Research on Carbon Emission of ICEV and BEV Based on Life Cycle Assessment

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Abstract. Under the carbon neutrality and carbon peaking goals, the automobile industry faces severe challenges in reducing the carbon emissions. This research adopts life cycle assessment to measure the carbon emissions in fuel cycle from ICEV (internal combustion engine vehicle) and BEV (battery electric vehicle) sold in China to provide reference for future work in carbon emissions' reduction.

Keywords: Life cycle assessment, carbon emission, ICEV, BEV.

1. Introduction

With economic development and technological progress, the number of cars in China is growing rapidly. Although the use of cars has brought a lot of convenience to people's life, its rapid growth has also caused pollution to the environment. Greenhouse gas emissions from China's automotive industry have important characteristics such as rapid growth in total volume, strong industry chain drivers and high carbon intensity per vehicle. Promoting carbon neutrality in the automotive industry is of great significance for China to achieve carbon neutrality [1]. In order to follow the global trend of new energy vehicles, reduce CO_2 emissions from vehicles, improve air quality and reduce dependence on international oil, China has set the development of new energy vehicles as one of its national strategies [2]. As a result, China is fully pursuing the development of new energy vehicles such as electric vehicles and implementing a comprehensive electrification strategy. Total electrification has been widely discussed to achieve China's carbon neutrality and carbon peaking goals. Several studies have been conducted by domestic and international experts and scholars on the full life-cycle carbon emissions of BEV and ICEV, but the results of the studies have been very different. What are the actual carbon emissions from the electric vehicle chain in China? Are the carbon emissions of BEVs less than those of ICEVs? What needs to be focused on for the future development of BEVs and ICEVs? Exploration of these questions is of great importance in examining whether China's electrification strategy has been effective.

LCA (life cycle assessment) is an important method to analyze the total carbon emissions of products. It analyzes the energy and resource utilization and pollution emission in the whole process of production, transportation, sale, use and recycling from the resources obtained from nature [3]. It has been used as the basic technological tool for China to establish environmental policies. The LCA method is needed to compare the carbon emissions of ICEV and BEV, because simply looking at the greenhouse gas emissions of vehicle operation, ICEV is much larger than the carbon emissions of BEV. Therefore, the purpose for using LCA method is to make a more systematic and comprehensive evaluation.

Based on LCA method, this study selects the ICEV and BEV to compare their carbon emissions in three stages: raw material processing, vehicle production, and vehicle operation. This study establishes a material cycle mathematical model for upstream materials and key components of the motor vehicle. Based on the basic parameters of the two models given by the companies, the life cycle carbon emission (specifically CO_2) evaluation method for upstream materials, upstream fuel and vehicle operation is further established and corresponding recommendations for energy saving and emission reduction of the vehicle are given by the data model.

2. Method

2.1. System Boundaries

This paper adopts the Life Cycle Assessment (LCA) method to measure the life cycle carbon emissions of ICEV and BEV models sold in China. The research object of this paper is ICEV and BEV of a brand at the same price. The basic system boundary of vehicle's LCA study include vehicle material cycle and vehicle fuel cycle. The vehicle material cycle includes Auto Spare Parts Production, Vehicle Assembly and Maintenance. The vehicle fuel cycle includes fuel production (WTP) and fuel use (PTW), as shown in Fig.1. However, the system boundary of this study only does research on the carbon emissions of vehicle fuel cycle, which means the research only focuses on the carbon emissions from WTP and PTW phase. The carbon emissions generated by transportation of raw materials; the maintenance of automobile is not within the system boundaries of this study.

