

Comparative environmental impacts of Internal Combustion Engine Vehicles with Hybrid Vehicles and Electric Vehicles in China—Based on Life Cycle Assessment

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Abstract: In China, the growth of new energy vehicles is especially rapid and the explosive growth of the automobile brought an increasing impact on the environment. This paper selected Electric Vehicles, Hybrid Vehicles and Internal Combustion Engine Vehicles of the same model of BYD as the object. We established a Life Cycle Assessment with GaBi6 software and CML2001 model. The results show that in the whole life cycle, the influences of ADP, GWP and ODP of Electric Vehicles are less than that of Hybrid Vehicles and Internal Combustion Engine Vehicles. The impact of Electric Vehicles are 39%, 50%, and 4% of the Internal Combustion Engine Vehicles and the Hybrid Vehicles' impact are 65%, 78% and 85% of the Internal Combustion Engine Vehicles. Electric Vehicles and Hybrid Vehicles have a clear improvement in these three types of impacts. The comparison results of AP, EP, FAETP, MAETP and POCP show that the potential impact of Electric Vehicles is greater than that of Hybrid Vehicles and Internal Combustion Engine Vehicles. At present, improving production technology and reducing the consumption of energy during production phase are effective measures to reduce the environmental impact of Internal Combustion Engine Vehicles and Hybrid Vehicles of China.

1. Introduction

Vehicle emissions are one of the main causes of urban traffic pollution in China. In the world, 60% of CO emissions, 50% of NO emissions and 30% of HC emissions is caused by automobile. In China, the automobile industry has developed rapidly in recent years and the private cars ownership has reached 219 million in 2017[1]. The rapid growth of automobiles has brought a series of negative effects, such as heavy oil consumption, environmental pollution and traffic congestion. Therefore, China has put forward to develop new energy vehicles and proposed many support policy such as subsidies and no travel restrictions [2]. In 2017, China produced 794 thousands and sold 777 thousands new energy vehicles, the production share reached 2.7% of all automobiles and ranked first in the world for three consecutive years. While new energy vehicles are being promoted in China, they encounter the controversy of whether the new energy vehicles are environment friendly.

With the development of the new energy vehicles, they have been seen as a promising potential long-term solution to sustainable personal mobility. However, the true ability of new energy vehicles to reduce the environment impact can only be properly assessed by comparing a life cycle assessment of their Greenhouse Gas emissions with a similar assessment for conventional internal combustion vehicles. Hybrid vehicles and electric vehicles offer low cost climate benefits in China. Transit

from conventional to hybrid and electric vehicles can achieve carbon emissions reductions at a negative cost.

In the use phase, compared with the Internal Combustion Engine Vehicles, new energy vehicles have the advantages such as the fossil consumption is low, the energy utilization efficiency is high and there is nearly no emissions in driving process. However, in the whole life, the production phase consumes a lot of energy and the production process of electric generates large quantities of pollutions. Under the current energy structure of China with more than 70% coal fired power, whether the new energy vehicle is environment friendly is controversial. The life cycle assessment is used for the whole vehicles or some key parts of the vehicles, such as power system and the battery.

In China, the research on the environmental impact comparison of different kinds of vehicles is still lacking. A case study of electric and gasoline powered taxis has been made in which the electric vehicle transformation in Beijing and the comparative eco-environmental impacts has been analyzed [3]. The analysis of the battery electric vehicle's potentiality of environmental effect of Beijing from 2016 to 2020 has been made but it has no comparison of different vehicles [4].

For the life cycle assessment of the parts of new energy vehicles, life cycle assessment was always applied to analyze and compare the environmental impact of lead acid battery, lithium manganese battery and lithium iron phosphate battery within the system boundary of "cradle-

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to-gate”. A Life Cycle Assessment to evaluate the energy consumptions and environmental emissions of an engine with Integrated Hybrid Life Cycle Inventory analysis method has been conducted[5].A comprehensive life cycle assessment on a potential next-generation lithium battery with molybdenum disulfide anode and Nickel-Cobalt-Manganese oxide cathode has been made in[6]. A novel life cycle assessment model for comprehensive environmental impact assessment of a Li-S battery pack using a graphene sulfur composite cathode and a lithium metal anode protected by a lithium-ion conductive layer, for actual Electric Vehicles applications has been made [7] .

