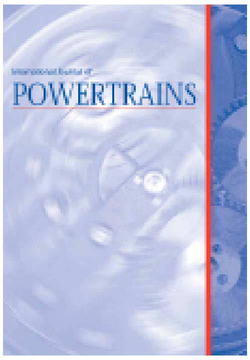

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Energy consumption analysis of extended-range electric vehicles with different driving cycle and different modes

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Abstract: To reduce the energy consumption and extend the driving range of extended-range electric vehicles, an extended-range electric vehicle with different modes is employed to analyse the energy consumption characteristics and driving range under different driving cycle. The vehicle working mode is divided into hybrid mode and pure electric mode. The results show that under CLTC, the difference between the actual speed and the required speed in the two operating modes is the smallest. Driving resistance is the main factor that affects the energy consumption and driving range of the vehicle; brake recovery also has a certain impact on driving mileage. In the pure electric mode, the driving range of the vehicle is the longest under the NEDC. And in the hybrid mode, the engine loses the highest energy. These results are helpful for the study of energy consumption law of extended-range electric vehicles and the design of energy management strategies.

Keywords: extended range electric vehicles; energy consumption; driving cycle; energy management.

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1 Introduction

In this era, environment and energy problems are becoming more and more serious. Therefore, electric vehicles (EVs) are more promising. However, the current EV technology is not particularly mature, and there are bottlenecks in driving range, battery cost, charging time and other aspects (Wei et al., 2021; Chen et al., 2019). Hence extended-range EVs have been on the horizon. Compared with pure EVs, extended-range EVs add an engine, which can solve the problems faced by pure EVs such as driving range, battery, charging time and so on (Zhang et al., 2016). There are two operating modes of extended-range EVs, namely, hybrid mode and pure electric mode (Chen, 2017).

Energy consumption is the core index to evaluate the performance of extended range EVs. Many scholars at home and abroad have studied the influencing factors of vehicle energy consumption through experiments or model building. By analysing the operating data of Nissan Leaf and Tesla Roadster EVs, Hayes et al. (2011) explored the impact of braking energy recovery, battery attenuation, ventilation equipment, air conditioning and other on-board accessories on energy consumption. The results showed that the driving range was mainly affected by running speed, on-board air conditioning and battery attenuation. Denis et al. (2012) analysed the test data of plug-in hybrid EVs, and found that driving the vehicle consumes about 54% of the electricity, and the remaining 46% of the electricity is lost by mechanical braking, transmission system, engine, motor, power battery and vehicle accessories during the whole vehicle driving. Gennaro et al. (2014) explored the influence of different driving cycles and ambient temperature on energy consumption and driving range through experiments. The results show that energy consumption and driving range depend on the selection of driving cycles; Hou et al. (2015) compared Chinese and American PHEV energy consumption evaluation methods from two aspects of test standards and index calculation, pointed out that there were shortcomings in China's PHEV energy consumption evaluation, such as missing energy consumption label and not considering travel characteristics, and put forward suggestions to strengthen the study of travel characteristics to improve the PHEV energy consumption evaluation method in China. Chen et al. (2016) established a PHEV vehicle model based on Modelica language, simulated and analysed the energy consumption changes of each part of the vehicle under NEDC driving cycle, and focused on exploring the influence of average vehicle speed and acceleration/deceleration speed on the power consumption and fuel consumption in the power maintenance phase of PHEV, and revealed the influence rule of driving cycles on energy consumption. Wu et al. (2015) pointed out that travel characteristic parameters such as speed, acceleration and slope have a great impact on energy consumption.

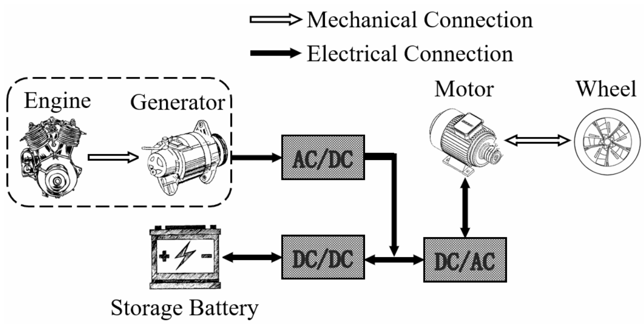
This paper takes extended-range EV as the research object, using the method of modelling and simulation analysis, from the vehicle in main components under different operating mode of the angle of the energy loss analysis, investigates the effects of NEDC driving cycle, WLTC driving cycles and driving cycle of China on energy consumption of extended-range EVs, compares the continuous driving range of extended range EVs under three different driving cycles.

