Research on the whole life cycle energy consumption and pollution emission of new energy vehicles and traditional fuel vehicles based on the perspective of single vehicle currency of the same vehicle model

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Abstract: To construct an evaluation framework based on whole-life energy consumption and pollution emissions, the control variable method is used when selecting vehicles for comparison. By assessing a new energy vehicle (the Audi Q2L e-tron) and a traditional fuel vehicle (the Audi Q2L) of the same model, differences in emission and energy consumption are solely attributed to power forms. Results are monetized to facilitate analysis of the societal benefits of new energy vehicles, reflecting environmental impact in monetary terms. The results of the paper show that although the replacement of traditional fuel vehicles by new energy vehicles can achieve carbon emission reduction and considerable energy savings in the energy cycle, due to the fact that new energy vehicles produce more sulphur dioxide (SO_2) and nitrogen oxides (NO_x) in the production phase, the full replacement of traditional fuel vehicles by electric vehicles at this stage will not be able to achieve an improvement in the overall welfare of the society. Therefore, under the current conditions, the improvement of new energy vehicles should start with finding cleaner and more environmentally friendly ways in the manufacturing stage of automobiles, as well as modifying the way of producing electricity.

1. INTRODUCTION

As environmental and resource problems such as climate change, emission pollution, and the shortage of traditional fossil fuels become more and more serious, the State has gradually attached importance to energy conservation and environmental protection. In order to support the development of new energy vehicles, the State has listed new energy vehicles as one of the strategic emerging industries in the "Outline of the Fourteenth Five-Year Plan and Vision 2035 for the National Economic and Social Development of the People's Republic of China". Additionally, it has proposed the "New Energy Vehicle Industry Development Plan (2021-2035)" which aims to ensure that by 2025, the sales volume of new energy vehicles will reach the total sales volume of new automobiles. In the "Development Plan for New Energy Vehicle Industry (2021-2035)", it is proposed that the sales volume of new energy vehicles will reach about 20% of the total sales volume of new vehicles by 2025.

However, are new energy vehicles truly more low-carbon and environmentally friendly compared to traditional fuel vehicles, and is the cost of their utilization lower? Presently, China lacks a comprehensive assessment system for evaluating emissions reductions in new energy vehicles. This deficiency impedes China's new energy vehicles from progressing towards the objectives of low pollution and high developmental returns. Based on this, this paper through the development of China's new energy vehicles to systematically grasp the status quo, control the car with the same brand and the same model to ensure that the vehicle appearance, vehicle manufacturing process, automotive material composition, the type and number of parts, the overall quality, wind resistance coefficient, and other aspects of the data are the same, which is measured by the different emissions and energy consumption results are entirely caused by the different forms of power to compare a single new energy vehicle with a traditional fuel car. Comparing the pollution emission and energy cost of a single new energy vehicle with that of a conventional fuel vehicle over the whole life cycle, and subsequently monetising the data obtained, the final results can be more intuitively seen whether the replacement of fuel vehicles with new energy vehicles has significantly improved the social benefits, thus revealing the social impacts of replacing conventional fuel vehicles with new energy vehicles, and the social changes that may be triggered by the rapid emergence of the new energy automobile industry in China. Furthermore, this paper furnishes valuable insights for

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discussions on pertinent issues and aids in formulating policy proposals.

2. RESEARCH METHOD

This paper uses the life cycle assessment (LCA) methodology.The life cycle[1] refers to the entire process from production to use to end-of-life recycling, and the LCA methodology can be used to derive the environmental impacts of products at each stage. In the case of automobiles, this paper divides the life cycle of automobiles into the automobile manufacturing stage, the production of power batteries, the use of automobiles, and the end-of-life stage of automobiles. Otherwise, the impacts on the environment have been categorized into energy consumption and pollution emissions.

In this paper, the Audi Q2L and Audi Q2L e-tron have been chosen as the respective models for comparison between fuel-powered and electric vehicles. The aim is to control variables effectively, with both vehicles being sourced from the MQB platform of the Volkswagen Group in Germany. The only discernible difference between them is the type of energy source. Other key aspects such as vehicle exterior, interior, construction, body structure, materials, type and quantity of components, overall mass, and wind resistance exhibit nearly identical characteristics. This uniformity ensures that any variations in measured emissions and energy consumption are exclusively attributed to the differences in power forms, rather than the numerous other factors mentioned above. Notably, the paper does not encompass plug-in hybrid models. This omission is deliberate due to the fact that the emissions and energy consumption of such vehicles are contingent upon the owner's choice of using either fuel or electricity. Given the resultant variability in emissions based on usage patterns, plug-in hybrid vehicles are considered unsuitable for comparative analysis.

