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Modeling the CO₂ emissions and energy saved from new energy

vehicles based on the logistic-curve

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Abstract: The Chinese government has outlined plans for developing new energy vehicles (NEVs) to achieve energy conservation and emission reduction. This paper used a logistic-curve to predict the market share of NEVs in the next decade, and then calculated the potential environment benefits of each and every car or the total according to the report of IPCC (2006). The results indicated that NEVs were of benefit in achieving above goals, particularly electric vehicles (EVs). However, they will have a limited impact in the short term. Finally, considering the empirical results and the Chinese reality, this paper proposed corresponding recommendations. **Keywords**: New energy vehicles; Scenario analysis; Energy saving; CO₂ emissions

1. Introduction

NEVs have emerged as an alternative to conventional vehicles as they emit less greenhouse gas (GHG) and consume less petrol by using electricity. Because of their high energy efficiency and little pollution to the environment in the pump-to-wheel (PTW) stage, EVs are regarded as a trend in this industry. Driven by the national policy of energy conservation and emission reduction, the Chinese government is making great efforts to make NEVs more widespread.

Although NEVs can achieve low emissions by using less petrol in PTW, they indirectly produce CO_2 by consuming large amounts of electricity. China is a country based on thermal power. Except for some thermal power transformed from natural gas and petrol, coal is used to produce electricity, accounting for 49% of national total coal consumption. Moreover, when 1 per degree (kW • h) of electricity is consumed, 0.4kg coal is consumed, while CO_2 emissions increase 0.997kg (Gu, 2010). As different energies have different CO_2 emission coefficients, changes in power structures will lead to changes in emissions. Power supply structure is highly subject to the structures of energy production and consumption. China has long been working to improve the domestic energy consumption structure through expanding new energy industries. The recently released *Twelfth Five-year Plan* clearly pointed out that non-fossil energy's share of total primary energy will reach 11.48% in 2015. Taking other related information into consideration, we can see that China's energy structure is facing adjustments, i.e. reducing coal consumption and developing new energy.

At the same time, *energy-saving and the new energy vehicle development plan* has meant that over the next decade, the government will invest 100 billion RMB to support the NEV industry for the first time. However, some scholars object to this plan, since they do not think NEVs save

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energy or decrease emissions. Even with such a huge investment capital, the industry would still be immature due to current technology limitations, the limited number of charging stations and other issues. In this critical period of the industrialization of the NEV, we need to ensure that it is an effective way to achieve energy conservation and emission reduction. This has a strong practical significance in terms of the government's final attitude.

2. Literature review

Most scholars' evaluations of vehicles have concentrated on pollution emissions and energy consumption during operation. As to the emissions and energy consumption, the calculations have mainly comprised the engine fuel consumption and power consumption of rechargeable energy storage systems. Since NEVs have more complex operating modes, scholars have explored carbon emissions through a simulation and modeling approach. Frey et al. (2011) calculated that the mean average figure of CO₂ emissions of hybrid electric vehicles (HEVs) was 0.69g/s, based on actual working conditions, such as engine types of HEVs, traveling speed and different driving situations. Comparing EVs to ICVs, Smith (2010) found great potential and specific environmental benefits of EVs in different traveling models. Many domestic scholars (Chen, 2010; Ou, 2009) have tested the energy consumption and pollutant emissions of three kinds of HEVs, namely, the series, parallel and hybrid types, with the help of vehicle emissions testing technology under actual working conditions. From the perspective of primary and secondary energy, Gu (2010) pointed that EVs had zero emission during the driving stage, but were generating a great deal of CO₂ by consuming electricity. He also found that emissions from Chinese EVs greatly exceeded those from Japan, and even those from ICVs, hence drawing the conclusion that China should not promote NEVs blindly.

