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# Cost–benefit assessment and implications for service pricing of electric taxies in China

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ABSTRACT

This paper presents a methodology to assess the cost–benefit and develop the service pricing strategy of electric taxies in Shanghai, China. There are 4 kinds of electric taxi models being structured. The total life cycle cost model for cost–benefit assessment is developed with consideration of purchase cost, usage cost, and other operation cost. Three scenarios are defined, including gasoline price increasing, electricity price increasing, and battery cost decreasing. Then the service pricing model is proposed. The results indicate that the profitability of battery-swapping model is higher than that of the charging model. The taxi models with longer driving range have greater profitability than those with shorter driving range. With annually increasing rate of 8% of gasoline price, the electric taxi will obtain the same profit with the gasoline taxi in 5 years. With annually increasing rate of 20% of electricity price, the service price of electric taxies will rise by 1%. When the battery cost decreases by 49%, the service price of electric taxies will be 4% lower than that of gasoline taxies.


## Introduction

Since the year 2009, China has become the world's largest car market by sales. It is forecasted that the sales volume would rise to 30 million by 2020 and the growth would last for a long time (Wang et al., 2011). The growing number of cars will lead to the increasing oil demand and greenhouse gas emission, which will pose a great challenge for the development of social economy and environment. Electric vehicles are considered as an effective technological innovation to reduce energy use and greenhouse gas emission, which has raised great attention among the government and car manufacturers (Granovskii et al., 2006; Hoyer, 2008). In China, the electric vehicle technologies are being promoted as securing the future of mobility. In 2012, the Chinese government issued the "Planning for the Development of the Energy-saving and New Energy Automobile Industry (2012–2020)," in which the electric vehicle has been chosen as the main strategic orientation to promote new energy vehicle technologies and thus develop Chinese automobile industry (The state council of the People's Republic of China, 2012). A series of policies to promote electric vehicle industrialization and commercialization have been introduced in recent years, including pilot demonstration projects (Ministry of Science and Technology (MOST), http://www.gov.cn/zwgk/2009-02/05/content_1222338.htm, 2009), production standards (Ministry of Industry and Information Technology (MIIT), http://www.miit.gov.cn/n11293472/n11293832/n11294057/n11302390/12427300.html, 2009), and purchase subsidies (National Development and Reform Commission and Ministry of Finance, http://jjs.mof.gov.cn/zhengwuxinxi/zhengcefagui/201005/t20100531_320528.html, http://www.miit.gov.cn/n11293472/n11293832/n12843926/n13917042/15629217.html, 2010 and 2013). Some Chinese car manufacturers have already launched their EV models and made mass production plans, such as the BYD E6, BAIC E150, JAC iev4, Zotye 5008EV, Roewe E50, and Shanghai GM Springo EV. In some cities of China, EV plays an important role in public transport areas. The electric taxi is one of the most important vehicle types for demonstration of public service vehicle fleets.

There are some studies in consumer awareness and purchase barriers of vehicle owners. Maris Yetano Roche (Yetano Roche et al., 2009) analyzed the consumers' attitudes and demands for electric vehicles with the quantitative methods, and the results indicated that the purchase price and usage cost are the most important factors for purchase decision of private consumers. Another survey by Tongji University has also come to the same conclusion (http://auto.sohu.com/s2011/tjdx1/index.shtml, 2011). They surveyed 2702 online consumers in China about the willingness to purchase electric vehicles through SOHU website. The survey implied that 80% of the interviewers considered the high purchase cost as the most obstructive factor and 90% considered the low usage cost as the most attractive factor in terms of purchasing an electric vehicle. Some studies have analyzed the overall costs of the electric vehicles. Christian Thiel (Thiel et al., 2010) calculated the total life cycle costs of electric vehicles and gasoline vehicles with the same class in terms of various driving range and gasoline price. The results showed that the electric vehicle had no

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cost advantage over gasoline vehicle. Andreas Schroeder (Schroeder and Traber, 2012) focused on the operation cost of the electric vehicle charging infrastructure and the calculation results showed that it was difficult to gain profit for charging infrastructure at present.

As for the electric taxi, Chuanfu Wang (Chuanfu, 2011), the president of BYD Auto, stated that the fuel consumption and emission of 1 internal combustion engine taxi equal to 10 private cars and the electric vehicle was more suitable to be applied in public traffic sector than private sector in the initial stage. Now there are 800 electric taxies of BYD E6 being demonstrated in Shenzhen. Theo Lieveni (Lieven et al., 2011) illustrated that 15.4% of taxi buyers would like to choose electric vehicles, which is higher than other sectors of vehicle purchase. There are two operation modes of the electric taxi in China: charging model and battery-swapping model, which are demonstrated in Shenzhen and Hangzhou, respectively. There are some unique characteristics of taxies, such as long driving range, non-fixed routes, and driven by economic interests. This study focuses on the cost–benefit and the service pricing strategy of electric taxies. We investigate different electric taxies with two operation modes and present a cost–benefit assessment methodology and the service pricing strategies for electric taxies.

In this study, the cost–benefit assessment is based on the model of total life cycle cost. The total life cycle cost (TLCC) of the electric taxi includes the purchase cost, battery repurchase/depreciation cost, charging/swapping cost, maintenance cost, insurance cost, and drivers' salary. It is assumed that the nominal lifetime of the traditional gasoline taxi (TG) is 5 years. Then the profits of the battery-charging electric taxi (TC) and battery-swapping electric taxi (TS) in 5 years are calculated in terms of different electricity prices to assess the cost–benefit of electric taxies. Finally, the service pricing model of electric taxies can be developed based on the calculation.

The whole calculation process can be divided into three parts:

1) Parameters of 5 vehicle models: The 5 vehicle models consist of 2 battery-charging electric taxies, 2 battery-swapping electric taxies, and 1 traditional gasoline taxi, which are developed based on the analysis of taxi operational and technical requirements. To determine the suitable battery capacity for each vehicle model, the vehicle dynamic simulation model is made by the Cruise Software to calculate the energy consumption of different electric vehicles. The parameters of the energy consumption, battery capacity, and curb weight of different vehicle models for TLCC calculation are determined in this part.
2) Cost–benefit assessment: The battery purchase cost, gasoline fuel price, and fuel consumption are predicted to calculate the TLCC of the 5 vehicle models in 5 years. A bottom up, component-based forecasting model of battery costs, and an ARIMA prediction model of gasoline fuel prices are developed. The Monte Carlo analysis model is made to calculate the TLCC of the 5 taxi models in 5 years nominal lifetime, and the profit results of TC and TS vehicle models are compared to the TG vehicle model based on scenarios of the residential and commercial electricity price.
3) Service pricing model of electric taxies: The service pricing model is developed in the scenarios of different gasoline prices, electricity prices, and battery costs. The electric taxi service price is calculated to make the profit of electric taxies equal to that of gasoline taxies in 5 years.

## Power supply modes for electric vehicles

There are two modes for electric vehicles to obtain energy: the battery-charging model and the battery-swapping model.