2 Structure and modelling

2.1 Basic structure

Extended-range EV includes engine, generator, motor, battery, etc. The motor is used to drive the vehicle, while the engine is only used to drive the generator and does not drive the vehicle directly. Its structural diagram is shown in Figure 1.

Figure 1 Schematic diagram of extended-range EV



2.2 Modelling

The extended-range EV studied in this paper can charge the on-board battery through the external power grid. When the battery does not provide enough energy to meet the driving needs, the range extender is started and the engine drives the generator to generate electricity. The output electricity can be transferred to the battery or the drive motor.

Vehicle parameters are shown in Table 1. Based on the ADVISOR, the vehicle model of the extended range EV was established (Wu et al., 2015) according to the vehicle parameters in Table 1.

Table 1 Basic vehicle parameters

Category	*Name of parameter*	*Parameter values*
Vehicle parameters	Curb weight (kg)	1,643
	Full load mass (kg)	2,028
	Air resistance coefficient	0.327
	Windward area (m^2)	2.27
	Tyre rolling radius (m)	0.31
	Rolling resistance coefficient	0.0078
Drive system	Final ratio	9.3
Engine	Maximum power (kW)	88
	Maximum speed of revolution (r/min)	6,000
Generator	Maximum power (kW)	31
	Maximum torque (N·m)	182
	Maximum speed of revolution (r/min)	6,000
Battery	Maximum voltage (V)	23.4
	Battery capacity (A·h)	57
Motor	Maximum power (kW)	100
	Maximum torque (N·m)	270
	Maximum speed of revolution (r/min)	12,000

2.2.1 Dynamical model

Vehicle dynamic performance refers to the motion characteristics of the vehicle along the driving direction. Along the direction of the car, the driving force and driving resistance of the car comply with Newton's laws of motion. According to the car theory, the driving equation (Zeng and Gong, 2017; Yu, 2009) of the car is:

$$F_t = F_f + F_w + F_i + F_j \tag{1}$$

$$F_t = \frac{T_{mc} i_{gb} i_{fd} \eta_T}{r} \tag{2}$$

$$F_f = mgf \tag{3}$$

$$F_w = \frac{C_D A u^2}{21.15} \tag{4}$$

$$F_i = mgi \tag{5}$$

$$F_j = \delta m \frac{du}{dt} \tag{6}$$

In the above formulas, F_t is the driving force of the vehicle, N; F_f is the rolling resistance, N; F_w is the air resistance, N; F_i is the slope resistance, N; F_j is the acceleration resistance, N; T_{mc} is the torque of driving motor, N·m; i_{gb} is the transmission ratio of the transmission; i_{fd} is the transmission ratio of the main reducer; η_T is the transmission efficiency; r is the automobile wheel radius, m; m is the vehicle mass, kg; g is the gravitational acceleration, 9.81 m/s^2; f is the rolling resistance coefficient; C_D is the air resistance coefficient; A is the windward area, m^2; u_a is the vehicle speed, km/h; i is the slope; δ is the conversion coefficient of vehicle rotating mass, $\delta > 1$; $\frac{du}{dt}$ is the acceleration of driving, m/s^2.

2.2.2 Engine model

The engine is a device that uses gasoline or diesel and other chemical substances to burn to produce energy, which drives the crankshaft to rotate and converts chemical energy into mechanical energy output. The working state of the engine has a great influence on the energy conversion of vehicle.

The output torque and rotate speed of the engine are T_{fc_out} and η_{fc_out} respectively, then the fuel consumption rate of the engine is:

$$m_{fc} = b \cdot P_{fc} \tag{7}$$

$$P_{fc} = T_{fc\_out} \cdot \eta_{fc\_out} \tag{8}$$

In the above formulas, b is the specific fuel consumption of the engine, g/(kW·h). The actual working condition of the engine has an important influence on its specific fuel consumption. The fuel consumption of the engine is completely different at different working points (Zeng and Gong, 2017). Therefore, the engine should work along the optimal efficiency curve as far as possible to improve its fuel economy during the whole vehicle running.

2.2.3 Motor model

The whole vehicle model in this paper is based on the extended-range electric vehicle developed by an enterprise. Due to the characteristics of the power structure of extended-range EV, its driving power is only provided by the motor. Therefore, this paper only considers the motor when establishing the driving model. In this paper, the motor is a permanent magnet synchronous motor, with a higher torque to weight ratio, power factor, faster motor response; when problems occur, it is easy to repair and maintain, and can quickly monitor the start, acceleration, deceleration and stop of the vehicle. These advantages meet the performance requirements of the driving motor for the powertrain of extended-range EVs.