Because there is considerable historical data on traditional vehicles, scholars can use the time-series method or establish models based on various factors which influence the amount of cars, to predict their number. However, the NEV industry is an emerging one, so the prediction methods are few. Brady and O'Mahony (2011) used the logistic-curve method to predict the number of EVs in 2020 in different scenarios, namely, high (20%), medium (15%), and low (10%), and calculated corresponding CO_2 emissions. The research showed that if great numbers of EVs were used, transportation reduction could be effectively realized. That is to say, the impact would be limited by introducing NEVs in the short term. Draper et al. (2008) used a logistic-curve to predict the number of NEVs in future decades when they studied the influence of NEV application on the US economy. Ma et al. (2009), using the maximization principle of customer utility, analyzed the weights of NEVs' cost, reliability, image, and safety, with the establishment of a prediction model of market share of NEVs in low, medium and high scenarios.

Doucette et al. (2011), based on a model which calculated emissions of plug-in hybrid electric vehicles, found that the reduction effects were different in the US, France and China, since the three countries had different energy structures. They stated that the effect in China would be relatively worse than in the other two countries, since China relied on coal to produce electricity. Moreover, many domestic scholars (Lin, 2010; Chen, 2010; Ou, 2009) compared the energy consumption and emissions of ICVs and NEVs and calculated the amounts of reduction and energy consumption from 2010 to 2030.

In short, scholars have conducted both qualitative and quantitative analyses of energy consumption structure and the effect of its change on emissions as well as the outcome of the conservation and reduction of EVs. Since the NEVs industry is a emergent one, there is little empirical research on China's energy consumption structure, power supply structure and the effects of their changes on the conservation and reduction of NEVs. Therefore, this paper will adopt an internationally-used method of CO_2 emissions to analyze the effects. Based upon the results of the analysis, the paper will provide corresponding policy recommendations and specific measures to help China achieve its formulated aim of energy conservation and emission reduction by introducing NEVs.

3. Methodology

3.1, Predicting the number of vehicles in China based on the modified Gompertz model

3.1.1 Establishing the basic Gompertz model

Based on Chinese GDP per capita, the number of cars and the total population at the end of the years from 1985 to 2009, we could establish the following model:

$$V(X) = \gamma e^{\alpha \exp(\beta X)} \tag{1}$$

Where V(X) is the ratio of the number of cars to population, X is GDP per capita, α and β are parameters to be estimated. The assumed rate of satiation γ , for industrial countries, is 0.62, but it is 0.5 in developing countries. The basic model formula (2) obtained from formula (1) is

$$\ln(\ln y - \ln(V(X))) = C + \beta X + \varepsilon$$
⁽²⁾

3.1.2 Model testing and improving

Table 1

By testing, we knew there was serious autocorrelation problem in the basic model (2), and DW statistic was 0.0916228. As a result, this model cannot be used to reflect the economic relationships. In addition, the test of omitted variables and the plot of residuals-X indicated that model (2) had omitted some variables. Because the omission variable was not linear or related to X, this paper added x^2 or ln(X) to address this issue, as models (3) and (4) show:

$$\ln(\ln \gamma - \ln(V(X))) = C + \beta_1 X + \beta_2 X^2 + \varepsilon$$
(3)

$$\ln(\ln \gamma - \ln(V(X))) = C + \beta_1 X + \beta_2 \ln(X) + \varepsilon$$
⁽⁴⁾

Regression results of models				
Variable	M1	M2	M3	
Х	-0.3146	-0.5379	-0.5164	
	(0.0181)	(0.0383)	(0.0114)	
X^2		0.0963		
		(0.0157)		
Ln(X)			-0.1081	
			(0.0068)	
Cons	1.5956	1.6593	1.3844	
	(0.0185)	(0.0158)	(0.0145)	
Ν	27	27	27	
R^2	0.9204	0.9676	0.9927	



Fig. 1. Regression residual plots of different models

From the regression results (Table 1), it was found that the variable Ln(X) increased the R-squared value of the model, which improved the estimated effect. Compared to the regression residual plots of each model in Fig. 1, the regression residual of model 4 is closer to the zero-axis than the others. We obtained DW statistic 0.4390943 through a Durbin-Watson autocorrelation test and F statistic 11.64 through a Ramsey RESET test. These results told us that the autocorrelation and omitted variables problems had improved somewhat.