The battery-charging model is the most general and feasible way for electric vehicle to charge at charging stations, parking lots, and garages. However, the charging time of electric vehicles is much longer than gasoline cars. In general, an electric vehicle can be fully charged in 6–10 h with 220 V power input, or 3–4 h with 380 V power input. Another method of quick charging can charge 50% ~ 80% of the capacity within 20 ~ 30 minutes (Lairong, 2011), yet it has bad effects on battery lifetime.

The battery-swapping model can effectively overcome the inconvenience caused by long charging time. In the electric taxi battery-swapping station of Hangzhou, it takes 5 minutes to manually swap the battery pack. In the battery-swapping station of the Better Place, it only takes 1 minute to finish the swap with automatic devices (Feng, 2012). In this model, the battery is owned by the battery-swapping station, and consumers only need to pay for the battery charging and battery depreciation cost with no purchase cost. This model is ideal for the electric vehicle power supply, yet it is difficult to make it widely applied due to poor compatibility of different battery types and high investment of battery purchase.

## Requirement for taxi operation in Shanghai

### *Status of taxi operation in Shanghai*

There are 50,683 taxies in Shanghai in the year 2012. The cumulative driving mileage for the taxi operation is 6.377 billion km, in which the service mileage is 3.984 billion km with revenues of 16.774 billion CNY (Zhixiong and Junxian, 2012). The empty-loading ratio of gasoline taxies is 38%. The average operation mileage of a taxi is 344.7 km per day. The average revenue is 4.21 CNY/km. More than 90% of the taxies are Santana of Shanghai Volkswagen based on the platform of Passat B2.

The property and management rights of taxies belong to the taxi operation companies (Yingying, 2009). Two drivers own one taxi and each of them works 15 days per month. The average driving time is 18.5 h per day and the average income of one driver is 6000 CNY/month (Sports College, 2011). The average vehicle speed is 19.2 km/h. Thus every driver works 277.5 h per month and the income is 21.5 CNY/h.

### *Taxi operation requirement of two power supply models*

#### *Taxi operation requirement of charging model*

For the charging model, the electric taxi is fully charged by 380 V three-phase power for 3.5 h in order to improve charging efficiency. There are two charging scenarios for our vehicle model. The first one is the battery with large capacity such as BYD E6, which can be fully charged at night and obtained 30% capacity for 1 h quick charging in the daytime. The average driving time is 8.75 h when the battery is fully charged. The second one is the battery with mid-size capacity, which needs to be fully charged for twice in the afternoon and at night. The average driving time is 7.5 h when the battery is fully charged.

For the first charging scenario, the taxi is required to drive 17.5 h with 130% of the battery capacity, which means the driving mileage with full charge should be equal to 258 km (19.2 km/h × 17.5 h/130%). For the second charging scenario, the driving mileage with full charge is required to be 144 km (19.2 km/h × 7.5 h).

The driving range of electric taxies should be greater than the required driving mileage, which is determined to be 10% larger than the actual requirement. Thus, the driving ranges of the two scenarios are calculated to be 284 km and 158 km, respectively, which are named TC284 and TC158 for charging model taxies.

#### *Taxi operation requirement of battery-swapping model*

For the battery-swapping model, there is no need to determine the fixed charging time for electric taxies due to the short battery-swapping time. In this model, the battery capacity should be relatively small in order to make the swapping process efficient and safe. 100 km and 150 km are selected as the driving range of two swapping taxi models, which are noted as TS100 and TS150. The battery-swapping time is assumed to be 10 minutes.

As the driving range of electric taxies is required to be 10% larger than the actual requirement, the actual driving ranges of TS100 and TS150 per swapping are 91 km and 136 km with the corresponding operation time of 4.9 h and 7.25 h including battery-swapping time. When the whole operation time per day is 18.5 h, TS100 and TS150 are required to swap the battery for 3.8 and 2.6 times, respectively.

### *Taxi operation parameters*

The following parameters of electric taxi models are proposed:

1) The average vehicle speed is 19.2 km/h;
2) The average empty-loading ratio is 42% for TC and 45% for TS, which are higher than TG because of the limited driving range;
3) The average revenue for mileage is 4.21 CNY/km;
4) The operation time should be no less than 14 h per day, which is 75% of TG. The operation time should also be no more than 18.5 h, which is the same with TG;
5) The income of electric taxi drivers can be calculated with the operation time (without the refueling time) and the average income is 21.5 CNY/h, which is the same with the income of gasoline taxi drivers.
6) The driving range of the two TC vehicle models is 284 km and 158 km, respectively. The driving range of the two TS vehicle models is 150 km and 100 km, respectively.

The operation parameters of different taxi models are shown in Table 1.

## Vehicle model selection and energy consumption analysis

### *Vehicle model parameters*

The Santana Vista of Shanghai Volkswagen is chosen as the vehicle model of TC284, TC158, TS150, and TS100, which is widely used as gasoline taxies in China. The vehicle parameters are shown in Table 2.

**Table 2**
Parameters of Santana Vista Gasoline Taxies.

| Length*width*height (mm) | 4687*1700*1450 |
|---|---|
| Wheelbase (mm) | 2656 |
| Curb weight (kg) | 1210 |
| Maximum speed (km/h) | 120 |
| Load mass (kg) | 150 |

### *Drive motor parameters*

In order to develop the energy consumption simulation model of electric taxies with the Cruise Software, the permanent-magnet brushless motor MC_PM49 in the Advisor Software is selected based on the automobile theory, which can meet the requirements of the taxies in our research (Zhisheng, 2008). The parameters are shown in Table 3, and the MAP chart is shown in Fig. 1.

### *Energy consumption analysis*

The curb weight and energy consumption are different among the four electric taxi models due to the different driving mileage and battery capacity. Thus the energy consumption simulation of electric taxi models is developed to figure out the correlation between curb mass and energy consumption.

The Cruise Software is used to simulate electric taxi energy consumption with various curb mass based on the New European Driving Cycle (NEDC). The vehicle dynamic simulation model and the velocity, acceleration results are shown in Figs. 2 and 3, respectively.

When the other parameters of the electric taxi remain constant, the curb mass increases by 50 kg from 1100 kg to 2000 kg, and the corresponding energy consumption is calculated. Based on the simulation results, the scatter plot is drawn, which is shown in Fig. 4. The linear equation of the linear fitting can be defined as

$$e = 0.004m + 13.508 \tag{1}$$

where $e$ denotes the energy consumption in kWh/100 km and $m$ is the curb mass in kg. The adjusted $R^2$ is equal to 0.998, which indicates that there is strong linear correlation between the energy consumption and the curb mass.

In our study, the curb mass of electric taxies is equal to the curb mass of gasoline taxies without the mass of engine and transmission but adding up to the mass of battery system and motor system. According to the interview of a technical engineer from Shanghai Volkswagen, Santana Vista's EA111 engine mass is 110 kg and 5MT mass is 35 kg. The mass of MC_PM49 motor is 60 kg. The battery energy density is 145 Wh/kg. Eq. (2) describes the correlation between driving range, battery capacity, and energy consumption. Then Eq. (3), presenting the correlation between curb mass and battery capacity, is listed as below, which is calculated with Eqs. (1) and (2).

$$R = 100Q/e \tag{2}$$

$$m = 1275 + 6.897Q \tag{3}$$

where $R$ is the driving range of electric taxies in km and $Q$ is the battery capacity in kWh.