In terms of data collection, this paper argues that most academic articles use the Argonne National Laboratory's GREET vehicle life cycle database for life cycle calculations and that the databases for pollution and energy consumption at the vehicle manufacturing stage, vehicle use stage, and vehicle end-of-life stage originate from this model, which makes the data lack of relevance. In comparing the energy consumption and emissions of fuel-electric vehicles with those of new energy-electric vehicles, we have selected the Audi Q2L and Audi Q2L e-tron. However, the GREET model is essentially a weighted average of all the mainstream vehicles currently on the market. Equating this average to the Audi Q2L and Audi Q2L e-tron is inherently inaccurate. Therefore, we used the following method to calculate the lifecycle energy consumption and pollution emissions of fuel and electric vehicles.

3. ENERGY AND POLLUTION LAWS OVER THE LIFE CYCLE OF FUEL AND ELECTRIC VEHICLES

3.1 Energy consumption and pollutant emissions during the manufacturing phase of vehicle production (excluding batteries)

The Audi Q2L and Audi Q2L e-tron are equipped with a start-stop battery, while the Audi Q2L e-tron is also equipped with a power cell. When calculating the energy consumption and pollutant emissions of the vehicle's manufacturing phase, the start-stop battery is included in this case without the power cell.

The material of the main part of a car can be simplified to steel, cast iron, aluminium, copper, plastic, glass, rubber, and others.

Based on the data built into the GREET model in the Argonne National Laboratory's LCA report[2], it is possible to derive the percentage of each material excluding the power battery of an electric vehicle but including the start-stop battery of both. Combined with the energy and pollution coefficients of the various raw materials used in the manufacturing process (derived from the GREET model data for the entire life cycle of the vehicle), the emissions and energy consumption of both are shown in the following Table 1:

Table 1. Pollutant Emissions and Energy Consumption in Vehicle Production (excluding batteries)

Type of vehicle	Energy consumption (kJ)	Pollutant emissions (kg)						
		CO_2	CO	SO_2	NO_X	dust	CH_4	VOC
Audi Q2L	9×10^7	9623.99	166.47	87.6	24.47	159.9	21.56	0.62
Audi Q2Le-tron	8.68×10^7	9689.25	160.05	123.97	25.01	154.47	20.95	0.53

3.2 Energy Consumption and Pollution Emissions in the Production of Power Battery Stage

Although electric vehicles do not directly emit polluting gases during their use. However, their lithium-ion power batteries still generate energy consumption and pollution during the manufacturing process. As the mass of the lithium-ion power battery of an electric vehicle is very large, it will far exceed the energy consumption and pollution generated by the lead battery of a fuel vehicle during the manufacturing process. The data referenced at this stage is mainly based on the data provided by the GREET model, see Table 2:

Table 2. Pollution emissions and energy consumption in the production of automotive batteries

Type of vehicle	Energy consumption (kJ)	Pollutant emissions (kg)						
		CO_2	CO	SO_2	NO_X	dust	CH_4	VOC
Audi Q2L	1.58×10^5	8.74	0.0093	0.262	0.019	0.058	0.08	0.014
Audi Q2L e-tron	3.55×10^7	2925.6	1.1	15.16	4.5	5.51	11.02	0.58

3.3 Stages of vehicle use

3.3.1 Calculation methods and formulae in this paper

The GREET model data lacks specificity as it provides a weighted average of mainstream cars, failing to capture the unique characteristics of vehicles like the Audi Q2L and Audi Q2L e-tron. However, the reason we previously used GREET model data for the production phase of the vehicle was that it was difficult to accurately obtain data on energy consumption and pollution emissions for the Audi Q2L and Audi Q2L e-tron during the production phase. In contrast, data on fuel consumption, electricity consumption, and harmful gas emissions are relatively easy to obtain during the vehicle's driving phase, so we decided to discard the LCA research methodology[3].