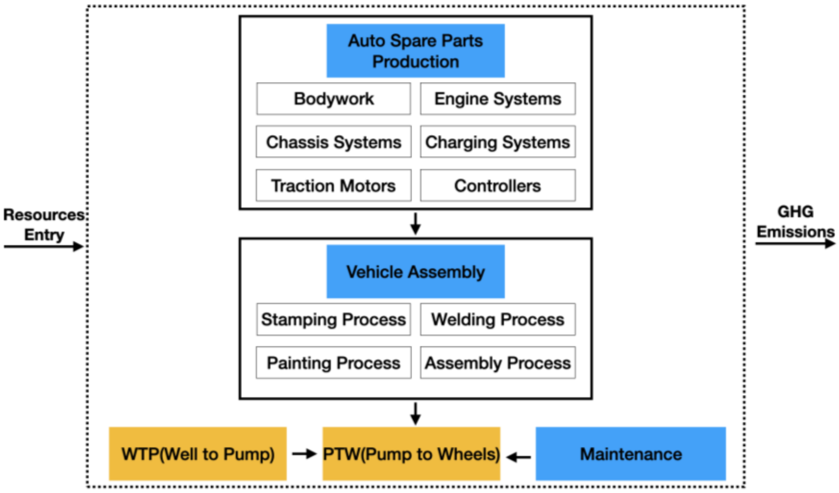

Figure 1. System Boundary

2.2. WTP Phase Life Cycle Calculation

Stages included in WTP phase are raw material extraction, raw material processing and conversion. WTP phase of the vehicles' life cycle is divided into two main types: the gasoline fuel production phase of ICEV and the BEV electrical energy supply phase. Their CO_2 emission coefficients are calculated separately and these data will be added to the calculation of the total CO_2 emissions of the PTW phase.

3. Result and discussion

3.1. Gasoline Fuel Production

3.1.1 The Production Process of Petrol

The production of gasoline can be divided into the following five processes: 1. the extraction of crude oil; 2. the transportation of crude oil(through pipeline) and the storage of crude oil tank; 3. crude oil in crude oil tanks is subjected to atmospheric and vacuum distillation to produce wax oil; 4. wax oil is subjected to catalytic cracking to become light oil and catalytic diesel; 5. light oil is subjected to S-ZORB to become S-ZORB gasoline; catalytic diesel is subjected to diesel reforming to become diesel reforming. gasoline. The mass ratio of S-ZORB gasoline to diesel reformate is 4: 1 [4, 5].

3.1.2 Calculation Formula

The following two formulas are used to calculate the carbon emission coefficient of gasoline production.

$$E_1 = \sum(E_i \times \frac{Q_i}{P}) + E_{H_2} \times W_{H_2} + \frac{H}{P} \times (\frac{44}{12}) \quad (1)$$

E_1: Carbon emission coefficient of the unitary installation in $\mathrm{t\,CO_2\,e \cdot t^{-1}}$
E_i: Carbon emission coefficient for different emission sources in $\mathrm{t\,CO_2\,e \cdot t^{-1}}$
Q_i: Consumption for the different emission sources in t
P: mass of oil processed in t
H: amount of catalyst burned in the unit, in t
E_{H_2}: Hydrogen consumption per unit of the hydrogenation unit in $\mathrm{t\,H_2 \cdot t^{-1}}$
W_{H_2}: Emission coefficient for hydrogen production in $\mathrm{t\,CO_2\,e \cdot t^{-1}\,H_2}$.

$$E_a = \sum(E_{si} \times R_i) \quad (2)$$

Ea: Carbon emission coefficient for the production phase in $(\mathrm{t\,CO_2\,e \cdot t^{-1}})$
Esi: Carbon emission coefficient for the different unitary installations in $(\mathrm{t\,CO_2\,e \cdot t^{-1}})$
Ri: weight of the different unitary units obtained by the retrospective method.

As the emission coefficients for crude oil extraction vary from region to region, the data provided by the literature for Chinese companies is used. Also, as crude oil is transported by pipeline, the carbon emission coefficient of its transportation process is too small to be negligible, therefore, the carbon emission from crude oil transportation will not be considered in our calculation process. In addition, we do not consider greenhouse gas emissions from oil loss.

3.1.3 Basic Parameters

We took China's crude oil extraction process emission coefficient of 0.3856t CO_2 e/t as our emission coefficient for the crude oil extraction component. Based on the *Provincial Greenhouse Gas Emissions Inventory* and the National Grid Emission coefficient data, the emission coefficients for each source are shown in Table 1.

Table 1. Emission coefficients of various emission sources

Emission Coefficient /CO_2 e·t^{-1}	Numerical Values	Emission Coefficient /CO_2 e·t^{-1}	Numerical Values
Electricity/(t CO_2 e· MW^{-1}·h^{-1})	0.9680	Circulating Water	0.0002
Fuel Gas	3.0144	Demineralised Water	0.0037
3.5 MPa Steam	0.3294	Deaerated Water	0.0243
1.5 MPa Steam	0.2995	Nitrogen/(t CO_2 e· Nm^{-3})	0.0006
0.5 MPa Steam	0.2471	Compressed Air/ (t CO_2 e· Nm^{-3})	0.0001
Fresh Water	0.0006		

3.1.4 Crude Oil Tank Farm

Crude oil enters the crude oil tank farm for storage and the energy consumption of this crude oil tank farm is represented in Table 2. Calculations based on formula 1 combined with the data in Table 2 give a total emission from the crude oil tank farm of 0. 0042 t CO_2 e/t.

