Predictive Modeling and Policy Application of Electric Vehicle Ownership

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Abstract

In this paper, a method for forecasting electric vehicle ownership based on system dynamics is proposed. Firstly, based on the the theory of system dynamics ,the relationship between the electric vehicle and fuel cars is analyzed by considering such influence factors like personal sustainable consumption level, the national development degree as well as natural growth. Then the predictive model based on system dynamics of electric vehicle ownership is built, and it is applied to predict the Irish electric vehicle development. According to the forecast results, the number of electric vehicles in Ireland is roughly the s-shaped curve, which will be in a rapid growth stage after 10 a, and the number of electric vehicles will surpass the fuel vehicles after 25 a. Then it provides reference for electric vehicle development and distribution network planning.

Keywords

Electric vehicles, system dynamics, prediction, policy application.

1. Introduction

With the improvement of technology and environmental awareness, more and more people choose to use electric vehicles. Nowadays, various countries have adopted various mechanisms to promote the development and deployment of electric vehicles and charging facilities. At present, domestic and foreign scholars have conducted a lot of researches on the application and influence of electric vehicles in power system. The main focus is on the site selection, optimization configuration, operation mode, and the network and coordination planning of electric vehicle charging stations. However, the above studies rely on the accurate prediction of the size of electric vehicles [1]. Since electric vehicles are new things, lack of abundant data support and lack of necessary theoretical and analytical tools [2].

2. Predictive model based on SD of EV ownership

The system dynamics modeling can use the stock flow diagram to express the complex concept of the model, and then establish the mathematical relationship between variables through the model equation. And it's constantly being simulated in a virtual world of machines, and it's a loop between the reality of finding data and testing the feasibility of the model.

2.1 Problem Analysis

From the macro perspective, the electric car industry's ultimate goal is to improve the electric vehicle ownership. As a result, the rate of return of funds and manufacturing enthusiasm of electric vehicle manufacturers will increase substantially in the short term. With the increase of government subsidy investment in the expansion of the electric vehicle market, the price of EV will decrease further and the consumer’s ability to afford the price of electric cars will increase, which will further promote the increase in the number of electric vehicles. Electric car ownership ascension will further replace and suppress fuel car ownership, bringing the benefits of energy saving and emissions reduction (ESER). As the further improvement of the government's energy-saving emission reduction requirements, the fuel vehicle ban will restrain the ownership of fuel vehicles, at the same time, it will also increase the amount of electric vehicle ownership [3]. Combined with the above analysis, the cycle causality diagram of electric vehicle ownership and its influencing factors can be obtained, as shown in FIG. 1.

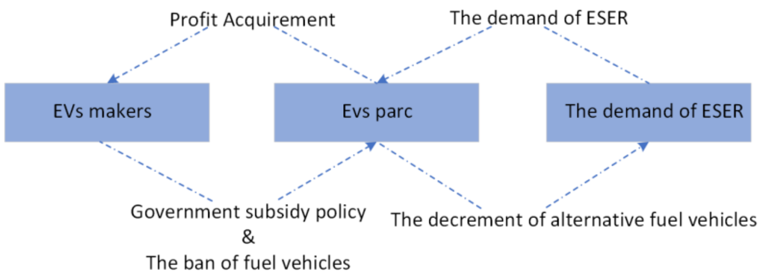

FIG 1 the Cycle Causality Diagram of Electric Vehicle Ownership

2.2 Dynamic Hypothesis

The amount of electric vehicle ownership is cumulative, which increases cumulatively with the annual increase. There are two sources of the amount of EV purchases each year, assuming that electric vehicles are not scrapped. One is the number of newly purchased electric vehicles, and the other portion is from replacing old fuel vehicles. The substitution rate of electric vehicles indicates the ratio of decision-making and selection of electric vehicles. The other part is due to the market effect of electric vehicles and the maturity of the relevant supporting constructions that promote the purchase intention of consumers. In order to determine the development of electric vehicles, the concept of electric ratio (R) is introduced:

$$R_{elec}(t) = P_{elec}(t) / P_{\text{all}}(t) \tag{1}$$

In the formula, $R_{\text{elec}}(t)$ means the electric ratio; $P_{elec}(t)$ is the electric vehicle ownership at t; $P_{\text{all}}(t)$ the car's ownership at t.

