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Cradle-to-gate greenhouse gas emissions of battery electric and internal combustion engine vehicles in China ☆

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Abstract

Electric drive vehicles are equipped with totally different propulsion systems compared with conventional vehicles, for which the energy consumption and cradle-to-gate greenhouse gas emissions associated with vehicle production could substantially change. In this study, the life cycle energy consumption and greenhouse gas emissions of vehicle production are compared between battery electric and internal combustion engine vehicles in China's context. The results reveal that the energy consumption and greenhouse gas emissions of a battery electric vehicle production range from 92.4 to 94.3 GJ and 15.0 to 15.2 t CO_2eq, which are about 50% higher than those of an internal combustion engine vehicle, 63.5 GJ and 10.0 t CO_2eq. This substantial change can be mainly attributed to the production of traction batteries, the essential components for battery electric vehicles. Moreover, the larger weight and different weight distribution of materials used in battery electric vehicles also contribute to the larger environmental impact. This situation can be improved through the development of new traction battery production techniques, vehicle recycling and a low-carbon energy structure.

Introduction

Electric Drive Vehicles (EDVs) are considered to be environmentally-friendly and have attracted much attention worldwide, and Battery Electric Vehicles (BEVs) are the most popular vehicles among all kinds of EDVs. In China, the country with the world's largest automotive market, the government is determined to develop BEV industry and produced over 250 thousand BEVs in 2015, and the annual growth rate was 420% [1]. In addition, according to the production plan, the cumulative output of BEVs in China will reach 5 million in 2020, meaning that BEVs will gradually replace Internal Combustion Engine Vehicles (ICEVs) [2]. Under such circumstances, the proportion of different kinds of vehicles produced worldwide will face significant changes in the coming years [3], which will influence the evaluation methods and results of the energy consumption and environmental impact associated with future vehicles, especially in China.

In recent years, many scholars have carried out research on this subject and provided several important results. However, many of them paid more attention to the use phase, which is also called the Well-to-Wheel (WTW) stage. Lewis (2014) evaluated the life cycle environmental benefits of vehicle electrification and weight reduction, which was mainly based on the fuel combustion during the use phase [4]. Yuan (2015) estimated the energy consumption and WTW CO_2 emissions of BEV range in China. It was indicated that short driving range and low speeds could help reduce the environmental impact [5]. Zeng (2016) paid attention to the WTW GHG emissions of conventional motor vehicles in China, pointing out that low-carbon policies in road transportation was necessary [6]. Oris (2016) provided the estimation results about the environmental impact of vehicles in five different countries, revealing that BEVs were the potential alternatives which can help reduce fuel consumption and emissions in the transport sector [7]. Bicer (2016) conducted research on the emissions from vehicles using different fuels, such as hydrogen, methanol and electricity. Hydrogen driven vehicles were proved to be more environmentally-friendly [8]. Onn (2017) compared the WTW emissions of several kinds of vehicles on the Malaysian electricity mix. The results indicated that Hybrid Electric Vehicles (HEVs) were promised to be cleaner for developing countries [9].

Although the use phase is dominant when considering the life cycle environmental impact, the production phase is an important supplement and has caused wide concern due to the great environmental impact of traction battery production. Hawkins (2013) established a complete Life Cycle Assessment (LCA) model for vehicles, including production, use, disposal and recycling. The author pointed out that although the energy consumption and emissions from the use phase generally accounted for the majority, the influence of the production phase is significant [10]. Sharma (2013) qualified the performance of BEVs on Greenhouse Gas (GHG) emissions under the Australian driving conditions [11]. The vehicle production phase was studied by decomposing the vehicles into several major parts. Wang (2013) estimated the life cycle emissions of different vehicles in China and pointed out that the performance of BEVs was not ideal with China's generation mix and manufacturing techniques [12]. Nanaki (2013) paid attention to both vehicle production and use phases of vehicles in Greece. It proved that the source of electricity could greatly affect the benefits of BEVs [13]. Tagliaferria (2016) calculated the total environmental burdens of BEVs under the technology system of Europe, finding that BEV production was the major impediment to performance [14].

Existing studies have provided an important conclusion that BEV production was not exactly perceived in many countries, and the situation must be improved to avoid a negative influence. In fact, with the rapid growth of the automotive industry, global vehicle production reached 90.8 million in 2015 [15] and contributed about 5.6 billion tons of CO_2 emissions to the total level of the manufacturing sector, which accounted for over one third of the energy-related CO_2 emissions [16]. When it comes to China's case, the government announced in the Intended Nationally Determined Contributions (INDCs) in 2015 that the national CO_2 emissions would reach a peak before 2030 and the CO_2 emissions per unit of Gross Domestic Product (GDP) were expected to decrease by 60–65% compared to the number in 2005 [17]. The development of BEVs has been prioritized to help achieve the target and BEV production has already become one of the major concerns.

