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Enhanced recycling network for spent e-bicycle batteries: A case study in Xuzhou, China

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Highlights

- The number of spent batteries recovered is lower than estimated numbers produced.
- Vendors are the backbone of used battery recycling.
- Low recycling prices reduce the number of waste lithium batteries recovered.
- Different users have different preferences for methods of disposal and recovery.

Abstract

Electric bicycles (e-bicycles) are a primary means of commuting in China because of their light weight, speed, and low maintenance costs. Owing to short service life and environmental pollution hazards, recycling and reuse of e-bicycle batteries has always been a focus of industry and academia. As a typical case of both production and use of large electric bicycles, 113 major sellers, 378 corporate and individual buyers, 147 large e-bicycle repair centers, and 1317 e-bicycle owners in Xuzhou City were investigated in order to understand the sales, use, recycling, and disposal of spent e-bicycle batteries. The findings show that the existing distempered recycling system is the main limitation of spent battery recovery, and the actual recovery rate of spent batteries is lower than the estimated output (*QW*) for the years 2011–2014. Electric bicycle sellers play a fundamental role in the collection of spent batteries in Xuzhou, accounting for 42.3 ± 8.3% of all batteries recovered. The widespread use of lithium batteries in recent years has resulted in a reduction in spent battery recycling because of lower battery prices. Furthermore, consumer preferences are another important factor affecting the actual recovery rate according to survey results evaluated using canonical correspondence analysis. In this paper, we suggest that a reverse logistics network system for spent battery recycling should be established in the future; in addition, enhancing producer responsibility, increasing publicity, raising of public awareness, developing green public transport, and reducing dependence on e-bicycles also should be pursued. This study seeks to provide guidance for planning construction and management policies for an effective spent battery recycling system in China and other developing countries.

Introduction

Since 1995, when the first electric bicycle (e-bicycle) was developed, China has experienced 20 years of rapid urban expansion and economic growth. Owing to their convenience, speed, and low maintenance costs, e-bicycles have become a major means of commuting in China, accounting for about 16.5% of the

country's total traffic (CCTA, 2014). In 2014, China produced and sold about 36 million e-bicycles, with an estimated e-bicycle ownership of about 180 million (MIIT, 2015). However, batteries, which are the key component of electric bicycles, typically last less than three years, requiring frequent replacement. Currently, e-bicycle batteries, including lead-acid, nickel-metal hydride, and lithium batteries, are primarily composed of heavy-metal ions such as lead, copper, cobalt, zinc, manganese, nickel, and electrolytes (Zeng et al., 2012, Zeng and Li, 2014, Contestabile et al., 2001, Li et al., 2009, Li et al., 2010, He et al., 2015). These substances have strong negative effects on soil and water, endanger ecological safety, and present a persistent public nuisance upon entering the environment (Nan et al., 2005, Brar et al., 2010, Sun and Qiu, 2012, Sun et al., 2015, Chen et al., 2016a, Chen et al., 2016b).

Spent batteries are typically cured and then buried, stored in abandoned mines, or recycled in the international community (Duan et al., 2008, Lisbona and Snee, 2011, Zeng et al., 2014). In recent years, techniques have been developed to recover metals from spent batteries with good results (Krekeler et al., 2012, Li et al., 2012, Xue et al., 2014, Chen et al., 2015). However, because many of these recovery methods are only effective for a specific type of battery, it costs recycling enterprises time and money to sort spent batteries (Hu et al., 2016). This sorting requires professional knowledge, further increasing recycling costs. Economic benefits, which are the focus of recycling enterprises, are generally estimated using the market supply model, the Stanford model, and the Carnegie Mellon model, and the data obtained from actual tests have established the amount of recovered metals as a key metric of recycling economics (Tan et al., 2014). The life-cycle model, system dynamics model, and genetic algorithm have been introduced in the hopes of extending battery life and improving the economics of recycling (Xará et al., 2009, Xará et al., 2014, Xará et al., 2015a, Xará et al., 2015b, Zhang et al., 2013, Subulan et al., 2015, Liu et al., 2015, Chen et al., 2016a, Chen et al., 2016b, Chen et al., 2016c). However, there has been some dispute in previous studies over the amount of metals extracted from spent batteries and the output of spent batteries (Zeng and Li, 2014). The sustained low prices of metal materials in recent years have also stifled recycling enterprises' incentives. Some recyclers and scavengers only collect the most valuable parts of spent batteries and discard the rest, which not only results in a

