Based on a comparison of life-cycle carbon and pollution emissions of fuel-fired light-duty vehicles and new energy vehicles and an analysis of the influencing factors

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Abstract. Using the GREET model and the WTW system, compare and analyse the carbon emissions of fuel-light vehicles (E10, liquefied natural gas) and new energy vehicles (pure electric vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, liquefied hydrogen energy) during the entire life cycle of automobiles and pollutant emissions and compare the carbon emissions of plug-in hybrid vehicles under different power structures. The conclusions of the emissions of the two models, the number of emission factors, the contribution of various links of the two models, upstream emissions, vehicle life, light materials, and power structure are drawn, and relevant suggestions are given based on the conclusions.

1. Introduction

With the continuous improvement of people's material living standards, China's per capita car ownership has been increasing year after year, which has led to an increasing amount of greenhouse gases emitted by vehicles in China. At the same time, their exhaust emission pollutants also pose a severe threat to the environment and people. In 2019, proper motor vehicle ownership reached 348 million units, an increase of 6.4% over 2018, of which the right of new energy vehicles reached 381.0 million units. The total carbon emissions of the whole industry chain of passenger vehicles in China in 2020 will be about 670 million tons of carbon dioxide, of which 74% come from the use of cars and 26% from the upstream manufacturing industry chain. However, according to the 2019 data, the total national emissions of four pollutants from motor vehicles initially accounted for 16.038 million tonnes. Of these, emissions of carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter were 7.716 million tonnes, 1.892 million tonnes, 6.356 million tonnes and 74,000 tonnes, respectively. Automobiles are the main contributor to total pollutant emissions, emitting more than 90% of the four primary pollutants, including carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter [1]. However, the total life-cycle carbon emissions of China's automotive industry reached 1.2 billion tonnes, of which passenger cars account for about 58%. Pure electric vehicles emit 43.4% less carbon than conventional gasoline vehicles [2]. Therefore, this paper investigates the GREET model to compare the life-cycle carbon and pollution emissions of fuel-fired light-duty vehicles with those of new energy vehicles and analyse the influencing factors to provide relevant recommendations for reducing emissions.

Wang Enci, Fan Song and others proposed a method that concluded that developing new energy vehicles, especially electric vehicles, will do better than harm to solve the air pollution problem in China, as well as reduce emissions for both traditional and new energy vehicles [3]. This paper also uses the "well-to-wheel" evaluation system proposed by the Argonne National Laboratory and the GREET model to take a control variables approach. However, Wei concluded to take a small car that uses gasoline as the energy source and a new energy vehicle that is hybrid, plug-in hybrid and pure electric as the object of study, comparing the differences in emissions, and at the same time will provide multifaceted analysis of their influencing factors. Jin Lina, Lu Yiya and others wrote that in terms of energy consumption, new energy vehicles are more energy-efficient than traditional internal combustion engines; in terms of total emissions of pollutants, new energy vehicles have a noticeable effect on greenhouse gas emission reduction, and in terms of cost, except for hydrogen fuel cell vehicles, all other new energy vehicles cost less than In terms of price, except for hydrogen fuel cell vehicles, all other new energy vehicles are less expensive than conventional internal combustion engines and some suggestions[4].

This paper focuses on changing fuel-cell vehicles to plug-in hybrids. In contrast, Wei focuses only on carbon and pollution emissions and analyse the factors that influence them to provide recommendations for emission reductions in the production and operation phases of the vehicle. The objective of Wei's research is to compare the emissions of CO_2, CO, NOx, VOC, $PM_{2.5}$ and PM_{10} in terms of data and bar charts and to analyse most aspects of the production and operation phases of the vehicle. The impact factors are also analysed from most vehicle production and operation stages.

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2. Analytical Methods and Data

2.1 GREE transportation simulation model

Currently, the GREET transport simulation model allows researchers not only to evaluate the total life-cycle emissions and energy consumption of multiple transport fuels, multiple vehicles and related technologies but also to simulate future developments using different methods and parameter assumptions to carry out a comprehensive evaluation of the air pollutant emissions and energy consumption of new technologies [3]. The upstream phase of the automotive fuel cycle well to pump (WTP) refers to the upstream stage of the automotive fuel cycle, including the extraction, transport and storage of primary energy and the production, transportation, distribution and storage of fuel. Pump to wheels (PTW) The fuel consumption phase in the operation of a vehicle [5].

