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Systematic Analysis and Comparison of Fuel Vehicles, Electric Vehicles and Hybrid Vehicles: A Take on the Suspension System

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Abstract. Due to the issue of environmental pollution and the development of transportation, countries around the world have vigorously advocated new energy vehicles in recent years, such as electric vehicles and hybrid vehicles[1]. However, traditional fuel vehicles, electric vehicles and hybrid vehicles have different advantages and disadvantages[2], and there is a lack of objective and accurate comparison of the three types of vehicles. When buying cars, consumers are hard to decide which type of cars they should buy since they don't know the specific difference between them.Therefore, this paper first starts with the driving device and operation principle, and then compares the driving range, cost and environmental impact, aiming to let readers intuitively understand the differences between the three models. By referring to a large number of relevant literature, and collecting the endurance mileage and other data, this paper makes a comparative analysis, and at the same time makes a prediction analysis of the cost. The research results are as follows: due to the difference in the basic drive device, the three models have different ranking order from high to low in three aspects. For the endurance mileage, the three models are ranked from highest to lowest: hybrid, fuel, electric; In terms of cost, the order is: hybrid, electric, fuel, electric vehicles are expected to be cheaper than fuel in the next decade; For environmental impact, the order of carbon emissions from most to least is: fuel, hybrid, electric. Therefore, combining the three factors and the future direction of automobile development, consumers buy electric vehicles most cost-effective.

Keywords: transportation, fuel vehicles, electric vehicles, hybrid vehicles, environment

1. Introduction

As environmental pollution intensifies, nations are placing greater emphasis on clean energy. With the advancement of transportation and technology, new energy vehicles (NEVs)—such as electric vehicles (EVs) and hybrid electric vehicles (HEVs)—are gradually replacing traditional fuel-powered cars [3]. Each vehicle type offers distinct advantages. Some researchers highlight the high endurance mileage of fuel vehicles [4], while others emphasize the lower CO_2 emissions and higher energy efficiency of EVs [5]. However, due to a lack of clear and objective comparisons, many

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consumers find it difficult to determine which option best suits their needs. This article seeks to fill that gap by providing a comprehensive comparison of fuel, electric, and hybrid vehicles, helping readers make informed decisions without unnecessary costs.

To establish a foundation for comparison, the article outlines the driving mechanisms of each vehicle type. Fuel vehicles rely on internal combustion engines powered by fuel oil, completing four working strokes within the engine. EVs convert battery-stored electrical energy into mechanical energy via a drive motor system. HEVs rely solely on the motor when the battery is sufficiently charged; as the charge drops, the internal combustion engine activates to assist propulsion. Understanding these basic principles allows for a deeper grasp of how drive systems influence the technical performance metrics compared later in the analysis.

This comparison focuses on endurance mileage, overall cost, and environmental impact. Quantitative data is used to support a balanced and objective analysis, ranking each vehicle across these parameters. In terms of endurance mileage, fuel vehicles demonstrate a significant advantage over electric and hybrid models [4]. Cost evaluation includes manufacturing costs, selling price, and maintenance costs. Since selling price is generally proportional to manufacturing cost, this relationship is used to guide the analysis. Maintenance costs are also considered to reflect real-world usage. For environmental assessment, CO_2 emissions data are presented, supplemented with bar graphs for visual clarity [5].

To account for ongoing technological advancements, market evolution, and supportive policy shifts, the article incorporates predictive analysis. This component forecasts future selling prices and the potential market share of each vehicle type, offering a forward-looking perspective. Taken together, the comparative and predictive insights aim to serve as a reliable reference for readers selecting the vehicle that best matches their individual needs and priorities.

2. Literature review

This research focuses on two primary aspects: the first examines the driving mechanisms and working principles of three vehicle types—fuel vehicles, electric vehicles (EVs), and hybrid electric vehicles (HEVs); the second analyzes their performance differences in terms of endurance mileage, environmental impact, and overall cost. To support the comparative analysis, relevant empirical data concerning endurance range, carbon emissions, and cost parameters have been collected from various published sources.