In the past, relative research of China focused more on pure electric vehicles and papers about hybrid vehicles is rare. Hybrid electric vehicles have high fuel economy performance and superior driving performance. With the assistance of electric motors, fuel consumption can be reduced and the high efficiency of fuel can be achieved. However, they have a complex structure and high manufacturing costs. In order to fill this gap, this paper will construct a life cycle environmental impact assessment model to compare Electric Vehicles, Hybrid Vehicles and Internal Combustion Engine Vehicles, analyze the environmental impacts in different regions of China.

2. Materials and methods

2.1 Goal and scope

The goal of this study is to compare the environmental impacts of different types of new energy vehicles and internal combustion engine vehicles. A comparative LCA based on a cradle-to-grave analysis was carried out to assess the health and environmental impacts of different power systems vehicles. This study takes the Electric Vehicles, Hybrid Vehicles and Internal Combustion Engine Vehicles versions of the same model of BYD as the object.

A cradle-to-grave product system was considered in this study. Thereby for these different types of vehicles, the following phases of the life cycle are considered: production phase, use phase and end of life phase. As described, LCA of vehicles usually compares vehicles belonging to the same class or segment, which is defined in terms of vehicle weight, size and powertrain [8]. Therefore, it is considered that the car body, chassis, wheel and interior decoration of Electric Vehicles and Hybrid Vehicles will be same with the Internal Combustion Engine Vehicles, the only difference is the power system. The main parameters of the three models are shown in Tab 1.

Tab 1. Main parameters of the vehicles

Vehicle model	BYD Song EV	BYD Song HV 1.5T	BYD Song ICEV 1.5T
Power type	Electric Vehicles	Hybrid Vehicles	Internal Combustion Engine
Power system	Lithium battery + Electric motor	Lithium battery + Electric motor+ Gasoline + Engine	Gasoline + Engine
Weight	2070kg	2120kg	1650kg
Charging efficiency	90%	90%	
Energy consumption	15.5 Kwh/100km	1.4L/20.9Kwh/100km	7.4L/100Km
Battery capacity	61.9Kwh	52L/ 17.6 kWh	66L
Voyage	400Km	80Km	-

2.2 System boundary

The functional unit is one of the important factors to consider when determining the scope of the study and is

also a standard used to measure the function of the system. The functional unit of this study is 1 km. In this study, battery and tire replacement are taken into consideration. Due to data limitations, the data about transportation, maintenance and sales are ignored. The system boundary is shown in Fig 1.