Table 2. Energy consumption of crude oil tank farm

Emission Sources	Number	Unit
Unit Processing Volume	464658	t
Electricity	6240.33	MW·h
Fresh Water	2002	t
Circulating Water	68455311	t
Compressed Air	1099831	Nm^3

3.1.5 Atmospheric and Vacuum Distillation

The crude oil is passed through an atmospheric and vacuum distillation unit to produce wax oil and the energy consumption of this atmospheric and vacuum distillation unit is represented in Table 3. formula 1 and formula 2, combined with the data in Table III, give a total energy consumption of 0.04286t CO_2 e·t^{-1} for the atmospheric and vacuum distillation unit.

Table 3. Energy consumption of atmospheric and vacuum distillation units

Emission Sources	Number	Unit
Unit Processing Volume	4646581	t
Electricity	28940.37	MW·h
Fuel Gas	47390	t
1.5 MPa Steam	65681	t
0.5 MPa Steam	23334	t
Fresh Water	4368	t
Circulating Water	11781425	t
Demineralised Water	43168	t
Nitrogen	25031	Nm^3
Compressed Air	3198568	Nm^3

3.1.6 Fluid Catalytic Cracking (FCC)

The emissions from the catalytic cracking process, which produces light oil and catalytic diesel, are divided into two components: energy emissions from its units and catalyst scorching emissions. The energy consumption emissions of a catalytic cracking unit are shown in Table 4. The energy consumption emission Coefficient of the FCC unit is calculated according to formula 1 as -0. 03112t CO_2 e/t. The total emissions from FCC are 0.02928 t CO_2 e/t according to formula 2.

Table 4. Energy consumption of FCC units

Emission Sources	Number	Unit
Unit Processing Volume	3273145	t
Electricity	68954.21	MW·h
3.5 MPa Steam	-336198	t
1.5 MPa Steam	-260093	t
Fresh Water	201948	t
Circulating Water	55694096	t
Demineralised Water	439564	t
Nitrogen	1956636	Nm^3
Compressed Air	59846543	Nm^3

3.1.7 S-ZORB

Light oil can be passed through the S-ZORB unit to produce S-ZORB gasoline feed. Its emissions can be divided into energy consumption emissions, char emissions and hydrogen consumption emissions. The energy consumption emissions of each emission source of the S-ZORB unit are shown in Table 5. According to formula 1, the energy consumption emission of S-ZORB unit is 0.02864t CO_2 e/t. According to the data provided by the enterprise, the amount of coke burned in S-ZORB unit is 300t, and according to formula 1, its char emission can be calculated as 0.0008t CO_2 e/t. Hydrogen used in S-ZORB comes from the enterprise 50,000 t hydrogen production. The emission Coefficient of hydrogen production is 5.15t CO_2 e/tH2. According to the company's statistics, the S-ZORB unit consumes 1,978 t of hydrogen in a certain year, and the hydrogen consumption emission Coefficient of the S-ZORB unit is 0.007158t CO_2 e/t. Finally, the total emission of S-ZORB is 0.02928t CO_2 e/t according to formula 2.

Table 5. Energy consumption of S-ZORB units

Emission Sources	Number	Unit
Unit processing Volume	1421226	t
Electricity	7159.02	MW·h
Fuel Gas	8462	t
1.5 MPa Steam	12291	t
Fresh Water	1978	t
Circulating Water	1225374	t
Deaerated Water	1503	t
Nitrogen	6152385	Nm^3
Compressed Air	6123992	Nm^3

3.1.8 Diesel Fuel Reformulation Unit

The catalytic diesel fuel becomes diesel reforming gasoline material through the diesel reforming unit. Its emissions are divided into two major parts, which are energy emissions and hydrogen consumption emissions. The energy emissions of each emission source of the diesel reformer are shown in Fig. 6. According to formula 1, the energy consumption emission of the diesel reformer is 0.05592t CO_2 e/t. The hydrogen used in the diesel reformer comes from the 50,000t hydrogen production unit of the enterprise, and the hydrogen production emission coefficient is 5. 15 t CO_2 e/tH2. 14,000 t of hydrogen is consumed in the diesel reformer according to the enterprise statistics. the hydrogen consumption emission coefficient of the diesel reformer is 0.1031t CO_2 e/t according to formula 1. Finally, the total emission of the diesel reformer is 0.03180 t CO_2 e/t according to formula 2.