According to Eqs. (1), (2), and (3), the energy consumption, battery capacity, and battery weight for each taxi model are calculated, and the results are shown in Table 4.

## Cost–benefit assessment

### *TLCC model*

From the view of the electric taxi operation company, the total life cycle ownership cost includes purchase cost and usage cost. The fixed purchase cost consists of manufacturer suggested retail price (MSRP), taxes, and subsidies. The variable usage cost is made up of battery repurchase/depreciation cost, energy consumption cost, and other costs. The TLCC of an electric taxi in year $i$ is:

$$C_{TLCC\ i} = C_{purchase} + C_{battery\ repurchase/\mathrm{depreciation}} + \left(C_{energy} + C_{other}\right) \cdot i \tag{4}$$

**Table 1**
Parameters of taxi operation.

| Vehicle model | TC284 | TC158 | TS150 | TS100 | TG |
|---|---|---|---|---|---|
| **Driving range (km)** | 284 | 158 | 150 | 100 | – |
| **Daily charging/swapping times** | 1.3 | 2 | 2.6 | 3.8 | – |
| **Daily operation time (hours)** | 17.5 | 15 | 17.9 | 18.1 | 18.5 |
| **Daily operation range (km)** | 335 | 288 | 353.6 | 345.8 | 335 |

**Table 3**
Parameters of MC_ PM49 motor.

| Maximum power (kW) | 49 |
|---|---|
| Maximum speed (rpm) | 8500 |
| Overload factor | 1 |
| Weight (*kg*) | 60 |

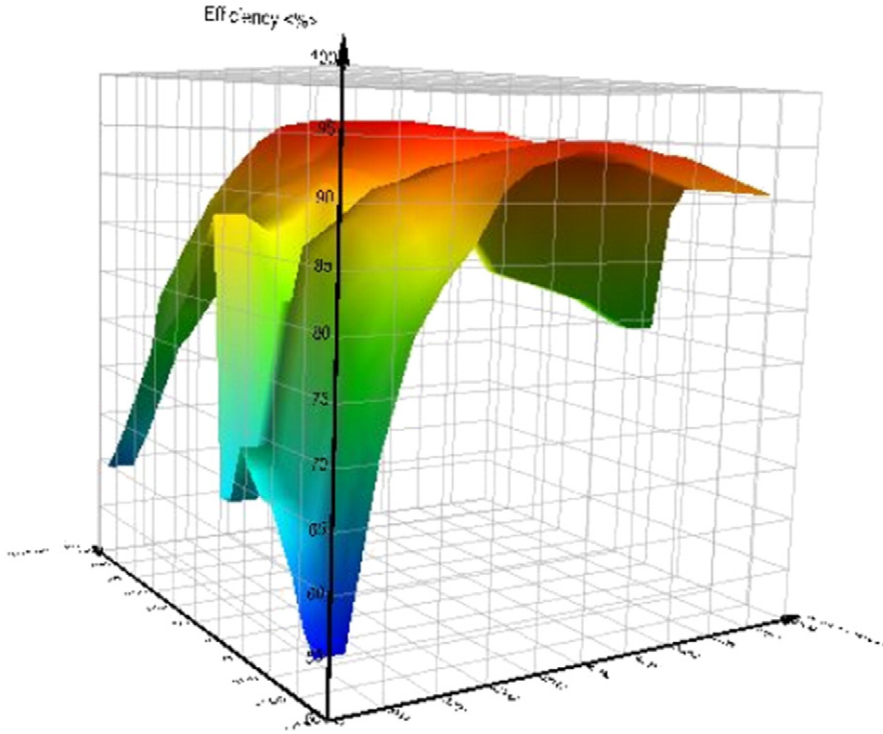


**Fig. 1.** The MAP chart of MC_PM49 motor.

The profit of an electric taxi in year $i$ is:

$$C_{\mathrm{profit}} = C_{\mathrm{TLCC}\ i} - C_{\mathrm{revenue}} \cdot i \quad (5)$$

where the cost unit of Eqs. (4) and (5) is CNY and $i$ denotes the time in years after the vehicle purchase, and $i = 0$ when the taxi is purchased.

*(1)Purchase cost*

As there is no electric version of Santana Vista, the market statistics analysis is developed to calculate the retail price of the 4 electric taxi models. The battery capacity and motor power of electric vehicles can determine the costs to a large extent. The larger battery capacity and power of motor lead to the higher electric vehicle price.

