Fleets of commercial vehicles

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Abstract. Global warming has become a significant issue in the world today. Although several other gases contribute a more substantial proportion to global warming, carbon emissions are the hottest focus of global warming due to their large volume and prevalence in everyday life. The development of new energy vehicles has been given a significant boost to address and control the severe pollution problems associated with carbon emissions. In describing China's 14th Five-Year Plan, the construction of an ecological civilization is proposed to be continuously improved. In particular, there are specific targets for the technological transformation of vehicles and the proportion of new energy vehicles and energy-efficient vehicles, which will contribute to a low-carbon development model and environmental protection. The purpose of this report is to compare the carbon emissions of three types of vehicles to estimate the effects of low-carbon technological transformation and promote technological progress in new energy vehicles while providing data to support the formulation of future relevant policies.

1 Introduction

For the whole world, one of the largest sources of greenhouse gas emissions from human activities is from burning fossil fuels for electricity, heat, and transportation [1, 2]. The situation in China is roughly similar. As a highly industrialized developing country, the two primary sources of carbon emissions concentrate on the generation side and industry side. In addition, transportation contributes a large percentage of carbon emissions and the latest data published by IEA (International Energy Agency). The power generation and heat production sectors account for more than 50% of fossil energy carbon emissions [3]. The transportation sector includes the movement of people and goods by cars, trucks, trains, ships, airplanes, and other vehicles. The number of vehicles increases gradually in city roads due to a confluence of factors, including population growth, economic growth, urban sprawl, and periods of low fuel prices. Recent reports demonstrate that the greenhouse gases released by vehicles contribute to over 90% of the roadside air pollution, and automobile pollution accounts for about 60% of total air pollution [4, 5]. In addition, carbon emission is one of the most major components of greenhouse gases. Although some other gases account for more percentages of global warming, carbon emissions have become the most popular focus of global warming, depending on its large amount and universality in daily life.

Conventional Vehicles are typical automobiles having mature techniques to use petroleum as an energy source, which becomes one of the most significant sources of air pollution and aggravates global warming. Therefore, the bans or limits aimed at conventional vehicles are proposed in many countries and regions, and it becomes an urgent mission to research new substitute products. New energy vehicles typically conclude Battery Electric Vehicles (BEVs), Plug-in-Electric Hybrid Electric Vehicles (PHEVs), and Fuel Cell Electric Vehicles (FCEVs). Hybrid Electric Vehicles consume less fuel than conventional vehicles, resulting from the electric driving technology being applied to boost vehicle efficiency through regenerative braking. However, Battery Electric Vehicles can be powered solely by electricity produced from natural gas, coal, nuclear energy, wind energy, hydropower, and solar energy. Another popular new energy technical path is Hydrogen Fuel Cell Electric Vehicles, whose essential techniques are hydrogen production and storage. The hydrogen production methods are mainly divided into four portions, respectively the transformation from coal, petroleum, natural gas, and water electrolysis [6]. In reality, the growth rate of conventional vehicles has slowed down. As some significant automobile consumers like China, traditional fossil fuel vehicles are still the first choice for people to purchase in daily life. The possible reason for this phenomenon is that consumers usually focus on the tangible cost but neglect the subsequent cost when driving and the environmental cost from gas emissions, falling to have a comprehensive comparison of the economic

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competitiveness of CVs and EVs [7].

To alleviate and control the severe pollution related to carbon emissions, the progress of new energy vehicles has been facilitated significantly. Presently, the comprehensive electric drive plan has replaced the ban on fossil fuel burning. Since 2009, the Chinese new energy vehicles market has experienced the bud phase (2009-2013), growth phase (2014-2018), and has entered the regulatory phase from 2019. With the incentive mechanism of financial politics, new energy vehicles have developed increasingly, which has become a significant breakthrough to reduce the pressure of city transportation and environmental issues [8, 9].

Furthermore, to support reducing carbon emissions, the Chinese government has proposed new environmental-friendly development patterns and encouraged breakthrough techniques. The Outline of the 14th Five-Year Plan of China (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 have been published. It maps out a blueprint for China's new journey toward the full construction of a modern socialist country, and serves as a program of action for Chinese people of all ethnic groups. In particular, there are specific technology renovations of vehicles and goals of the proportion of new energy vehicles and energy-efficient cars, which will contribute to the low-carbon development pattern and environment protection.[10] To achieve the goal of China's carbon neutral, the path is divided into three stages: (1) the first stage (2021-2030) achieve the peak of carbon emissions; (2) the second stage (2031-2045) the main task is to reduce carbon emissions quickly; (3) the third stage (2046-2060) accomplish deep decarbonization and achieve the final goal of carbon neutralization [3].