2.2 Data Selection

Currently, most fuel cars take E10 gasoline as their energy source, and such fuel cars are the target of this paper's fuel-light vehicle research. At the same time, as most current fuel cars and new energy vehicles adopt liquid energy, the target taken is liquid hydrogen energy and natural gas. The primary emissions are divided into carbon and pollution, as carbon dioxide accounts for a disproportionate share of carbon emissions. Because $PM_{2.5}$ and PM_{10} are the primary pollutants emitted from vehicles, sulphur dioxide and nitrogen oxides are the primary pollutants related to acid rain. At the same time, VOC is the representative of volatile gases, so the study is conducted.

3. Simulation comparison

In this paper, six vehicle types are selected for comparison. The GREET model is set up to calculate the carbon and pollution emissions of the six vehicle types and compare the differences between the six vehicle types.

3.1 Comparison of emissions between fuel-light vehicles and new energy-light vehicles

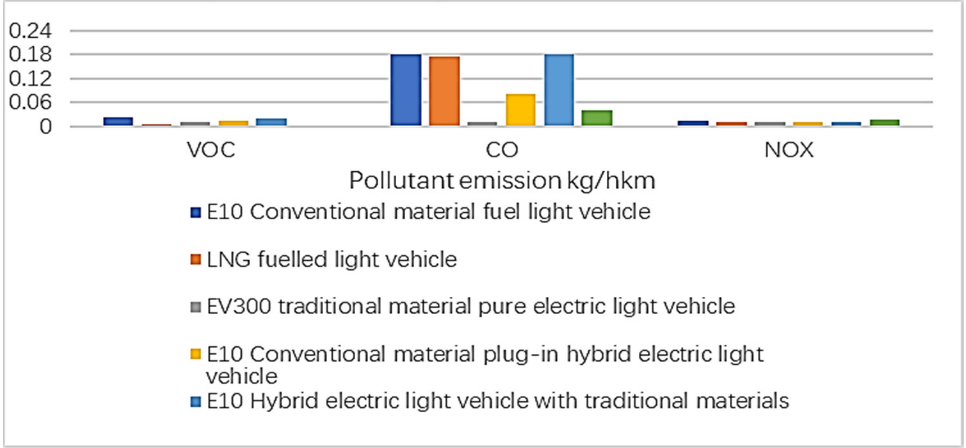

Fig. 1. Pollution emissions of fuel-light vehicles and new energy-light vehicles

The overall emission of fuel oil is higher than that of new energy light-duty vehicles. Pure electric and E10 fuel vehicles have the lowest and highest overall emissions, with a significant gap in CO emissions.Pollution emissions of fuel and new energy vehicles, as shown in Figure 1.

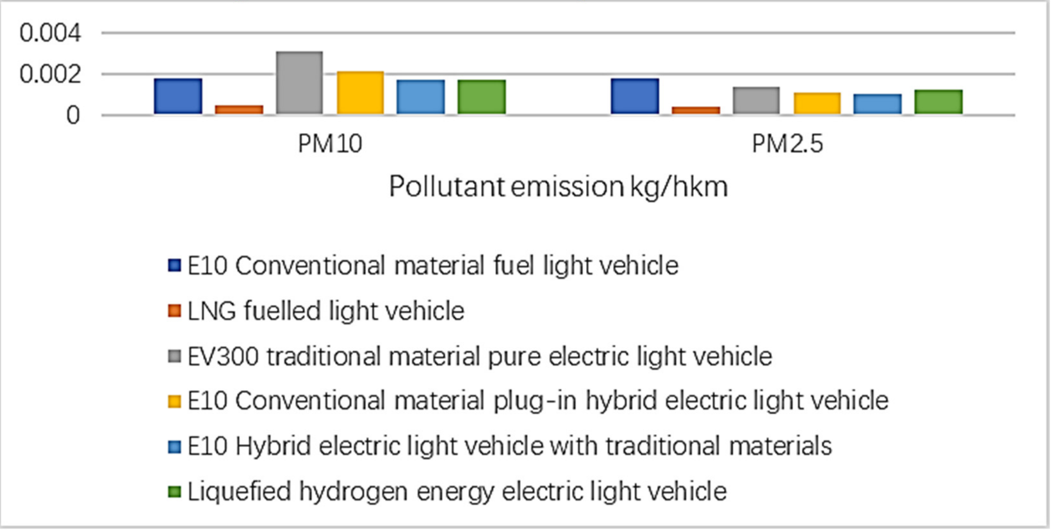

Fig. 2. $PM_{2.5}$ and PM_{10} pollution emissions of fuel-light vehicles and new energy-light vehicles

$PM_{2.5}$ and PM_{10} contribute to the overall pollutant emissions but cannot be ignored. For light-duty vehicles, the order of pollution emissions from largest to smallest is CO, VOC, NO_X, PM_{10}, and $PM_{2.5}$.As shown in Figure 2.

