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A Comprehensive Analysis for Widespread use of Electric Vehicles

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***Abstract*—**This paper mainly investigates the environmental and economic impacts of worldwide use of electric vehicles. It can be concluded that governments have good reason to promote the use of electric vehicles. First, the global vehicles population is evaluated with the help of grey forecasting model and the amount of oil saving is estimated through approximate calculation. After that, based on the game theory, the amount and types of electricity generation needed by electronic vehicles are established. Finally, some conclusions on the government's attitudes are drawn.

***Keywords*—**electronic vehicles, grey prediction, game theory

I. Introduction

DURING the last few decades, increased concerns over the environmental impact of the petroleum-based transportation infrastructure, along with the peak oil, has led to renewed interest in an electric transportation infrastructure. The fact is that about 15.9% of global carbon dioxide was from automobile exhaust, and the total carbon dioxide emissions will add to six billion tons in 2020 from three billion tons in 1990, which is estimated by International Energy Agency (IEA) in 2006. Meanwhile, the proved reserves of oil in 2009 only increased 0.5% than that in 2008, but the oil extraction rate and consumption growth rate reached 2.5% and 1.4% respectively. All these crises show the necessity and urgency for the rapid development of new energy vehicles. And it is well accepted that electric vehicles (EVs) allow for fuel economy improvements and emission reduction over the conventional internal combustion engine vehicles (ICEVs) in the majority of vehicle applications and in the majority of vehicle's operating conditions, e.g. [1–6]. Hence, research and development of EVs have become an utmost important issue in all automobile manufacturers throughout the world. As EVs include pure-electric vehicles (PEV) and hybrid-electric vehicles (HEV), large amount of studies have been performed to evaluate the efficiency of energy diversion, e.g. [6,7]. For the purpose of the studies presented in Ref. [8] an management system is proposed to coordinate multiple energy sources for EVs, which considers EVs diversifying alternatives such as wind and solar.

However, an issue posed by EVs being developed is that what the amount and type of EVs use that will produce the largest number of benefits to the environment, society, business, and individuals. And little literature is available on the amount and type of electricity generation that would be needed.

As an extension to the pervious paper, the primary focus of this paper is on the amount and type of electricity generation, according to the amount and type of EVs widespread use. Then based on the models we have established and the kinds of impacts we have analyzed, explain whether the governments should support the promotion of EVs and what have to do. Here, we only consider the market share of hybrid vehicles and pure EVs due to the battery technological deficiency in near future.

The paper is organized as follows: estimation about the amount and type of EVs after its widespread use as well as market share of different types needed in the future is made in Section 2, a game theory model about the amount and type of electricity generation is introduced in Section 3, results on the models are given in Section 4, and a recommendation about the role of governments to promote EVs and a conclusion is given in Section 5.

II. Prediction of the Number and Type of EVs

A. Forecast of Vehicle Population

As the data obtained is little, we will use the gray prediction theory to overcome it. So we first preprocess the data to get the series x_0 which meets the requirements. Then do a cumulative averaging to x_0 :

$$y_0(k) = \lambda x_1(k) + (1-\lambda) x_1(k-1) \quad k = 2,3,4,5$$

where $\lambda = 0.5$. Establish grey differential equation

$$x_0(k) + \lambda y_0(k) = \gamma \qquad k = 2,3,4,5$$

where $x_0(k)$ is known as the grey derivative, λ is the development system, $y_0(k)$ is the albino background value, and γ is grey action. Substituting $k = 2,3,\ldots,6$ into the above equation:

$$\begin{cases} x_0(2) + \lambda y_0(2) = \gamma \\ x_0(3) + \lambda y_0(3) = \gamma \\ x_0(4) + \lambda y_0(4) = \gamma \\ x_0(5) + \lambda y_0(5) = \gamma \end{cases}$$

The corresponding albinism differential equation is in the form of

$$\frac{dx_1}{d_t} + \lambda x_1(t) = \gamma$$

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Set

$$Y_N = \begin{pmatrix} x_0(2) \\ x_0(3) \\ x_0(4) \\ x_0(5) \end{pmatrix} \quad B = \begin{pmatrix} -y_0(2) & 1 \\ -y_0(3) & 1 \\ -y_0(4) & 1 \\ -y_0(5) & 1 \end{pmatrix} \quad u = \begin{pmatrix} \lambda \\ \gamma \end{pmatrix}$$

The above matrix can be rewritten as $Bu = Y_N$.