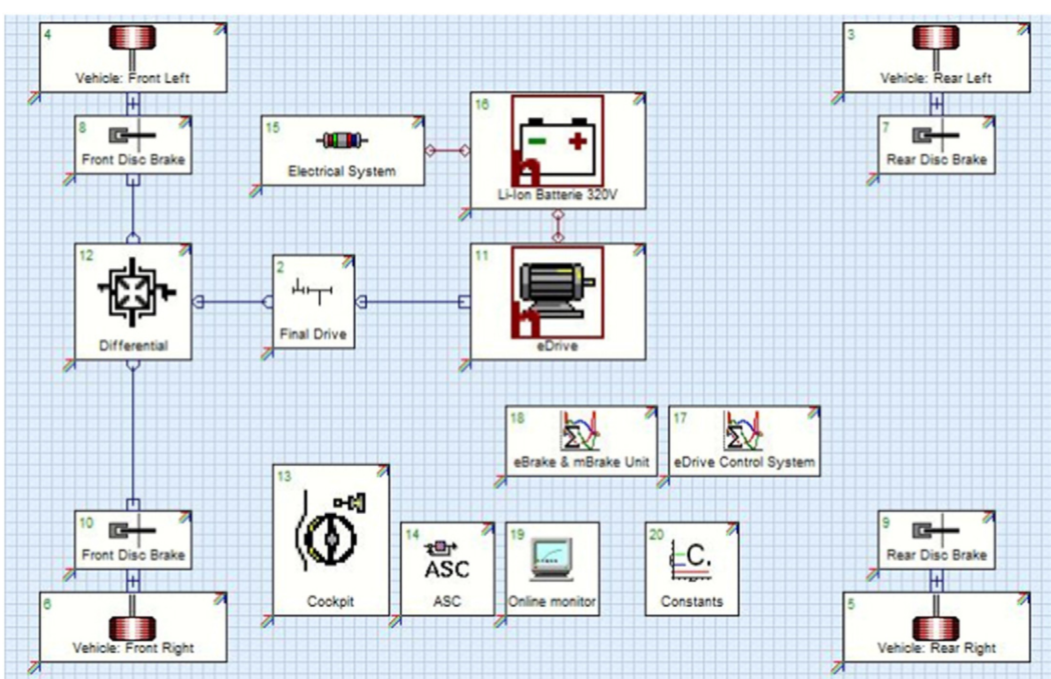


**Fig. 2.** Vehicle dynamic simulation model based on Cruise Software.

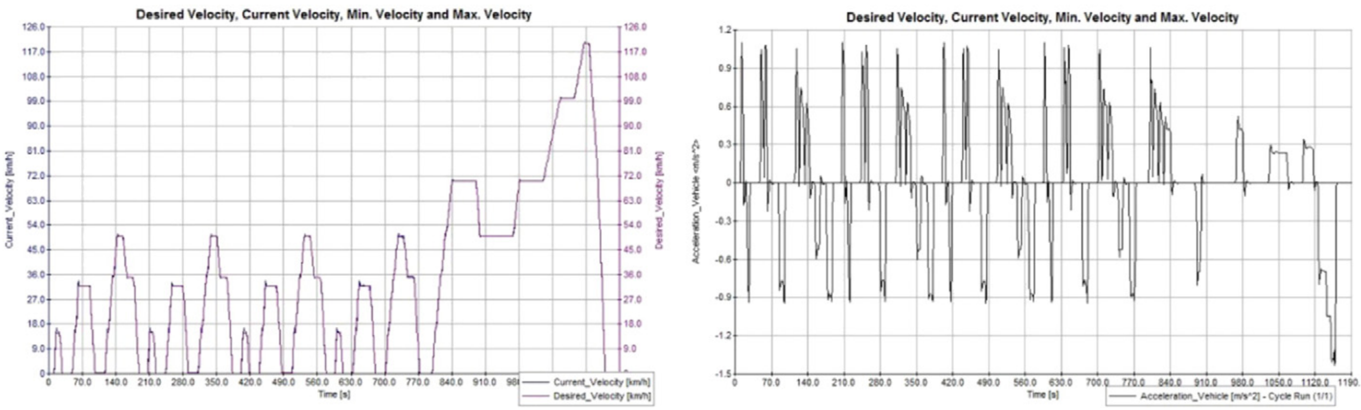


**Fig. 3.** Velocity and acceleration results of simulation model.

The price of an electric vehicle can be divided into two parts. The first part is the R&D and manufacturing cost of the body, chassis, interior, exterior, and the cost of vehicle logistics and marketing, which is the same with the gasoline car. The second part is the electric powertrain R&D and manufacturing cost, including the battery system (such as the battery management system, charging system, etc.) and electric motor system (such as the motor, transmission system, motor management system, etc.). The retail price of an electric vehicle ($P_{MSR}$) given by the manufacturers is calculated by:

$$P_{MSR} = 0.74P'_{MSR} + P^{+}_{MSR} \tag{6}$$

where $P'_{MSR}$ is the retail price of gasoline Santana Vista. 0.74 $P'_{MSR}$ is the first part cost, which is the gasoline Santana Vista retail price without the gasoline car powertrain cost (mainly for the engine, transmission system, etc.) (Xiaojia, 2012); $P^{+}_{MSR}$ is the cost of the electric powertrain. According to the research of Prof. Kalhammer (Kalhammer, 2007), the battery manufacturing cost has linear correlation with capacity, and the electric motor manufacturing cost has linear correlation with power. Then $P^{+}_{MSR}$ can be calculated using the binary linear regression equation: $P^{+}_{MSR} = aE + bP + c$. 12 electric vehicles of various brands are selected to fit the linear regression using the SPSS software, including Nissan Leaf, Mitsubishi i-MIEV, Ford Focus Electric, Honda Fit EV, Toyota RAV4 EV, Smart Fortwo Electric Drive, Lifan 620EV, Zoyte 5008EV, BYD E6, Zoyte M300EV, Haima Freema EV, and Shanghai GM Springo EV. The equation of the regression fit is $P^{+}_{MSR} = 2511.1E + 781.1P + 38003.3$, and the value of $R^2$ is equal to 0.795. The $P_{MSR}$ result is shown in Table 5, in which the current battery cost is 4073 CNY/kWh according to the calculation in the section "Energy consumption analysis".

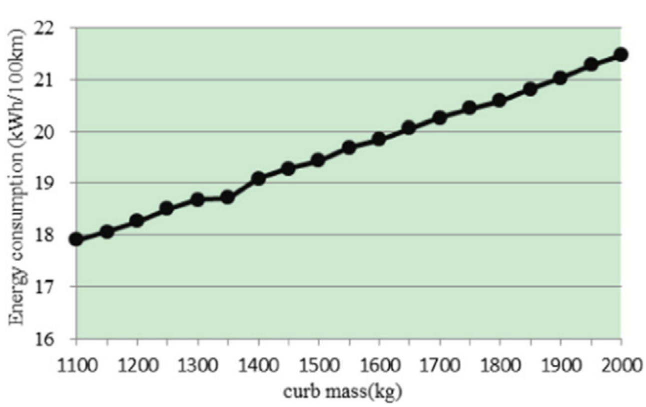


**Fig. 4.** Electric taxi energy consumption with different curb mass.

*(2)Taxes and subsidies*

In terms of taxes, pure electric vehicles will be exempted from purchase taxes since September 1, 2014 (The Ministry of Finance, the State Administration of Taxation and Ministry of Industry and Information Technology, 2014), which makes the value of taxes 0. As there are no clear policies of subsidies for electric taxies in Shanghai, no subsidies for the 4 electric taxies are included in the TLCC model. The purchase costs are shown in Table 5. We can conclude that the battery cost accounts for more than 50% of the purchase cost.

*(3)Battery repurchase/battery depreciation cost*

The battery cost per kWh needs to be predicted. A bottom-up, component-based prediction method of battery cost is developed in our study. The lithium iron phosphate battery is chosen as the research object, which is widely used for EV manufacturers in China. Considering the technology development of various battery components, we predict the future battery pack cost with three kinds of scenarios (optimism, basic, conservative) in Chinese battery market.

The total battery pack costs consist of three parts (Energy, 2012): the cell material component costs, pack packaging component costs, and other enterprise expenses. The cell material components mainly include cathode material, anode material, separator, electrolyte, and foil. The annual change rates of cathode material and anode material cost are obtained from the research results of Element Energy (Kalhammer, 2007). The annual change rates of the separator, electrolyte, and foil cost are referred to the Consultants R B S research (Consultants, 2011). The battery pack packaging components mainly include battery management system, power electronics, wiring harness and connectors, internal cell support, housing and temperature control system. Given that limited data of the battery pack packaging component are available, the learning rate theory is applied to calculate the pack packaging component costs. In our study, the results of learning rates from the Element Energy research are applied (Kalhammer, 2007). Other enterprise expenses include the manufacturing costs, enterprise profits, and margins. The manufacturing costs consist of financing, direct labor, and overheads. According to the research (Kalhammer, 2007), the financing cost accounts for 16%–17% of the battery cost. The labor cost is 20 CNY/h in China and will increase by 10% after 5 years. The overheads include