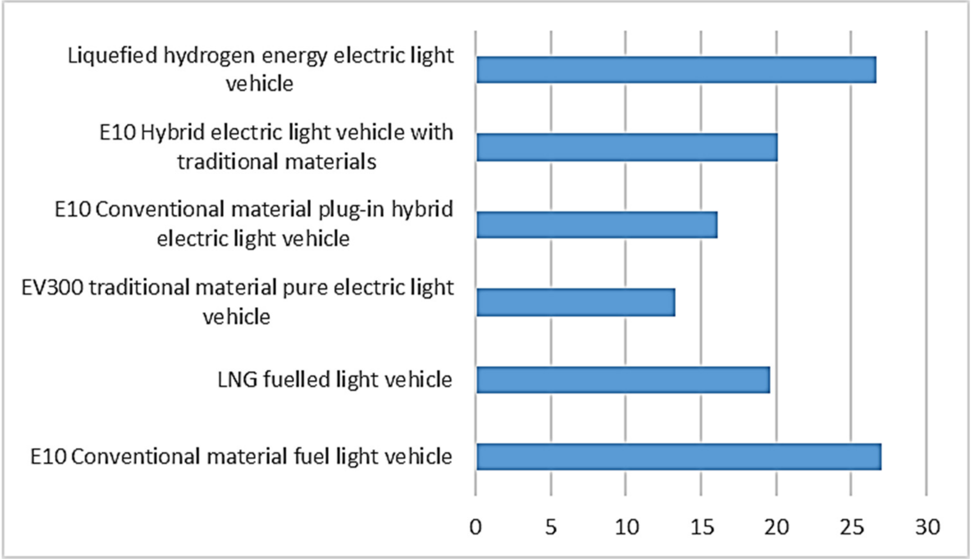

Fig. 3. Carbon emissions of fuel-light vehicles and new energy-light vehicles

The new energy has higher overall carbon emissions than fuel light vehicles, with E10 transmission fuel vehicles and pure electric vehicles having the most elevated, low carbon emissions, respectively, and liquefied hydrogen vehicles having the highest carbon emissions in new energy vehicles due to fuel.As shown in Figure 3.

3.2 Proportion of each link of fuel light vehicles and new energy-light vehicles

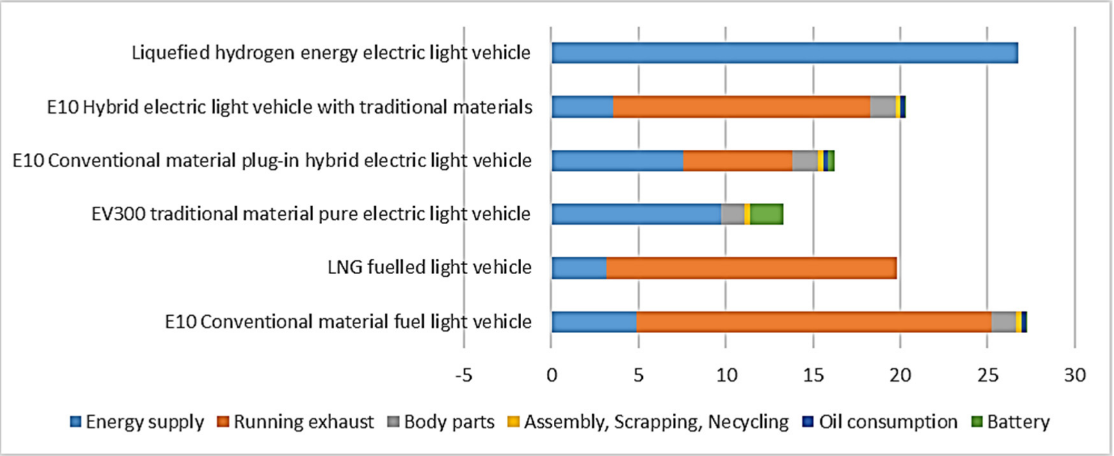

Fig. 4. Proportion of each link of emission of fuel-light vehicles and new energy-light vehicles

