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Full length article

Life cycle assessment of lithium-ion batteries for greenhouse gas emissions

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ABSTRACT

The optimized design of lithium ion secondary batteries using combination of carbon footprints and life cycle assessment (LCA) was proposed in this study. The carbon footprints of the batteries were obtained by four stages, and relevant reduction strategies were implemented accordingly. The carbon footprints of three different batteries were compared in this study: lithium ion secondary battery, nickel metal hydride battery and solar cell were evaluated. The result indicated that the carbon dioxide equivalence of the assembly process for raw materials sequence was nickel metal hydride battery (124 kg CO_{2eq}) > solar cell (95.8 kg CO_{2eq})> lithium ion secondary battery (12.7 kg CO_{2eq}). The result also proposed the lithium ion batteries' environmental friendliness with numeric illustration and the calculation of carbon footprints of the product was developed as reference to battery selection for human use.

1. Introduction

Along with the enhancement of people's environmental consciousness and the development of carbon label, companies increasingly felt the pressure from low carbon tendency. Thus, the calculation of product carbon footprints and the low carbon management of supply chain will become one of energy conservation and emissions reduction tasks of many brands and retailers in the future. China is now in the beginning of the low carbon economic transformation. With the vigorous promotion of energy conservation and emissions reduction work in the "12th Five-Year-Plan" period, the mechanism of carbon trading and carbon tax has been introduced gradually. It is necessary to reduce product carbon footprints of manufacturing enterprises in China, so as to attract more downstream invents and consumers. The carbon label as the unique identifier to quantitative product carbon footprints is increasingly concerned. Therefore, it is urgent to understand the calculation of product carbon footprints in China.

Carbon Footprint (CFP) originated in ecological footprint (Johnson, 2008), which also considered as carbon emissions, was used to describe the emissions of greenhouse gases (GHGs) from organization, product or individual. Meanwhile, the product carbon footprint, named carbon label, was a research hot spot in all over the world. Wiedmann and Minx (2007) defined CFP as the emissions of CO_2 which was caused by an activity during the whole life cycle of a product both directly and indirectly. While, most activities may also emit other kinds of GHGs, that also need to be considered. Therefore, the term carbon dioxide equivalent (CO_{2eq}) is widely used in CFP assessments.

The methods of product carbon footprints are divided into two sorts: "top-to-down" model and "bottom-to-up" model (Wang et al., 2010). Life cycle assessment (LCA) is a kind of "bottom-to-top" method, which includes the process "from start to finish" of the product. It is generally recognized as a quantitative and qualitative analysis tool of environmental impact caused by life cycle of product at the international level. LCA first appeared in the United States, where the company Coca-Cola commissioned a research institution to make a quantitative analysis and track from raw material mining to waste of the beverage container in 1969. LCA is a commonly used tool for evaluating environmental features of electronic products in nowadays.

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Lithium ion secondary battery (Wu, 2009) developed as a new battery after nickel cadmium battery, which has become an important technical way to mitigate the crisis of energy and resources and solve environment pollution problems. Lithium-ion battery has been widely used in cell phones, laptops, digital cameras and many other products due to its high energy density, high voltage, low self-discharge, non-memory effect, long cycle life and environmental friendliness. With the increasing market demand for lithium ion battery, further research about its performance is in need. In recent decade, the market share and sales of lithium ion battery continued to soar, which was comparable to that of nickel cadmium battery and nickel metal hydride battery (Battery Industry Association, 2011). The research of product carbon footprints in China is still at the beginning presently, and very few research about carbon footprint assessment of lithium ion battery. However, the secondary environmental problems of widely used lithium ion battery should not be ignored, which requires further research.

Recently, there has been many researches on the carbon footprint calculation and the environmental impact assessment of lithium ion battery. Yajun Ge (2008) proposed the LCA method for wasted secondary battery, in which Shenzhen city was used as an example, mainly conducted quantitative assessment on chronic public health impact of nickel cadmium battery, nickel metal hydride battery, lithium ion battery and lead-acid battery. Zackrisson et al. (2010) studied how LCA could be used to the optimization design of lithium-ion batteries for plug-in hybrid electric vehicles, and then the environmental impact of two different solvents batteries were compared. The environmental impact of lithium ion battery used in battery-powered electric cars was measured in Ecoindicator 99 points (Dominic Notter et al., 2010). Majeau-Bettez et al. (2011) made a comparison among nickel metal hydride (NiMH), nickel cobalt manganese lithium-ion (NCM) and iron phosphate lithium-ion (LFP) batteries in three different functional units, which expressed the results through thirteen impact categories. Linda Ager-Wick Ellingsen et al. (2013) evaluated an Li (NixCoyMnz)O_2(NCM) traction battery in three different functional units and compared with preceding researches. Yu et al. (2014) assessed four kinds of cathode active materials, and brought forward a method for assessing cathode active materials that accounts for both the environmental impact and the electrochemical performance to filter cathode active materials that are friendly to environment and with excellent performance. Messagie et al. (2015) first proposed the availability and demand of lithium, then compared a lithium manganese oxide (LMO) and a lithium iron phosphate (LFP) battery by means of LCA, which indicated the whole environmental performance of the battery was strongly dependent on its efficiency and directly tied to the energy mixes associated with its uses. The above researches evaluated the environmental impact of lithium ion battery from different angles. However, there are few studies focusing on the carbon footprint assessment of lithium ion battery products, failing to analyze the impact from each stage.

