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2019-01-0724 Published 02 Apr 2019

Costs, Benefits and Range: Application of Lightweight Technology in Electric Vehicles

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Citation: Shi, T., Zhao, F., Hao, H., and Liu, Z.and "Costs, Benefits and Range: Application of Lightweight Technology in Electric Vehicles," SAE Technical Paper 2019-01-0724, 2019, doi:10.4271/2019-01-0724.

Abstract

The lightweight technology takes an important role in electric vehicle(EV) energy conservation domain, as lighter vehicle means less energy consumed under same condition. In this paper, the typical energy requirement in an NEDC cycle is investigated, and the relationship between lightweight rate and energy consumption reduction effectiveness is given. The benefit of lightweight to EV come from the less battery cost because of less energy requirement. For EVs, with less battery cost, a certain lightweight rate can be obtained with less total cost. On the other hand, if lightweight rate is very high, the battery cost won't be able to cover the lightweight cost. Besides, the relationship between driving range and battery capacity is discussed in this paper. It is found that there is a limitation of EV driving range, which is determined by the battery energy density.

Introduction

With the serious energy and environment problems today, energy conservation becomes an important issue for further development [1, 2, 3, 4, 5, 6]. Many solutions have been presented in transportation and vehicle domain. Lightweight technologies are among them [7, 8]. Lightweighting can reduce energy consumption of vehicles in several ways [9, 10, 11, 12]. Firstly, it reduces the rolling resistance of tires, which is proportional to the weight of vehicle. Secondly, it reduces the amount of energy required to accelerate a vehicle or climb a hill, which ultimately reduces the amount of energy loss to friction brakes. Thirdly, lightweighting reduces the energy needed to meet the same acceleration and grade performance. Fourthly, it could reduce the battery energy needed in an electric vehicle (EV) to achieve the same range, which reduces the total cost. There are several options to realize vehicle lightweighting. Major technologies include the application of high strength steel, aluminium, magnesium, polymer composites and the related technologies [13, 14, 15, 16, 17, 18]. These options could realize different mass reductions with certain cost.

Although there are significant benefits for vehicle lightweighting, studies on the effectiveness of energy conservation for mass reduction are still lacked. In this paper, the relationship between lightweight rate (LTR) and energy consumption reduction (ECR) for lightweighted vehicles is described considering a typical 1.5t sedan vehicle. Furthermore, the benefit of EV lightweighting is discussed considering the energy conservation effectiveness and cost of battery. In addition, as EV driving range is highly related to energy consumption, the relationship between EV driving range and battery characteristics is also discussed.

Relationship between LTR and ECR

Basic Methodologies

The resistances in vehicle driving are related to curb weight. Mass reduction would bring energy saving in vehicles. Energy consumption of a certain vehicle could be obtained as follow:

The longitude force for driving a vehicle is obtained by the vehicle dynamic Equation (1). In the equation, rolling resistance, gradient resistance, aero resistance, acceleration resistance, inertia resistance are included. Multiplying the force obtained from Equation (1) to the vehicle speed, we can obtain the power requirement. Then the total energy consumption under a certain condition could be obtained by integrating the power requirement by time. With different vehicle parameters or different running conditions, the energy consumption result would be different. Applying different Lightweight rate in vehicle, the curb mass parameter in Equation (1) will differ, then different energy consumption reduction occurs. The vehicle dynamic formula is shown as follow:

$$F = m*g*f + \frac{Cd*A*u^2}{21.15} + m*a + \frac{I_r + I_e*i_T^2*i_0^2*\eta}{r^2}*a \quad (1)$$

Where F is the longitude force to drive the vehicle; m is the curb weight; g is the gravitational acceleration; f is the rolling resistance coefficient; Cd is the drag coefficient; A is front face area; u is the running speed; I_r is the rotary inertia

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of wheel; I_e is rotary inertia of engine; r is radius of wheel; i_T is the gear ratio of transmission system; i_0 is the gear ratio of final drive; η is mechanical efficiency of power system.

With above methodology, the vehicle energy consumption calculation model is built in Matlab. In this paper, the NEDC condition is applied for calculation. The NEDC condition is presented by European Union (EU), and is also applied in China. In an NEDC cycle, the vehicle is running according to given velocity curve. The total cycle lasts for 1200 seconds, with top speed of 120km/h, as shown in Figure 1. We applied the standard NEDC cycle data in the calculation of vehicle energy consumption. With vehicle velocity as input data, the force and power needed in a NEDC cycle for a typical car is obtained as shown in Figure 1. The total energy consumption in NEDC cycle is obtained by integration of power data.

This process can be applied to the original vehicle and the lightweighted vehicle respectively. Then their energy requirements could be obtained. The energy requirement of vehicle with different LTR can also be obtained by same method.