Since the drive motor is the only driving device of the extended-range EV, the drive motor will act as a generator when the vehicle is braking. Therefore, the main function of the driving motor is to provide driving force for the vehicle and charge the battery when the braking energy is recovered. When the driving motor model is established in this paper, the demand power of the vehicle driving is taken as the input, and the speed and torque of the motor are taken as the output. Its operating power can be expressed as:

$$\begin{cases} P_{mc} = \dfrac{T_{mc}\omega_{mc}}{\eta_{mc\_drv}} \text{(driving mode)} \\ P = T_{mc}\omega_{mc}\eta_{mc\_reg} \text{(braking mode)} \end{cases} \tag{9}$$

In the above formula, T_{mc} and ω_{mc} are respectively the torque and rotation angular velocity of the motor, η_{mc_drv} and η_{mc_reg} are the working efficiency of the motor in two modes, and the values of η_{mc_drv} and η_{mc_reg} are determined by the actual working state of the motor (Yang et al., 2021).

2.2.4 Battery model

In this paper, the whole vehicle model is based on an extended-range EV developed by an enterprise. Lithium-ion battery is selected as the battery model. Lithium-ion battery has the advantages of high energy density and power density, long cycle life, high voltage of single battery, and has the ability of fast charging and deep discharge. These advantages meet the demand of battery pack for power system of extended-range EV.

When establishing the power battery model in this paper, the demand power of the driving motor is taken as the input, and its current SOC value is taken as the output. In the process of use, the ratio of the remaining capacity of the battery to the total capacity is called the state of charge, the state of charge is 100% when fully charged; The state of charge after full discharge is 0%. SOC is a function of discharge current (or charging current) *i*, and in the time interval of *dt*, its expression is:

$$\Delta SOC = \frac{i\ dt}{Q(i)} \tag{10}$$

In the above formula, $Q(i)$ is the capacity of the battery group, and the unit is A·h. Discharge, $i > 0$; When charged, $i < 0$. Then the state of charge of the battery group can be expressed as:

$$SOC = SOC_0 - \int \frac{i\,dt}{Q(i)} \quad (11)$$

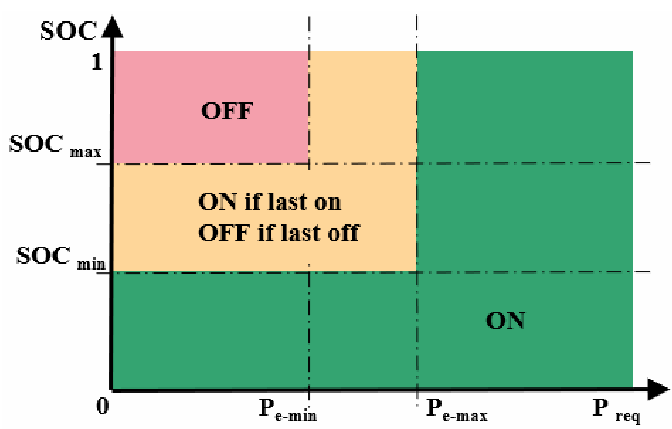
In the above equation, SOC_0 is the initial state of charge (Zeng and Gong, 2017).

The establishment of the simulation model in this paper is based on the parameters of the extended-range EV developed by the enterprise. Due to the confidentiality principle of the enterprise, the vehicle experiment of simulation model verification cannot be described in detail here. The simulation test of this paper is compared with the enterprise vehicle experiment, which meets the research needs of this paper.

2.3 *Energy management strategy*

Energy management strategy is the core of extended-range EV. For extended-range EVs, the vehicle operation mode can be divided into power maintenance stage and power consumption stage according to battery SOC state, namely hybrid mode and pure electric mode. At present, the energy management strategies applied to extended-range EVs mainly include thermostat control strategy, power following control strategy, etc. The series power following control strategy is adopted in the simulation model in this paper. The strategy adjusts the running state of the engine according to the power demand of the vehicle and the SOC of the battery, so that the battery can work in the vicinity of the ideal power, which is helpful to maintain the stability of the power. When SOC is less than SOC_{min} or the vehicle power demand is too high, the engine provides the vehicle power. When SOC is larger than SOC_{max} and the demand power is small, the engine is shut down and the battery provides the whole vehicle power. A state holding area is set between engine start and stop to avoid frequent engine start and stop. Its control principle is shown in Figure 2.

Figure 2 Control principle (see online version for colours)



3 Energy consumption analysis

3.1 Driving cycle parameter

In this paper, the extended-range EV is taken as the research object, and the vehicle model is simulated under NEDC, WLTC and Chinese driving cycle. Among them, CLTC-P curve of light passenger vehicle (hereinafter referred to as CLTC) was selected for Chinese driving cycle, and characteristic parameters of the three driving cycles were compared, as shown in Table 2.