As shown in Figure 4. Emissions from the energy supply process are lower for fuel-fired light vehicles than for new energy light vehicles, with almost all carbon emissions from liquefied hydrogen energy vehicles being in the energy supply phase. For fuel-fired vehicles, most emissions are in the vehicle operation phase, with a small proportion in body parts, oil consumption and assembly, end-of-life and recycling. For new energy vehicles, most emissions are on the energy supply side. In contrast, liquefied hydrogen energy vehicles are almost entirely in the emissions produced by the energy supply. In contrast, hybrid light vehicles have significant emissions in the running phase, mainly because they cannot use electricity directly as an energy source like plug-in vehicles and need to burn oil to convert it into electricity when there is not enough electricity in the running process. Also, body parts, assembly, end-of-life, recycling and batteries must be addressed entirely, especially for purely electric vehicles, where battery emissions are the second largest of the total emissions. This is mainly because the electricity needed for electric cars comes from power plants, and electric vehicles burn coal, only shifting the pollution from operation to the energy supply stage near the power plant, for example. The manufacture of recycled batteries also brings in many emissions, so the overall emissions from electric vehicles are reasonable.

4. Simulation analysis

The carbon calculation refers to the total carbon emissions over the entire life cycle of a vehicle, and the carbon emissions target is different for each vehicle. It includes the design and production of the car, the output of each component, the production of the whole vehicle, the way the oil used in the car is refined, the total number of miles run, the amount of oil used and the amount of carbon emitted throughout the life of the car, and finally the end-of-life and recycling of the vehicle [6].

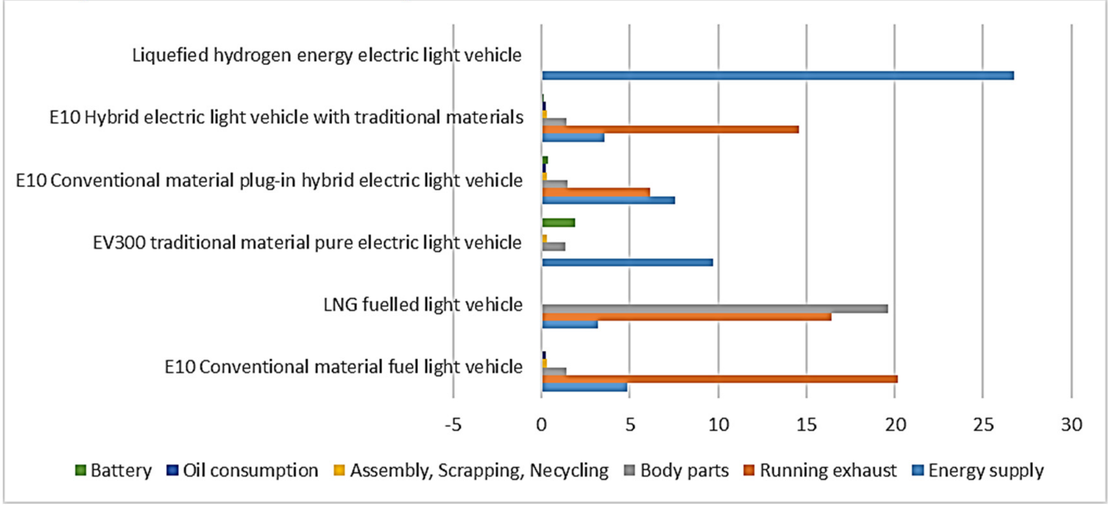

Fig. 5. Life cycle carbon emissions of light vehicles

As shown in Figure 5.For fuel-fired and hybrid electric vehicles, carbon emissions during the operation phase account for a large proportion of the total carbon emissions, mainly because gasoline is burned to convert heat energy into mechanical energy, eliminating many greenhouse gases. In contrast, heat energy is converted into electricity for hybrid vehicles. For new energy vehicles, carbon emissions are high in the energy supply phase, especially in the case of liquefied hydrogen vehicles, mainly because the charging and discharging process converts electrical and chemical energy during operation and does not release substances, so no CO_2 is emitted. For plug-in hybrids, both electricity and petrol can be used as energy supply, but as the number of kilometres travelled and the number of times the vehicle is charged and discharged increases, the amount of electricity stored in the battery decreases and petrol is still used in most cases, resulting in carbon emissions in the operating phase. However, the body parts of new energy vehicles also account for a certain proportion of carbon emissions, particularly in the case of liquefied natural gas vehicles, mainly because of severe upstream carbon emissions, such as the immaturity of the technology used to manufacture electric cells.