The relationship between car ownership and time is as follows:

$$P_{\text{all}}(t) = P_{\text{all}}(t-1) + VARP_{\text{all}}(t) \tag{2}$$

$$VAR_{elec}(t) = NEW_{\text{ecle}}(t) + REP_{\text{elec}}(t) \tag{3}$$

$$VAR_{fuel}(t) = NEW_{\text{fuel}}(\text{t}) + REP_{fuel}(t) \tag{4}$$

$$VARP_{\text{all}}(t) = NEW_{elec}(t) + NEW_{fuel}(t) \tag{5}$$

$$R_{elec}(t) = P_{elec}(t) / (P_{all}(t-1) + NEW_{elec}(t) + NEW_{fuel}(t)) \tag{6}$$

The formula $VARP_{all}(t)$ is the amount of change in car ownership at t when compared to t-1. $VAR_{elec}(t)$ represents the change in purchase value of EV at t; $NEW_{\text{elec}}(t)$ is the number of newly purchased EV, and $REP_{elec}(t)$ is the number of replaced old fuel cars at t. $NEW_{\text{fuel}}(t)$ represents the change in the purchase value of the fuel car; $REP_{\text{fuel}}(t)$ is the number of newly-purchased fuel cars to replaces old-fuel cars at t.

2.3 Equation of State

The system state variables determine the variables of the system's behavior, which change with time [4].

$$P_{elec}(t) = P_{elec}(t_0) + \int_{t_0}^{t} VAR_{elec}(\pi) \mathrm{d}\pi \tag{7}$$

$$P_{\text{fuel}}(t) = P_{\text{fuel}}(t_0) + \int_{t_0}^{t} VAR_{\text{fuel}}(\pi)\mathrm{d}\pi \quad (8)$$

In the formula, $P_{\text{elec}}(t)$ stands for EV ownership; $P_{elec}(t_0)$ is the initial amount of EV; $VAR_{elec}(t)$ is EV growth. $P_{\text{fuel}}(t)$ represents the fuel vehicle ownership; $P_{\text{fuel}}(t_0)$ is the initial amount of fuel vehicle; $VAR_{\text{fuel}}(t)$ is fuel vehicle growth.

3. Model Simulation

3.1 Model Establishment

According to the research on prediction of car ownership, the number of private cars shows S-type changes over time, and Logistic model is a commonly used model [5]. The model is $F(t) = \frac{1}{1+ae^{-bt}}$, where a & b is a constant; $F = \frac{y(t)}{m}$, $y(t)$ is the number of products that can be used in the market at t, m is the maximum capacity of the market, F is the ratio of market holdings to the maximum market holdings at t. According to the above analysis and based on the causal benefit transfer mechanism, various factors were integrated and modeled using Vensim software. The model is set up as follows:

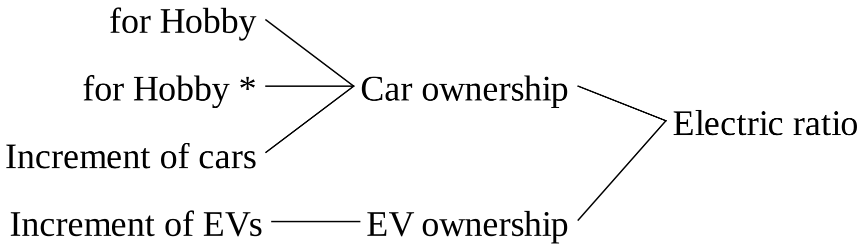

FIG 2: the Cause and Effect of the Electrification Ratio

This model is based on the data background about Ireland 2016, where main formulas and variables of each module are set as follows: The base year is 2016, and the ending period is 40 years. Therefore, the system is set to expire in 2046. And dynamics equation as: $FINAL \quad TIME = 2046$. GDP is the horizontal variable, which is set as stock. From the previous year's data analysis, the GDP growth rate is set to 0.052 in the model, and the system dynamics equation is: GDP = INTEG (GDP growth rate, 203.49). The level of personal affordability is calculated by the relationship between per capital affluence and per capital annual income. Per capital annual income is calculated by dividing GDP by population. Population growth rate is set by reference to population growth rate in the past five years. It is 0.02. About 2.4 million vehicles are owned by private cars.