By the least squares method, we can make $J(\hat{u}) = (Y_N - Bu)^T (Y_N - B\hat{u})$ reach the minimum requirements.

$$\hat{u} = \begin{pmatrix} \hat{\lambda} \\ \hat{\gamma} \end{pmatrix} = (B^T B)^{-1} B^T Y_N$$

Then we have the following predictive value:

$$x_1(k+1) = \left(x_0(1) - \frac{\hat{\gamma}}{\hat{\lambda}} \right) e^{-\hat{\lambda}k} + \frac{\hat{\gamma}}{\hat{\lambda}} \qquad k = 1,2,\ldots,5$$

Substituting the global vehicles ownership from 2004 to 2008 [9] into it, we have

$$x_1(k+1) = 323819262477.9 * e^{0.02733k} - 31534485259.9$$

B. The Promotion of EVs in the Proportion and the Number Forecasts

According to Ref. [10], we can establish electric vehicle retain ratio prediction model as follows:

$$\frac{df}{dt} = c \frac{f(1-f)^2}{1-(1-d)f}$$

Where f denotes EVs possession, c means the internal factors, d means retardation coefficient and denotes the relatively optimistic degree.

C. On the Types of EVs

To evaluate the strength and weakness of two kinds of vehicles, a fuzzy comprehensive evaluation is used and four main indexes were chosen in Table I .

TABLE I
THE BASIC EVALUATION INDEX

Index / Type	Efficiency x1	Price x2	Range x3	Emission x4
BYD pure EVs	0.14	30	300	0.3
BYD hybrid vehicles	0.195	14.98	430	0.2

- Ideal alternative:

$$u = \left(u_1^0, u_2^0, u_3^0, u_4^0\right) = (0.195, 14.98, 430, 0.3)$$

Where

$$u_i^0 = \begin{cases} \max\{a_{ij}\} & a_{ij} \text{ is beneficial} \\ \min\{a_{ij}\} & a_{ij} \text{ is cost} \end{cases}$$

- Relative deviation fuzzy matrix:

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \end{bmatrix}$$

where

$$r_{ij} = \frac{\left|a_{ij} - u_i^0\right|}{max\{a_{ij}\} - min\{a_{ij}\}}$$

- Weight numbers $w_i \ (i = 1,2,3,4)$

$$v_j = \frac{s_j}{\bar{x}_j} \qquad w_j = \frac{v_j}{\sum_{j=1}^{4} v_j}$$

The four weight numbers are: 0.19, 0.38, 0.20, and 0.23.

- Comprehensive evaluation model:

$$F_i = \sum_{j=1}^{4} w_j r_{ij}$$

If $F_t < F_s$, then F_t is in the front.

III. The Amount and Type of Electricity Generation

A. Parameters

S —The total cost that users using EVs pay

C —The total cost that charging station operators in the business carried out

Z — The total cost of government to promote the development of EVs

Y_1 —The income of EVs users after promoting EVs

Y_2 — The income of charging station operators after promoting EVs

Y_3 —The income of government after promoting EVs

P_1 —The probability of charging station operators carrying out business

P_2 — The probability of EVs users purchasing EVs

P_3 —The probability of government support

P_4 — The probability of government support and success

B. Considering the following situations:

- Users buy EVs and charging station operators provide the charging service but governments don't support them.
- Users buy EVs and charging station operators provide the charging service and governments support them but the business fails.
- Users buy EVs and charging station operators provide the charging service and governments support them and the business fails.
- Users don't buy EVs and charging station operators don't provide the charging service and governments support them.
- Users buy EVs and charging station operators provide the charging service but governments don't support them.

C. Game theory

When the charging station to charge carriers with probability, the expected return of the Government supporting strategy is

$$U_1 = P_1\left[(Y_3 - Z)P_4 + (-Z)(1-P_4)\right] + (1-P_1)\left[P_4(-Z) + (1-P_4)(-Z)\right] \quad (1)$$

The expected return of the Government not supporting strategy is

$$U_2 = 0$$

When there is no difference between the expected return of support and nonsupport from governments, namely $U_1 = U_2$, we gain the most probability of charging station operator carrying out business in governments' game equilibrium. The maximum probability is

$$P_1 = \left(\frac{Z}{Y_3}\right)P_4 \quad (2)$$

When the probability of buying EVs is P_2, the expected return of the government supporting strategy is

$$U_3 = P_2\left[(Y_3 - Z)P_4 + (-Z)(1-P_4)\right] + (1-P_2)\left[P_4(-Z) + (1-P_4)(-Z)\right]$$