Calculation of Different Vehicles

With basic methodology given above, the energy requirements of different vehicles could be obtained. The traditional internal combustion engine vehicle(ICEV) and electric vehicle(EV) are both considered for comparison. The 1.0t, 1.5t and 1.8t typical sedan car are used in this paper. Major parameters are listed in Table 1. The curb weight are average values for small to middle sized cars. A five speed transmission system which is applied in a mid-sized car is selected in this paper [19]. The rotation inertia of wheel is estimated, assuming the wheel mass as 8kg, wheel radius as 0.3m. The final values is average in vehicles. The rotation inertia of engine system is obtained by literature review [20]. Final drive ratios is set as 4.5 considering the value is usually set between 4 and 6 in sedan cars. The transmission efficiency is set as 0.9, which is also an empirical value. In general, these values are typically applied in vehicles. As for the EV, major parameters of an EV is similar with those in an ICE vehicle, including the curb mass, rotation inertia of wheels, final drive ratios, and transmission efficiency. While the transmission system used in electric vehicles are quite different with those in gasoline vehicles. The EV transmission are usually designed as two or three speed. In this paper, a two speed transmission for EV is applied [21] for the calculation. Besides, the power system also shows difference between the EV and ICE. A typical traction motor with power rate 50kw, peak power 105kW is selected for estimation of rotation inertia of traction motor.

With major parameters and NEDC condition data ready, the energy consumption of 1.5t mid-sized sedan car with different lightweight rate is calculated. The results of ICE vehicle and electric vehicle are analyzed respectively.

As shown in Figure 2, the relationship between LTR and ECR are not completely in corresponding. The main influence of the lightweight technology in vehicle energy consumption is the rolling resistance and gradient resistance. Considering the aero resistance, inertia resistance, and other loss, the effectiveness of energy consumption reduction is a little lower than the lightweight rate. In the case of ICEV, 10% mass reduction brings approximately 8.4% of energy consumption reduction, for example. Besides, it must be figured out that despite it looks like a linear relationship between LTR and ECR, they are not linearly corresponded.

In addition, it can be seen that the effectiveness of lightweight technology applied in EV is slightly better than that applied in ICE vehicle. In EV, a 10% mass reduction brings 8.7% energy consumption reduction, which is better than that of 8.4% in ICE vehicle. This is because that the rotation inertia resistance of traction motor is lower because of lower transmission ratios, as in Equation (1).

The total energy consumption is calculated under NEDC condition, with the vehicle parameters as previous given. If the working condition or major parameters changed, the results may show some difference. However, the key trends of the relationship between LTR and ECR is still reliable. In the study of National Research Council(NRC), the effectiveness of fuel consumption reduction is 8% in a small sized car, considering 10% mass reduction. Their result is close to those obtained in this paper.

Cost and Benefit of EV Lightweight

Cost Study of Lightweight Technology

Vehicle weight is expected to decrease, but with constraints. Vehicle lightweight technology must be along with necessary safety measures in order to meet the safety regulation. At the same time, comfort and convenience is also considered in vehicle weight study. There will be an increase in weight due to increased luxury and comfort accessories. The major challenges for vehicle lightweight technology are those two mentioned.

In order to realize ideal vehicle mass reduction, with acceptable safety and comfort quest, auto manufactures find many ways. Studies show that technologies that reduce mass without compromising crashworthiness are available. So the cost became the main constraint. It is generally recognized that mass decreases in vehicles in recent years have resulted from improving performance, efficiency, emission, and even ride quality in right design. The use of advanced materials such as high stress steel, aluminium alloy, magnesium alloy, composite materials, are applied in vehicles to realize mass reduction. Advanced design techniques has contributed to additional increment in mass reduction. With more strict regulations for fuel economy and emissions today, greater focus on net mass reduction is expected in the future. However, there will be a cost to achieve this result.

The technology route to realize vehicle lightweight are substantially different across manufactures for similar vehicle models. With exceptions for performance-oriented vehicle designs, the cost and complexity generally progress as follow:

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FIGURE 1 Major output in a NEDC simulation