**Table 4**
Battery parameters of 4 electric taxi models.

| Model | TC284 | TC158 | TS150 | TS100 |
|---|---|---|---|---|
| **Energy consumption (kWh/100 km)** | 20.19 | 19.46 | 19.41 | 19.14 |
| **Battery capacity (kWh)** | 57.34 | 30.75 | 29.12 | 19.14 |
| **Battery weight (kg)** | 395.47 | 212.06 | 200.81 | 132.01 |
| **Curb weight (kg)** | 1670.47 | 1487.06 | 1475.81 | 1407.01 |

**Table 5**
Purchase cost of electric taxi and gasoline taxi models Units: CNY.

| Model | TC284 | TC158 | TS150 | TS100 | TG |
|---|---|---|---|---|---|
| **Battery price** | 234,146 | 125,147 | – | – | – |
| **Retail price** | 339,468 | 230,469 | 105,322 | 105,322 | 80,000 |

R&D, sales and administration, maintenance (and other indirect labor), utilities, and insurance, which accounts for 13% of the battery cost. Enterprise profits in the manufacturing industry are usually 5%–15% of the battery cost. Here 7% is selected because the future competition will be significantly fierce in the battery market. The margins include defective battery replacement and battery recalls, which are set to be 3%.

The forecasting results of the battery pack cost are obtained in Fig. 5. According to our study, the battery cost will be less than 3000 CNY/kWh in 2015 and in the optimism scenario less than 2000 CNY/kWh in 2020.

For the battery-charging taxies, the batteries cannot be used for 5 years in the current technological level, thus it is necessary to consider the battery repurchase cost in our model. If the remainder of the operating year ($N$) divided by the battery lifetime ($L_N$) is greater than 0 and less than 1, the repurchase cost should be calculated into the usage cost model. The equation is

$$C_{battery\ repurchase} = \begin{cases} V_C \times Y_b - C_S, & \text{if } 1 > MOD\left(\frac{N}{L_N}\right) > 0 \\ 0, & \text{else} \end{cases} \quad (7)$$

where $V_C$ is the battery capacity in kWh, $Y_b$ is the battery cost in CNY/kWh, $C_S$ is the battery residual value in CNY. The values of $Y_b$ and $C_S$ vary from year to year. The residual value rate of the battery is assumed to be 25% in our study. As for the battery lifetime ($L_N$), it can be calculated as the battery cycle times divided by charging times in 1 year. According to the survey in the city of Hefei, the battery cycle times are 2000 at present. The charging times are equal to the annual driving mileage divided by the driving range. Then the battery lifetime of TC284 and TC158 is 4.8 years and 3.11 years, respectively.

For the battery-swapping taxies, the taxi operation company should pay the battery swapping price for the battery depreciation cost. It is assumed that there will be 1.7 batteries supplied for each TS model in our study. The battery depreciation equation is

$$C_{\text{battery depreciation}} = \frac{Y_b \times V_C - C_s}{L_N} \times N_s \quad (8)$$

where $N_s$ denotes the average amount of batteries supplied for each TS.

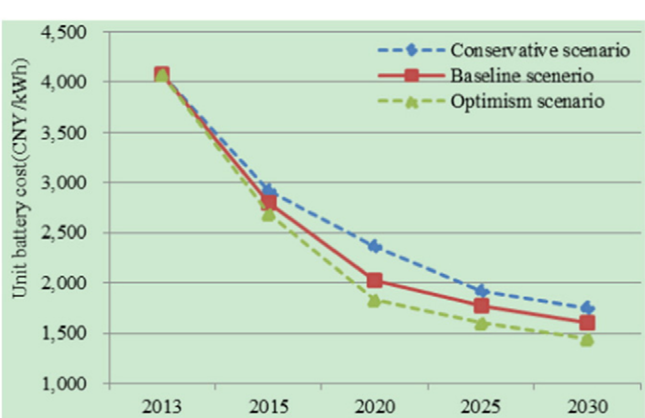


**Fig. 5.** Battery pack cost forecasting results.

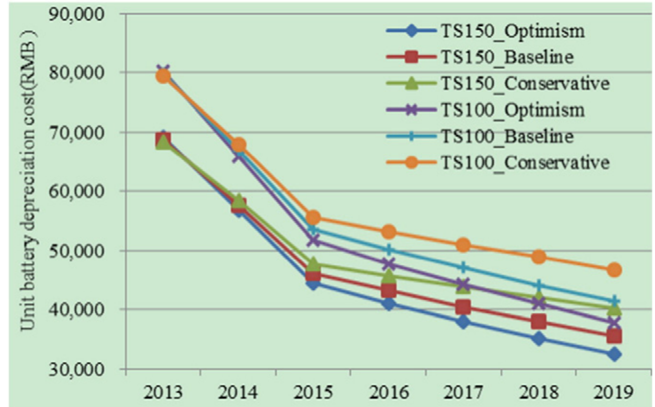


**Fig. 6.** Battery depreciation cost of TS.

The battery depreciation cost of TS is shown in Fig. 6. As the battery capacity and operation mileage in 1 year of TS are different from TC, the battery lifetime ($L_N$) for TS150 and TS100 is also different, which is 2.4 and 1.64 years, respectively.

*(4)Energy consumption cost*

For both electric taxies and gasoline taxies, the annual energy consumption cost is the annual driving mileage multiplied by the energy consumption per km, and then multiplied by the energy price. However, the charging/swapping prices of electric vehicles are still unclear in China. In Shenzhen, as the charging price mechanism has not yet been established (Li and Ouyang, 2011), the commercial electricity price is applied based on the TOU pricing system which means that if you charge your car during daytime, the charging price is approximately 1 CNY/kWh (http://www.news.qq.com/a/20100901/000041.htm). In our study, the residential electricity price (0.617 CNY/kWh) and the commercial electricity price (1.044 CNY/kWh) in Shanghai are applied in the TLCC model.

For TC, the annual energy consumption cost is:

$$C_e = P_C \times E \times 0.9R \times i_C \times 360 \quad (9)$$

where $P_C$ is the charging price in CNY/kWh, $i_C$ is the annual charging times, which is 1.3 and 2 for TC284 and TC158, respectively.

For TS, the annual energy consumption cost is the battery swapping cost, which includes two parts. One part is the battery depreciation cost; the other part is the operation cost of the battery-swapping station. The battery depreciation cost has been calculated in the section "Battery repurchase/battery depreciation cost", so the battery swapping price (without battery depreciation) mentioned here is to compensate the operation cost. It is assumed the battery swapping price be 1.4 CNY/kWh. The calculation of the annual energy consumption cost is the same with that of TC.

For TG, the rising gasoline price leads to increase of the total ownership cost, which makes electric taxies have possible competitive advantages over gasoline taxies. The ARIMA model is developed to forecast the future gasoline price. Due to the special gasoline pricing mechanism in China, the time series modeling method is adopted to forecast the future gasoline price trends. Through calculation and analysis of the gasoline price data, ARIMA (1,1,1)(0,0,0) prediction model is established. The result shows that the normalization BIC is −2.513, which indicates that the model is appropriate for the prediction. Fig. 7 is the model residual figure. The model residual sequence is white noise, which indicates the validity of the prediction model.