Though researches related to carbon emissions of new energy vehicles by life cycle assessment are hotspots in academics, most researches are designed to create a new model to calculate and analyze the environmental impact of each stage in the whole life cycle of vehicles. Limited studies focus on comparing conventional vehicles, electric vehicles, and hydrogen fuel cell vehicles from carbon emissions. The technical and economic comparisons oriented by the latest politics lack relatively. This article focuses on quantifying and comparing their environmental impact on conventional vehicles, electric vehicles, and hydrogen fuel cell vehicles. The analysis results will evaluate the advantages and disadvantages of three types of vehicles, especially from the point of their performance and environmental impact. This study has three significant contributions: (1) estimating the effect of low-carbon technique reformation; (2) promoting the technical progress of new energy vehicles; (3) offering data support to the future relevant policy formulation.

2 Methodology

This article compares three types of vehicles: conventional vehicles, electric vehicles, and fuel cell vehicles. And we analyzed the sustainable properties of these three cars by using carbon emission. As for the time horizon, we determined 2020 as a symbol year to assess the life cycle of typical model cars selected to represent each type of vehicle.

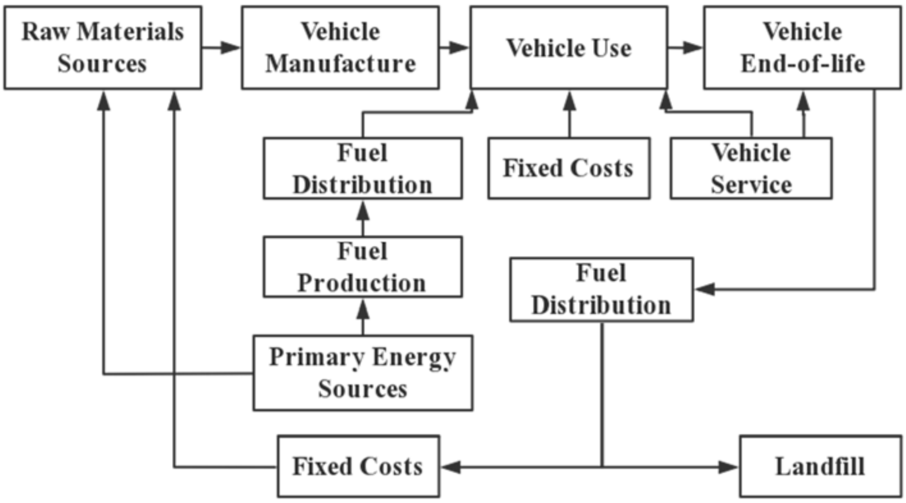

Figure 1. Simplified life cycle analysis diagram for automobile

2.1 Conventional vehicles

A conventional car is a kind of car that only uses fuel oil as energy. It's the most cars on the market.

2.1.1 Model vehicle Considering the price and the sale volume, we choose the BMW3 320i as the model vehicle for the Conventional vehicle.

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Table 1. Vehicle configuration parameters of BMW3 320i

Parameter name	Parameter	Unit
Maximum speed	222	km/h
Aerodynamic drag coefficient	0.28	-
Axles distance	2851	mm
Driving mode	Rear wheel drive	-
Petrol consumption	6.2	L/100km

We divided its CO_2 emission into three sections for conventional cars: the fuel production process, the usage stage of the vehicle, and the recycling stage. We calculated the CO_2 emission of each part and then summed them up to get the final results.

2.1.2 Fuel production process The petrol is produced by catalytic cracking of petrol, and the schematic diagram of the catalytic cracking of petrol is shown in Figure 2. The crude oil is used to produce gasoline and other products through catalytic cracking. To simplify the model, we can assume that all the petrol is produced by catalytic cracking of gasoline, and the petrol yield in the FCC unit is 35%.

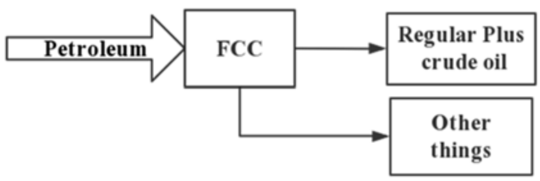

Figure 2. Catalytic cracking of petrol schematic diagram

To calculate the mass of carbon dioxide from the production of petrol, we can easily list the following equation:

$$m_1 = \alpha \times \rho \times V \div 35\% = 4.0211\ \mathrm{kg/100km} \quad (1)$$

The mass of producing 1-kilogram petrol by catalytic cracking of petroleum. V is the volume of Regular Plus petroleum consumption per 100km. ρ is the density of the Regular Plus petroleum.