We get the modified Gompertz model through model 4:

$$V(X) = \gamma e^{\alpha \exp(\beta_1 X) e^{\beta_2 X}}$$
⁽⁵⁾

In this model, the dependent variable is GDP per capita. Thus we obtained vehicle ownership rates in China in the next decade through predicting GDP per capita. Domestic scholars combined the birth rate, gender ratio, mortality rate and so forth to forecast the Chinese population in the future. According to the predictive values, the numbers of cars from 2010 to 2020 can be predicted.

3.2 Forecasting the number of NEVs in different scenarios based on logistic models

The NEVs studied in this paper include HEVs and EVs which have relatively mature technology. Based on analyzing the development of foreign NEVs, planning objectives and market trends, combined with the introduction of China's *energy-saving and new energy industry planning, auto industry restructuring and revitalization of planning* and the related introduction of the pilot-city plans, as well as the relationship between the consumption of previous items and income level, we set three scenarios, namely, high, medium, low. In these three scenarios, the market shares of NEVs will be 10%, 8%, and 5% respectively in 2020. The high scenario is based on the prediction for Ireland which is at a similar stage of development stage to China. The medium scenario is 8%, calculated by the average growth rate of pilot cities in recent years. The low scenario is set based *on energy-saving and the new energy industry plan*. Since the logistic-curve can simulate trends of things more accurately, we use it to predict the market share of China's NEVs in the next few years. The specific model is as follows:

$$p(t) = \frac{1}{1 + e^{-k(t-m)}}$$
(6)

Where t is time, k and m are parameters to be estimated, p(t) is the market share of NEVs at time t.

3.3 The calculation of consumption and emissions

In driving stage, ICVs consume fossil fuels and also produce large amounts of emissions. When calculating this, we use the average petrol consumption per hundred kilometers based on online survey results for 19 types of vehicles with different prices and emissions. When calculating the emissions, taking into account improvements in the technological level, we obtain the limited indicator 162.3g / km in 2012, referring to the CO_2 emission limits of China's automotive industry.

With petrol consumption as well as with electricity and many operation modes, it is difficult to evaluate the performance of HEVs. Thus the amount of consumption and emissions are derived from domestic and foreign scholars' simulation outcomes. The emissions generated indirectly by HEVs and EVs due to their consuming electricity, are calculated following IPCC (2006), based on the power structure of China. The specific calculation methods are shown as follows:

Emissions from electricity consumption = fuel heat release * CO₂ emissions coefficients Fuel consumption of ICV = mileage * consumption per kilometer Emissions of ICV= mileage * the limitation of carbon emissions Fuel consumption of HEV = mileage * fuel consumption per kilometer Electricity consumption of HEV = mileage *electronic power consumption per kilometer Emissions of HEV = emissions from fuel and electricity Electricity consumption of EV= mileage * electricity consumption per kilometer Emissions of EV= emissions from electricity

4. Analysis and Discussion

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4.1 Sources and description of data

Table 2

Source and description of data

Variables	Source	
Population	China Statistical Yearbook (1985~2009)	
Number of cars	China Statistical Yearbook (1985~2009)	
Per capita income	China Statistical Yearbook (1985~2009)	
Mileage	http://news.hexun.com/2011-03-11/127866475.html	
Petrol consumption per 100	Results of online survey	
miles	http://bbs.fdc.com.cn/showtopic-4128008.aspx	
CO ₂ emissions	Chen A., 2010. Cars' emissions Limited Regulations and coping	
	strategies of Shanghai Moto. Shanghai Moto 9, 3-11.	
Petrol consumption per 100	Liu S., Gu L., 2008. Analysis about the powertrain by establishing a	
miles of HEV	model and using simulation based on Hybrid Electric Vehicles of	
	Crusie. Powertrain Technology 22(4), 44-48.	
Electricity consumption per	S. Liu, L. Gu, 2008. Analysis about the powertrain by establishing a	
100 miles of HEV	model and using simulation based on Hybrid Electric Vehicles of	
	Crusie. Powertrain Technology 22(4), 44-48.	
Electricity consumption per	Liu Z., Wu Q. and Zong Z., 2001. A Research on Electric Vehicles'	
100 miles of EV	Energy Economy Based on Bench simulation. Acta Scientiarum	
	Naturalium Universitatis Sunyatesni 50(1), 44-50.	