For the fuel car Audi Q2L, it is assumed that its unit fuel consumption is C L/km, the total mileage during its life cycle is S km, the density of petrol is ρ kg/L, the calorific value of petrol is Q kJ/kg, and the total energy consumption is EC kJ. its total energy consumption during its life cycle is calculated by Equation (1) as follows:

$$\mathrm{EC} = \mathrm{C} \cdot \mathrm{S} \cdot \rho \cdot \mathrm{Q} \tag{1}$$

Currently, the National Stage VI Motor Vehicle Pollutant Emission Standard specifies the limit value of Likg/km for pollutants emitted per unit km from fuel vehicles, so the total mass M of pollutants emitted over the life cycle of the Audi Q2L can be calculated by Equation (2):

$$\mathrm{M} = \mathrm{Li} \cdot \mathrm{S} \tag{2}$$

For the electric vehicle Audi Q2L e-tron, it is assumed that the unit power consumption is C kWh/km, the total driving range over the life cycle is S km, and the total energy consumption is EC kJ. According to the unit conversion, 1kWh = 3600kJ. Its total energy consumption during its life cycle is calculated by Equation (3) as follows:

$$\mathrm{EC} = \mathrm{C} \cdot \mathrm{S} \cdot 3600 \tag{3}$$

Pollution from electric vehicles comes mainly from the electric energy production stage. The energy consumption calculated in the above equation is the actual energy consumed by the vehicle. However, electricity is lost in the production stage, transmission stage, and charging stage. Therefore, the efficiency of electricity generation is not 100 percent. These efficiency ratios are available in official ONS data and the relevant literature. Setting the efficiency as η and the raw energy consumption as EC0 , Equation (4):

$$\mathrm{EC}_0 = \eta \times \mathrm{EC} \tag{4}$$

By reviewing the literature, it can be learnt that the mass of pollutants to be emitted per 1 kWh of electricity produced is m. Then the total mass of pollutants emitted during electricity production, M, can be calculated by Equation (5):

$$\mathrm{M} = \mathrm{m} \cdot \mathrm{EC}_0 \tag{5}$$

3.3.2 Calculation of energy consumption in the use phase of the vehicle

Determining the mileage of a car during its operational phase is a critical consideration. There are significant differences in the usage habits of different car owners, so there is no uniform standard for the mileage of each car during its usage phase. To ensure precision, reliance on official data is essential. According to the "Regulations on Compulsory Motor Vehicle Retirement Standards" issued by the State, both vehicles are classified as small and micro non-operating passenger vehicles, and their service life is recommended to be retired after 600,000 km. Therefore, we have established the mileage of these vehicles to be 600,000 kilometres.

Let the total mileage driven by the Audi Q2L during the use phase be S_1 , the fuel consumption per unit mile be c_1 , the density of petrol be ρ, the calorific value of petrol be q, and the total energy consumed during the use phase be Q_1 . The total energy consumed by the Audi Q2L is given by:

$$\mathrm{Q}_1 = \mathrm{S}_1 \cdot \mathrm{c}_1 \cdot \rho \cdot \mathrm{q} \tag{6}$$

According to the official data, S_1 = 600,000km, c_1 = 6.1L/100km, ρ = 0.73kg/L, q = 46,000kJ/kg. The calculation gives the total energy consumed by the Audi Q2L over its life cycle as Q_1 = 1.23 x 10 9kJ

Data from the National Bureau of Statistics shows that China's total refining efficiency over the last decade has been 95%, indicating that the efficiency of refining crude oil into petrol is 95%. Therefore, the actual energy consumption of the Audi Q2L during its lifetime is 1.23×10 9 ÷ 95% = 1.3×10 9kJ.

Let the total distance travelled by the Audi Q2L e-tron during the use phase be S_2 , the electricity consumption per unit mile be c_2 , and the total energy consumed during the use phase be Q_2 . The formula for calculating the total energy consumed is:

$$\mathrm{Q}_2 = \mathrm{S}_2 \cdot \mathrm{c}_2 \tag{7}$$

According to the official data, S_2 = 600,000km, c_2 = 13.9kWh/100km, 1kWh = 3,600kJ. The calculation gives the total energy consumed by the Audi Q2L e-tron over its life cycle as Q_2 = 83,400kWh = 3×10 8kJ

Taking the above data into account, we can conclude that, all other indicators being equal, the total energy consumption of a purely electric vehicle is only 23 per cent of that of a purely fuel-efficient vehicle.

As evident from the previous figures, the Audi Q2L has a total mass of 1,405 kilograms and the Audi Q2L e-tron has a total mass of 1,610 kilograms. This is due to the fact that the mass of the powertrain of an electric car is much greater than that of a fuel vehicle, and the battery in particular is significantly greater than that of fuel. Despite the theoretical expectation that electric cars should consume more energy, the opposite holds true. This is because the energy conversion efficiency of an electric motor is much higher than that of an internal combustion engine[4].