Table 2 Comparison of characteristic parameters of three driving cycles

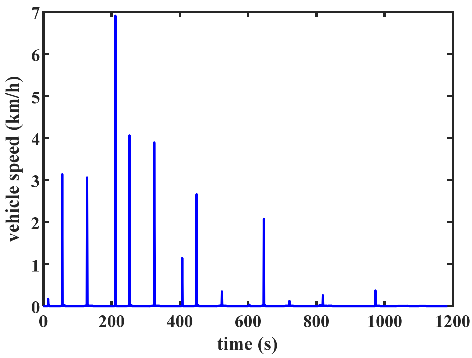
Driving cycle	*NEDC*	*WLTC*	*CLTC*
Time (s)	1,184	1,800	,1800
Mileage (km)	10.93	23.59	14.48
Average speed (km/h)	33.21	47.17	28.96
Idling proportion (%)	25.15	11.83	23.28
Maximum speed (km/h)	120	130.7	114
Average deceleration (m/s^2)	–0.79	–0.37	–0.4
Decelerating proportion (%)	15.7	43.67	35.61
Average acceleration (m/s^2)	0.54	0.39	0.36
Accelerating proportion (%)	22.87	42.22	39.61

As shown in Table 2, it can be seen that the proportion of idle speed in NEDC driving cycle is high. The average driving speed in WLTC driving cycle is high, and frequent acceleration and deceleration are required. In CLTC driving cycle, the average speed is low, and the proportion of idle speed is high. The travel is mainly in urban and suburban areas, and frequent acceleration and deceleration are also needed.

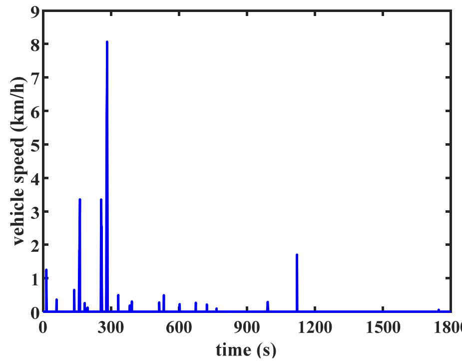
3.2 Hybrid mode

In hybrid mode, the speed tracking of extended-range EV under three driving cycles is shown in Figure 3. Where, (a), (b) and (c) represent the differences between the actual speed and the required speed under NEDC, WLTC and CLTC driving cycles, respectively. As can be seen from the figure, in the early stage of NEDC driving cycle, there are many times when the actual speed differs from the driving cycle speed, and the maximum difference can reach about 7 km/h. In the WLTC driving cycle, as in the NEDC driving cycle, there are many periods when the actual speed differs from the working speed in the early driving cycle, and the maximum difference can reach about 8 km/h. However, in the CLTC driving cycle, in the middle of the driving cycle, there are many different times between the actual speed and the driving cycle speed, and the maximum difference is less than 5 km/h. Generally speaking, in the three driving cycles, the difference between the actual speed and the required speed under the CLTC driving cycles is small, while under NEDC and WLTC, there is little difference in the speed difference between the two driving cycles, which is larger than that under CLTC driving cycle.

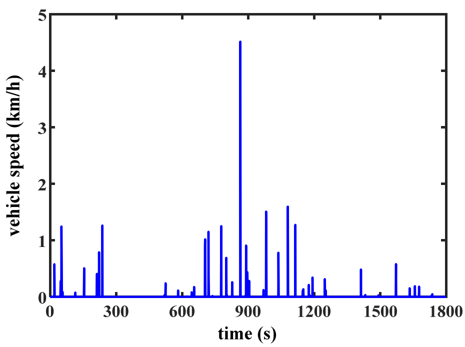
Figure 3 Speed tracking under three driving cycles in hybrid mode, (a) differences between the actual speed and the required speed under NEDC (b) differences between the actual speed and the required speed under WLTC (c) differences between the actual speed and the required speed under CLTC (see online version for colours)



(a)

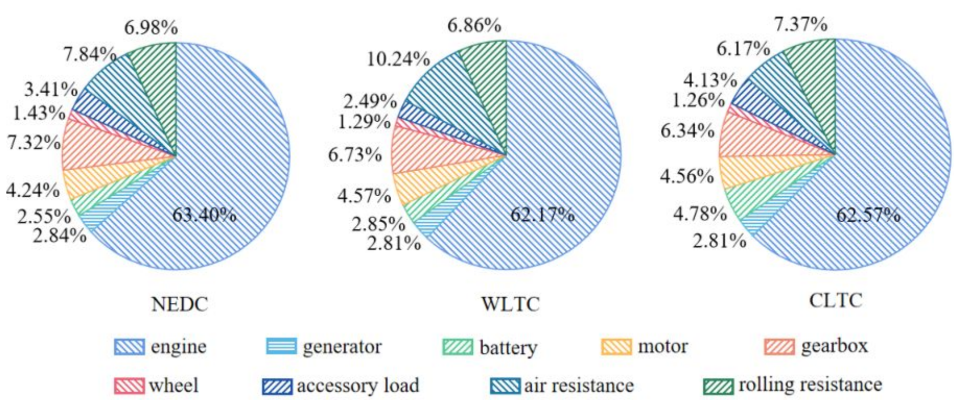


(b)



