



Exploring the development of electric vehicles under policy incentives: A scenario-based system dynamics model



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ABSTRACT

Recently, the energy scarcity and environmental pollution have greatly promoted rapid development of the electric vehicles (EV) industry. In this context, we established a scenario analysis using system dynamics model to analyze the development of EV in China under policy incentives. Four scenarios were set in this paper: scenario 1 (Without any policy), scenario 2 (Only direct policy), scenario 3 (Only indirect policy), scenario 4 (Both direct & indirect policy). It is shown that the EV industry was in preliminary stage in 2010. After a period of development, in 2040, the total amount of EVs will reach 4.03, 8.61, 4.2 and 8.85 million in scenario 1–4. The results indicate that China's EV market penetration is mainly dominated by state policies, especially the financial supports. Reducing the governments' financial supports for EVs will put EV manufacturers at a cost disadvantage in the automobile markets. In addition, because of our emerging carbon market and low average carbon price, participating in carbon trading market cannot promote a rapid growth by stimulating investment passion. In all, cutting the financial supports is not a good option, because the large-scale market penetration still requires the clear and strong policy incentives.

1. Introduction

With the rapid pace of economic development, the environmental problems have become increasingly serious (Edenhofer and Seyboth, 2013; Coates, 2016; Xu and Lin, 2015). Against this backdrop, The Chinese government and leaders have begun to put emphasis on the environmental problems and by-products caused by the high-speed economic growth (Wang and Lin, 2010; Liang and Wei, 2012; Liu et al., 2015).

In recent years, the energy scarcity and environmental pollution greatly promoted the rapid development of electric vehicles (EV) industry (Weiller and Neely, 2014; Günther et al., 2015; Taefi et al., 2016). Several researches revealed that the EV has been widely considered as a promising solution to the problems of environmental degradation and energy depletion (Muneer et al., 2015; Nanaki and Koroneos, 2016; Yu and Stuart, 2017). The “Global EV Outlook 2016” issued by the International Energy Agency (IEA) put forward that the world has witnessed the roaring development of the EVs. There were only hundreds of new energy vehicles all around the world ten years ago, and only about half of today's stock existed in 2014. It is noteworthy that the year 2015 saw the global threshold of 1 million EVs

exceeded, closing at 1.26 million, which signals a remarkable accomplishment highlighting the joint efforts by society and governments. Although the ambitious development goals have lowered the production cost of EVs, and extended the vehicle range and reduced the consumer barriers in lots of countries, the large-scale market penetration of EVs still requires a clear and strong policy support to achieve widespread adoption.

The current researches on electric vehicles can be mainly classified into two categories: literature review and modeling approaches. Table 1 shows some literatures relevant to electric vehicles. We also reviewed the regions, methods and contents of these literatures.

As shown in Table 1, the first category mainly includes the literature review on electric vehicles. Based on the policies formulated by Chinese government to promote the industrialization of EV industry in China, many scholars have reviewed the policy on EV industry (Zheng et al., 2012; Zhou et al., 2013; Hao et al., 2014; Zhang et al., 2017; Zhang and Bai, 2017). To investigate the policy effects, Du and Ouyang (2017) reviewed the progress of Chinese electric vehicles industrialization and found that China's EV market penetration is dominated by state policies. Meanwhile, many foreign scholars have also investigated the policy on EV industry in foreign countries (Ahman, 2006; Zhou et al.,

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Table 1
List of relevant literatures.

	Research	Region	Methods	Contents
1	Zhang et al. (2017)	China	Literature Review	Sorting and collecting all the relevant policies
2	Zhang and Bai (2017)	China	Literature Review	Analyzing policy system and policies linkage
3	Du and Ouyang (2017)	China	Literature Review	Analyzing progress of Chinese electric vehicles industrialization
4	Ahman (2006)	Japan	Literature Review	Analyzing government's role in the process of EV industrialization
5	Meyer et al. (2016)	18 countries	Literature Review	Analyzing and summarizing the progress of global EV market
6	Daina et al. (2017)	worldwide	Literature Review	Reviewing modeling methods in EV
7	Zhou et al. (2015).	worldwide	Literature Review	Analyzing market penetration and incentives
8	Kumar and Revankar (2017)	/	Literature Review	Reviewing of electric vehicle technology and key strategy
9	Ma et al. (2017)	China	Panel co-integration	Analyzing government incentives under vehicle purchasing restrictions
10	Eppstein et al. (2011)	US	Agent-based model	Analyzing impact of policy interventions
11	Silvia and Krause (2016)	US	Agent-based model	Analyzing market penetration of EV
12	Lee et al. (2016)	Korea	System dynamics model	Analyzing market penetration and the best policy mix
13	McLellan et al., (2013)	Japan	Scenario analysis	Analyzing necessity of technical flexibility in government support scheme
14	Woo et al. (2017)	70 countries	Well-to-wheel analysis	Calculating GHG emissions associated with EVs
15	Langbroek et al. (2016)	/	Transtheoretical Change Model	Analyzing policy incentives and the influence of socio-psychological determinants

2015; Daina et al., 2017; Kumar and Revankar, 2017). For instance, Meyer et al. (2016) analyzed and summarized the progress of global EV market in 18 countries, which laid a solid foundation for further researches on EV markets.