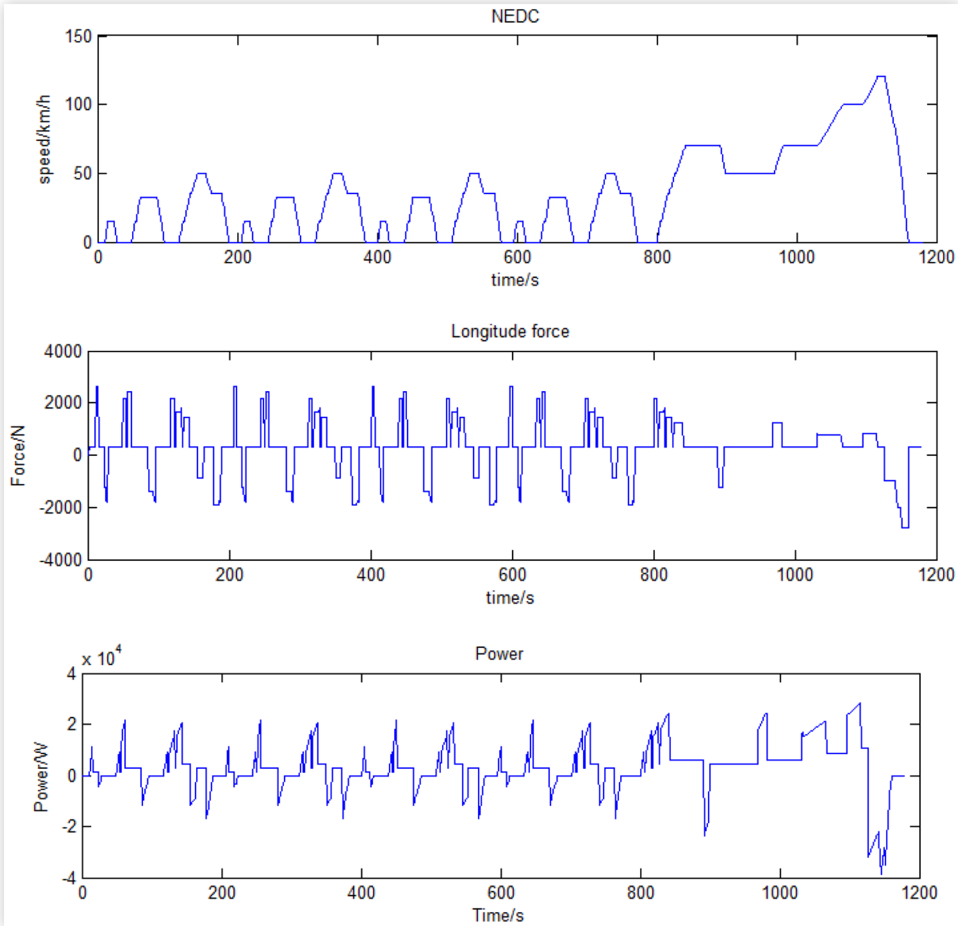

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TABLE 1 Major parameters of selected vehicles

Parameters	ICEV		EV	
m	1000kg、1500kg、1800kg			
i_T	Gear 1	2.804	Gear 1	2.1
	Gear 2	1.978	Gear 2	1.34
	Gear 3	1.531	-	-
	Gear 4	1.000	-	-
	Gear 5	0.705	-	-
I_r	0.36kg/m²			
I_e	0.46kg/m²		0.5kg/m²	
i_0	4.5			
η	0.9			

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Level 1: Mild steel to high-strength steel and composites/ plastics for non-structural or semistructrual parts.

Level 2: Steel to aluminium hang-on panels and limited use of small amounts of magnesium for brackets.

Level 3: Steel doors to aluminium doors, and additional aluminium in chassis components.

Level 4: More aggressive use of high-strength steel, aluminium, magnesium, and composites for other structural components and, potentially, and aluminium-intensive body and chassis.

Projecting the future cost to mass reduction rate is very difficult. Serial researches for obtaining the cost and effectiveness of light duty vehicle fuel economy technologies was processed and the results are illustrated by National Research Council [22]. Lightweight technologies are included in their study. Although the market conditions are different in China or US, the base data is still mostly in common. The data is firstly obtained by tear down research. In the tear down research, the cost of a lightweight technology is consist of material, labor, end item scrap, packaging, profit, manufacturing overhead and so on. For a technology using same structure and material, the core cost elements are similar in different regions. Some similar research have been done in Europe and China referring to base data of NRC [23, 24, 25]. Thus applying the cost data in China is reasonable. Besides, currently there is not a thorough research on vehicle lightweight technology cost in China case. The final estimation for the costs of mass reduction is shown as in Table 2, it is illustrated with cost per weight (RMB/kg).

It can be seen that modest lightweight may be at very low cost, or even negative cost, because of technological advances in materials and related technologies. With more mass reduced, the cost is increasing even fast. On one hand, the increase cost come from the more application of advanced materials and related technologies. On the other hand, with a more lightweight vehicle, the manufactures will have to face variable performance constraints or objectives such as safety,

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FIGURE 2 Relationship between LTR and ECR