2.1.3 Usage stage Because the Regular Plus petroleum has a complex composition, we can assume that carbon content n in petroleum is as follow [11]:

$$n = \frac{8m \times 95.8\%}{M_{C8H18}} \quad (2)$$

$$m_2 = n \times M_{CO_2} = 13.5164\ \mathrm{kg/100km} \quad (3)$$

Here m is the mass of petrol. M_{C8H18} is the molar of C_8H_{18}. m_2 is the mass of CO_2 emission in the usage stage.

2.1.4 Recycling stage We have searched the literature and chosen to take a pyrotechnical wet combination recycling method to recycle the car [12], assuming that a car has an end-of-life mileage of 200,000km. The average CO_2 emission per 100km is 2.4537kg per car.

2.1.5 Total CO_2 emission The total CO_2 emission m equals:

$$m = m_1 + m_2 + m_3 = 19.9894\ \mathrm{kg/100km} \quad (4)$$

2.2 Battery electric vehicles

2.2.1 Study object and assumption

2.2.1.1 Study object Being the best-selling electric vehicle by 2020, Tesla Model 3 (Standard Range Plus) is selected as the case study.

Table 2. Vehicle configuration parameters of Tesla Model 3 (Standard Range Plus)[13, 14]

VEHICLE BODY		
Curb weight	1756	kg
Aerodynamic drag coefficient	0.23	
Wheelbase	2875	mm
Static weight distribution (empty car)	47.8/52.2	Front %/Rear %
Drivetrain	Rear wheel drive	
POWERTRAIN		
Number of motor(s)	1	
Motor type	Permanent magnet AC synchronous electric motor	
Voltage	320	V
Maximum power/at rpm	180/6000	kW/ rpm
Maximum torque	327	Nm
TRANSMISSION		
Type	Single-speed transmission	

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Gear ratio	9:1	
Front/rear tires size	P235/45R18	
BATTERY		
Chemistry	Lithium-ion	
Charging efficiency	≤95	%
Battery pack weight	260	kg
Nominal battery pack energy	52	kW·h
PERFORMANCE		
Top speed	225	km/h
Acceleration (0-100 km/h)	5.6	s
Electric range (U.S. EPA)	353	mile
Energy consumption (EPA Combined)[15]	24	kW·h/100 mi

2.2.1.2 Study assumption The whole study assumes that we ignored small-scale power plants of 6000 kW and less.

2.2.2 Using Phase

2.2.2.1 Electricity consumption from the power grid Because of the loss in charging, storage, driving, and transmission, electricity consumption from the power grid is as follows:

$$e' = e \div \eta = 15.70 \text{ kW·h/100km} \quad (5)$$

Here, e is electricity consumption from the battery (loss in storage, driving, and transmission included), η is charging efficiency.

2.2.2.2 Fossil energy consumption According to China Electricity Council, in 2019, the national coal consumption for power supply of thermal power plants of 6000 kW and above was 306.4g/kW·h, the service power consumption rate of power plants of 6000 kW and above was 4.70%, the line loss rate was 5.93%. [16]

Fossil energy consumption of battery electric vehicles can be calculated as follows[17]:

$$E = e' \div (1 - \Delta A) \div (1 - \Delta B) \times br \times Q = 157237.0 \text{ kJ/100km} \quad (6)$$

Here, E is the total fossil energy consumption per 100 miles, e' is electricity consumption from the power grid, ΔA is service power consumption rate of power plants, ΔB is line loss rate in the grid, br is the national coal consumption for power supply of thermal power plants of 6000 kW and above, Q is the calorific value of standard coal.

2.2.2.3 CO_2 emission According to China Electricity Council, in 2019, the carbon dioxide emission per unit power generation in China is about 577 g/kW·h.[16]

CO_2 emission of battery electric vehicles can be calculated as follows:

$$M = e' \div (1 - \Delta A) \div (1 - \Delta B) \times m = 10.1 kg/100\,km \quad (7)$$

Here, M is the total CO_2 emission per 100 miles, m is CO_2 Emissions per unit, e', ΔA and ΔB are the same as above.