Environmental concerns have been a driving force behind the growing attention to new energy vehicles. Zhao et al. emphasized that the rise of NEVs is largely driven by the need to combat environmental pollution [1]. Bo et al. highlighted that fuel, electric, and hybrid vehicles each possess distinct advantages and disadvantages [2]. Fan further analyzed the substitution effect of NEVs over traditional fuel-powered vehicles [3]. In the context of consumer choice, Du noted the high endurance mileage typically associated with fuel vehicles [4], whereas Li focused on the low CO_2 emissions and high energy efficiency of electric and hybrid vehicles [5].

Regarding technical configurations, the working principle of fuel vehicles involves delivering fuel to the cylinder, where it is ignited to generate power. Dai et al. described how spark ignition is used in this combustion process [6]. Dahham et al. identified four operational strokes of the gasoline engine: intake, compression, combustion, and exhaust [7]. For electric vehicles, the drive motor plays a central role. As discussed by Hong, the motor is the core power source in EVs [8]. Cai classified drive motors into four types, reflecting the range of technological diversity in electric drivetrains [9]. Wang et al. emphasized the importance of thermal management in EVs, noting that cooling systems help regulate motor temperature [10].

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Hybrid vehicles integrate both internal combustion engines and electric motors. Zhou categorized hybrids based on their drive modes [11], while Gu introduced another classification scheme based on whether an external charging source is present [12]. Pielecha further divided hybrids into micro-, mild-, and full-hybrids according to their electrification levels [13]. Verma explored the interaction between the engine and motor in hybrid systems, providing insight into how power is distributed and managed [14].

In terms of endurance mileage, Ziółkowski argued that performance varies based on vehicle type and several influencing factors [15]. Wu et al. found that good road conditions positively affect vehicle range [16]. Guo and Ji reported that, under ideal conditions, electric vehicles produced by both domestic and international manufacturers can achieve a range of 300–500 kilometers [17]. A vehicle testing platform further provided brand-specific EV endurance data [18]. Wang outlined the main variables influencing EV range, including battery capacity, driving behavior, and environmental conditions [19]. For hybrids, Brtka et al. found that a fully charged and fueled hybrid vehicle can travel over 1,000 kilometers [20]. Xu and Zhang noted that tandem hybrids typically achieve a pure electric range of 200–300 kilometers [21]. However, Mamala cautioned that temperature drops can significantly reduce battery efficiency and therefore mileage [22].

Cost analysis is also a key part of this study. Offer et al. identified four primary components of vehicle cost: manufacturing, energy, infrastructure, and maintenance [23]. Pu highlighted how advancements in battery technology and an expanding EV market may reduce manufacturing costs over time [24]. Lustey et al. provided a comparative report outlining the cost structure of all three vehicle types [25]. Liu emphasized that hybrid vehicles often incur additional maintenance costs due to their dual-powertrain systems [26].

In the context of carbon emissions, Feng et al. provided detailed cost and emissions data across fuel, electric, and hybrid vehicles [27]. Mei stressed that while EVs produce no tailpipe emissions, their overall carbon footprint includes emissions from manufacturing, battery production, and end-of-life recycling [28].

3. The drive and working principle

As the core of fuel vehicle, gasoline engine mainly includes cylinder, spark plug, exhaust system, connecting rod, crankshaft, ignition system and so on. The cylinder is the core of the whole engine structure. It is equipped with pistons and can move up and down inside the cylinder. The piston is connected with the connecting rod and the crankshaft, and the crankshaft is connected with the connecting rod, and the force from the connecting rod will be rotated to drive the engine accessories to work. In addition, the fuel system delivers fuel from the tank to the cylinder to provide fuel for the engine; the spark plug in the ignition system ignites the fuel inside the cylinder to make it burn [6]. Since the power source of a fuel vehicle is mainly the explosive force generated by the combustion of gasoline, the principle and working process of a gasoline engine are as follows: putting gasoline and air together into a sealed container which is the cylinder, and then ignite to produce an explosion phenomenon. The energy generated by a gasoline combustion explosion is converted into mechanical energy to power a fuel-powered vehicle.