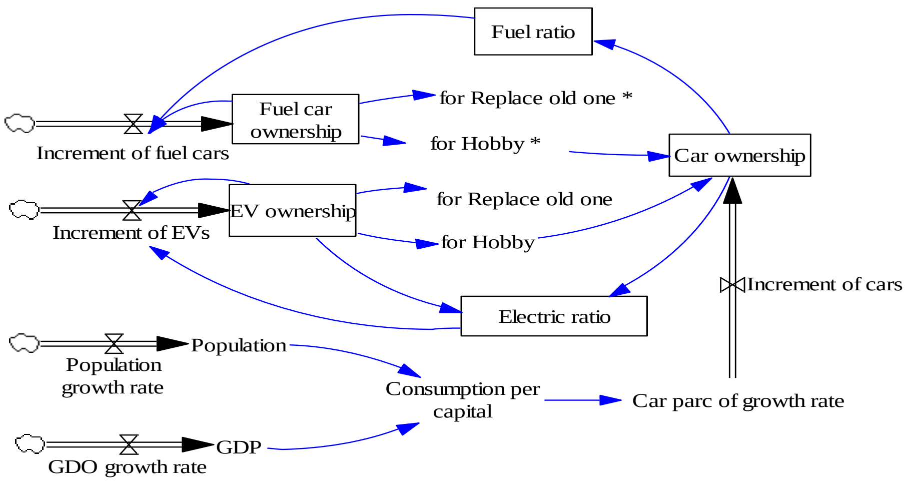

FIG 3 Analysis of Dynamics Modeling of Electric Vehicle System

3.2 Test Results

Using Vensim software, by taking the above equations and parameters into the simulation, to obtain the electric vehicle ownership, the fuel car ownership, the total car ownership, and electrification ratio in each of the next 40 years, as shown in Figure 4.

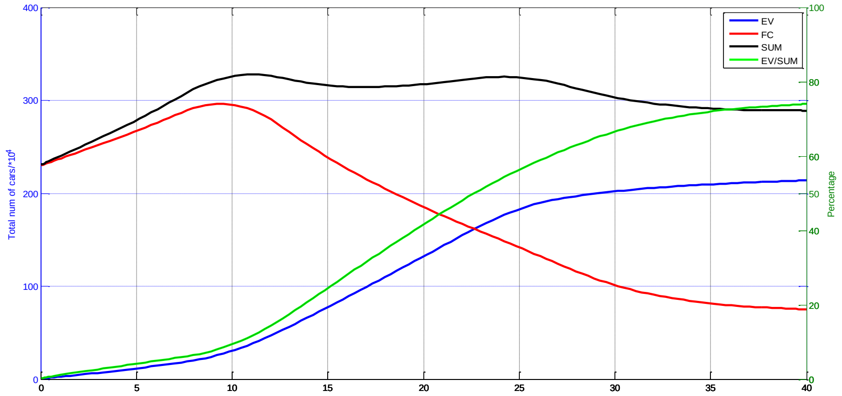

Figure 4 Trends of EV ownership and fuel vehicle ownership

3.3 Analysis and evaluation

According to the simulation results, the electric ratio (green) is roughly the s-shaped curve. Therefore, this paper makes an analogy between the electric ratio curve and the biological growth rate curve. The electric ratio curve reached the maximum growth rate at 15a, which is the tangent maximum point. Because EV and fuel cars are substitutes for each other, a ban on fuel cars will result in fewer sales of fuel cars, while demand for EV will rise. Therefore, when it reaches the maximum tangential point, the release of the fuel vehicle ban will further promote the electric car sales, thereby increasing the electric riot, and maintain a higher rate of growth.

Judging from the EV ownership (blue), the number of EV remained low before the 10 a. However, the strong national economic and policy support will keep the growth rate of EV increasing year by year. From 10a to 25a, EV shows a clear and rapid growth trend, and this stage mainly depends on the market mechanism to operate. After 25a, growth gradually slowed down. For fuel vehicles (red), the total amount of change can be divided into two phases. The first phase shows a growing trend, and the second phase shows a downward trend. The cut-off point is at 10a. Mainly due to the trial run and promotion stage of the first phase of electric vehicles, but also face some technical problems, so the fuel car is still playing an important role in the automotive market. In the second stage, as the development of electric vehicles is approaching maturity, fuel vehicles are gradually replaced by electric vehicles, due to environmental requirements and policy guidance.

4. Conclusion

In this paper, the SD model is established to predict the electric vehicle ownership. From the simulated data, the first 10a of EV is in the initial stage of development, and the growth is relatively slow. By 10-25 a, it is in the rapid growth stage, and the maximum growth rate of the electric riot curve is reached in 15a. After 25a, the growth rate gradually decreased and the market was close to saturation. The automobile market is a complex and large system with many factors and uncertainties, such as state social and economic situation, government policy, infrastructure improvement, consumer preference, etc. Due to the complexity of the problem, not all factors are considered in the model of this article. This model only provides a new way of prediction, and many of the entries are based on second-hand data and experience judgment, so there are many shortcomings. It is hoped that through future research, we can obtain more first-hand data to improve the model.

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