2.2.3 Battery Recycling Phase The average power consumption in battery recycling of battery electric vehicles is 84.6kJ/kg. The average CO_2 emission in battery recycling of battery electric vehicles is 7.543 kg/kg.[18]

In consideration of the warranty of 160000 km, the power consumption can be calculated as follows:

$$E = 84.6 \text{kJ/kg} \times 260 \text{kg} \div 1600 = 13.7 \text{ kJ/100km} \quad (8)$$

And CO_2 emission can be calculated as follows:

$$E = 7.534 \text{kg/kg} \times 260 \text{kg} \div 1600 = 1.2 \text{ kg/100km} \quad (9)$$

2.2.4 Summary Fossil energy consumption of the model is 157250.7kJ/100km, and CO_2 emission is 11.7kg/100km.

2.3 Fuel cell vehicles

The fuel cell vehicle is a vehicle powered by electricity generated by an onboard fuel cell device. Hydrogen is the main energy source of fuel cell vehicles, which means that the fuel cell has high energy density and low carbon emission. But now, because the technology is far from mature and the relative facilities are not so perfect, the market share of fuel cell vehicles is meager. Therefore, fuel cell vehicles have great potential for sustainability development.

To estimate the CO_2 emission of fuel cell vehicles, we choose Toyota Mirai (XLE) as the typical fuel cell vehicle because Mirai is one of the first mass-produced fuel cell vehicles and the most popular one globally.

For fuel cell vehicles, we also divided their CO_2 emission into four sections: the fuel production process, the fuel transportation process, the usage stage of the vehicle, and the recycling stage. We calculated the CO_2 emission of each part and then summed them up to get the final results.

2.3.1 Usage stage The main chemical reaction of the hydrogen fuel cell is:

$$2H_2 + O_2 = 2H_2O \quad (10)$$

There was no carbon being involved in the reaction, so we neglected the CO_2 emission in the usage stage.

2.3.2 Fuel production process

Table 3. Global hydrogen demand and production sources [19]

INDUSTRY SECTOR	KEY APPLICATIONS
CHEMICAL	·Ammonia ·Polymers ·Resins
RFEINING	·Hydrocracking ·Hydrotreating
IRON&STEEL	·Annealing ·Blacketing gas ·Forming gas
GENERAL INDUSTRY	·Semiconductor ·Propellant fuel ·Glass production ·Hydrogenation of fats ·Cooling of generators

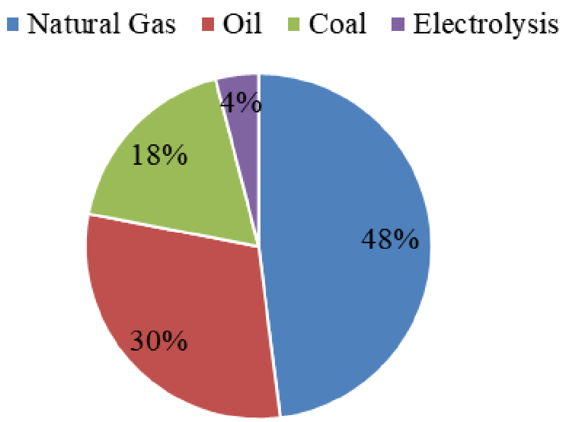

Figure 3. Hydrogen Sources [19]

The second part is the fuel production process. Several major hydrogen production methods and the hydrogen production sources are listed in Figure 3 and Table 3. And the CO_2 emissions of each production source is listed in Table 4.

Table 4. The CO_2 emissions comparison of different hydrogen production methods

Production methods	Technology	CO_2 emission ($kgCO_2/kgH_2$)	State
Hydrogen production from coal [20]	Conventional coal gasification	19	Using now
	Conventional coal gasification + CCUS	<2	future
Hydrogen production from natural gas [20]	SMR	9.5	Using now
	SMR+CCUS	<1	future
Hydrogen production from oil and its industrial by-products [21]	Conventional	13	Using now
Electrolysis of water[20]	Grid power	38-45	Using now
	hydro (electric) power	<1	future
	photovoltaic power	<3	future

a. Use 40 $kgCO_2/kgH_2$ to calculate the CO_2 emission of electrolysis of water.
b. Using now means the technology is using and the future means the technology will probably be used in the future. We all use the data of the technology using now to calculate.
c. The CO_2 emission of hydrogen production from oil and its industrial by-products is estimated from the reference [22], and other data is cited from reference [23].