Then, the second category mainly includes the modeling approaches on electric vehicles. Some scholars began to analyze government incentives, policy interventions, and market penetration of EV by establishing quantitative models (Lee et al., 2016; Langbroek et al., 2016; Ma et al., 2017; Woo et al., 2017). To study the market penetration, Eppstein et al. (2011) and Silvia and Krause (2016) established an agent-based model to assess the impact of policy interventions and study market penetration of plug-in hybrid electric vehicles. Ahman (2006) and McLellan et al. (2013) analyzed the Japanese government's role in the process of EV industrialization, and the necessity of technical flexibility in government support scheme. More importantly, several scholars started analyzing the problems related to electric vehicles from a systematic way. Lee et al. (2016) proposed a hybrid electric vehicle market penetration system dynamics model to describe the dynamic circular market penetration process as well as its interaction with macroeconomic conditions and government policies. Note that the above literatures emphasized the importance of investigating the problems related to electric vehicles from a systematic view (Silvia and Krause, 2016; Lee et al., 2016).

System dynamics (SD), which begins with the world modeling projects conducted in the early 1970s by the SD Group at MIT (Forrester, 1969, 1971), has been used for energy planning and policy analysis for more than forty years due to its solid theoretical basis and good feature in modeling the dynamic structure (Kuai et al., 2015). Based on the principle of system thinking and feedback control theory, SD helps us understand the time-varying behavior of complex systems by time-dependent variables. Currently, the system dynamics models have been widely applied in many fields, such as the energy system (Xiao et al., 2016a), the ecosystem (Gao et al., 2016), the economic system (Jo et al., 2015) and the "3E" system (Shih and Tseng, 2014; Xiao et al., 2016b). For instance, it has been applied in the field of policy-making (Qudrat-Ullah, 2013; Barisa et al., 2015; Jeon et al., 2015).

It can be seen from the above literatures that most of Chinese scholars only reviewed the policy on EV industry, whereas there are few researches analyzing the policy effect by establishing an energy model. In addition, there is no research using system dynamics model to analyze the development of EV industry, let alone the research considering the interactive effects of policy package on China's EV industry. To fill this gap, we established a scenario analysis using the system dynamics model to analyze the policy effect on China's EV industry. This paper's contributions are shown in four aspects, from both practical and theoretical perspectives: (1) This paper systematically investigated the

policy environment and the current development status of EV in China; (2) A policy package, consisting of direct and indirect policies, is analyzed as a possible solution to help the Chinese government promote the development of EV industry; (3) A system dynamics model was established to analyze the development of EV industry under different policy incentives; (4) In addition, we carried out a scenario analysis to investigate the effects of direct and indirect policies.

The rest of the paper is organized as follows: Section 2 presents an overview of EV in China. Section 3 provides a SD model. Section 4 shows the results and discussion, and Section 5 discusses the conclusions in this paper.

2. An overview of electric vehicles in China

In this section, we mainly focused on the current situations of electric vehicles in China. The development situation of electric vehicles in China was discussed in Section 2.1. Then, we collected the relevant policies on electric vehicles including direct and indirect policies in Section 2.2.

2.1. The development situation of electric vehicles in China

With the emergence of problems caused by global climate change, the EV industry is widely regarded as a solution to the problem of environmental deterioration and energy exhaustion around the world (Lin and Tan, 2017; Ma et al., 2017; Shi et al., 2016). Confronted with such situation, the Chinese government has vigorously promoted the development of EV industry. Fig. 1 displays the situation of China's EV and hybrid EV production and consumption. It is note that the electric vehicle can be classified into two categories: pure electric vehicle and plug-in hybrid electric vehicle. The EV industry has developed preliminarily in the year 2011 in China. At that time, the total amount of EV and hybrid EV was only 8368. With the rapid growth of EV industry, the consumption and production of EV and hybrid EV are soaring exponentially in recent years. Owing to the rapid expansion of supply and demand at the average rate of nearly 200% per year, the total amount of EV and hybrid EV increases tenfold in 2014. The year 2015 has been a milestone year for EV industry, and it also marks a milestone for the Chinese automobile manufacture. Along with the national policy incentives and technical innovation, the EV will become a main tool of transportation in the further. In 2015, the production of EV and hybrid EV reached 254633 and 85838, and the consumption of EV and hybrid EV reached 247482 and 83610, which signaled that China became the largest EV producer in the world. However, the EV industry is still at its preliminary stage. Unquestionably, there is still a long way to go before we can achieve the popularity and marketization of electric vehicles.

As electric vehicle battery is one of the core systems, the charging

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