in fluorescent lamps, on 18th February, 2013 (MIIT et al., 2013), with the goal of eliminating the obsolescent liquid mercury technology used for FL production, and replacing it with amalgam technology, in preparation for the upcoming Minamata Convention on Mercury.

Meantime, recovering rare earth elements in phosphors from waste FLs could be a promising approach to compensate for the source of rare earth elements when the waste FLs effectively collected (Tan et al., 2014). As a consequent, the need for environmentally sound management of waste FLs has become more and more urgent in China, especially since no collection or disposal system for the increasing stream of waste FLs is being effectively developed or managed. Prediction of the generation rate of obsolescent FLs should be a key issue for the proper management of this mercury-containing waste. This study intends to provide a better understanding of the trends of waste FL generation and distribution in China by quantified estimation based on production data and regional lighting demands.

2. Methodology

2.1. Production and waste generation prediction methods

In response to the rapid generation of e-waste (electronic waste) over the past several years, a number of studies throughout the world have developed methods to try to forecast its volume, and to provide guidance for management policies and measures, for both governments and private organizations (Wang et al., 2013). These methods include the Time Step Method, the Market Supply Method, the Carnegie Mellon Method, the Approximate Method, the Estimate Method, the Stanford Method, the "ICER" Method, the Gompertz Curve Method and the population balance model (Feszty et al., 2003; Kim et al., 2013; Li et al., 2006; UNEP, 2007; Wilkinson et al., 2001). To utilize these methods, a number of different assumptions, parameters, and variables have been developed to take into account market saturation, product lifespans, inventory and sales. The resulting growth curves have been widely used for determining the penetration rate of technological products (Meade, 1984; Winsor, 1932). A time-varying extended logistic model was proposed by Meyer and Ausubel (1999) to address the difficulty of estimating the market share capacity for other growth curves, such as the Gompertz curve. A dynamic capacity (upper limit) varying over time was used for the extended logistic model, and it showed good prediction results when evaluations were carried out for 22 selected products (Trappey and Wu, 2007, 2008).

When using the original Market Supply Method to determine the sources of waste generation, two phases were included—sales and reuse (UNEP, 2007). For FLs, however, no reuse or refurbishment values exist; when they come to their end of life, they flow directly into the waste stream. Consequently, a modified Market Supply Method that does not consider reuse (or refurbishment) was adopted in this study, to ensure that relevant data were acquired and calculated for estimating the quantities of discarded FLs (Table 1).

2.2. Waste fluorescent lamp generation and distribution evaluation

In order to evaluate the distribution of waste FL generation in the various provinces (or municipalities) in mainland China, the lighting demands of every province (or municipality) were estimated based on the floor space of buildings and the average illuminance requirements for various types of buildings (Table 2). The yearly usage figures for the three categories of FLs by region was then estimated based on the predicted total number of FLs that would be used every year and the relative proportion of regional lighting demands (from Equation (2)).

The floor space of buildings yearly completed were grouped by purpose and region in the 'China Real Estate Statistics Yearbook'. Four categories of buildings were divided, including residential, office, commercial, and other. The statistics from 1997 to 2011 were collected for this study. The total floor space of all the buildings and the residential buildings, grouped by region, at the end of 2004, has been collected in the 'China Statistical Yearbook of the Regional Economy.' The regional totals for the latter three categories (office, commercial and other) at the end of 2004 were evaluated based on the total floor space of all buildings and the yearly completed floor space of the three categories of buildings from 1997 to 2004. The yearly completed floor space values after 2011 were estimated by applying the average value over the latest five years prior to the predicted year.

$$D_r = \sum_{b=1,2,3,4} S_{r,b} \times I_{r,b} \quad (1)$$

$$N_r = \sum_{l=1,2,3} N_{r,l} = \sum_{l=1,2,3} \frac{D_r}{\sum\limits_{r=1,\cdots,31} D_r} \times N_{T,l} \quad (2)$$

where D_r is the lighting demand for a specific region (province or municipality) from all categories of buildings; $S_{r,b}$ and $I_{r,b}$ are the floor space and relevant illuminance requirements for a category of building (b) in a region (r); N_r and $N_{r,l}$ refer to the quantity of all FLs and the type of FL (l) used in region (r), respectively; and $N_{T,l}$ is the total quantity of FL 'l' used in mainland China. Consequently, the quantity of waste FLs in a particular region can be evaluated using the Modified Market Supply Method.

2.3. Data collection

2.3.1. Fluorescent lamp production status in China

As discussed above, the Chinese fluorescent lamp industry is undergoing rapid growth, and China is one of the largest manufacturers and exporters of fluorescent lamps. Table 3 shows the

Table 1
Methods used in this study.

Methods	Estimation formula	Source(s)
The Modified Market Supply Method	$Q(t) = S(t - d_N)$ $Q(t)$ is the estimated quantity at the year t; $S(t - d_N)$ is the quantity of products sold during the years $(t - d_N)$; t is the number of years; and d_N is the average lifetime of new products (FLs).	(UNEP, 2007)
The Extended Logistic Model	$N(t) = m \times y(t) = m \times \frac{k(t)}{1+c\times e^{-bt}} = m \times \frac{1-d\times e^{-at}}{1+c\times e^{-bt}}$ $N(t)$ is the estimated cumulative volume for the year t; m represents the total population; $y(t)$ is the estimated saturation of specific products for the year t; $k(t)$ is the capacity fluctuating over time; a,b,c,d are the parameters determined using a regression method; and t is the number of years.	(Trappey and Wu, 2007, 2008)