(c)

Figure 4 Proportion diagram of fuel consumption distribution under three driving cycles (see online version for colours)



In order to explore the influence of driving cycle on the energy consumption of the vehicle, the energy consumption data of each part was obtained according to the energy use data table in the simulation results, averaging to 100 km, and the energy loss distribution ratio of each part of the vehicle under three driving cycles was obtained, as shown in Figure 4.

As can be seen from Figure 4, under the three driving cycles, engine energy loss accounts for the largest proportion, about 62%~64%. The second is the energy consumed to overcome the driving resistance (air resistance and rolling resistance). Under the CLTC driving cycle, the energy consumed to overcome the driving resistance is the least, accounting for about 13.5% of the total energy. WLTC accounted for about 17% at most. Among them, the minimum energy consumption ratio of air resistance under CLTC is 6.17%, and the maximum energy consumption ratio of air resistance under WLTC is 10.24%. Next, this paper will analyse the energy consumption of the engine and the energy consumption to overcome the driving resistance in detail.

3.2.1 Energy loss from the engine

The energy loss of an engine includes mechanical loss and heat loss. Among them, the mechanical loss is caused by the internal friction of the engine under the condition that the engine does not burn. It accounts for less in the total energy loss and is relatively stable, so it will not be analysed additionally. The heat loss is the main factor that causes the engine energy loss. Only a small part of the heat energy from engine combustion will be converted into useful work, while the rest will be consumed in the form of exhaust loss, cooling loss, time loss, etc. (Wei, 2019a, 2019b). Therefore, the energy loss caused by the heat loss of the engine is mainly analysed here. Heat loss of engines under three driving cycles is compared, as shown in Table 3.

Table 3 Engine heat loss under three driving cycles

	NEDC	*WLTC*	*CLTC*
Average amount of heat emitted (kW)	5.16	6.76	3.56
Average heat loss power (kW)	8.91	11.98	6.04

As can be seen from Table 3, in a single driving cycles, the heat emission and heat loss power under the WLTC driving cycles are the largest, followed by NEDC, and the heat loss is the smallest under the CLTC.

Therefore, the engine energy loss is:

$$W_{fc\_loss} = \int P_{fc\_loss} dt \tag{12}$$

According to equation (12), the energy loss of the engine is related to the average power loss and running time. By referring to Table 2 and Table 3 and taking into account the two factors of average power loss and running time, it is calculated that the average engine energy loss per kilometre is the lowest in CLTC driving cycle and the highest in NEDC, and WLTC is slightly lower than NEDC.

3.2.2 Energy loss against air resistance

According to vehicle dynamics, the calculation formula of air resistance is:

$$F_w = \frac{C_D A u^2}{21.15}$$

where C_D is the wind resistance coefficient; A is the windward area, m^2; u_a is the speed, km/h; F_w is the air resistance, N.

According to formula (4), the air resistance is proportional to the quadratic of the speed, which is the graph of the change of air resistance with the speed. As shown in Figure 5, the speed has a very important influence on the air resistance. The speeds of the three driving cycles were divided into low speed (0–60 km/h), medium speed (60–80 km/h), high speed (80–100 km/h) and ultra-high speed (> 100 km/h), as shown in Table 4.

Figure 5 The variation curve of air resistance with speed

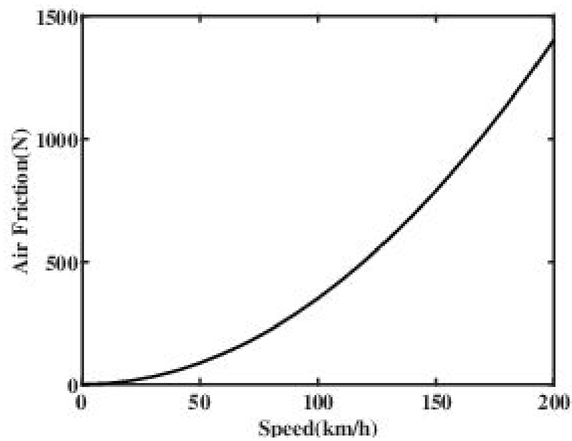


Table 4 The distribution ratio of each speed interval in three driving cycles

Driving cycle	*NEDC*	*WLTC*	*CLTC*
Idle speed proportion (%)	25.15	11.83	23.28
Low speed proportion (%)	55.19	5.22	64.72
Medium speed proportion (%)	11.31	13.67	7.22
High speed proportion (%)	5.23	8.78	2.78
Ultra-high speed proportion (%)	3.12	10.50	2.0