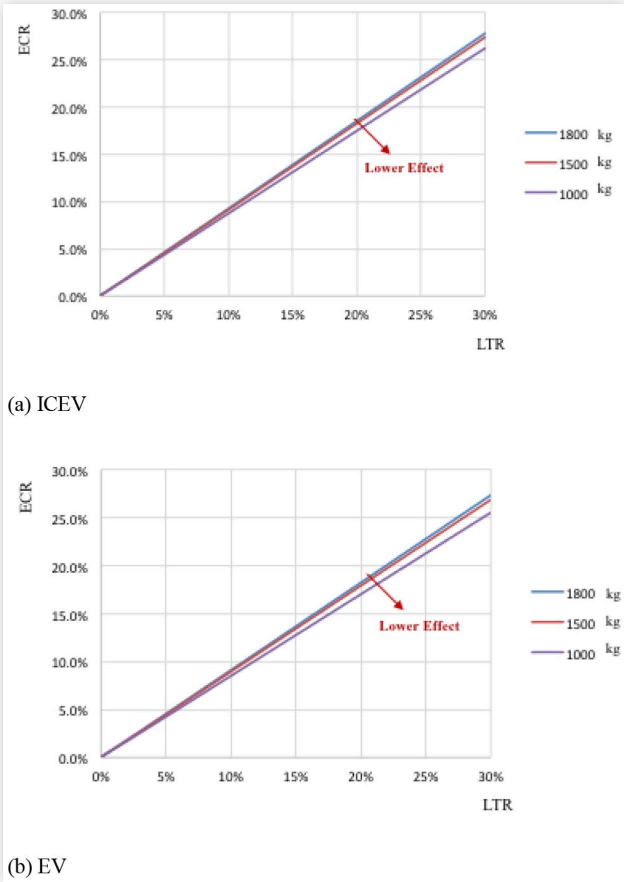

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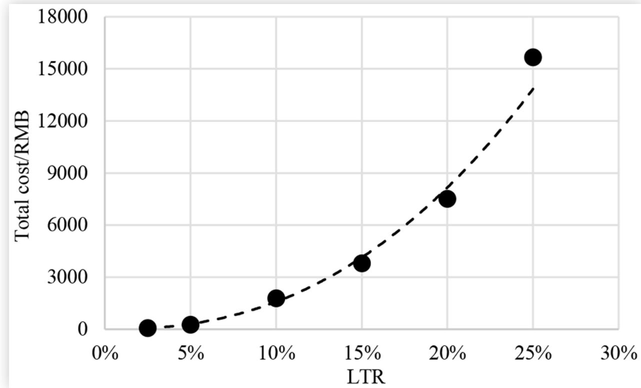
FIGURE 3 Mass reduction cost of a typical 1500kg vehicle



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stiffness, noise transmission, ride comfort. Those constraints and objectives will cause more cost.

With the base data shown in Table 2, the cost in 2017 for a typical 1500kg sedan vehicle mass reduction could be obtained as follow in Figure 3. It can be seen that when the lightweight rate reaches 15%, the cost increases fast. Furthermore, there is a sharp increment when lightweight rate reaches 25%, as more than ¥15000. As previous presented, more advanced materials have to be applied in vehicles when lightweight rate is high enough. The related technologies such as the production and design of new materials also demands more investment. Besides, the performances such as crash-worthiness, ride comfort, stiffness, would become major constraints for vehicle lightweight. Cost increases for dealing with these problems.

Major Parameters of EV

In this part, the energy consumption of EV in driving would be calculated, with the typical parameters of an EV. Then the battery capacity of EV would be estimated in respect of the energy consumption. The major parameters of typical EV is set as in Table 3. It is an example of a 1500kg class vehicle, assuming the electric driving range is 200km. As the total range of an NEDC cycle is 11km, with 1.4kWh energy consumption of 1500kg vehicles, the battery capacity of the EV is set as 32kWh considering the charging efficiency and mechanical efficiency. Further, the battery capacities of 1000kg, 1200kg and 1800kg vehicles are also calculated.

In order to validate the data calculated in Table 3, several EV products in the market are selected, their driving range and battery capacity are checked as in Table 4. As the driving range of EVs in Table 4 are different with each other, we have converted them all to 200km for comparison. Some of the vehicle types show large difference in curb mass, which are

TABLE 3 Major parameters of typical EVs

Curb Mass	1000kg	1200kg	1500kg	1800kg
Driving range	200km	200km	200km	200km
NEDC range	11km	11km	11km	11km
NEDC energy consumption	1.1kWh	1.2kWh	1.4kWh	1.8kWh
Charging Efficiency	90%	90%	90%	90%
Motor Efficiency	90%	90%	90%	90%
Battery Capacity	25kWh	28kWh	32kWh	40kWh

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TABLE 2 Cost of Lightweight

LTR	Cost (RMB/kg) 2017	2017-average	2020	2020-average	2025	2025-average
2.5%	0.00-3.64	1.75	0.00-3.64	1.75	0.00-3.64	1.75
5%	0.00-7.28	3.49	0.00-7.28	3.49	0.00-7.28	3.49
10%	6.40-17.17	11.79	6.26-17.02	11.64	6.26-16.73	11.50
15%	12.51-21.24	16.88	12.22-20.81	16.51	11.93-20.23	16.08
20%	20.37-29.54	25.03	19.93-28.81	24.37	19.06-27.65	23.36
25%	35.79-47.73	41.76	34.48-45.98	40.23	32.30-43.07	37.68

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not selected in this paper, avoiding to much deviation in calculation. For example the A00 class vehicle shares 700kg and 800kg vehicle types, but not included in Table 4. As in 1800kg class, there are rather less EVs in sale, in this paper only one EV in this class is selected. It can be seen in Table 4 that the battery capacity of 1500kg EVs shows larger difference between the calculation in Table 3 and market investigation in Table 4. This is because the curb mass and functional configuration of vehicles are rather different in this class. However, the deviation of battery capacity estimation in 1500kg class is still acceptable. Generally, the battery capacity estimation in this paper is reliable.

Benefit Study

Cost is the biggest problem for EVs to get spread, and the battery cost takes more than 30% of total cost of a EV, thus the reduction of battery cost is significant for EV development. Considering the EV range being constant, with lightweight technology applied, lower energy consumption of EV is required to achieve the target range, thus the battery capacity is reduced. Less battery capacity means lower cost, thus the cost of EV is related with energy consumption in this way . Although the mass reduction of vehicle will cause cost increment, total cost in EVs will be lower than that in ICEVs.