3.3.3 Calculation of pollution emissions during the use phase of the vehicle

The Audi Q2L complies with the most stringent China 6B emission standards, including carbon monoxide (CO) at 500 mg/km, non-methane hydrocarbons (NMHC) at 35 mg/km, nitrogen oxides (NOX) at 35 mg/km, and particulate matter (PM) at 3 mg/km. Through calculations, the pollutants emitted by the Audi Q2L over its entire 600,000-kilometer usage cycle are shown in the Table 3:

Table 3. Emissions of pollutants from the Audi Q2L over its lifetime

Type of pollutant	CO	NMHC	NO_X	PM	CO_2
Pollutant mass (kg)	300	21	21	1.8	81830

3.3.4 Calculation of energy consumption and pollutant emissions during the electricity production phase

The Audi Q2L e-tron does not emit pollutants directly into the atmosphere during its life cycle. However, as the country's electricity generation relies mainly on thermal power generation, the environmental pollution caused by electric vehicles is mainly concentrated in the electricity production phase. According to the National Bureau of Statistics, around 45 per cent of the thermal energy in the process is converted into electricity, while the remaining 55 per cent is wasted in the form of heat.

Based on the emission standards for power plants, the mass of pollutants emitted per 1kWh of production, and taking into account the wasted heat, the total pollutant emissions during the electricity production phase were calculated as: 2.7 kg of dust, 39,685 kg of carbon dioxide, 18.6 kg of sulphur dioxide, and 26.7 kg of nitrogen oxides.

The combined calculations give us the energy consumption and pollution emissions of the Audi Q2L and Q2L e-tron in the use phase, as detailed in Table 4.

Table 4. Energy consumption and pollution emissions of the Audi Q2L and Q2L e-tron in the use phase and in the electricity production phase

Type of vehicle	Pollutant type and emission (kg)							Energy consumption (kJ)
	CO	CO_2	SO_2	NO_x	NMHC	PM (dust)	PN (particulate matter)	
Audi Q2L	300	81830	-	21	1.8	1.8	3.6×10^{11} pcs.	1.3×10^9
Audi Q2L e-tron	-	39685	18.6	26.7	-	2.7	-	5.71×10^8

Upon comparing the calculated results, we observe that electric vehicles exhibit approximately 50% lower greenhouse gas emissions in terms of CO2 and energy consumption during the usage stage, compared to conventional fuel vehicles. However, there are differences in the types of pollutants emitted by each vehicle. Both types emit NO_X and PM. Conventional fuel vehicles emit additional pollutants such as CO, NMHC, and PN, while electric vehicles emit additional SO_2, although the difference in emission quantities is not significant. Thus, from this perspective, the advantage of electric vehicles over conventional fuel vehicles in mitigating environmental pollution is not particularly pronounced. Their most significant advantage lies in reducing energy consumption and mitigating the trend of climate change.

3.4 Calculation of energy consumption and pollutant emissions at the end-of-life stage of a vehicle

China has not yet established a standardised vehicle scrapping standard. In order to ensure the fairness of the data, we chose to use the data in the GREET model.

Yan Huajun *et al.* (2018) selected Santana, a fuel vehicle weighing 1100 kg, and BYD E6, an electric vehicle weighing 2295 kg, as their research subjects. They calculated their pollutant emissions and energy consumption at the end-of-life stage by using the GREET model data. However, the pollutant emission coefficients of these two vehicles at the end-of-life stage are not provided in the paper. Nevertheless, it is possible to extrapolate the pollutant emissions of the Audi Q2L and Audi Q2L e-tron from their calculations.

Table 5. Pollutant emissions and energy consumption at end-of-life for the Audi Q2L and Audi Q2L e-tron

Type of vehicle	Energy consumption (kJ)	Pollutant emissions (kg)						
		CO_2	CO	SO_2	NO_x	dust	CH_4	VOC
Audi Q2L	2.54 x 106	218.41	0.04	0.85	0.33	0.17	0.77	0.02
Audi Q2L e-tron	3.82 x 107	3283.14	0.53	12.77	4.98	2.5	11.58	0.29

It can be deduced from the data in the Table 5 that electric vehicles emit significantly more pollutants and consume significantly more energy at the end-of-life stage than fuel vehicles. This phenomenon is attributed to the fact[5] that the power batteries of electric vehicles contain more complex metal ions, which makes the end-of-life and recycling process more complicated.

3.5 Comparative analysis of life cycle energy consumption and pollution emissions

Summing the energy consumption and pollutant emissions of the four phases of vehicle manufacturing,

 https://doi.org/10.1051/e3sconf/202452803018

fuel and electricity production, vehicle use, and vehicle end-of-life, table 6 is obtained.