In order to make gasoline and air enter the cylinder and eventually explode to produce energy, a working cycle of the gasoline engine needs to complete four strokes, namely: suction, compression, combustion and exhaust [7].

Suction Stroke: the intake valve opens, the exhaust valve closes, the piston moves down, the crankshaft rotates half a turn, and the air-fuel mixture enters the cylinder.

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Compression stroke: intake valve exhaust valve is closed, piston upward movement, crankshaft rotation half circle, so that the air and fuel mixture in the cylinder is compressed, increase the temperature of the gas and mix more evenly, provides more power for fuel-powered cars.

Work Stroke: intake valve exhaust valve is still closed, spark plug out of high-pressure electric spark, igniting the gas to explode; the explosion of the force to push the piston downward movement, crankshaft rotation half circle.

Exhaust Stroke: the intake valve is closed, the exhaust valve is opened, the spark plug moves up, the crankshaft rotates half a turn to eliminate the residual exhaust after combustion.

The following diagram shows the engine stroke, from left to right: inspiration stroke, compression stroke, work stroke, exhaust stroke.

An engine often has more than one cylinder, so the cylinder arrangement is also different, mainly l-shaped and v-shaped. L-shape is the cylinder arranged in a straight line, v-shape is the cylinder is divided into two groups, adjacent cylinders by a certain angle arranged together, side view is v-shaped. When the number of cylinders increases, the engine length will increase, the crankshaft length will also increase, eventually leading to an increase in car length, so v-shaped engine can effectively solve this problem. However, the v-shaped engine is less balanced and more complex than the l-shaped engine.

3.1. The drive and working principle of the electric vehicle

Electric vehicles (EVs) operate without internal combustion engines, instead using onboard power supplies to drive the wheels through an electric drive system. This system typically includes a power converter, motor controller, drive motor, mechanical transmission components, and wheels, making it structurally simpler than that of conventional vehicles. At the core is the drive motor, which replaces the engine by converting battery-stored electrical energy into mechanical energy [8]. It also functions as a generator, enabling energy recovery by converting mechanical energy back into electricity for storage.

Drive motors are classified into four types: DC motors, AC induction motors, permanent magnet synchronous motors (PMSMs), and switched reluctance motors [9]. Among these, AC induction motors and PMSMs are most commonly used in EVs. AC induction motors offer lower cost and broad power coverage but have lower power density. In contrast, PMSMs deliver higher power density and compact size but at greater cost and with reduced environmental adaptability. For instance, PMSMs utilize U-, V-, and W-phase windings controlled by a motor controller. When the rotor, equipped with permanent magnets, is driven by the mechanical transmission, it cuts through these windings to generate three-phase electric power. In addition to the rotor and windings, the drive motor includes components such as a rotary transformer, temperature sensor, cooling channels, and protective casing.

When electrical energy is converted to mechanical energy: in order to drive the motor to drive the car, to power the battery as the source of DC power through the high-voltage distribution box, and then under the control of the controller into AC power, to complete the conversion of electrical energy to mechanical energy.

When mechanical energy is converted to electrical energy: the vehicle generates kinetic energy when it is gliding or braking, using kinetic energy and the motor controller to drive the motor to generate electricity; at the same time, in order for the recovered energy to be stored in the power battery, three-phase electric power returns to direct current.

In the above process, because the drive motor has been kept in working state, it is easy to appear the temperature is too high. To solve this problem, the coolant in the cooling circulation channel can

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help cool the drive motor [10].