The result of gasoline price forecast is shown in Fig. 8. The upper and lower limits of gasoline price prediction of 95% confidence interval are

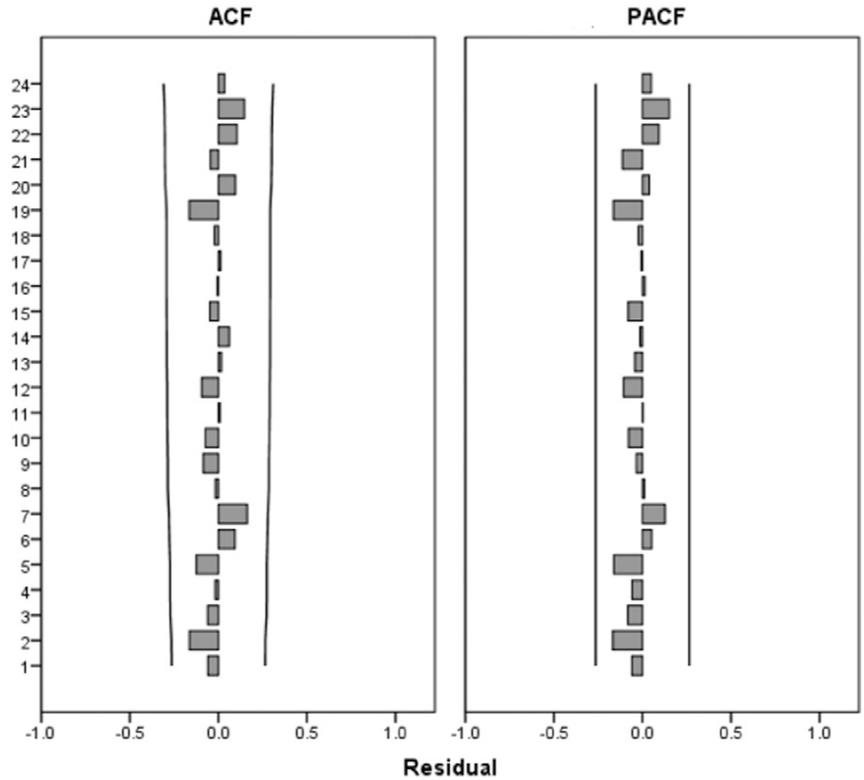


**Fig. 7.** ARIMA (1,1,1)(0,0,0) model residual figure.

provided. In the calculation of energy consumption, the data of the baseline forecast are applied in the TLCC model.

The energy consumption of the gasoline Santana Vista is about 8 L/100 km in China (MIIT, 2010). The national policies and regulations should be taken into consideration in the forecast of the gasoline car fuel consumption of three scenarios. In the optimism scenario, the annual decline rate of fuel consumption is 3% in 2013–2015 and 5% in 2015–2020 according to the goal of the "Planning for the Development of the Energy-saving and New Energy Automobile Industry (2012–2020)." In the baseline scenario, the annual decline rate of fuel consumption is 1% in 2013–2015 and 3% in 2015–2020 according to the "Auto Enterprise Average Fuel Consumption Plan" (ICET, 2011). In the conservative scenario, the annual decline rate of fuel consumption is 1% in 2013–2015 and 1.5% in 2015–2020 according to the goal of average fuel consumption in Japan (Dong et al., 2012). The gasoline consumption result is shown in Table 6.

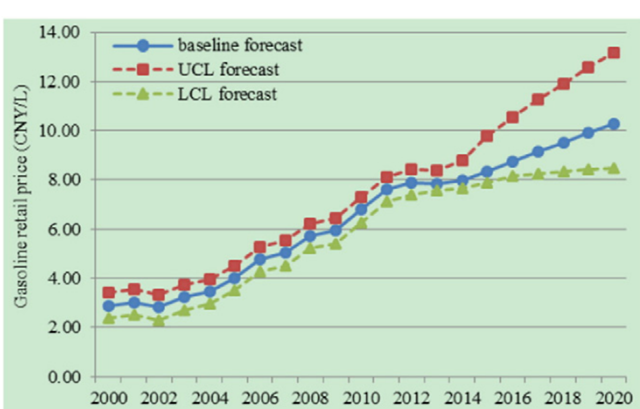


**Fig. 8.** Gasoline retail price forecast result.

*(5)Other costs*

The other costs include the maintenance cost, insurance cost, and drivers' salaries. The average maintenance cost of electric vehicles is 6.16 CNY/100 km. The maintenance cost of gasoline cars is 14 CNY/100 km including the machine oil change, filter change and powertrain maintenance, etc. (Jie, 2010).

As for the insurance cost, it is necessary to pay 1800 CNY for compulsory insurance, 2400 CNY for DLW insurance, and 1560 CNY for third-party liability insurance annually, which is 5760 CNY in 1 year.

According to the salaries of taxi drivers in Shanghai as 21.5 CNY/h, the annual salary for two drivers can be calculated as $C_{driver} = 21.5 \times t \times 360$, where $t$ is the daily operation time (hours).

*Operation revenue*

The annual operation revenue is calculated as:

$$C_{revenue} = P_S \times R \times (1-i_R) \times 360 \tag{10}$$

where $P_S$ is the average service price, which is 4.21 CNY/km of gasoline taxies in Shanghai according to the data in the section "Taxi operation

**Table 6**
Gasoline consumption forecast result Units: L/100 km.

| Scenario | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|
| **Optimism** | 8.00 | 7.76 | 7.53 | 7.15 | 6.79 | 6.45 | 6.13 | 5.82 |
| **Baseline** | 8.00 | 7.92 | 7.84 | 7.61 | 7.38 | 7.16 | 6.94 | 6.73 |
| **Conservative** | 8.00 | 7.92 | 7.84 | 7.72 | 7.61 | 7.49 | 7.38 | 7.27 |

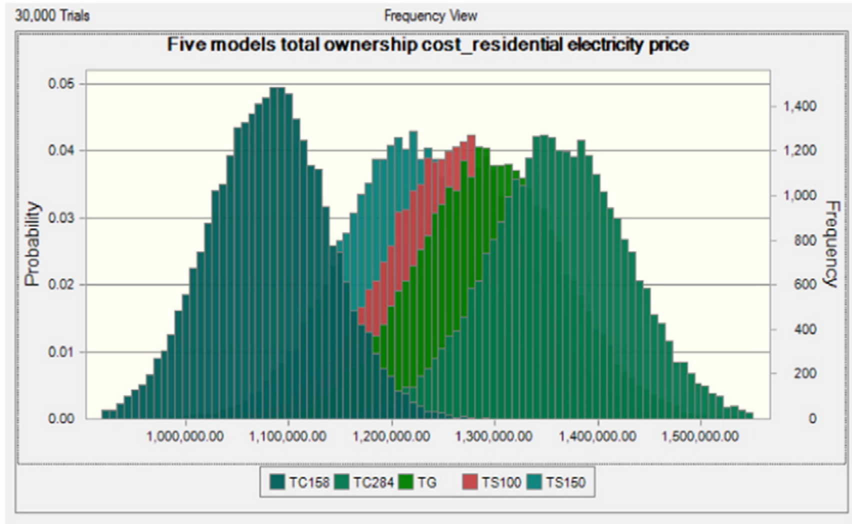


**Fig. 9.** Monte Carlo analysis result of residential electricity price scenario.

requirement of charging model"; $R$ is the driving range in km; $i_R$ is the empty-loading ratio, which is 38%, 42%, and 45% of TG, TS, and TC respectively.