4.2 China's effort to promote NEVs would greatly affect their future production

Based on the improved Gompertz model, the regression results for the number of cars in 2020 is shown as follows:

$$\ln(\ln 0.5 - \ln(V(X))) = 1.384 - 0.15643X - 0.10806$$
⁽⁷⁾

By forecasting China's per capita GDP in 2015 and in 2020 and taking them into equation (7), the car ownership rate can be predicted. There will be 204 million cars in 2020 (as Table 3 shows) according to the population, which is predicted by domestic scholars. This result means that the car industry of China would maintain a high growth rate, which is consistent with China's rapid economic development, and also with the prediction of Xiangmu Zhang of Ministry of Industry and Information Technology of the People's Republic of China.

Year	Population (thousand)	Per capita GDP (thousand RMB)	Market Share	The number of cars (thousand)
2015	1427328	41	8.1797%	116752
2020	1479722	60	13.8080%	204320

Prediction of car ownership rates in China in 2015 and 2020

Table 3

After considering several factors such as the scale of the government's promotion, income levels of consumers, infrastructures and so forth, we used a logistics-curve to forecast the market share of NEVs in the next few years under different scenarios (shown in Fig. 2).



Fig. 2. The market share of NEVs under different scenarios

With the estimated number of ICVs and the market share of NEVs in 2020, we reached the conclusion that the number of NEVs will be 20.43 million, 16.35 million or 10.22 million in different scenarios. It can be seen that government incentives have a close relationship with the development of NEVs. If more incentives are promulgated by the government, the number will rise to 20 million from 16 million in the medium scenario, otherwise it will fall to about 10 million. In a word, the NEV industry is very sensitive to the intensity of the government's promotion. This also indicates that the government of NEVs in the early stages. Therefore, the government should take measures to accelerate the industrialization and commercialization process by supporting research and development, infrastructures, laws and regulations, and so forth. These measures can help to lay a solid foundation for this industry, improve the competitiveness of Chinese cars, and then realize the sustainable development strategy by saving energy and reducing

CO₂ emissions.

4.3 EVs excel in emission reduction

According to the methodology of the third part, we can calculate the fuel and electricity consumption and emissions of each and every ICV, HEV and EV in the driving state. Fig. 3 directly indicates that the ICV consumes more energy and discharges significantly more than the HEV and the EV. Although consuming no petrol, the EV still produces a certain amount of CO_2 by using electricity, but this is still less than the ICV and the HEV. Therefore, a conclusion can be drawn that the HEV and the EV achieve the goals of energy conservation and emissions reduction. In the short-term, the HEV is a very competitive type of NEV, being 30% or more economical in terms of fuel than the ICV due to its optimized structure. In the long-term, the EV is seen as the final version of the NEV, since it relies completely on electricity as its sole power resource. Hence, to date, the EV has become the focus of R & D and government subsidies internationally.



Fig. 3. Comparison among every single ICV, HEV and EV

Based on the total number of cars, the predicted number of NEVs, China's energy-generating structures and emission coefficients of all types of energy, we can calculate the total amount of petrol and electricity consumption and emissions of China's auto sector in three scenarios in 2020; the specific results are shown in Table 4. The results imply that with the number of HEVs and EVs increasing, electricity consumption will grow substantially, and in the high scenario this growth is twice as great as that in the low scenario. The results also demonstrate that compared to the low scenario, petrol consumption and emissions are around 10 billion tons of CO_2 less than in the high scenario.