The expected return of the Government not supporting strategy is

$$U_4 = 0$$

When there is no difference between the expected return of support and nonsupport from governments, namely $U_3 = U_4$, we gain the most probability of charging station operator carrying out business in governments' game equilibrium. The most probability is

$$P_2 = \left(\frac{Z}{Y_3}\right)P_4 \quad (3)$$

When the probability of government support is P_3, the respectively expected return for charging station operators to charge or not is

$$V_1 = P_3\left[(Y_2 + Z_2 - C)P_4 + (Y_2 + Z_2 - C)(1-P_4)\right] + (1-P_3)(Y_2 - C)$$

$$V_2 = 0$$

When there is no difference between the expected return of charge and non charge from charging station operators, namely $V_3 = V_4$, we gain the optimal decision of governments supporting in changing station operators' game equilibrium.

We can get

$$P_3 = \frac{(C - Y_2)}{Z_2} \quad (4)$$

When the probability of government support is P_3, the respectively expected return for users to buy electric vehicles or not are

$$V_3 = P_3\left[(Y_1 + Z_1 - S)P_4 + (Y_1 + Z_1 - S)(1-P_4)\right] + (1-P_3)(Y_1 - S)$$

$$V_4 = 0$$

When there is no difference between the expected return of purchase and non purchase from EVs users, namely $V_3 = V_4$. We gain the optimal decision of governments supporting in changing station operators' game equilibrium. We can get

$$P_3 = \frac{(S - Y_1)}{Z_1}$$

To sum up, mixed strategy Nash equilibrium of game model is:

$$P_1 = P_2 = \left(\frac{Z}{Y_3}\right)P_4 \quad P_3 = \frac{(C - Y_2)}{Z_2} \quad P_3 = \frac{(S - Y_1)}{Z_1}$$

IV. Results

A. The mount and Type of EVs

According to the forecast model and with the global vehicles ownership from 2004 to 2008 substituted from Ref. [9] into it, we have

$$x_1(k+1) = 323819262477.9 * e^{0.02733k} - 31534485259.9$$

Thus the forecast data are worked out (see table II).

TABLE II
PREDICTIVE VALUE OF CARS AND OWNERSHIP RATIO OF EVS

Year	The amount of cars	Ownership ratio of EVs	The amount of EVs
2011	1056859545	1%	10568595
2012	1086130975	2%	21722620
2013	1116213125	3%	33486394
2014	1147128448	4%	45885138
2015	1178900020	5%	58945001
2016	1211551558	6%	72693093
2017	1245107433	7%	87157520
2018	1279592692	8%	102367415
2019	1315033075	9%	118352977
2020	1351455038	11%	148660054
2021	1388885765	12%	166666292
2022	1427353196	14%	199829447
2023	1466886046	16%	234701767
2024	1507513821	18%	271352488
2025	1549266848	20%	309853370
2026	1592176292	22%	350278784
2027	1636274183	24%	392705804
2028	1681593436	26%	437214293
2029	1728167879	29%	501168685
2030	1776032276	30%	532809683

Calculating residuals series

$$\varepsilon_1 = \left|\frac{X - \mathrm{x1}}{\mathrm{x1}}\right|$$

Then

$$\varepsilon_1 = (0.03\% \ 0.009\% \ 0.13\% \ 0.07\%)$$

Fig.1 is a scatter plot chart about the practical and estimated values. By doing this, we can verify that this model has certain accuracy. And results of this model have high reliability.

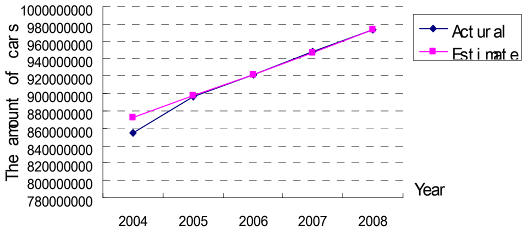

Fig.1 The graph of actual and estimated value

Meanwhile, the promotion factors of a EVs market include environmental protection degree, onward travel distance, fuel supply the degree of difficulty, vehicle economic performance, driving conveniences, comfortableness, social effect, popularize strength and other indexes. Thus we can get the proportion and number of EVs (see Table II). It is not difficult to conclude that the proportion of car ownership is at a steady growth rate, while EVs will be a new fashion trend in the long run.