To sum up, the electric drive system provides the driving force needed by the vehicle, and ensures the vehicle's form power, stability and other functions. At the same time, the electric drive system also has the power feedback function which the engine does not have: when driving the vehicle, through the electric drive system's own power generation characteristics, the vehicle's kinetic energy is converted into electric energy and stored in the vehicle power supply system.

3.2. The drive and working principle of the hybrid vehicle

Different from the fuel vehicle and the electric vehicle, the hybrid vehicle, that is, the hybrid vehicle, has the engine and the electric motor two heat source systems, may realize the fuel and the electric energy hybrid. Therefore, the hybrid vehicle combines the advantages of the two systems, which not only has the advantages of good engine power and long working time, but also has the advantages of low motor noise and less environmental pollution.

According to the different drive modes that hybrid vehicles have,hybrid vehicles can be divided into three types: series hybrid system, parallel hybrid system and hybrid hybrid system [11].

Series hybrid system: the engine produces power, which drives a generator to produce electricity, which is then transmitted by a controller to a battery, which is then converted into kinetic energy, so that can the car. The power system is mainly used in urban buses, but not in cars.

Parallel hybrid power system: the system can be applied to a variety of driving conditions, especially the more complex road conditions, has the advantages of simple structure, low cost. Parallel hybrid electric power system has two systems, engine system and motor drive system. The two systems can work together or drive the car as two independent systems.

Hybrid hybrid system: in contrast to a hybrid system, a hybrid engine system and an electric drive system have gears or planetary gears between them, can effectively adjust the speed relationship between the engine and the motor. The system can adjust the engine and motor according to the specific situation, and has high flexibility. However, due to the complexity of the system, the cost of the hybrid system is also relatively high.

According to whether there is external charging power supply, hybrid vehicles can be divided into plug-in and non-plug-in type [12]. In addition, hybrid cars can be divided into micro-hybrid, light-hybrid and heavy-hybrid according to the degree of hybrid power from weak to strong [13].

Taking the series hybrid vehicle as an example, the working principle and process of the hybrid vehicle can be summarized as follows: when the storage power of the storage battery is full, the drive motor system can meet the energy requirements of the vehicle , at this time, only the drive motor system works, the engine does not work; after a certain distance, the battery is insufficient, the engine will participate in the work, in order to provide a part of the energy for the vehicle, alleviate the motor working pressure. The combined operation of the two systems can better achieve complementary advantages, increase the range of hybrid vehicles and save energy [14].

4. Comparison of parameters and characteristics

The definition of endurance mileage is mainly the maximum distance that a car can travel when fully charged or fueled. As an important indicator for comparing fuel vehicles, electric, and hybrid vehicles, endurance mileage has a significant impact. It is directly related to the durability of a car and whether its selling-price price is cost-effective. Different types of vehicles have different factors that influence their endurance mileage [15]. Taking electric vehicles as an example, the factors of electric vehicles include temperature, battery capacity, etc. The following will elaborate on the

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endurance mileage and factors of fuel vehicles, electric vehicles, and hybrid vehicles respectively, and finally conduct a comparative analysis.

Since fuel vehicles always need to be refueled in their service life and the oil price is relatively expensive , consumers usually pay more attention to fuel consumption compared to endurance mileage. Fuel consumption refers to the amount of gasoline or diesel required for a car to travel one kilometer. By dividing the remaining fuel in the fuel tank by the fuel consumption, the endurance mileage can be gotten. Due to the various factors that can influence the endurance mileage, a family car is taken as an example here. A household car has a fuel tank capacity of approximately 45-55 liters, which can meet the needs of a fuel vehicle traveling 500-1000 kilometers. So in general, the endurance mileage of a fuel vehicle is about 500-1000 kilometers. As mentioned earlier, the endurance mileage of a fuel vehicle is influenced by multiple factors. According to the equation: endurance mileage-fuel level in the tank/average fuel consumption, the endurance mileage is related to the tank capacity and average fuel consumption. And the average fuel consumption will be influenced by actual road conditions and driver driving habits. Therefore, the factors of endurance mileage mainly include: fuel tank capacity, average fuel consumption, actual road conditions, and driver driving habits.