## Results of cost–benefit assessment

### Monte Carlo analysis of TLCC

Monte Carlo methods are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results; typically, one runs simulations many times over in order to obtain the distribution of an unknown probabilistic entity. The essence of the method is to use various distributions of random numbers, each distribution reflecting a particular process in a sequence of processes such as the diffusion of neutrons in various materials, to calculate samples that approximate the real diffusion history (Anderson, 1986).

Monte Carlo methods vary but tend to follow a particular pattern:

1. Define a domain of possible inputs.
2. Generate inputs randomly from a probability distribution over the domain.
3. Perform a deterministic computation on the inputs.
4. Aggregate the results.

The Monte Carlo model is made to calculate the probability of the TLCC of 5 taxi models in 5 years nominal lifetime, which is based on Eq. (5). We assume that the battery repurchase cost of TC, battery depreciation cost of TS, and the fuel consumption cost of TG follow the triangle distribution. The charging cost, swapping cost, maintenance cost, and driver salaries obey the normal distribution. The results are shown in Figs. 9 and 10 in scenarios of two different electricity prices. In the scenario of residential electricity price, the TLCC of TC284 is the highest, which is 1.4 million CNY. The TLCC of TG is higher than TS and TC158 due to the higher annual mileage. The TLCC of TC158 is the lowest and has the highest concentration. In the scenario of commercial electricity price, the TLCC of TS100 is greater than TG.

### Profitability analysis

The TLCC calculation could not indicate the actual economic benefits due to different annual mileage of various taxi models. It is necessary to calculate the profitability of the electric taxies for taxi operation

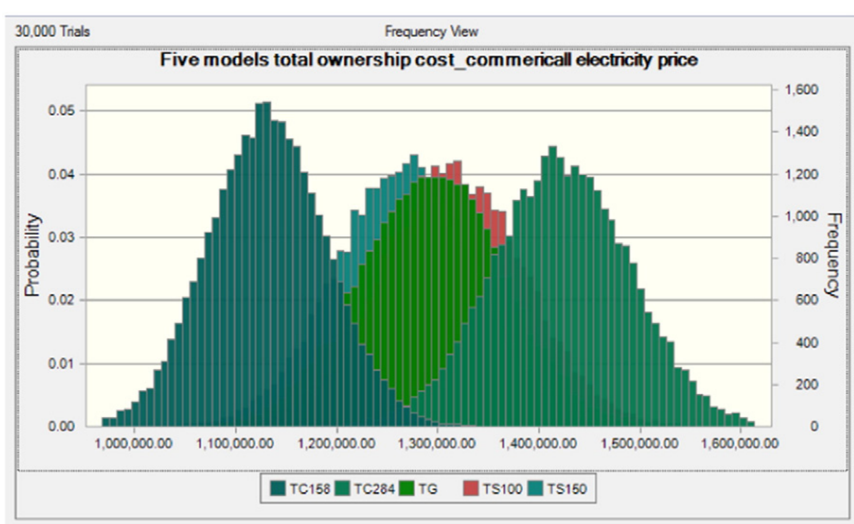


**Fig. 10.** Monte Carlo analysis result of commercial electricity price scenario.

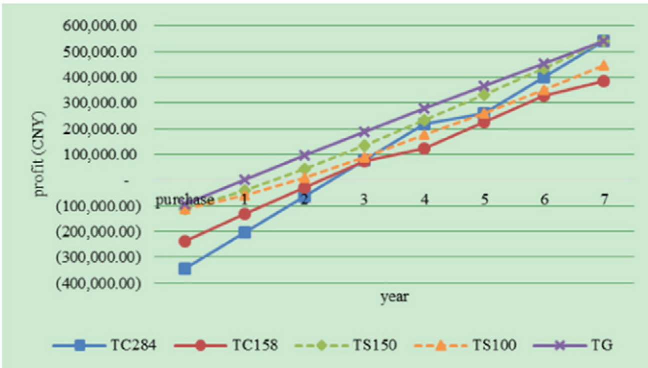


**Fig. 11.** Profit in the residential electricity price scenario.

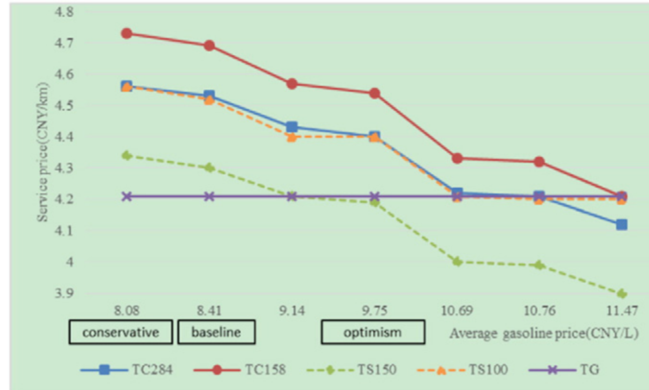


**Fig. 13.** Electric taxi service price in different gasoline price scenarios.

companies. In our study, different electricity charging prices/swapping prices are considered in the total life cycle cost model. There are two scenarios in terms of the charging/swapping price, which are the residential electricity price (0.617 CNY/kWh) and the commercial electricity price (1.044 CNY/kWh). The baseline scenario forecast results of the battery cost, gasoline price, and gasoline consumption are used in the calculation of the profitability. Then the profitability results of the 5 vehicle models in different scenarios are shown in Figs. 11 and 12 based on the Eq. (5).

In Fig. 11, when the charging/swapping price is the residential electricity price, TG begins to make profits in the first year and have greater profitability than the other electric taxi models in 5 years due to the high operation revenue. The two TS models begin to make profits in the second year and have greater profitability than the two TC models. The profitability of TC is low due to the limited operation time. The two TC models begin to make profits in the third year. In Fig. 12, when the charging/swapping price is the commercial electricity price, the profits of TG are the highest compared to the other taxi models in 7 years. The TS models still have greater profitability than the TC models. According to Figs. 11 and 12, we can conclude that both the TC and TS models, the taxi models with longer driving range will have greater profitability than those with shorter driving range.

## Taxi service pricing model

According to the analysis in the section "Vehicle model selection and energy consumption analysis," the profitability of electric taxies is considerably poor compared to gasoline taxies under current conditions. In order to make the profitability of electric taxies equal to that of gasoline taxies, there are three solutions. The first one is raising the service price of electric taxies to be higher than that of gasoline taxies (4.21 CNY/km). The second one is reducing the battery costs. The third one is altering the electricity price and gasoline price to make the electric taxies costs more competitive.