Take the 1500kg EV as an example. Assuming that 20% mass reduction is reached with serial lightweight technologies. According to Figure 4, 8200RMB is needed to achieve this mass reduction. On the other hand, the 20% mass reduction would bring 17.9% energy saving benefit, which means 17.9% less battery capacity is needed to achieve same driving range. In this case, the battery capacity is reduced to 24.6kWh comparing with the original 35kWh, which brings 22880RMB cost reduction (calculated by 2015 battery cost of 2.2RMB/Wh).

In reference [26], the battery costs of EV in China in different years are forecasted, in which the battery cost in 2015 is estimated as 2.2RMB/Wh, and cost in 2020 as 1.0RMB/Wh. With their study as base data, the battery cost in 2017 is estimated as 1.8RMB/Wh. As the battery technology developing, the battery cost may be reduced to 1.0RMB/Wh in the future. Further, we considered the long-term case of 0.6RMB/Wh battery cost. The cost benefit brought by battery reduction is shown in Figure 4, in which the 1.8RMB/Wh case, 1.0RMB/Wh case and 0.6RMB/Wh case are listed.

Combining the cost reduction caused by less battery capacity, and the cost increment brought by the lightweight technologies, the total cost of EV lightweight could be obtained as shown in Figure 5. The ICEV lightweight cost curve is also listed as comparison. It can be seen that the total cost of EV lightweight goes down first, then goes up afterwards. In order to describe this characteristics of the cost curve of EV lightweight, several definitions are given as follow:

Turning Point (TP): It illustrates the LTR point that most cost benefit brought by lightweight of an EV. This point is noted as a triangle in Figure 5.

Zero Point (ZP): It illustrates the LTR point when the cost of lightweight technologies is equal to the benefit

FIGURE 4 Cost benefit of mass reduction

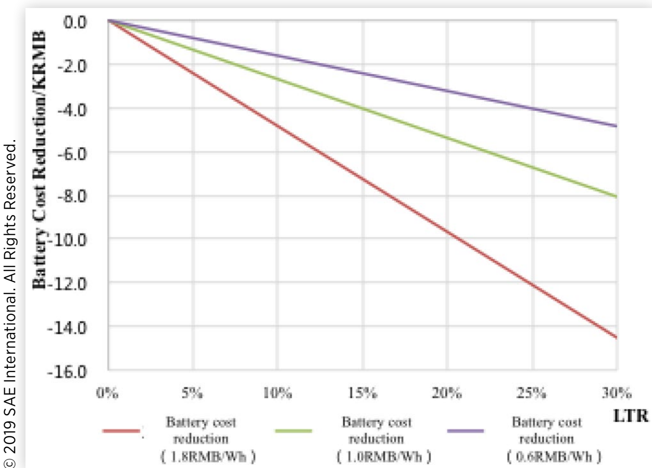

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FIGURE 5 Cost curve of EV lightweight

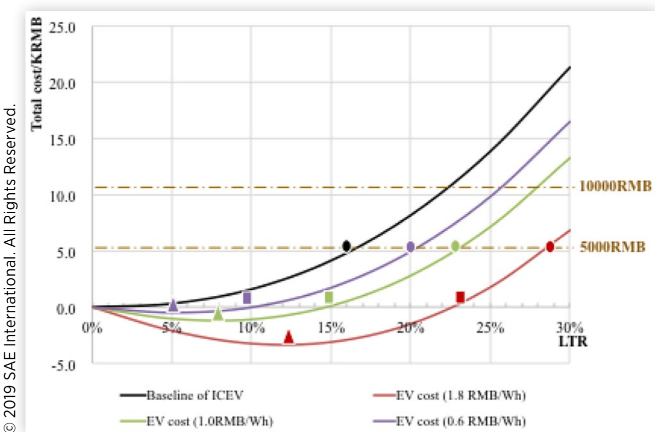

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TABLE 4 Validation of EV parameters

Vehicle Type		Curb Mass/kg	Designed Range/ km	Designed Battery Capacity/kWh	Battery Capacity of 200km/kWh	Battery Capacity of 200km/kWh
1000kg Class	A1	1080	170	22.4	26.3	25
	A2	1040	155	20	25.8	
1200kg Class	B1	1200	134	19.2	28.5	28
	B2	1295	200	30.2	30.2	
1500kg Class	C1	1570	253	45.3	35.8	32
	C2	1370	174	43	31.7	
1800kg Class	D	2090	217	47.5	43	40

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brought by battery capacity reduction. This point is noted as a square in Figure 5.

Balance Point (BP): It illustrates the LTR in certain cost investigation. For example, with 5000RMB total cost, the 1500kg EV could achieve 23% LTR when battery cost is 1.0RMB/Wh. This point is noted as a circle in Figure 5.

The reason that the cost curve of EV lightweight goes down first is: the cost of low LTR lightweight technologies is rather low because new material and new structure designs are not involved; and the cost reduction brought by battery capacity reduction is considerable, especially when the battery cost is high. These factors caused the decrement of EV lightweight cost. The negative cost can be considered as benefit, the largest benefit of EV lightweight is noted as TP. The value of TP would decrease with the battery cost goes down, as shown in Figure 5.

When the LTR is higher than TP, the cost of EV lightweight would increase along with the LTR. This is caused by the cost of lightweight technologies are increasing rapidly. It can be seen that the curve in Figure 5 shows a cross point with the x axis, which is the ZP. In ZP, the benefit of battery capacity reduction and the cost of lightweight. That is, the EV could achieve a certain value of LTR, without any total cost increment.