When the average fuel consumption remains constant, the larger the fuel tank volume is, the greater the mileage is; When the fuel tank volume remains constant, the lower the average fuel consumption is, the greater the mileage is. At the same time, affected by road conditions, fuel consumption will increase in poor road conditions (such as mountains and rugged terrain); At high speed and other good road conditions, the fuel consumption will be reduced, thus increasing the endurance mileage [16]. If the driver is used to braking sharply and stepping on the accelerator when driving normally, it can also cause fuel consumption to increase, making the endurance mileage to be reduced.

As a new developing technology, the electric vehicle is considered to be the one that has the shortest endurance mileage in the three types of cars. This is still a sever problem even if the battery life has improved. According to the endurance mileage that domestic and foreign car making companies have tested in the idealize condition, the electric vehicle can travel for 300 to 500 kilometers [17]. In daily life, however, it is impossible for the electric vehicle to keep traveling in the idealize condition, so the actual endurance mileage might not be 300 to 500 kilometers.

According to the data showed by Shandong Automobile circulation Association [18], in 2024's test of new energy vehicles, the endurance mileage consumed are : 311,398,363,212 kilometers; And the actual mileage are:197,246,210 and 90 kilometers, their efficiency is between 42% and 63%.It can be seen that there is a certain gap between the displayed mileage and the actual range, and the range of the electric vehicle is about 200-300km in the full state of power.

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Table 1. 2024 NEV endurance mileage test results

		1	2	3	4
brand		NETA V	Leapmotor C11	XPengP5	Audi Q4 e-tron
type		EV	EV	EV	EV
seats		5	5	5	5
trunks		3	4	4	4
Traveled distance		16272	17445	74409	4936
Initial data	Displayed mileage	400	500	459	287
	Displayed electric quantity	100	100	99	73
Terminal data	Displayed mileage	89	102	96	75
	Displayed electric quantity	20	20	20	20
Test result	mileage consumed	311	398	363	212
	actual mileage	197	246	210	90
	efficiency	63	62	58	42

According to Jin,W's research in "Research Analysis and Optimization of Electric Vehicle Driving Range", the main factors that affect electric vehicles are battery capacity, system efficiency, body mass, rolling resistance coefficient, air resistance coefficient and windward area [19].

The capacity of a battery is similar to the volume of a oil tank, and the more charge it stores, the more power it can provide for the electric vehicle,the longer the mileage is. System efficiency includes battery utilization and mechanical system efficiency. Due to the increase of use time and battery inconsistency, the utilization rate of battery is reduced. Friction between the motor and the drive system can cause power loss. In addition, the lightweight body can reduce the total kinetic energy and increase the driving range. The increase of rolling resistance coefficient, air resistance coefficient and windward area will reduce the driving range.

4.1. Material selection of suspension

Because of having two drive systems, compared with the above two models, the range of the hybrid car has been significantly improved. Taking series-type (extended-range) hybrid vehicles as an example, the endurance mileage can reach more than 1000km in the case of full charge and full fuel [20]. According to the research done by Min,X and Yijia, Z in "China's Hybrid Vehicle Power train Technology Progress", the pure electric endurance mileage of tandem hybrid vehicles can reach 200-300km [21].

The main factors of hybrid vehicles are temperature, road conditions, driving habits, battery capacity and engine efficiency. When the temperature drops, the performance of the battery will also be weakened, resulting in a reduction in mileage [22]; And because the battery performance is weakened, the consumption of the battery will be accelerated, which will have more miles to use the engine to provide power, which will lead to increased fuel consumption. Small battery capacity and low engine efficiency can also lead to reduced range.