As can be seen from Table 2 and Table 4, among the three driving cycles, the average speed of the WLTC driving cycle is the largest, while the average speed of the CLTC driving cycle is the smallest, and the average speed of the NEDC driving cycle is the middle. In addition, the proportion of high speed interval in WLTC driving cycle is the largest, followed by NEDC, and the proportion of high speed in CLTC is the smallest. In the distribution of ultra-high speed interval, the proportion of WLTC is the largest, the proportion of CLTC is the smallest, and the proportion of NEDC is the middle. The distribution proportion of WLTC in ultra-high speed interval is much larger than that of the other two driving cycles, and the distribution proportion in idle speed interval is much smaller than that of the other two driving cycles. The distribution of CLTC driving cycle is relatively large in idle speed and low speed interval, but small in high speed and ultra-high speed interval, so the energy loss to overcome the air resistance: WLTC > NEDC > CLTC.

3.2 Energy loss against rolling resistance

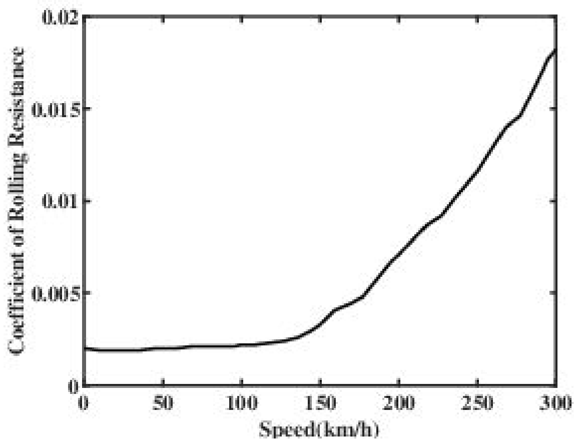
The formula of rolling resistance is as follows:

$$F_f = mgf$$

where F_f is rolling resistance, N; m is vehicle mass, kg; g is gravity acceleration, 9.81 m/s^2; f is the rolling resistance coefficient.

According to equation (3), when the vehicle weight is constant, the rolling resistance is proportional to the rolling resistance coefficient. The relationship between rolling resistance coefficient and speed is shown in Figure 6.

Figure 6 Relation curve of rolling resistance coefficient/rolling resistance and speed