4.1 Upstream emission source analysis

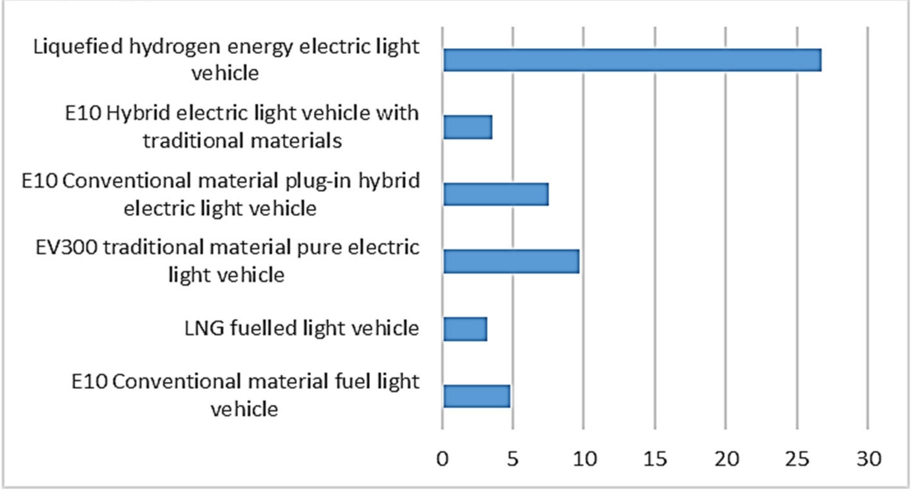

Fig. 6. The Whole Life Cycle of the Upstream Emission Source (WTP)

As shown in Figure 6.Upstream emission sources mainly refer to removing energy from the oil well to the fuel pump to supply the vehicle. Statistically, the upstream emission sources of fuel vehicles are smaller than those of new energy vehicles, mainly because the technology is not environmentally friendly and requires other non-renewable energy sources to convert electricity. For example, thermal power is required.

4.2 Vehicle life analysis

In terms of design life, the engine of a fuel car is designed to last 15 to 20 years, while the electric motor of a pure electric vehicle lasts around 20 years, so there is little difference between the two. So, the lifespan of electric and fuel vehicles depends mainly on the respective powertrains. In terms of service life, according to the Regulations on Compulsory Scrapping Standards for Motor Vehicles [7], which came into effect on May 1, 2013, small microcars need to be compulsorily scrapped after 600,000 km, and traditional fuel taxis generally run for about 1 million km before they are discarded. However, the batteries commonly used in new energy vehicles are ternary lithium batteries and lithium iron phosphate batteries. According to the life of the ternary lithium battery, the cycle life of the battery is around 2000 times. However, with the increase in recharges, the influence of the seasonal environment will reduce the storm's life, which will shorten the vehicle's life. The end-of-life of new energy vehicles is closer than that of fuel vehicles, which makes the recycling phase of new energy vehicles higher than fuel vehicles in terms of carbon emissions under the same conditions.

4.2.1 calculation

This calculation takes a control variant to forecast how many years of use of a new energy vehicle must be reached before the carbon emissions exceed those of a fuel vehicle. The relevant data are shown in Table 1 and Table 2.

Table 1. Vehicle parameters

Vehicle type/vehicle parameters (km, year)	Driving mileage	Obsolescence years	Average annual mileage
Pure electric vehicle	150000	9.375	16000
E10 traditional material fuel vehicle	300000	15	20000

Table 2. Emissions

Vehicle type/stage (kg/hkm).	Running exhaust gases	Energy supply	Body parts	Assembly, scrapping, recycling	Oil consumption	Battery
Pure electric vehicle	0	9.7045	1.3369	0.3033	0.0294	1.8748
E10 Chuan material fuel vehicle	20.1611	4.8675	1.4055	0.3033	0.2268	0.012

Adopting the same variable principle based on the data in the table above.