The service price of the taxi determines its profitability. The service price of electric taxies should be developed based on the service price of gasoline taxies and the profitability of electric taxies calculated above. The going-rate pricing method is mainly used in our study and the break-even pricing method is also an important reference.

In Shanghai, the multi-step time-of-use pricing is implemented as the service price strategy of gasoline taxies. The price is determined by the time and driving distance. To simplify the calculation, the multi-step time-of-use price is converted to the average price per kilometer. According to the calculation in the section "Taxi operation requirement of charging model", the gasoline taxi price is 4.21 CNY/km.

The principle of the electric taxi service pricing is making more profits or at least less loss. Besides, the electric taxi service price should not be significantly higher than gasoline taxi service price. In our study, the electric taxi service price is adjusted to make the whole profit of electric taxies equal to that of gasoline taxies in 5 years under the scenarios of different gasoline prices, electricity prices, and battery costs.

### *Gasoline price increasing scenarios*

In this scenario, the gasoline prices applied in our study are the average values of 5 years. Firstly, the forecast results of the three scenarios (conservative, baseline, and optimism) are applied to calculate the service prices of the 4 electric taxies. Then we calculate the average gasoline prices when the service price of electric taxies equals to that of gasoline taxies. The results are shown in Fig. 13. When the average gasoline price is less than 9.14 CNY/L (annual growth rate of 8%), the service prices of the 4 electric taxi model are higher than that of gasoline

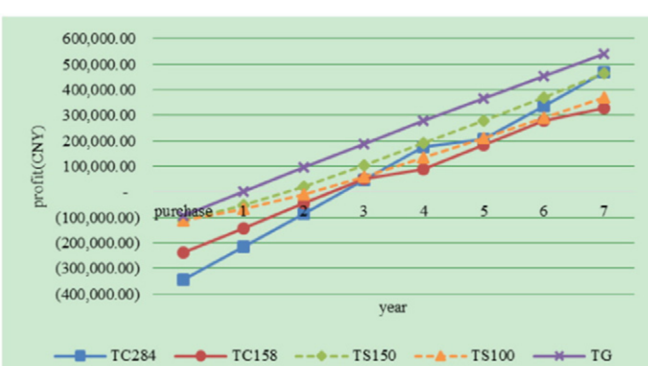


**Fig. 12.** Profit in the commercial electricity price scenario.

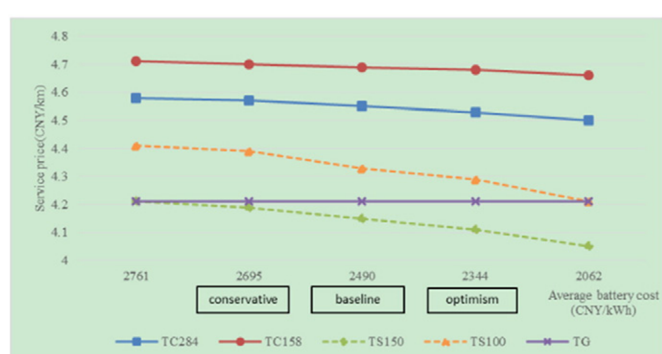


**Fig. 14.** Electric taxi service price in scenarios of different battery costs.

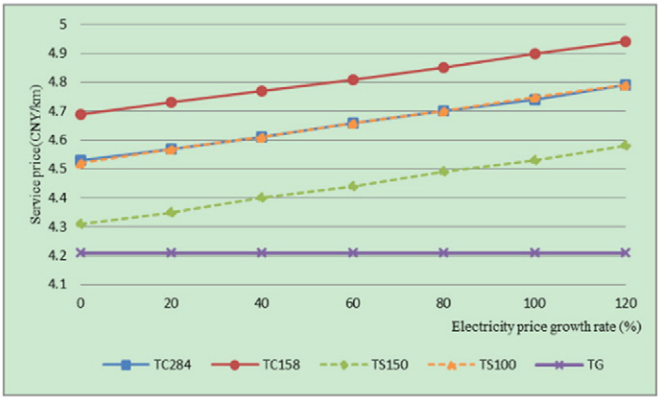


**Fig. 15.** Electric taxi service price in scenarios of different electricity prices.

taxies, which means that the electric taxies have no advantages over gasoline taxies of economic benefits in this scenario. When the average gasoline price is 9.14 CNY/L, the service price of TS150 can be equal to that of TG, which indicates that TS150 is more competitive than the other models. When the average gasoline price is 11.47 CNY/L (annual growth rate of 19%), the service price of all the 4 electric taxies can be lower than that of TG and the service prices of TC284 and TS150 can decrease by 0.1 CNY/km and 0.3 CNY/km, respectively.

*Battery cost decreasing scenarios*

In this scenario, the battery costs applied in our study are the average values of 5 years. Firstly, the forecast results of the three scenarios (conservative, baseline, and optimism) are applied to calculate the service prices of the 4 electric taxies. The results are shown in Fig. 14.

When the average battery cost is 2761 CNY/kWh (annual decrease rate of 19%), the service price of TS150 can be equal to that of TG, which indicates that TS150 is rather competitive even if there is no decrease of the battery cost in 5 years. When the average battery cost reduces to 2062 CNY/kWh (annual decrease rate of 34%), the service price of TS100 can be equal to that of TG and the service price of TS150 can decrease by 0.16 CNY/km. However, the service prices of the TC models will not be less than that of TG even if the battery cost reduces to 0 CNY/kWh. In conclusion, in the scenarios of reducing battery costs, TS models are more competitive than TC models.

*Electricity price increasing scenarios*

In this scenario, the electricity prices applied in our study are the average values of 5 years. The electricity price is set to increase by different growth rate from 0% to 120% based on the residential electricity price. The results are shown in Fig. 15. For both TS and TC models, when the electricity price increases by 20%, the service prices need to increase by 0.8%–1.1%.

## Conclusions

This study has analyzed the economic benefits and service pricing strategy of electric taxies based on the actual situation in Shanghai. We have compared the profitability of electric taxies and gasoline taxies. The service pricing model is developed on condition that the profit of electric taxies is equal to that of gasoline taxies in 5 years. Through the comparison of the service prices, we can come to the following conclusions:

1) Under the current circumstances in China, the service prices of all the electric taxies are higher than that of gasoline taxies. The electric taxies have no market competitiveness without government subsidies.
2) Without considering the technology issues of the battery-swapping model, the service price of the TS models is lower than that of TC models due to the low purchase cost and high profit.
3) In terms of driving range, the electric taxies with long driving range can obtain more profits than those with short driving range, thus can have the lower service price.
4) The gasoline price, battery cost, and electricity price have a great influence on the profitability and service pricing of electric taxies. When the average gasoline price increases to 11.47 CNY/L, the service prices of the electric taxies (both for TC and TS) can be lower than that of TG. When the average battery cost reduces to 2062 CNY/kWh, the service prices of the TS model can be lower than that of TG. If the electricity price is set to be higher than the residential electricity price, the service price of electric taxies cannot be lower than that of TG.

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