Table 4

The total energy consumption and CO ₂ emissions			
	Fuel consumption	Electricity consumption	CO ₂ emissions
	(billion tons)	$(billion kW \cdot h)$	(billion tons)
High	231.63	19.12	382.72

Medium	234.98	15.30	386.80
Low	240.01	9.56	392.92

4.4 Electricity-generating structure matters

By using electricity transformed from primary energy, NEVs indirectly produce some CO_2 . When we apply the emission coefficients (IPCC 2006) to this calculation, we can see that the number has been influenced significantly by the state's electricity-generating structure and the amount of thermal power generation through primary energy. As illustrated in Fig. 4, the conclusion can be drawn that China's electricity-generating structure is clearly different from that of the world. China's thermal power accounts for more than 80% of the world's total, and most of it is coal power generation. As we know, coal has a higher emission coefficient, which means that China's NEVs, while utilizing clean energy, would still produce more CO_2 than those of other countries.



5 Conclusions and recommendations

Upon the basis of an empirical analysis, this paper concludes that NEVs contribute to conservation and reduction, while the effect is subject to the population of NEVs and China's electricity-generating structure. Considering the special conditions of China with regard to energy, it is difficult for China to adjust its energy consumption patterns and its electricity-generating structure on a large scale in such a short time. Therefore, in order to alleviate the energy crisis as well as the pressure of excessive emissions, drastically developing the NEV industry and increasing the number of energy-saving vehicles could be more effective as a current option. Combining the empirical analysis with the reality of China, this paper recommends the following:

5.1 More incentives to promote

Compared to a scenario in which no NEVs were introduced, through the development of NEVs, carbon emissions in the transportation sector could be reduced by 5.1%, 4.1%, and 2.5% respectively in three scenarios. The setting of the low scenario is based on *energy-saving and new energy industry planning*; therefore, according to the current planning in China, the transportation sector will achieve a carbon emission reduction of only 2.5% by 2020. For a better realization of conservation and reduction in this sector, the government can refer to and learn from the basis of

the formulation of the other two scenarios while complementing or supplementing the policy system.

At present, the Chinese government's preferential policies for the NEV industry focuses mainly on R&D funding for firms, subsidies for consumers purchasing them, tax relief and zero traffic limitations and so forth. Besides all these incentives, the government can also increase and expand the demonstration cities and areas, such as no longer limiting them to the current planning provisions of 25 cities or the areas of government, sanitation, public transport and others. More subsidies should be paid directly to the consumer, so that they can enjoy the most direct benefits. In addition, it is necessary to increase preferential tax policies, such as exempting or reducing the purchase tax, road maintenance fees, etc. of NEVs, and by rewarding those customers who prematurely discard their non-NEVs for a NEV by granting them a tax allowance. All these incentives will guide the development of NEVs.

5.2 Increase energy supply, improve the power network and establish charging stations

Along with the development of NEVs, the industry will consume much more electricity than it did before. Table 4 has shown that the power consumption of NEVs in the high scenario is twice that of the low scenario, suggesting that the rapid development of NEVs has led to higher requirements for the national electricity supply, power network planning and the construction of charging stations.

The increase in the NEV population will lead to another huge demand for electricity. In the short term, the national grid can increase the electricity supply by making full use of idle or inefficient generators to. However, from the long-term perspective, China should establish a national smart grid such as those in the USA or European countries as soon as possible to confront the challenge from the electricity supply, considering the high cost of transferring electricity or the marginal cost of using inefficient generators. In addition, the EV driving range is short; hence the popularity of NEVs needs the support of charging stations. In addition, the state should carry out a rational distribution of charging gas stations. To be specific, the government should encourage the national grid to involve in the charging network's construction by tax incentives vigorously. Secondly, certain modes like franchising should be permitted to carry forward charging network's construction and operation. And in order to speed up the foundation of charging network and market process of operation, the government should consummate relevant regulations.

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