Then, we quickly calculated the CO_2 emission to produce 1kg hydrogen M' from Table 4:

$$M' = 13.48\ kg/kgH_2 \quad (11)$$

From the reference [22], we knew that the hydrogen consumption of Toyota Mirai is 0.85kg/100km. So, we calculated the CO_2 emissions of the production process M_2:

$$M_2 = M \times 0.85\ kgH_2/100km = 11.458\ kgH_2/100km \quad (12)$$

2.3.3 Fuel transportation process The third part is the fuel transportation process. We also need to consider the loss in the transportation process. From the reference [23], we assume that the loss rate of hydrogen in the transportation process μ is 1.4%.

2.3.4 Battery recycling stage From the reference [22], we knew that the total CO_2 emission in battery recycling of fuel cell vehicles M_{total} is 9270kg.

As the warranty of the fuel cell of fuel cell vehicles on the official website [24] is 150000 mi, we estimated the total driving distance s is 240000 km. So, the CO_2 emission in the battery recycling stage M_3 could be calculated as follows:

$$M_3 = \frac{M_{total}}{s} = 3.863\ kg/100km \quad (13)$$

2.3.5 Total CO_2 emission The total energy consumption of fuel cell vehicles M is:

$$M = M_1 + \frac{M_2}{1-\mu} + M_3 = 15.48\ kg/100km \quad (14)$$

Here, M_1 is the CO_2 emission of usage stage, M_2 is the CO_2 emission of the production process, M_3 is the CO_2 emission of the battery recycling stage, μ is the loss rate of hydrogen in the transportation process.

3 Result and discussion

3.1 Result

The results were listed in Table 5 and Figure 4 as follows.

Table 5. The CO_2 emission comparison of different kind of vehicles

	CO_2 emissions (kg/100km)		
Types of vehicles	**usage**	**recycle**	**total**
Conventional vehicles	13.50	2.45	19.95
Electric vehicles	0	1.20	11.30
Fuel cell vehicles	0	3.86	15.48

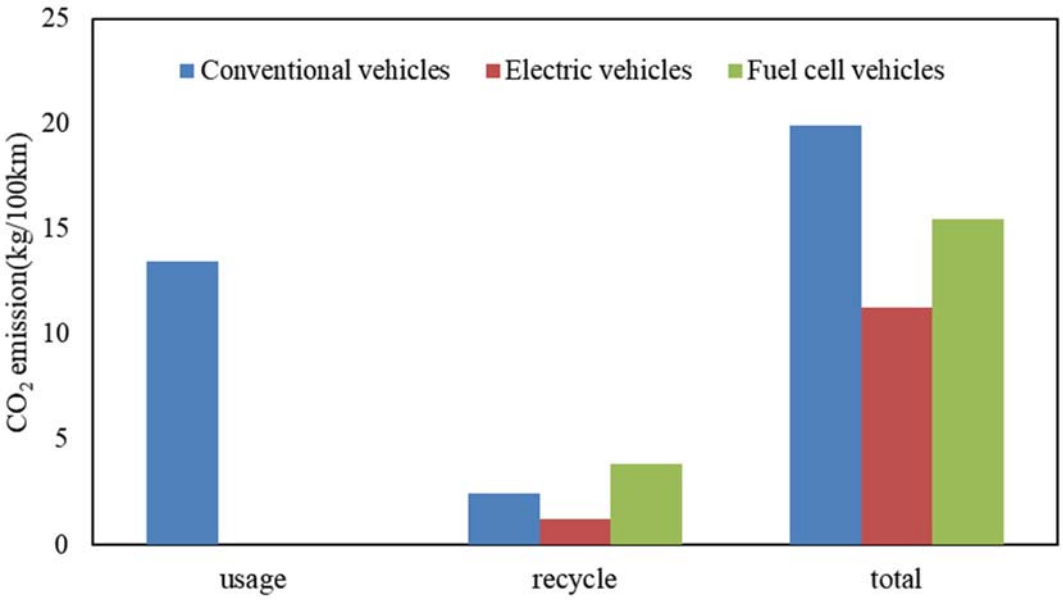

Figure 4. The CO_2 emissions comparison of different kind of vehicles

From Table 5 and Figure 4, we concluded that:

1) Both electric vehicles and fuel cell vehicles have better performance on CO_2 emissions. Also, the advantage is not apparent because fossil fuels still dominate the current energy structure.