The influence of battery cost is also analyzed. It can be seen in Figure 5 that with lower battery cost, the cost curve of EV lightweight and ICEV lightweight are more coincident. In EV, the energy saving caused by lightweight is constant, which means the battery capacity reduction is constant in certain LTR. Thus the cost benefit would decrease with the battery cost goes down.

Further Studies

(1) Further Study on Different Vehicle Types

Further study on different vehicle types is processed with same methodology. The 1000kg, 1500kg, 1800kg electric vehicle classes are considered. The cost curves of these EVs applying lightweight technologies are given, the TP, ZP, BP points are checked as shown in Table 5.

Several conclusions can be obtained by studying data in Table 5. There is more benefit of EV lightweight, as the battery cost and vehicle curb mass increase. With heavier curb mass, the ZP value of EV lightweight is higher, which means that the heavier EV could achieve higher LTR without cost investigation. With the decrement of battery cost, the benefits of EV lightweight prone to decrease.

(2) Benefits in Using Stage

Considering that mass reduction would bring energy saving, which reduces the cost in using stage of vehicles. If the saved usage cost could be reinvestigated into lightweight technologies application in vehicle, higher LTR would be achieved. The following case is considered to discuss this issue: a 1500kg EV; with 15% mass reduction; assuming the battery cost being 1RMB/Wh.

The using life of vehicle is often expressed by total driving range. Take the Chinese case as example, in this country the life usage driving range is set as 600000km. If the mentioned EV finishes its 600000km life range in NEDC condition, about 12700kWh energy could be saved. With electric charge for citizens as 0.55RMB/kWh, 7000RMB total usage cost could be saved for a 1500kg EV with 15% mass reduction.

Investigating the saved usage cost to further lightweight of EV, higher LTR could be achieved as shown in Figure 6. With the saved 7000RMB usage cost, the LTR would increase to 21% from the original 15% if half of this finance is investigated; and 25% LTR could be achieved with all the saved usage cost investigated. It should be figured out that in the given example of the 1500kg EV lightweight case, the original 15% LTR could be achieved without cost investigation. The cost to achieve further 25% LTR is from the saved usage cost. Thus considering the lifecycle usage of the given EV, 25% mass reduction could be achieved without additional cost. At the same time, although the traditional ICEV could also realize usage cost saving, its lightweight cost is too much. The benefit of EV lightweight still shows superiority.

FIGURE 6 Lightweight of EV considering usage

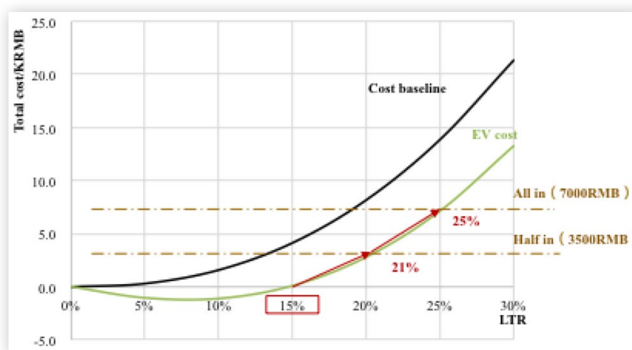

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TABLE 5 Study on different vehicle types

Vehicle Type		1000kg Class			1500kg Class			1800kg Class		
		Battery Cost			Battery Cost			Battery Cost		
Parameters		2.2RMB/Wh	1.0RMB/Wh	0.6RMB/Wh	2.2RMB/Wh	1.0RMB/Wh	0.6RMB/Wh	2.2RMB/Wh	1.0RMB/Wh	0.6RMB/Wh
Cost on TP/RMB		4200	1000	450	4900	1100	500	7000	2000	900
ZP		29%	17%	11%	26%	15%	10%	28%	16%	11%
BP	2000RMB	>30%	22%	18%	28%	19%	16%	30%	19.5%	15.5%
	5000RMB	>30%	25%	>30%	>30%	23%	20%	>30%	23%	19%
	10000RMB	>30%	>30%	>30%	>30%	27%	22%	>30%	27%	24%

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Battery and EV Driving Range

Above sections discussed the benefit of EV lightweight, the calculations are under the assumption of constant range. However, driving range of EV is also a significant problem. This problem is highly related to the EV energy consumption and battery capacity. These two factors are influenced by EV lightweight technology application: less curb weight means less energy consumption, and more battery capacity. Among the two factors, battery characteristics is more important in EV range study. As the relationship between battery and the driving range is closely related to the mass study of EVs, it could be considered as the further study on EV lightweight.

On the other hand, the curb mass of EV could not be reduced unlimited because of the power density of batteries [27, 28, 29, 30, 31]. For a midsized vehicle, the weight of battery system could be more than 200kg, which is a burden for EV to achieve a longer range. Besides, more battery is needed to fulfilling the long driving range, bringing mass increment of EV. The key factor of this problem is whether the breakthrough in power density of battery will occur, which is not yet to be seen in short term. Thus studies on battery and EV driving range are significant, and the studies are processed in following chapter.