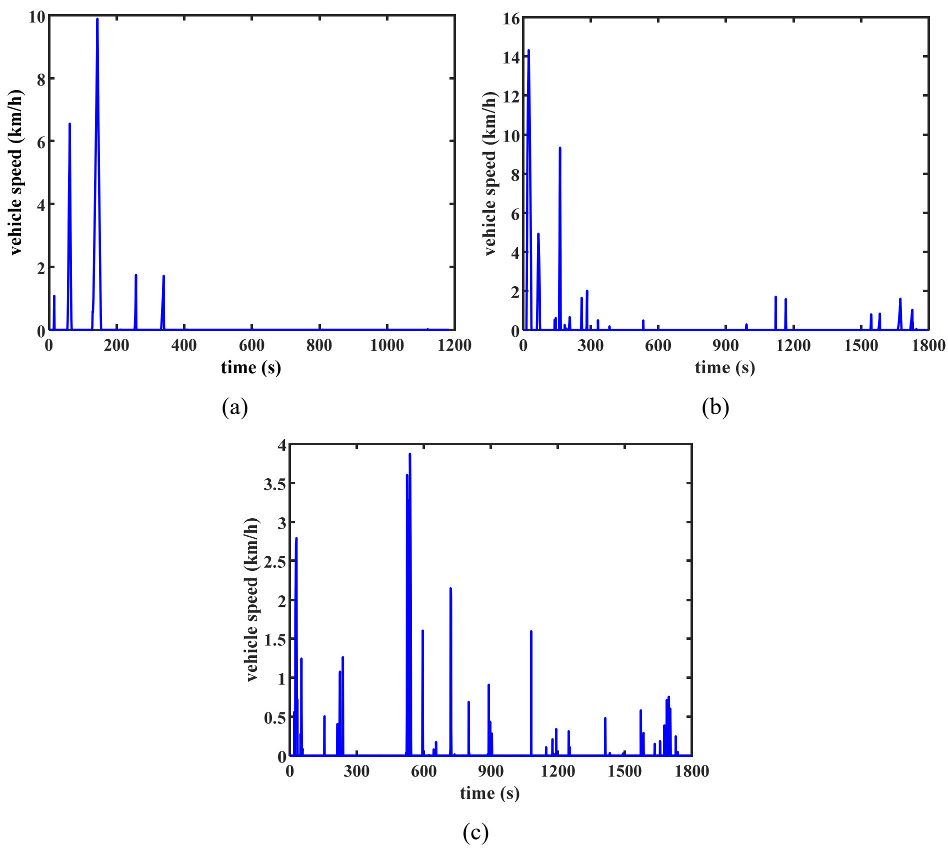


As can be seen from Figure 6, the rolling resistance has little or no change when the speed is less than or equal to 125 km/h. Only when the speed is higher, the rolling resistance gradually increases with the increase of the speed. Therefore, according to the characteristic parameters of the three driving cycles, the energy loss to overcome the rolling resistance is basically the same in the three driving cycles.

3.3 Pure electric mode

In pure electric mode, the speed tracking of extended-range EV under three driving cycles is shown in Figure 7. Where, (a), (b) and (c) represent the differences between the actual speed and the required speed under NEDC, WLTC and CLTC driving cycles, respectively. As can be seen from the figure, at the early stage of NEDC driving cycle, there are many times when the actual speed differs from the driving cycle speed, and the maximum difference can reach about 10 km/h. In the WLTC driving cycle, as in the NEDC driving cycle, there are many periods when the actual speed differs from the driving cycle speed in the early driving cycle, and the maximum difference is more than 14 km/h. In the later driving cycle, there is also a small speed difference. Under the CLTC driving cycle, the difference between the actual speed and the driving cycle speed reaches the maximum in the middle of the driving cycle, which is close to 4 km/h. Generally speaking, under the three driving cycles, the difference between the actual vehicle speed and the required vehicle speed under the CLTC driving cycle is generally small, but the difference takes a long time to appear. In the WLTC driving cycle, the difference between the actual speed and the required speed is the largest. The velocity difference in NEDC is between WLTC and CLTC, but the time of the difference is relatively short.

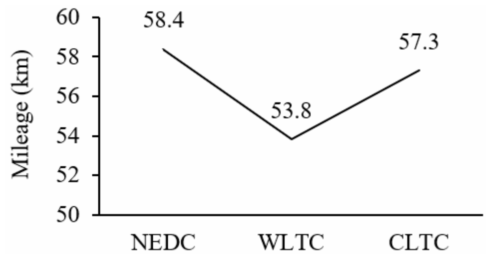
Figure 7 Speed tracking under three driving cycles in pure electric mode, (a) differences between the actual speed and the required speed under NEDC (b) differences between the actual speed and the required speed under WLTC (c) differences between the actual speed and the required speed under CLTC (see online version for colours)



The pure electric mode is the stage when the power battery serves as the power source. The battery provides energy for the whole vehicle to drive the car, so the energy consumed in this stage is mainly electric energy.

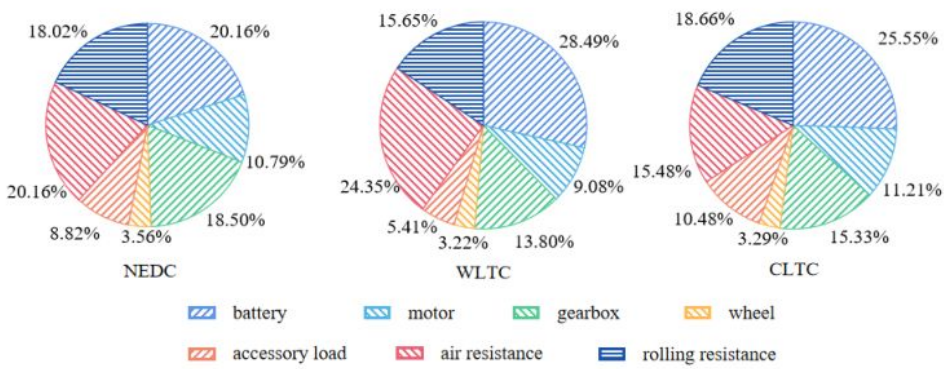
As can be seen from Figure 8, when the extended-range EV is driven by pure electricity, it has the longest driving range under the NEDC driving cycle, which can travel 58.4 km. The shortest driving distance under WLTC is 53.8 km.

Figure 8 Driving range under three driving cycles



In order to explore the influence of driving cycles on the vehicle's electricity consumption, the energy consumption data of each part was obtained according to the simulation results, averaging to 100 km, and the energy loss distribution ratio of each part of the vehicle under three driving cycles was obtained, as shown in Figure 9.