The lithium ion battery was used as an case study and compared with nickel metal hydride battery and solar cell. The carbon footprint assessment of secondary battery product was caculated by LCA method theory. Therefore, the results can be used to provide effective support for managers and evidence for people to choose environmentally friendly products.

2. Lithium ion battery in China

2.1. Production situation

In recent years, lithium-ion battery industry is developing rapidly in China. During 2010 and 2014, the production of lithium ion battery increased approximate linearly from 2.69 billion to 5.29 billion (CBIW, 2011–2015), as shown in Fig. 1. The long-term consumption growth of electronic products and the substitution effect in the field of electric tools and electric bicycle will lead to steady growth of lithium ion battery.

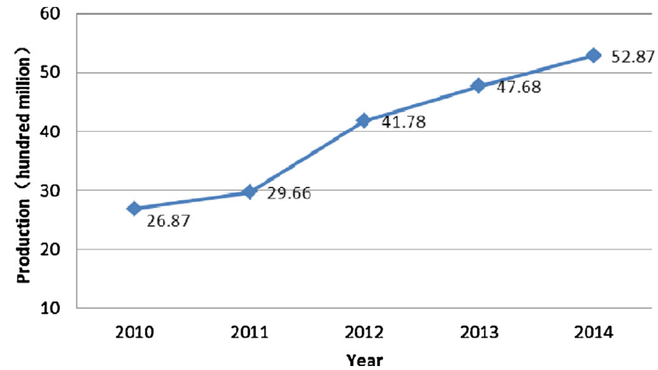

Fig. 1. National production of lithium ion battery from 2010 to 2014.

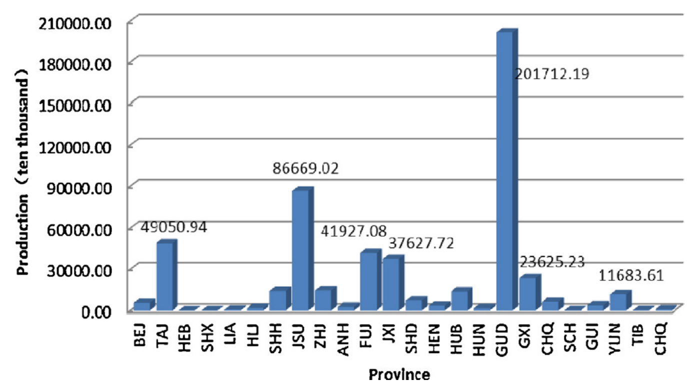

Fig. 2. Production of lithium ion battery in provinces in 2014.

According to the statistics of China Industrial Association of Power Sources (CIAPS), China's lithium ion battery exports reached 1.32 billion (USD 5.48 billion) in 2014 and 1.13 billion (USD 4.80 billion) in 2013, up by 16.8% (14.1%) from a year earlier. The sales revenue of lithium reached USD 10.7 billion in 2014, up by 21.1% from USD 8.8 billion yuan in 2013. The lithium ion battery used in IT market accounted for 81.1% of the lithium-ion battery market, new energy vehicles and electric bicycles with power lithium ion batteries accounted for 16.8%, and communication and new energy storage with lithium ion batteries took 2.1% of the lithium ion battery market (2015).

The production of the lithium ion batteries in 2014 for different provinces in China is shown in Fig. 2. The battery production in Guangdong, Jiangsu and Tianjin ranked top 3, up to 2.02,0.87 and 0.49 billion. At the same time, the production in Fujian, Jiangxi, Guangxi and other places were relatively high, reaching 0.42, 0.38 and 0.34 billion respectively, while the production in Shanxi, Jilin, Sichuan and other places were relatively low.

2.2. Enterprise distribution

The global lithium ion market consists of China, Japan and South Korea, and the lithium ion battery in China is developing rapidly. The battery enterprises are mainly distributed in Guangdong, Jiangsu, Zhejiang Province et al., accounting for 70% of national total. The lithium-ion battery industry (CCID Consulting, 2011) in China is mainly concentrated in the Pearl River Delta repre-