Relationships between Battery and EV Driving Range

The vehicle dynamic characteristics in Equation (1) considered the rolling resistance, gradient resistance, aero resistance, acceleration resistance, inertial resistance. In fact the inertial resistance could be included in the acceleration resistance. Thus the inertial resistance and the acceleration resistance are combined together in many cases, which makes Equation (2) to the following presence.

$$F = m * g * f + \frac{Cd * A * u^2}{21.15} + (1+\delta) m * a \tag{2}$$

The parameters in Equation (2) are the same as in Equation (1). The power could be obtained as follow:

$$P = F * u \tag{3}$$

Thus in an NEDC cycle, the total energy consumed could be obtained as:

$$W_{NEDC} = \int_{NEDC} P dt = \int_{NEDC} (\mathrm{m} * \mathrm{g} * \mathrm{f}) dt + \int_{NEDC} \left(\frac{\mathrm{Cd} * \mathrm{A} * u^2}{21.15} \right) dt + \int_{NEDC} \left((1+\delta) \mathrm{m} * a \right) dt \tag{4}$$

In Equation (4), the first and third terms in the equation are proportional functions of curb mass, the second term is constant after integration. Thus Equation (4) could be written as:

$$W_{NEDC} = k_1 * m + C \tag{5}$$

Equation (5) indicates that the energy consumed in an NEDC cycle could be considered as a proportional function of vehicle curb mass. The condition parameter k_1 could be obtained by solving Equation (4) in a single NEDC cycle.

Using D_{NEDC} as the driving distance of a single NEDC cycle, which is about 11km, and D_{total} as the total driving range, W_{total} as the total energy consumption, Equation (6) could be obtained as follow:

$$\frac{W_{NEDC}}{W_{total}} = \frac{D_{NEDC}}{D_{total}} \tag{6}$$

Taking k_2 as the battery energy density, and assuming $k_3 = 1/k_2$, m_{batt} as the battery system weight, following equation is obtained:

$$W_{total} = k_2 * m_{batt} = (1/k_3) * m_{batt} \tag{7}$$

There are battery system mass m_{batt} and non-battery system mass m_0 in EV, which is represented as:

$$m = m_0 + m_{batt} \tag{8}$$

Combining Equations (5)-(8), the following relationship of "battery mass - EV range" could be obtained:

$$D_{total} = \frac{k_2 m_b * D_{NEDC}}{k_1 (m_0 + m_b) + C} = \frac{k_2 m_b * D_{NEDC}}{k_1 m_b + k_1 m_0 + C} \tag{9}$$

Similarly, the relationship between the battery capacity and EV range is shown as:

$$D_{total} = \frac{W_{total} * D_{NEDC}}{k_1 k_3 W_{total} + k_1 m_0 + C} \tag{10}$$

If the battery cost is represented as k_4, as:

$$C_{batt} = k_4 * W_{total} \tag{11}$$

Combining Equations (10) and (11), the relationship between battery cost and EV range is shown as:

$$D_{total} = \frac{(1/k_4) * C_{batt} * D_{NEDC}}{k_1 k_3 (1/k_4) C_{batt} + k_1 m_0 + C} \tag{12}$$

Those above are the relationships of battery characters to EV range.

Characteristics of "Battery: EV Driving Range"

The weight, cost and energy capacity of battery are closely associated. Equation (9), (10), (12) could be induced to each other, thus they share the similar significance to EV driving range. Studies in any parameter would be a good reference to others. In this paper, the relationship between battery cost and EV driving range is selected for further study. Because

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the cost problem is major obstacles for spreading EV, and the cost issue is also deeply concerned by researches and engineers.

It can be seen from Equation (12) that energy density and cost are key parameters. With technologies developing, those two parameters are changing fast. Predictions on the development of battery energy density and cost are processed by major countries. Those predictions show that the battery energy density might be more than 250Wh/kg, cost might be less than 1.0RMB/Wh in the long term [26, 32, 33, 34, 35]. In referring to their predictions, different cases of 1.0RMB/Wh, 0.6RMB/Wh in cost, and 260Wh/kg, 300Wh/kg in energy density are chosen to process further analysis. Taking those values into Equation (12), the results are shown in Figure 7.