waste of resources, but also causes pollution. The European Union issued a new battery directive in 2004 that requires all battery products to be recycled and producers and retailers to assume responsibility for the recycling and disposal of spent batteries. The directive also stipulated that consumers deliver spent batteries to recycling stations for management (ERM – Environmental Resources Management, 2006, EEA, 2009). In Japan, an act of the Promotion of Effective Utilization of Resources requires the relevant producers to collect and recycle small rechargeable batteries (Terazono et al., 2015). According to the goal of "zero waste" in the United States, the states of California and New York are likely to require collection and recycling of waste batteries in the near future by issuing statewide disposal bans on rechargeable batteries (Wang et al., 2014, Hendrickson et al., 2015). However, similar types of such mandatory measures have not been put into practice in China. Although the Chinese government has attached great importance to the recycling of spent e-bicycle batteries, their overall recovery is lower than 60% due to the poor enforcement of environmental regulations, enterprises' consideration of economic benefits, and low public awareness of environmental dangers (Zeng et al., 2013). Battery recycling is an essential part of the e-bicycle industry, and is of great significance to sustainable development and resources and to environmental protection. This study, based on Xuzhou City, Jiangsu Province, investigated the sales of e-bicycles and their battery life and composition; the data collected were used to re-estimate the output of spent batteries and propose new methods of recycling. A complete reverse logistics network for spent battery recycling was established based on the characteristics of individual users in order to improve recycling efficiency. The experience of Xuzhou, which is a typical city, can serve as a reference for similar cities and developing countries.

Section snippets

Data collection

Xuzhou, a traditional industrial city in China, has an urban resident population of 1.86 million and a Gross Domestic Product (GDP) of 286.3 billion RMB as of 2015. Not only does the city have an enormous number of e-bicycles in use, it is also China's most important e-bicycle manufacturing center, producing about 10% of the country's e-bicycles. From July to September 2015, 37 students investigated the recycling of spent e-bicycle batteries in Xuzhou. The research group investigated 113 major …

Number of e-bicycles and proportions of use of various batteries

The number of e-bicycles in Xuzhou for 2008–2014 was obtained from the vehicle registry of the local tax bureau (http://tj.xz.gov.cn/TJJ/tjgb/ ↗). Records for 2008 showed 45,600 vehicles registered, with that number increasing significantly to 168,200 vehicles in 2012 (Fig. 1a). The number of registered e-bicycles declined in the following two years, most likely due to the approximate saturation of market ownership of e-bicycles. According to actual sales data, the market ownership of e-bicycles …

Establishing a reverse logistics network system for spent battery recycling

The results of this investigation indicated there is a simple recycling system for spent batteries in Xuzhou, but that it is missing the following two important factors: governmental regulation and the participation of the grassroots community. Recycling spent batteries is not simply an economic activity, but it also protects the environment (Li et al., 2014, Li et al., 2015). Therefore, recycling spent batteries cannot rely completely upon market behavior. According to CCA and factors of …

Conclusions

The recycling of spent batteries is an aspect of the e-bicycle industry that cannot be ignored since it is of great significance for sustainable development and the protection of resources and of the environment. On the basis of an extensive investigation of the recycling of spent e-bicycle batteries in Xuzhou, the following results were obtained:

(1) The actual number of spent batteries recycled in Xuzhou for 2011–2014 was as much as 17.6% less than the estimated output. …

(2) Electric bicycle retailers …

…

Acknowledgements

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