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4.2. Self-adjustment and self-moderation of suspension

According to the comparison of the endurance mileage and factors of the three types of vehicles in table 2, it can be concluded that: Among the three types of vehicles, the electric vehicle has the lowest endurance mileage and the hybrid vehicle has the highest. There is a huge difference between them.Besides,due to the various factors that can influence the endurance mileage, the specific endurance mileage should be combined with the actual situation.

Table 2. the endurance mileage and factors of fuel,electric and hybrid vehicles

Types of the vehicle	Endurance mileage/km	Factors
fuel	500-1000km	Oil tank volume, average oil consumption,real road conditions,driving habits
electric	100-300km	Battery capacity, system efficiency, body mass, rolling resistance coefficient, air resistance coefficient, windward area
hybrid	>1000km	temperature, road conditions, driving habits, battery capacity, engine efficiency

4.3. Cost

Generally speaking, the cost of a car includes manufacturing costs, energy costs, infrastructure costs and maintenance costs [23]. For consumers, there is also a need to consider the selling price, which is the purchase cost, and as the endurance mileage of the car increases, or considering the environmental benefits of the car, its purchase price will be more cost-effective at that time.

According to the current situation, the manufacturing cost of electric vehicles is generally higher than that of fuel vehicles, and the difference in manufacturing costs between the two is mainly reflected in the manufacturing cost of electric vehicles' batteries. At the same time, the selling price, that is, the purchase cost, is also affected by the manufacturing cost, so the selling price of electric vehicles is generally higher than that of fuel vehicles. However, with the expansion of the future electric vehicle market size and the advancement of battery manufacturing technology [24], electric vehicles are expected to reduce their manufacturing costs and achieve a reduction in selling prices, even cost the same money or lower than fuel vehicles.

According to the Cost and Benefit Assessment of electric vehicles in China (2020-2035) released by ICCT (International Council on Clean Transportation) [25], the cost data of battery systems in 2015-2020 and the cost prediction of battery systems in 2020-2035, both the existing cost data and the prediction of ICCT USA or ICCT China, The cost of the battery system is reduced year by year, which further confirms the above.

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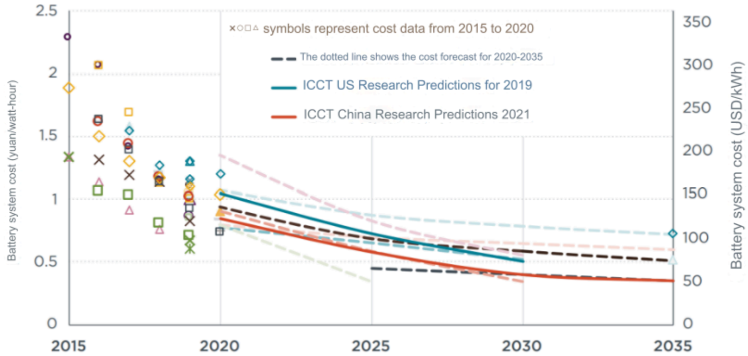

Figure 1. The cost data of battery systems in 2015-2020 and the cost prediction of battery systems in 2020-2035

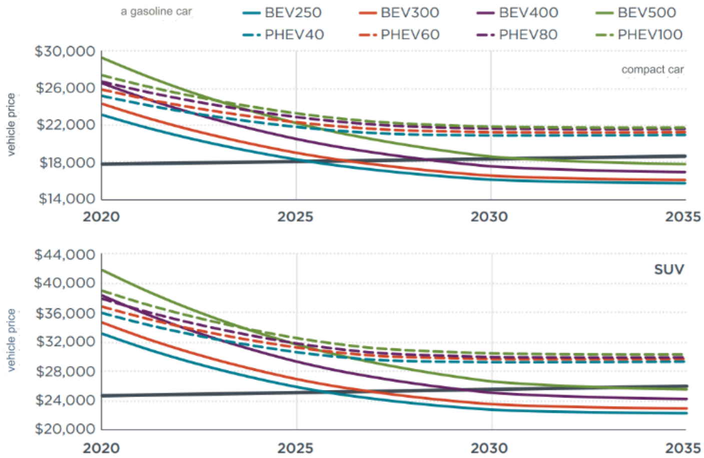

Figure 2. The selling prices of fuel vehicles and electric vehicles(2020-2035)