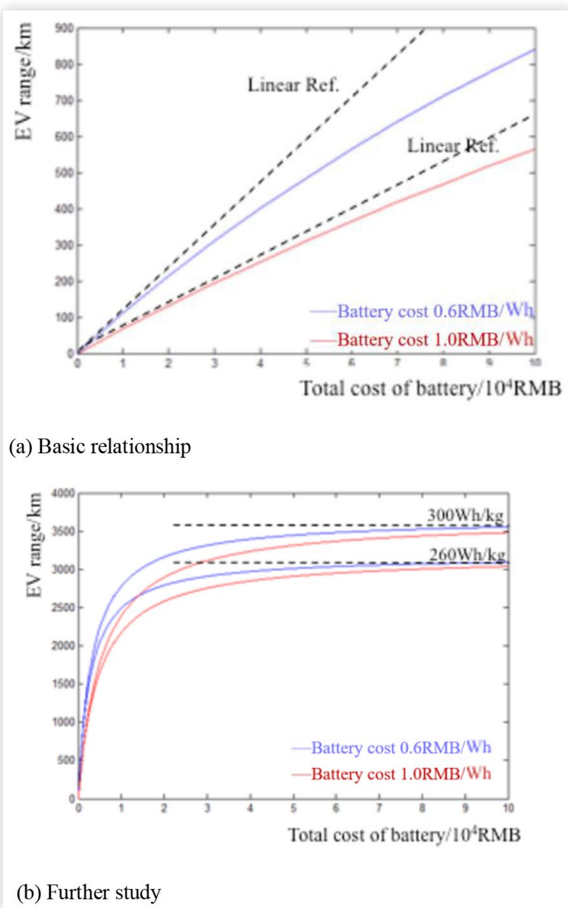
More battery capacity means longer EV range. When EV range is short, the range has an approximate proportion relationship to battery cost, as shown in Figure 7(a). The linear reference lines are also labeled in Figure 7(a), shown as the dash lines. It can be seen that the relationship curve between cost and range deviates from the linear reference with the increment of cost, which means the increment of range. This is because the relationship curve is obtained basing on Equation (12), which is not a linear expression. In Figure 7(b), the range and cost are extended. It can be seen that, with the battery capacity increasing, the EV range will not increase as fast. There is a limitation for EV range no matter how much battery capacity could achieve. As for an EV equipping battery with 260Wh/kg energy density, the limit EV range is 3000km; as for the 300Wh/kg battery, the limit range is 3500km. However, the total cost investigation on battery would be millions to achieve the limit range. Also the curb weight of EV would be unacceptable. Thus the limit case is not likely to happen in the real world, but is a phenomenon with academic value. In addition, different battery cost are also considered in Figure 7, which are 1.0RMB/Wh and 0.6RMB/Wh. With different battery costs, the relationship curves are slightly different, but the final limitation are the same.

It can be seen in Equation (12) that, the limitation is only influenced by parameters of k_1, k_3. This means that in a certain running condition, the limit EV range is decided by battery energy density. The physical meaning of limit range is that there is so much battery in EV, the mass of other systems could be ignored. This case means the battery is driving its self. Besides, the limit range also occurs in other energy storage systems, the value is decided by its power density.

There is little practice application of limit range, but the cost in low EV range should be discussed, as shown in Figure 8. Major parameters in this figure are as follow: battery cost 1RMB/Wh, power density 260kW/kg. It can be seen that when the EV range is over 1200km, the relationship curve becomes rather flat, which means the cost effectiveness is rather low. At the same time, the total cost would increase sharply when EV range is too high. Generally, 500000RMB could support 1600km EV range, 200000RMB would bring 1000km range, and 100000RMB could support 600km range.

To decided the EV driving range, many factors must be considered such as cost, requirements from customers, layout space and so on. Different auto-makers may have different considerations, and their final decisions may be different. To giving a universal used range suggestion is unrealistic. However, we could still try to give a roughly suggested EV range by studying the relationship between cost and EV range. In short terms, 600km EV range should be feasible. In the case of Figure 8, the cost investment is 100000RMB when EV range reaches 600km. This is the future case in 2025. This value is too much for a passenger car except for some luxury cars. Thus the 200km or 300km range is suitable for average cars, while the luxury cars could adopt longer distance like 500km or 600km. For a luxury car, the higher price could cover the cost increment brought by battery. Besides, a luxury car is usually heavier in curb weight, which provides lightweight technologies to reduce the battery cost as shown in previous chapters.

FIGURE 7 Relationship between cost and EV range



(a) Basic relationship

(b) Further study

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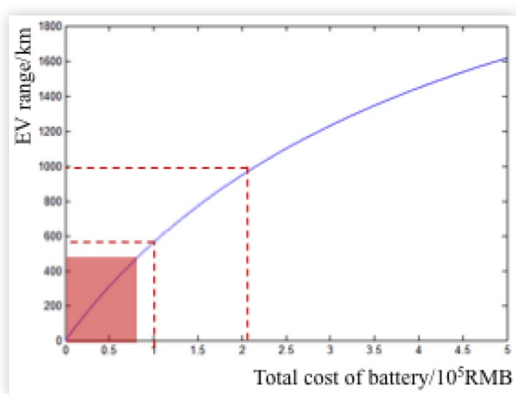
FIGURE 8 Analysis of low EV range



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Conclusion

With the research of EV lightweight, several conclusions have been obtained as follow:

1. EV lightweight is of high significance. 10% mass reduction brings 8.7% reduction in energy consumption in EVs as compared to 8.4% reduction in ICEs. The battery capacity and cost is also reduced correspondingly.
2. EV could realize lightweight with rather low cost, or even without cost. 15% lightweight rate could be achieved when battery cost is1.0RMB/Wh. With the decrement of battery cost, this benefit would decrease, too.
3. With energy saving effects brought by mass reduction, the usage cost of EV could be reduced. The lightweight rate will increase from 15% to 25% with the reduced usage cost used in further lightweight.
4. There is limit in EV driving range. The limit is influenced by battery energy density. The limit range is 3000km when equipping battery with 260Wh/kg energy density.

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ISSN 0148-7191