2) Electric vehicles and fuel cell vehicles have significant potential for sustainable development because the CO_2 emissions during the usage stage are near zero.

3) The primary CO_2 emissions of electric vehicles and fuel cell vehicles are in the production chains. So, we can predict that with the improvement of energy structure and relative technology, sustainability will increase continuously.

4) In the recycle stage, electric vehicles have the best

performance.

5) Electric vehicles have better performance on CO_2 emissions than fuel cell vehicles have. It’s partly because the technology of electric vehicles is more mature, and the related material is easier to recycle.

6) Nowadays, because of the lack of related facilities and the technology's immaturity, electric vehicles and fuel cell vehicles still need time to develop.

3.2 Discussion

We found that both electric vehicles and fuel cell vehicles had better CO_2 emissions from the results. But up till now, conventional vehicles were still the mainstream of the market. Also, as fossil fuels dominated the energy structure, electric vehicles and fuel cell vehicles still had significant CO_2 emissions. These factors caused that transportation was one of the largest sources of CO_2 emissions, which led to the greenhouse effect and global warming. So, we wanted to discuss several main factors that led to the CO_2 emissions reduction and the possible optimizations which may happen in the future.

3.2.1 Optimization of energy structure

First, the optimization of energy structure is one of the most important methods to reduce CO_2 emissions. The primary CO_2 emission of electric vehicles and fuel cell vehicles is in the production chains. It is primarily because most of electricity and hydrogen is produced by the fossil fuel. So, if we improve the energy structure, we can significantly decrease the CO_2 emissions.

From Table 3, we quickly find that most of the hydrogen is produced by coal, oil, and natural gas for fuel cell vehicles. But the electrolysis is undoubtedly the cleanest way to produce hydrogen because, as in equation (10), there’s no carbon to take part in the reaction. From reference [25], we can know that until 2035, the electrolysis will become the source of 30% hydrogen, and until 2050, the electrolysis will become the source of 70% hydrogen.

So, for electric vehicles and fuel cell vehicles, producing electricity is also very important. In Table 4, we can find that there’s a huge gap between the carbon emission of producing electricity through grid power now and producing clean electricity ideally. So, there’s large development potential inside it. However, from the “14th Five-year plan” of China, the country has defined the proportion of fossil energy should be lower than 20% in 2035

Suppose we neglect the carbon emission in the production of clean electricity and assume that the CO_2 emissions of other methods don’t change. We can estimate conservatively that the unit carbon emission of electric vehicles and fuel cell vehicles will decrease by 80% and 32% until 2035.

3.2.2 Optimization of the vehicle structure.

Second, the optimization of vehicle structure is also a very important method to reduce CO_2 emissions. We can find that the CO_2 emissions of electric vehicles and fuel cell vehicles are lower than the conventional vehicles and will decrease continuously. But up till now, the proportion of traditional vehicles, electric vehicles, and fuel cell vehicles is 98.25% ,1.75%, 0% [26]. We can find that conventional vehicles still mainstream the market. It means that the large carbon emissions potential inside the vehicle structure. Also, in the “14th Five-year plan” of China, the country has defined the new energy vehicles to become the mainstream market in 2035. Due to the maturity of the related technology, we estimate that the proportion of conventional vehicles, electric vehicles, and fuel cell vehicles will be 20%, 60%, 20% in 2035. With the optimization of energy and vehicle structure, we can list changes in CO_2 emissions in Table 6.

Table 6. Changes after optimization

Vehicle types	CO_2 emissions (kg/100km)	Decrease in optimization of energy structure (%)	Proportion in 2020 (%)	Proportion in 2035 (%)
Conventional vehicles	19.95	0	98.75	20
Electric vehicles	11.3	80	1.25	60
Fuel cell vehicles	15.48	32	0	20

From Table 6, we can know that after optimizing energy and vehicle structure, the total CO_2 emissions decrease can be calculated below.

$$E = 1 - \frac{19.95 \times 20\% + 11.38 \times 20\% \times 60\% + 15.48 \times 68\% \times 20\%}{19.95 \times 98.75\% + 11.3 \times 1.25\%} = 62.4\% \quad (15)$$

We can find that the CO_2 emissions decrease is tremendous, especially on a large scale.

4 Conclusion

Although Conventional vehicles are still the mainstream vehicles, with the introduction of the national "14th Five-Year Plan" and the continuous advancement of technology, Electric vehicles and fuel cell vehicles will eventually replace fuel vehicles to reduce carbon emissions and improve sustainability of domestic transport development.

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