Let the use of new energy vehicles be x years so that the overall carbon emissions of new energy vehicles are less than those of fuel vehicles.

$$3000 \times (1.3369 + 0.3033 + 1.8478) + (0.0294 + 9.7045)x \times 200 = 3000 \times (1.4055 + 0.3033 + 0.012) + (20.1611 + 4.8675 + 0.2268) \times 200 \quad (1)$$

The solution gives.

$x \approx 1.73$

Therefore, the predicted result is the use of new energy vehicles is calculated to be 1.73 years, making the overall carbon emissions of new energy vehicles less than those of fuel vehicles.

4.3 Light material analysis

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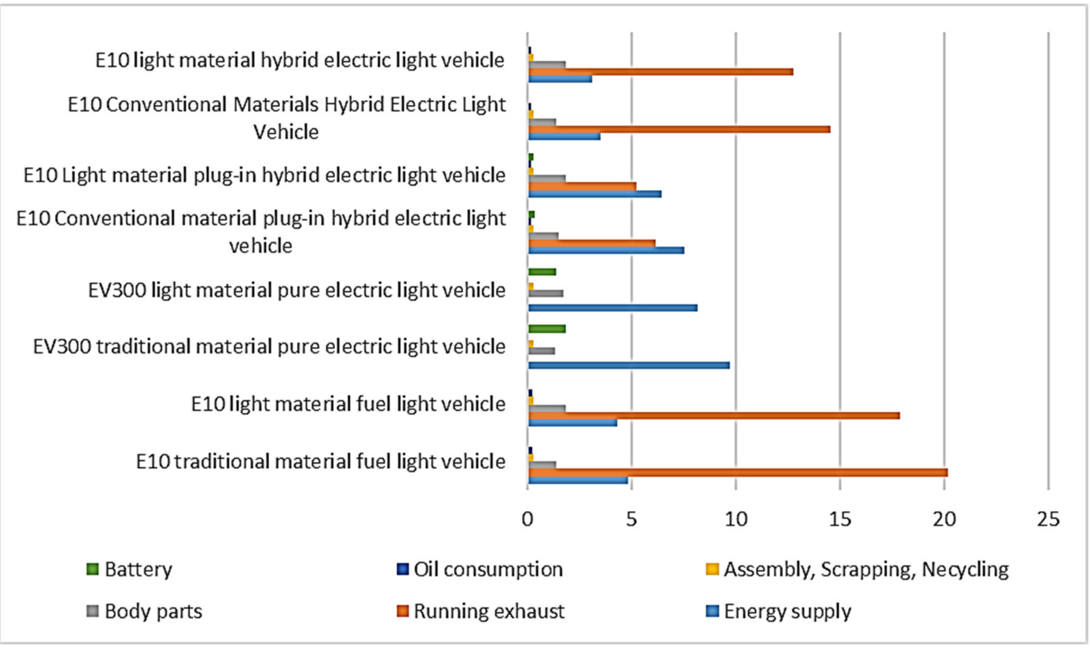

Fig. 7. Comparison of life cycle carbon emissions of electric vehicles with different power structures

As shown in Figure 7.In terms of overall carbon emissions, lighter materials are less carbon-intensive than traditional materials. The primary metal materials used in vehicles are steel, aluminium, iron and copper, which generate many carbon emissions while mining raw materials and manufacturing metals. [8] Because the new materials contain less metal resulting in less need for a lot of metal raw materials and lighter-weight vehicles, they naturally consume less fuel energy. For example, magnesium alloys with almost zero flexural asymmetry and high ductility are new engineering alloys that are strong and ductile and can be superplastic at higher strain rates, reducing manufacturing time, effort and cost overall; moreover, such alloys are light and help to reduce the carbon footprint of vehicles as lighter vehicles require less running fuel and are more energy efficient.