Table 6. Comparison of life cycle energy consumption and pollutant emissions between fuel and electric vehicles

Type of vehicle	Energy consumption (kJ)	Pollutant emissions (kg)						
		CO_2	CO	SO_2	NO_x	dust	CH_4	VOC
Audi Q2L	1.39×10^9	91681.14	466.51	88.71	45.82	161.92	22.41	0.65
Audi Q2L e-tron	8.78×10^8	55582.99	161.68	170.5	61.19	165.19	43.55	1.4

3.6 Calculation of environmental impact potential over the life cycle

The potential environmental impacts of the Audi Q2L and Audi Q2L e-tron are shown in Table 7:

Table 7. Potential environmental impacts over the life cycle of fuel and electric vehicles

Type of vehicle	global warming (PRC usage)	acidification	photochemical smog	Smoke and dust
Audi Q2L	92151.79 kg	120.78 kg	14.26kg	161.92kg
Audi Q2L e-tron	56497.50 kg	213.33 kg	6.86kg	165.19kg

It's evident that fuel cars exert a greater impact on global warming and photochemical smog, while electric cars have a greater impact on acidification. The reason for this is that fuel cars emit more CO_2 and CO, and electric cars emit more SO_2 and NO_X in the process of electricity production.

4. ANALYSIS OF RESULTS

4.1 Analysis of energy consumption

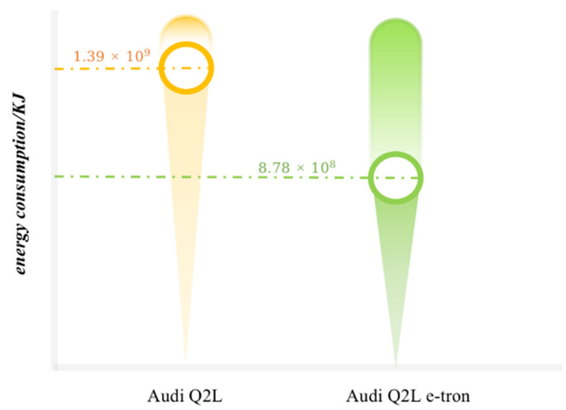

Figure 1. Full life cycle energy consumption of the Audi Q2L and Audi Q2L e-tron

From Figure 1 we get the full life cycle energy consumption of Audi Q2L is 1.39×109 KJ while the full life cycle energy consumption of Audi Q2L e-tron is 8.78×108 KJ.

Firstly, the relatively high energy consumption of the Audi Q2L (Fuel Vehicle) is mainly related to the fact that Fuel Vehicles rely on fossil fuels in their use. Thermal power generation is usually one of the main sources of fossil fuels, and the energy costs of fuel vehicles can be affected by the price and stability of fuel supply[6]. In addition, certain energy losses in thermal power generation reduce the energy efficiency of the whole system.

In comparison, the Audi Q2L e-tron (New Energy Electric Vehicle) is superior in terms of energy consumption. Firstly, electric vehicles use batteries as energy storage devices, and the manufacturing process of batteries may involve some energy consumption. However, EVs are more energy efficient in the use phase, as electric motors are typically more efficient at conversion than internal combustion engines. In addition, the overall environmental impact of electric vehicles will be lower if the electricity comes from renewable sources, rather than relying on high-emission energy sources such as thermal power generation.

Taking energy costs, thermal power generation and energy efficiency into account, the Audi Q2L e-tron offers advantages in terms of energy consumption and environmental impact over the entire life cycle. This underlines the potential of electric vehicles as a sustainable mode of mobility, particularly in the context of the drive to use renewable energy sources.

4.2 Analysis of pollutant emissions

4.2.1 Emissions perspective

Table 8. Total Pollutant Gas Emissions by Life Cycle Stage for Audi Q2L and Audi Q2L e-tron

Type of vehicle	Total pollutant gas emissions			
	The automotive production stage	Battery production stage	Utilisation stage and electricity production stage	end-of-life stage
Audi Q2L	10084.61	9.1823	82152.8	220.59
Audi Q2L e-tron	10174.23	2963.47	39733	3315.79

Table 9. Audi Q2L and Audi Q2L e-tron life cycle stages CO_2 emissions

Type of vehicle	CO_2				
	The automotive	Battery production	Utilisation stage and	end-of-life stage	entire life cycle

	production stage	stage	electricity production stage		
Audi Q2L	9623.99	8.74	81830	218.41	91681.14
Audi Q2L e-tron	9689.25	2925.6	39685	3283.14	55582.99

The emissions of the Audi Q2L and Q2L e-tron in the use phase and the electricity production phase account for the majority of the life cycle emissions, and the most important of these emissions is CO_2.as shown by Table 8 and Table 9.