Figure 9 Power loss in each part of the three driving cycles (see online version for colours)



As can be seen from Figure 9, in pure electric mode, the power consumption to overcome driving resistance is the largest, followed by the battery. Under CLTC driving cycle, the power consumption to overcome the driving resistance (air resistance and rolling resistance) is the least, accounting for about 34.14% of the total energy. WLTC accounted for about 40% at most. Among them, the minimum energy consumption ratio of air resistance under CLTC is 15.48%, and the maximum air resistance ratio under WLTC is 24.36%. However, the power consumption to overcome the rolling resistance is the least under the WLTC, which is 15.65%, and the energy consumption of the rolling resistance under both NEDC and CLTC reaches 18%. The proportion of battery to power consumption is the largest under the WLTC, which is 28.49%, and the minimum under the NEDC, which is 20.16%. The following two aspects will be focused on the driving resistance and battery analysis.

3.3.1 Electricity loss against driving resistance

According to the above analysis, both air resistance and rolling resistance are related to the vehicle speed. In the simulation of pure electric and hybrid modes, the same three driving cycles are adopted, so the speed characteristics of the vehicle in the simulation of pure electric mode are consistent with those in the hybrid mode, so the energy loss of the vehicle in the two working modes is basically the same.

Analysis of energy consumption of air resistance: in the three driving cycles, the average velocity of WLTC is the largest, and the average velocity of CLTC is the smallest. WLTC has the largest proportion of high-speed interval and ultra-high-speed interval, while CLTC has the smallest proportion. WLTC has the smallest proportion of idle interval and low interval, and CLTC has the largest proportion. Therefore, the energy loss to overcome air resistance in WLTC driving cycle is the largest, CLTC driving cycle is the smallest, and NEDC is in the middle.

Energy analysis of rolling resistance consumption: when the speed of the vehicle is less than or equal to 125 km/h, the rolling resistance of the vehicle changes very little, and it can be approximated that the rolling resistance value tends to be constant. According to the speed parameters of the three driving cycles, the energy loss to overcome the rolling resistance is almost equal in the three driving cycles.

Therefore, in pure electric mode, the energy loss to overcome the driving resistance is: WLTC > NEDC > CLTC.

3.3.2 Electricity loss from the battery

Due to the different requirements of each driving cycle, the internal resistance heat generation of the battery is different, so that the battery temperature changes caused by it are different, so the energy loss of the battery is not the same. Table 5 shows the comparison of battery energy consumption under three driving cycles.

Table 5 Battery efficiency under three driving cycles

Driving cycle	*NEDC*	*WLTC*	*CLTC*
Average temperature (°C)	24.29	29.69	25.29
Average power loss (kW)	1.728	3.471	1.725

After simulation, the power loss of battery in different periods of vehicle running is obtained. The relation between power loss and energy loss of a battery is expressed as follows:

$$W_{ess\_loss} = \int P_{ess\_loss} dt \quad (13)$$

According to equation (13), the energy loss of the battery is related to the average power loss and the running time. By referring to Table 2 and Table 5 and taking into account the two factors of average power loss and running time, it is calculated that the average engine energy loss per kilometre is the highest in the WLTC driving cycle, the lowest in the NEDC, and the CLTC is in the middle.

4 Conclusions

By comparing and analysing the energy consumption laws of range extended EVs under different working modes, the energy consumption distribution of range extended EVs under NEDC, WLTC and CLTC driving cycles was explored. The results show that:

1. Under the two operating modes, the influence of Chinese driving cycle on the speed of extended-range EVs is small, and the difference between the actual speed and the required speed is the smallest under CLTC; it is of reference significance to study the energy consumption of extended-range EVs under Chinese driving cycle.
2. In the hybrid mode, the energy consumption of the extended range EV is the lowest in the CLTC driving cycle and the highest in the NEDC driving cycle; At this stage, the engine loses the most energy. Therefore, when designing energy management strategies suitable for extended-range EVs, the engine efficiency can be taken as the index to set the minimum engine efficiency threshold. When the actual engine efficiency is lower than this threshold, the mode of extended-range EVs can be switched to reduce the energy loss of the engine.
3. In pure electric mode, the driving range of the extended range EV is the longest in NEDC driving cycle and the shortest in WLTC driving cycle. At this stage, the energy used to overcome the loss of driving resistance is highest. However, due to the high idle speed ratio and low average speed in Chinese driving cycle, the energy loss of the vehicle to overcome the driving resistance in Chinese driving cycle is low. Since the Chinese working conditions require frequent braking, when designing energy management strategies suitable for extended-range EVs, the ability of braking energy recovery of vehicles can be strengthened to reduce the total energy consumption of vehicles, thus extending the driving range of vehicles in pure electric mode.

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