On the other hand, the environmental impact of vehicle production vary greatly owing to discrepancies in manufacturing techniques. Although several referential results have provided by former research, they are far from perfect due to the huge regional differences. Since nobody has anticipated the rapid growth of electric drive vehicles in China, the country with relatively weak manufacturing base and coal based energy structure, most of the former studies were based on the manufacturing process in developed countries and paid little attention to China's case. Only a few studies have mentioned the situation in China with little detailed analysis concentrated on the production phase.

To delve into this subject, this study places emphasis on energy consumption and GHG emissions from vehicle production, especially for BEV production in China, a promising country with the world's largest vehicle output. In order to describe the situation comprehensively, this study employs a Cradle-to-Gate (CTG) framework, in which all the processes, including material production, energy transformation, components production and assembly, are considered. Furthermore, a China-specific database consisting of the relevant data from representative enterprises and a wide range of literature studies is established. This study aims to provide important results on energy consumption and GHG emissions associated with each component, material and energy source throughout the entire vehicle production process in China, which is an important reference for the government to make decisions. Furthermore, the results can help find out major reduction opportunities in the future.

Section snippets

Assumptions and system boundary

A complete CTG system has been employed in this study, including material production and transformation, component manufacturing, battery and other attachment production, assembling and replacements. According to the enterprise investigation and literature review, most of the materials and energy consumed during vehicle production are produced in China. Only a few ores, such as lithium ores, are imported from other countries because China does not have enough resources, and this situation…

Overview

Fig. 2 presents the detailed energy consumption and GHG emissions of each component, material and energy source. It has been revealed that the total energy consumption and GHG emissions of a BEV with an NMC/LFP battery are 92,392 MJ, 15,005 kg CO_2eq/94,341 MJ, 15,174 kg CO_2eq, which is 45%, 50%/48%, 52% greater than the level of an ICEV, 63,515 MJ, 9985 kg CO_2eq, respectively. In order to concisely highlight the core sectors, several sectors accounting for only a little proportion are not labeled in…

Comparative simulation results

Several former research studies have provided benchmarks for the energy consumption or GHG emissions of ICEVs or BEVs. Argonne National Laboratory estimated the level in the U.S. and revealed that the GHG emissions of an ICEV are 7052 kg CO_2eq, and the number for an equivalent BEV with NMC/LFP battery was 9,450/9222 kg CO_2eq [18], which were significantly lower than the values in China. The more advanced Li-ion battery production techniques and matured vehicle recycling industry were the…

Conclusions

In order to reflect the environmental impact when ICEVs are replaced with BEVs in China, the country with the largest BEV output and automotive market worldwide, this study estimates the CTG energy consumption and GHG emissions of vehicles, which is an important phase during the vehicle life cycle. Standard mid-size passenger ICEV and BEV with NMC/LFP batteries are chosen as the reference vehicles. The total energy consumption and GHG emissions are 63,515 MJ, 9985 kg CO_2eq for an ICEV, 92,392 MJ,…

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References (55)

C. Bauer *et al.*
The environmental performance of current and future passenger vehicles: life cycle assessment based on a novel scenario analysis framework
Appl Energy (2015)

A.M. Lewis *et al.*
Vehicle lightweighting vs. electrification: life cycle energy and GHG emissions results for diverse powertrain vehicles
Appl Energy (2014)

X. Yuan *et al.*
Energy and environmental impact of battery electric vehicle range in China
Appl Energy (2015)

Y. Zeng *et al.*
Greenhouse gas emissions of motor vehicles in Chinese cities and the implication for China's mitigation targets
Appl Energy (2016)

C.C. Onn *et al.*
Vehicle electrification in a developing country: status and issue, from a well-to-wheel perspective
Transport Res Part D: Transport Environ (2017)

R. Sharma *et al.*
Conventional, hybrid and electric vehicles for Australian driving conditions. Part 2: life cycle CO_2-e emissions
Transport Res Part C: Emerg Technol (2013)

D. Wang *et al.*
Life cycle analysis of internal combustion engine, electric and fuel cell vehicles for China
Energy (2013)

E.A. Nanaki *et al.*
Comparative economic and environmental analysis of conventional, hybrid and electric vehicles – the case study of Greece
J Clean Prod (2013)

R. Jing *et al.*
Comparison of greenhouse gas emission accounting methods for steel production in China
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☆ The short version of the paper was presented at ICAE2016 on Oct 8-11, Beijing, China. This paper is a substantial extension of the short version of the conference paper.

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