In the use phase of the Audi Q2L, the emission of 81,830 kg of CO2 raises concerns, significantly surpassing the 39,685 kg of CO2 emitted during the electric power production phase of the Audi Q2L e-tron. During the use phase of a fuel vehicle, CO_2 from the combustion of petroleum is the main source of pollution. This results in fuel cars contributing a significant amount of greenhouse gas emissions during use, which have a negative impact on the climate. The release of these greenhouse gases negatively impacts global warming, triggering extreme weather events and affecting the ecological balance. In terms of human health, extreme temperatures and meteorological events caused by climate change pose a threat to public health. As for electric vehicles, CO_2 emissions mainly come from the electricity production stage. At this stage, the way electricity is produced directly affects the overall environmental performance of electric vehicles. If the electricity comes from coal-fired or other high-carbon energy sources, CO_2 emissions will be relatively high. However, if renewable energy sources are used, CO_2 emissions will be significantly lower.New energy electric vehicles have made outstanding contributions in three aspects: environmental protection, energy protection, and energy security.

From the perspective of CO_2 emissions and the greenhouse effect, new energy electric vehicles have relatively low CO_2 emissions during the electricity production phase, especially if the electricity comes from renewable sources. This results in electric vehicles contributing less greenhouse gases over their lifecycle and a smaller burden on global climate change, which contributes to climate change mitigation and reduces the impact of global warming.

From the perspective of energy diversification and renewable resources, electrical energy can be produced from a wide range of renewable energy sources, such as solar and wind, thereby reducing dependence on finite fossil fuels, such as oil. This can help to promote energy diversification and reduce the overexploitation of finite resources[7].

From the perspective of improving energy security, the promotion of new energy electric vehicles has a positive impact on the country's energy security, as the country is able to reduce its dependence on imported oil, mitigate geopolitical risks, and build a more localised and sustainable energy system, thereby improving overall energy security. This is important for the country's economic stability and sustainable development.

4.2.2 Money volume perspective

Here we use monetary values to quantify greenhouse gas and air pollutant emissions. Regarding the cost of environmental pollution, there are many studies at home and abroad, and the commonly used methods to measure the cost of environmental pollution include the productivity change method, preventive expenditure method, replacement cost method, opportunity cost method[8], disease cost method and human capital method, alternative market method, etc. (Xu Songling, 1995; Zhou Yihong, 2004).

In this paper, the total social cost of pollutants is calculated by corresponding to the unit cost of the pollutant and the emission of the pollutant (Meng Xianchun, 2007), and the specific formula is as follows.

$$\mathrm{C} = \sum \mathrm{e_i} \times \mathrm{d_i} \tag{8}$$

Where: C is the total cost of pollutant emissions; ei is the amount of pollutant emissions; di is the unit cost of emissions of the corresponding pollutant.

The calculation of pollutant emission costs in this paper refers to Meng Xianchun (2007)[9], China's corresponding pollutant unit emission costs di .

$$\mathrm{d_i} = \mathrm{d'_i} \times \frac{\text{China's CPI in 2016}}{\text{China's CPI in 2000}} \times \mathrm{R} \tag{9}$$

Where: R is the annual average exchange rate of the euro to the renminbi in 2000; d'i is the unit emission cost of the corresponding pollutant in Europe in 2000, EUR/kg, from External Cost Values for EE SUT Framework (IER, 2010). d'i is the unit cost of emissions of the corresponding pollutant in Europe in 2000 in EUR/kg from the External Cost Values for EE SUT Framework (IER, 2010). d'i is obtained by adjusting d' using the Consumer Price Index (CPI) at constant 1978 prices and the annual average exchange rate of the euro to the renminbi for the year 2000 (1 euro = 7.63 yuan). The results are shown in Table 10.

Table 10. Unit costs for individual pollutant gases

emission	Unit cost/(€/t)	Unit cost/(Yuan/kg)
CO_2	21	0. 227
CH_4	480	5. 191
NO_x	6 700	72. 465
SO_x	6 500	70. 301
CO	62	0. 671
VOC	870	9. 410
dust	63 000	681. 384

Accordingly, we calculated the monetary value of pollution emissions at each stage.