B. Analysis of the EVs Types

Although there are many types of EVs, hybrid vehicles and pure electric vehicles are the most popular. For hybrid vehicles, it can reduce oil dependency and carbon dioxide emissions but still not completely. While given the current energy conversion technology, PEVs have a limitation, good only for short hauls. So it is necessary to analyze how much market share occupied by HEVs and PEVs is optimal in the short term.

Through a fuzzy comprehensive evaluation and direct calculation, we have

$$F_1 = 0.7704 \qquad F_2 = 0.2296$$

Thus, hybrid vehicles are better and the proportion of pure EVs is

$$l_1 = \frac{F_2}{F_1 + F_2} = 0.23$$

The proportion of hybrid EVs is

$$l_2 = \frac{F_1}{F_1 + F_2} = 0.77$$

As a result, the market share of pure EVs and hybrid EVs are 23% and 77% respectively.

C. Electricity Generation

The issue of EV versus gasoline vehicle emissions is scientifically complex, and the outcomes are highly dependent upon assumptions made about how and where electricity is generated, as well as normative expectations of gasoline vehicle use. Because of diversities of renewable energy, the fact that none of the available energy sources can solely fulfill all the demands of EVs, a game theory model is present to meet the environmental, social, business and personal benefit-maximizing requirements. Let the probability of buying EVs be , the vehicle population be . About 1% of the EVs need charging and the power consumptions for pure and hybrid EVs are 20.8kWh and 6.93kWh. Then the amount of electricity generation can be estimated by the following formula:

$$W = (20.8 * 0.23 + 6.93 * 0.77) * N_i * P_2 * 0.01 = 36.94 * N_i * P_2$$

The types of electricity generation mainly include solar, nuclear, hydroelectric and wind.

To determine the annual electricity generation types, we adopt the econometric model as follows:

$$\ln^{f} = \ell_0 + \ell_1 \ln^{f_1} + \ell_2 \ln^{f_2} + \ell_3 \ln^{f_3}$$

V. Conclusion

From the previous researches [1-6], EVs develop so inevitably in the future that the government should vigorously support the widespread use of electric vehicles to insure safe, efficient, effective transportation. Because the benefits caused by the widespread use of EVs are different according to the different types of electricity generation, governments should formulate the right development directions to guide promotion of EVs based on the primary type of electricity generation. For example, they can take their advantage products as development priorities, advocate those countries which use clean energy such as wind power, water power to generate electricity to use EVs and so on.

- Provide the Platform of Technology Innovation

Recently, what restricts the development of EVs seriously is the battery technology innovation. To achieve a breakthrough, governments should invest adequate capital for study.

- Establish the Standard Systems of EVs and Related Industry

The prerequisite of EVs commercialization and industrialization is that security and unity is assured. Governments should establish safety regulation about EVs, battery and supporting facilities, improve charging network system and changing technology standards.

- Use the Tax Industrial Policy Reasonably

As a macro regulator of the market economy, that governments use tax industrial policy physically may well simulate development of EVs. For tax industrial policy, adopt the tendency to industry and regional and take the rational distribution of the industry dependent on area resources, humanities and geographical advantages. For consumer policy, if governments can subsidize the consumer purchase appropriately, or relieve consumption tax and others, it must greatly stimulate the desire for consumption, which is explained in the Economic Model that the buying price difference between EVs and fuel vehicles will be made up by energy saving through 30 years. What's more, this kind of support may not cause losses to the government financials for government governance in the atmosphere will substantially reduce the capital investments when EVs are widely used.

Under the government strongly supports for the widespread use of EVs, we just consider pure electric vehicles and hybrid vehicles. Thus the pure electric vehicles and hybrid vehicles respectively proportion of the total electric we get are 0.23 and 0.77. According to the electric vehicles proportion prediction model, we can calculate the electric vehicles ownership from 2011 to 2030, and the annual electricity generation is estimated. Comprehensive consideration of the game behavior of government, charging suppliers and trolley user to get Nash equilibrium for mixed strategy. Finally, we would achieve the public benefit maximization, the supplier economic maximization, and EVs user personal utility maximization.

At last, we consider water power generation, nuclear power generation, wind power generation, and solar power generation, to determine the power form according to the actual need and estimate the amount of electricity generation needed by EVs.

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