Table 6. Energy consumption of diesel upgrading units

Emission Sources	Number	Unit
Unit Processing Volume	699189	t
Electricity	23694.67	MW·h
Fuel Gas	2768	t
3.5 MPa Steam	149983	t
1.5 MPa Steam	-160137	t
Circulating Water	19757632	t
Demineralised Water	26598	t
Deaerated Water	13671	t
Nitrogen	2816520	Nm^3
Compressed Air	3060131	Nm^3

3.1.9 Summary of Carbon Emissions from Gasoline Production

Finally, the gasoline composition produced by each unitary unit and the carbon emission coefficient of the corresponding unitary unit were derived from the calculations and icons as shown in Table 7. It totals 0.2563t CO_2 e/t, and adding China's carbon emission coefficient of 0.3856 t CO_2 e/t for extracted crude oil is the total emission coefficient of 0.6419 t CO_2 e/t for fuel production.

Table 7. Summary of carbon emissions during the gasoline production phase

Gasoline components	Specific gravity of the device	Unitary devices	Carbon emission coefficient /(CO_2 e·t^{-1})	Emissions /(CO_2 e·t^{-1})
Crude Oil	1	Crude Oil Storage Tanks	0.00427	0.00427
Wax Oil	1	Atmospheric and Vacuum Distillation	0.04286	0.04286
Light Oil	0.8	Catalytic Cracking	0.14810	0.1481
Catalytic Diesel	0.2			
S-ZORB Petrol	0.8	S-ZORB	0.0366	0.02928
Diesel Reformulated Petrol	0.2	Diesel Reformulation	0.159	0.0318
Total				0.2563

3.2. Electricity Production

3.2.1 Calculation Formula

We calculate the electricity production emissions based on this formula:

$$E_3 = \sum y_i \times \gamma_i \quad (3)$$

E_3: Total emissions from electricity production $g\,CO_2 \cdot (kWh)^{-1}$.
y_i: Emission coefficients for each electric power structure $g\,CO_2 \cdot (kWh)^{-1}$.
γ_i: Power generation ratio of each electric power structure.

3.2.2 Data and Conclusion

Based on the literature [6-9], we summarized the carbon emission coefficients of thermal power generation, hydroelectric power generation, wind power generation, solar power generation and nuclear power generation in China. What is worth mentioning here is that we found in the literature that the carbon emission range of hydropower stations is roughly 3.7 ~ 44g CO_2/(kWh). Therefore, we choose 20g CO_2/(kWh) as the carbon emission coefficient of hydroelectric power generation. According to the statistics of the National Bureau of Statistics, the proportion of China's power supply structure in 2021 is shown in Table 8, and the corresponding emission coefficient is weighted. So, we conclude that the total emissions from electricity production is 700.66g CO_2/(kWh).

Table 8. Different Electric Power Structures' Emissions

Electric Power Structure	Power Generation Ratio	Emission coefficient ($g\,CO_2 \cdot (kWh)^{-1}$)	Emissions ($g\,CO_2 \cdot (kWh)^{-1}$
Thermal Power	71.13%	975.24	693.69
Hydroelectric Power	14.60%	20	2.92
Wind Power	6.99%	9.5	0.66
Nuclear Power	5.02%	28.8	1.45
Solar Power	2.26%	86	1.94

3.3. PTW Phase Life Cycle Calculation

Next, we will calculate the carbon emission in the PTW phase [10]. The PTW phase here refers to the CO_2 emissions from fuel (electric) driven vehicles after they are in operation. We don't count the emissions they produce. In order to make our calculation results more representative, we used two medium-sized SUVs ---- BMW X3 and BMW iX3 [11, 12], which are of the same brand but of different energy types with high sales volume in China, for comparison calculation. The BMW X3 is ICEV and BMW iX3 is BEV. Their basic parameters are shown in Table 9.