Table 11. Monetisation of pollutant emissions over the life cycle of fuel and electric vehicles

Type of vehicle	Monetary value of pollutant emissions at each stage of the life cycle (Yuan)				
	The automotive production stage	Battery production stage	Utilisation stage and electricity production stage	end-of-life stage	entire life cycle
Audi Q2L	119298.987	61.721	21524.966	253.295	141133.539
Audi Q2L e-tron	118201.543	5873.793	14090.645	3770.548	141943.344

From Table 11, it's evident that the monetary value of the car production process constitutes the bulk of the total life cycle monetary value. Conversely, pollutant emissions dominate the total life cycle emissions during both the use and electricity production phases. The underlying reason for this phenomenon is that the dust generated in the automotive production process is of a much larger order of magnitude than in the use and electricity production phases (see Figure 2), and the unit cost of dust emissions is much higher than that of other pollutants (see Figure 3).

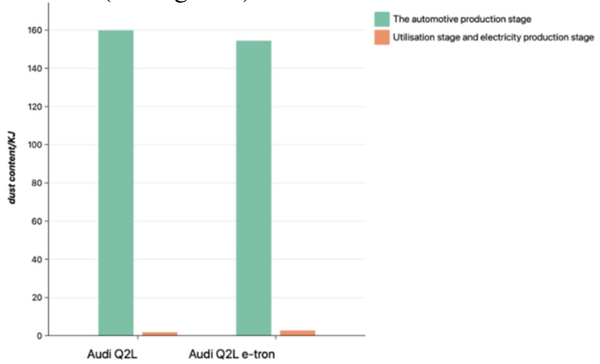

Figure 2. Dust emissions from the vehicle production phase versus the use phase and the electricity production phase

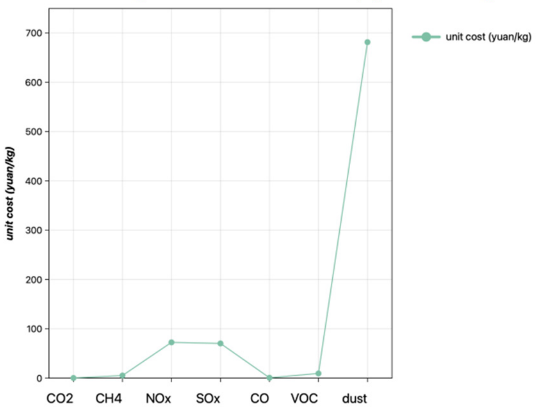

Figure 3. Line graph of unit costs for each pollutant

According to Figure 4, although electric vehicles emit significantly less greenhouse gases (CO_2) than fuel vehicles over their entire life cycle, the total greenhouse gas emissions are orders of magnitude greater than other pollutant gases. Theoretically, the social benefits of electric vehicles should be better than those of fuel vehicles, however, by calculating the monetary value, we find that the cost of pollutant gas emissions over the life cycle of electric vehicles is not lower than that of fuel vehicles. In fact, it is slightly higher, as depicted in Figure 5.

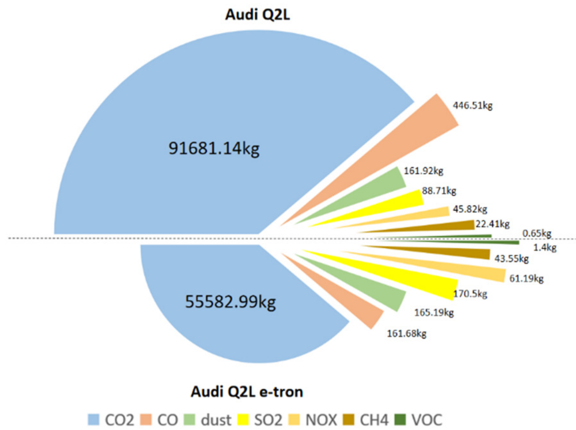

Figure 4. Emissions of individual pollutant gases over the entire life cycle of the Audi Q2L and Audi Q2L e-tron

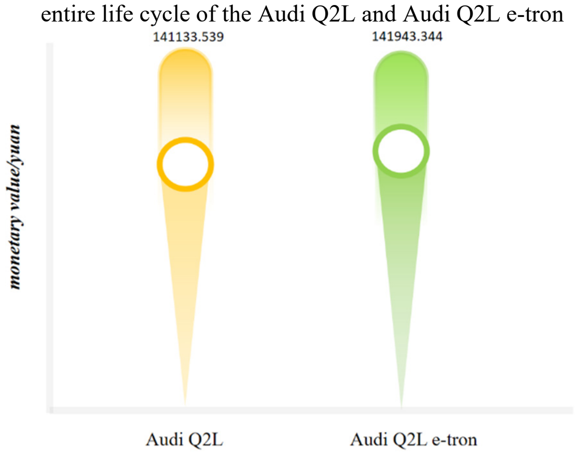

Figure 5. Monetary values over the entire life cycle of the Audi Q2L and Audi Q2L e-tron