4.4 Comparison of different power structures of new energy vehicles

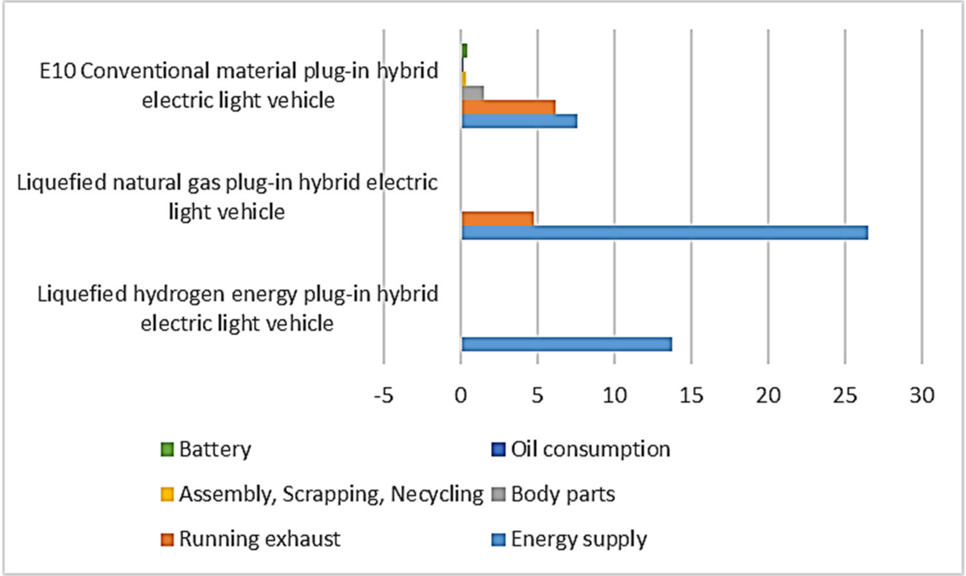

Fig. 8. Comparison of life cycle carbon emissions of electric vehicles with different power structures

As shown in Figure 8.This paper examines only the three more common hybrid electric new energy vehicles with different electrical configurations, with carbon emissions in descending order of LNG, E10 conventional materials, and LH energy.

5. Conclusions and suggestions

After comparing two fuel vehicles and four new energy vehicles, the conclusions of this paper are as follows.

Overall, most new energy vehicles have less carbon and pollution emissions than fuel vehicles, with liquefied hydrogen energy causing higher total emissions due to fuel, followed by hybrids. Carbon emissions account for the highest total emissions, followed by CO, VOC, NOX, PM10 and PM2.5.

The total emissions of new energy vehicles are mainly concentrated in the energy supply phase, and their carbon emissions are higher than those of fuel vehicles in the upstream stage. In contrast, the primary emissions of fuel vehicles are concentrated in the operation phase. At the same time, the carbon emissions of new energy vehicles in body parts and batteries cannot be ignored.

The lifespan of new energy vehicles is lower than that of fuel vehicles, increasing carbon emissions in the recycling and end-of-life stages. Lightweight materials contribute to reducing emissions compared to conventional materials.

The carbon emissions of new energy vehicles with liquefied hydrogen are most minor under the plug-in hybrid replaceable electricity structure.

Based on the above findings, the paper recommends the following.

(1) According to 2015, the cumulative installed capacity of renewable energy power generation in China reached 50 × 104MW, accounting for 33.3% of the total installed power generation capacity; the annual power generation capacity of renewable energy reached 13.93 × 108MW-h, accounting for 24.8% of the total power generation capacity [9]. According to the conclusion, the emissions of new energy vehicles are mainly concentrated in the energy supply stage. Therefore, the country needs to vigorously develop renewable energy generation technology to reduce the carbon and pollution emissions of new energy vehicles in the energy supply stage.

(2) Li Feilong and others concluded that lightweight could significantly reduce energy consumption throughout the life cycle of a vehicle. It is recommended that companies improve hot stamping technology, reduce the total weight of components, and battery box multiple material connection technologies to reduce carbon and pollution emissions from the body [10]. At the same time, reducing vehicle weight reduces fuel consumption and thus reduces emissions during the energy supply and operation phases.

(3) By the end of June 2022, the domestic ownership of new energy vehicles has exceeded the 10 million mark, reaching 10.1 million units, accounting for 3.23% of the total cars [11]. This shows that the proportion of new energy vehicles in China is still low; it is suggested that the state should adopt more incentive policies to ensure that every family can enjoy the subsidies for purchasing new energy vehicles. At the same time, more publicity should be given to the hazards of carbon and pollution emissions of fuel vehicles to the environment and human beings to prompt people to accept new energy vehicles. However, the state needs to pay attention to the construction of supporting infrastructure. Data shows that, to date, of the 6,618 highway service areas in the country, 3,102 service areas have built 13,374 charging piles. According to data released by the China Charging Alliance, by July 2022, there was 1.575 million public charging banks in China. The number of completed charging piles on highways is less than 1% of the total number of public charging piles nationwide [12]. The country needs to accelerate the construction of charging banks to encourage people to buy new energy vehicles confidently and thus reduce emissions.

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