Table 9. Basic Parameters of BMW X3 and BMW iX3

Projects	BMW X3	BMW iX3
Body Type	Five-door, Five-seat SUV	Five-door, five-seat SUV
Vehicle Weight (kg)	1857	2190
WLTC Combined Fuel Consumption (L/100km)	8.3	-
100km Power Consumption (kWh/100km)	-	15.1
Battery Capacity (kwh)	-	80
Fuel Tank Volume (L)	65	-
CLTC Pure Electric Range (km)	-	550

3.3.1 Calculation Formula and Calculation Results

We need to use two formulas to calculate fuel cycle emissions of ICEV and BEV respectively. The first is the ICEV emission formula:

$$E_I=0.725(E_1+E_2)\text{V} \tag{4}$$

E_i: the total emissions of ICEV in fuel cycle in $\mathrm{t\,CO_2}$
E_1: the emission coefficient in WTP phase for ICEV in $\mathrm{t\,CO_2\,e\cdot t^{-1}}$
E_2: the emission coefficient in PTW phase for ICEV in $\mathrm{t\,CO_2\,e\cdot t^{-1}}$
V: Consumption of gasoline
And the BEV emission formula is shown below:

$$E_B=E_3\times M \tag{5}$$

E_B: the total emissions of BEV in fuel cycle in g CO_2
E_3: the emission coefficient for BEV in $\mathrm{g\,CO_2\cdot(kWh)^{-1}}$
M: Consumption of electricity

When considering the PTW phase emissions of the two models, only ICEV has PTW phase emissions. When ICEV is running, the burning of gasoline fuel releases more carbon dioxide. The BEV, on the other hand, emits no tailpipes carbon dioxide emissions.

According to the Guidelines for Editing Provincial GHG Inventories, the CO_2 emission factor of gasoline combustion in China is 2.9251kg CO_2 e/kg. This data will be introduced into our formula 4 as E_2. We analyzed the basic parameters of BMW X3 and BMW iX3, and made the function of their driving distance and carbon dioxide emission, so as to observe their changing rules more conveniently.

Our function takes ICEV and BEV's driving distance as variable x and their CO_2 emission as variable y. We assume the driving distance in end-of-life phase of an EV is 250000km. So we take 50000km, 100000km, 150000km, 200000km, 250000km as the important points of EV's driving distance. The data of BMW X3 and BMW iX3 are shown in Fig.2.

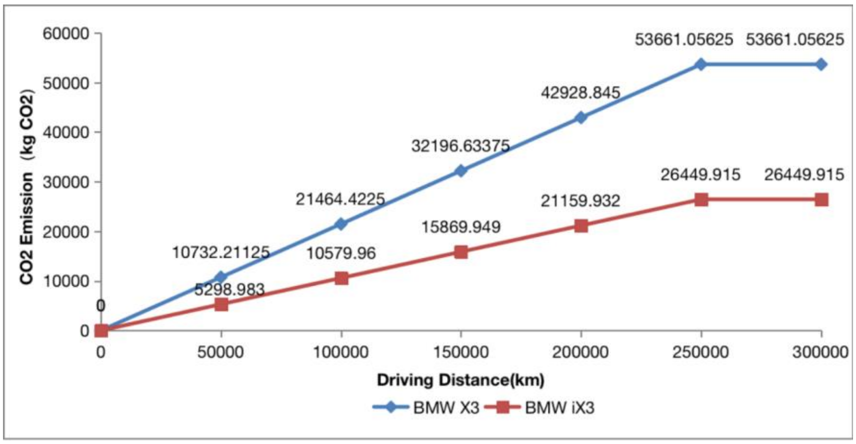

Figure 2. The CO_2 emissions of BMW X3 and BMW iX3

4. Conclusion

In this paper, LCA method was used to calculate the life cycle emissions of two ICEV and BEV passenger vehicles with high sales volume in the Chinese market, and a comprehensive comparative analysis of driving distance and carbon emissions was conducted. The main conclusions include the following. This study calculates the carbon emission coefficient of the fuel cycle stage of the two vehicles respectively from the WTP stage and PTW stage, and summarizes the emission coefficient of each stage and the total fuel cycle. The ICEV fuel cycle has a total emission factor of 3.5670kg CO_2 e $\cdot kg^{-1}$, while the BEV fuel cycle has a total emission factor of 0.70066kg CO_2/(kWh). We compared the relationship between driving distance and CO_2 emissions of BMW X3 (ICEV) and BMW iX3 (BEV). The conclusion shows that the carbon emission of BEV represented by BMW iX3 is 51% lower than that of ICEV represented by BMW X3. If only the fuel cycles of the two types of vehicles are compared, BEVs have significant carbon reduction advantages. This study did not calculate emissions during the assembly stage and maintenance stage of vehicles. According to

Kawamoto et al. 's calculations, the maintenance and assembly of BEVs will account for a large proportion of emissions, because the construction and maintenance of BEV batteries will emit a lot of greenhouse gases. This also makes the results of this study different from other studies.

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