The reason for this phenomenon is that although electric vehicles emit fewer greenhouse gases than gasoline vehicles throughout their entire lifecycle, the content of acid rain pollutants (SO_2) and nitrogen oxides (NO_X) is higher than that of gasoline vehicles (see Figure 6). Although the order of magnitude is smaller than greenhouse gases, the unit emission cost of acid rain pollutants and nitrogen oxides (NO_X: 72.465 yuan/kg, SO_x: 70.301 yuan/kg) The order of magnitude of CO_2 emissions is also much greater than the unit emission cost of greenhouse gases (CO_2: 0.227 yuan/kg). Therefore, when we separately calculate the emission costs of CO_2, SO_2, and NO_X throughout the entire lifecycle of fuel vehicles and electric vehicles, we found that although the CO_2 emission cost of fuel vehicles is higher than that of electric vehicles, the emission cost of SO_2 and NO_X of electric vehicles is also higher than that of fuel vehicles, and the sum of the emission costs of the three gases is similar for the two types of vehicles (see Figure 7).

Figure 6. Throughout the life cycle of the Audi Q2L and Audi Q2L e-tron SO_2 and NO_X content histograms

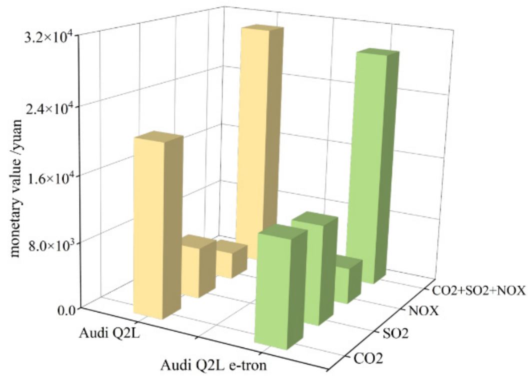

Figure 7. Audi Q2L and Audi Q2L e-tron throughout their life cycle CO_2 , SO_2 , NO_X Currency value histogram

Therefore, compared with fuel vehicles, although new energy electric vehicles greatly reduce greenhouse gas emissions throughout the life cycle, and play a role in addressing the problems of increasing climate change, serious emissions pollution, and shortage of traditional fossil fuels, as well as zero tailpipe emissions during driving and higher energy efficiency, they also increase sulfur dioxide as well as nitrogen oxides emissions, which aggravate the formation of acid rain, the destruction of the ozone layer, and the damage to plants and water. However, it also increases the emission of sulphur dioxide and nitrogen oxides, aggravating the formation of acid rain, the destruction of the ozone layer and the damage to plants and water bodies.From a monetary perspective, the social benefits of replacing fuel vehicles with new energy electric vehicles are not substantial when considering the monetization of pollutant gas emissions. Despite their environmental advantages, the overall impact on pollutant emissions does not translate into significant economic benefits.

5. CONCLUSIONS

This paper calculates the whole-life energy consumption and pollution emissions of the Audi Q2L and Audi Q2L e-tron, and presents the obtained results in monetary form, making the results more intuitively reflect the social benefits of the two vehicles.

The advantages of new energy electric vehicles in terms of total pollutant gas emissions remain significant, notably reducing carbon emissions and mitigating global warming. Therefore, the promotion of new energy electric vehicles is still imperative, but not directly in the national scope of the unified promotion, but should be first in the higher climate and health benefits and energy saving potential of the regional promotion, while the government incentives and subsidies in the policy should be maintained for a long time, in order to change the current electric vehicles and fuel vehicles in the competition, the status quo is still in a disadvantageous position.

However,due to the fact that new energy vehicles produce more sulphur dioxide (SO2) and nitrogen oxides (NOx) in the production phase, the full replacement of traditional fuel vehicles by electric vehicles at this stage will not be able to achieve an improvement in the overall welfare of the society. So under the existing conditions, the improvement of new energy vehicles should prioritize the adoption of cleaner and more environmentally friendly ways of producing vehicles at the manufacturing stage as well as reforming the way of producing electricity to improve the cleanliness of electricity[10]. At the same time, efforts should be made to find easier and cheaper ways to deal with nitrogen oxides and sulphur dioxide.

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