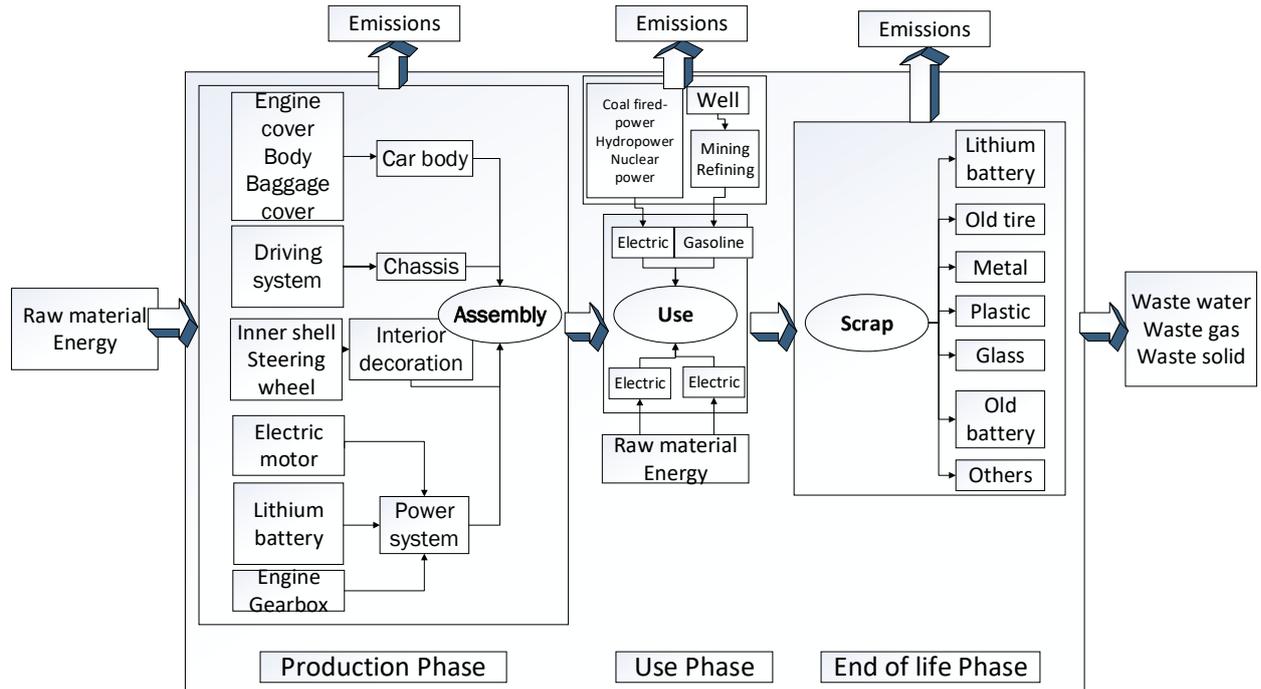


Fig 1. The system boundary of the Life Cycle Assessment

2.3 Inventory data

Inventory data analysis provides support for modeling. Collecting inventory data is a key step in life cycle assessment [9]. There are usually two sources of data: the actual production process and the database [10]. According to the goal and scope, we collect data of the vehicles are mainly the three types below.

(1) Data about manufacturing processes and power system production processes come from BYD official website and industry reports. In the raw material acquisition phase, some raw material mining data can't be accurately obtained, so we used approximate replacement for the raw materials that cannot obtain data.

(2) Data about vehicle energy consumption in use

phase and energy production come from the journals and references[34-38]. Data of crude oil, coal mining, gasoline refining, and electricity production were obtained from the National Bureau of Statistics.

(3) GaBi6 software has a built-in database, which contains the data of the scrapping and dismantling of the vehicles. The database is constructed by German PE International and the data have high accuracy [11]. The database is mainly built according to the German process level, so when obtained data from the database, we first select the data of China, then the global data, the German data and the EU data in order. The data structure of the vehicles' life cycle is shown in Tab 2.

Tab 2. Basic data of the vehicles

Type of vehicle	BYD Song Electric Vehicles	BYD Song Hybrid Vehicles	BYD Song Internal Combustion Engine Vehicles
	Ternary lithium battery	Ternary lithium battery	BYD476ZQA engine
	Electric Motor (single motor)	Electric motor (double motor)	Six-speed double-clutch gearbox
Power system	Disc brake	Disc brake	Disc brake
	Electric vehicle single speed gearbox	Six-speed double-clutch gearbox	
		BYD476ZQA engine	
	Frame	Steel, iron, aluminum, etc.	Steel, iron, aluminum, etc.
Body	Chassis wheel	Damping springs and metal parts	Damping springs and metal parts
		Rubber tires	Rubber tires
	Interior	Seats, windows, dashboards, etc.	Seats, windows, dashboards, etc.

2.4 Method

The study used an LCA framework that contains the goal and scope, inventory data and impact assessment based on the GaBi6 software and CML 2001 model. Life Cycle Assessment is the compiling and evaluation of the input and outputs and the potential environment impacts of a product system during its lifetime.[12] Based on the GaBi6 database and the additional data, the life cycle data of the three versions of BYD Song was constructed. On the basis of the Life Cycle Assessment and environment impacts, the system analyzed the key processes and

substances that cause damage [13].