In addition, ICCT gives the selling prices of fuel vehicles and electric vehicles in 2020-2035, including two mainstream types of vehicles, compact cars and SUVs. Among them, including gasoline vehicles, battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV). The price of gasoline vehicles will not fluctuate greatly in 2020-2035, and will remain stable at $18,000 or $24,000. From 2020 to 2024, it can be seen that the price of BEV and PHEV is significantly higher than that of gasoline vehicles, but the trend is decreasing year by year; In addition, during 2025-2030, the BEV price gradually reached parity with gasoline vehicles, and after 2030, the BEV price gradually became slightly lower than gasoline vehicles, which is consistent with the changing trend of battery system cost, indicating that the cost of battery systems is proportional to the selling price of electric vehicles. For PHEVs, the price slowly declines from 2020 to 2030, flattens out after 2030, and finally stabilizes at around $22,000.

Therefore, according to the above data analysis, it can be concluded that at present, the purchase cost of hybrid vehicles is the highest, followed by electric vehicles, and the purchase cost difference between the two is small, and the purchase cost of gasoline vehicles is the lowest; But over the next decade or so (2025-2035), the purchase cost of the electric vehicle will decrease along with the reduction of its manufacturing cost. Although the purchase cost of hybrid cars has decreased, the price is still the highest among the three types of vehicles.

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Because fuel vehicles need to be refueled to ensure normal running during their service cycle, their normal use cost is higher and they are greatly affected by oil prices. Electric vehicles usually need charging piles to charge, because China's electricity is much lower than oil prices, so the cost of electric vehicles is relatively low; In addition to the engine, the hybrid car also has a drive motor system, and two different power systems will also make the hybrid car in the daily use cost and maintenance [26].

5. Conclusion

Through the description of the drive and working principles of the three types of cars and the comparison of their endurance mileage, cost and environmental influence, the article finds that the difference between the drive and the power source of fuel, electric and hybrid vehicles influences the endurance mileage, cost and environmental influence of the three types of cars,causing these three types of cars have different order in each aspect.For the endurance mileage, because of having two drive systems, hybrid vehicles have the highest endurance mileage , followed by fuel vehicles, and electric vehicles are the lowest. In the other hand, the cost of hybrid vehicles is also the highest since it has two drive systems. At the same time, the purchase cost of electric vehicles is likely to be equal to or lower than fuel vehicles. Besides, electric vehicles are the one who have the lowest CO_2 emission in the life cycle, followed by hybrid vehicles, and the CO_2 emission of fuel vehicles is the highest. Therefore, considering the cost and other factors, buying electric vehicles is the most cost-effective choice to consumers. The reason for buying electric vehicles is the most-effective choice is that electric vehicles have the lowest C02 emission among the three types of vehicles, which means electric vehicles can help protect the environment. In addition, according to the predictive analysis of the cost, electric vehicles are likely to have the lower selling price than fuel vehicles that have the lowest selling price among the three types of vehicles now, so that consumers can spend less money buying an electric vehicle.The main contribution of the paper is that it fills the gap in the comparison of hybrid vehicles and other two types of vehicles,systematically describing the drive and the principles of each type of vehicles, helping understand the difference between the three types of cars in basic structure and the endurance mileage, the cost and the environmental influence. By doing this way, consumers can directly understand the difference between fuel vehicles, electric vehicles, and hybrid vehicles, so that they can make the most suitable choice for themselves when buying cars. The current study only compares the three types of cars from three aspects : endurance mileage, cost and the environmental influence, which is not comprehensive enough. The future study should set up more comparison aspects, such as second-hand car market, noise and so on.

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