The GaBi6 software includes many life cycle assessment methods, such as CML2001, Eco Indication99 and EDIP 97[4]. The CML2001 model is the method of the Centre for Environmental Studies of the University of Leiden and focuses on a series of environmental impact categories expressed in terms of emissions to the environment. The CML2001 model includes classification, characterization, and normalization.

3. Results

The explanation of the impact catalog is shown in tab3.

Tab3. Impact catalog

Impact catalog	Explanation	Impact catalog	Explanation
ADP	Abiotic depletion potential	ODP	Ozone depletion potential
GWP	Global warming potential.	HTP	Human toxicity potential
AP	Acidification potential	MAETP	Marine eutrophication potential
EP	Eutrophication potential	POCP	Photochemical potential
FAETP	Freshwater eutrophication potential	TETP	Terrestrial Eco toxicity Potential

The comparison of impact and proportions of the vehicles life cycle are shown in the Fig 2. In the whole life cycle, Abiotic Depletion Potential (ADP), Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) of Electric Vehicles are less than that of Hybrid Vehicles and Internal Combustion Engine Vehicles. The life cycle environment impact of Electric Vehicles is 1.7 times of the Internal Combustion Engine Vehicles and 1.4 times of the Hybrid Vehicles.

In the whole life cycle of Electric Vehicles, the environmental impact mainly occurs in the enabling stage, accounting for 88% of the total environmental impact., followed by raw material acquisition and manufacturing; For a single environmental emission impact type, the ranking is AP > GWP > POCP > EP > ODP. This is because the electric car consumes a lot of energy, in its use stage than the access to raw materials and the manufacturing stage of the comprehensive energy consumption much higher. For Internal Combustion Engine Vehicles, the environmental impact is mainly due to the use phase, which emits a lot of exhaust gas. The impact of hybrid cars on the environment also mainly occurs in the use stage.

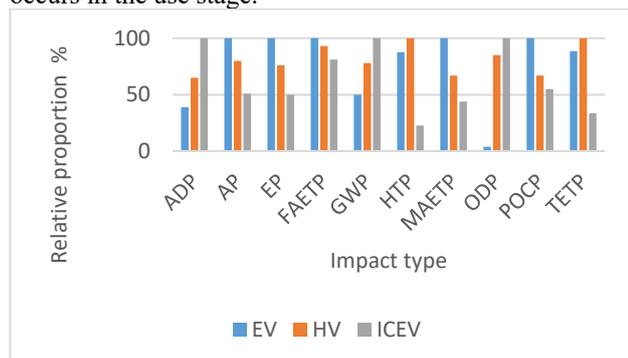


Fig 2. Comparison of environment impact in the life cycle

4. Conclusions

From the perspective of the life cycle of vehicles, Electric Vehicles has the potential to significantly improve the environmental impacts of ADP, GWP and ODP, especially for carbon emission reduction. It is nearly 50% of Electric vehicles' carbon emission reduction compared with the Internal Combustion Engine Vehicles. However, in the aspect such as AP, EP, FAETP, MAETP and POCP, Electric Vehicles has a bad performance compared with the Hybrid Vehicles and Internal Combustion Engine Vehicles.

With the increase of the proportion of clean energy, the carbon emission per unit mileage of electric vehicles has been greatly reduced and the efficiency of carbon emission reduction has gradually increased. The sensitivity of energy consumption in the use stage is greater than the sensitivity of energy consumption in the production stage.

Due to the heavy weight of the hybrid vehicle and the complicated manufacturing process, the use phase is more energy-saving and emission-reducing than the Internal Combustion Engine Vehicles. Therefore, the hybrid vehicle has a greater impact on the production phase than the electric vehicle and the Internal Combustion Engine Vehicles. In areas with a big proportion of coal-fired power in China, it is possible to give priority to the development of hybrid vehicles. Hybrid vehicles have advantages in terms of energy conservation and emission reduction than Internal Combustion Engine Vehicles and Electric Vehicles when the energy structure is led by the coal-fired power. Therefore, the hybrid vehicles have better environmental benefits when used in southern China and central China.

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