Leveraging Transdisciplinary Engineering in a Changing and Connected World
P. Koomsap et al. (Eds.)

doi:10.3233/ATDE230635

Investigating Government Subsidy and Policy to Encourage the Adoption of the Energy Storage System and Electric Vehicle: A System Dynamics Model Approach

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Abstract. Carbon dioxide is essential to the climate system and is crucial in increasing global greenhouse gas emissions. In several countries, one of the highest contributors to carbon emissions comes from burning fossil fuels for energy, supported by electricity consumption in industrial activities. Thus, using renewable energy and the rapid development of emerging technologies, such as energy storage systems (ESS) and electric vehicles (EVs), are promising strategies to reduce fossil fuel consumption, emit less carbon and GHG emissions, and be environmentally friendly. However, the adoption transition of ESS and EVs requires government support and other incentives to succeed in the goals to reduce emissions by 23% - 25% in 2030 and the ban on the sale of fossil fuel vehicles by 2040 in Taiwan. Therefore, this study investigates the impact of government policies and subsidies on promoting the adoption of energy storage systems (ESS) and electric vehicles (EVs). Then, using a system dynamics approach, a validated model is developed to capture the dynamic interaction among electricity generation, ESS, EVs, infrastructure, government subsidies, and consumer behavior. The findings emphasize the significance of purchase subsidies, research and development subsidies, and tax incentives in driving the adoption and private investment in ESS and EVs, thus contributing to the advancement of the industry.

Keywords. Electric Vehicle, Energy Storage System, Socio-Economic, System Dynamic, Government subsidy

Introduction

The amount of greenhouse gas emissions was 11.388 million metric tons CO_2 in 2020 based on long-term changes in Taipei City's greenhouse gas emissions. CO2 emissions from the transportation sector currently contribute 20.6% in Taipei City or 36 Mt CO2 in Taiwan [1]. Taiwanese government implements the 2050 Net-Zero Pathway with the

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milestone in transportation by changing travel behavior, reducing demand for transportation, and changing from Internal Combustion Engine Vehicles (ICV) to Electric Vehicles (EVs) to reduce carbon emission levels [2]. Driving an EV helps to reduce carbon emissions. In other words, since both are part of the government's greenhouse gas reduction program, electric cars and renewable electricity sources are an excellent combination for decarbonizing transportation [3]. However, renewable energy sources such as wind and solar PV have intermittent characteristics and unstable supply. Therefore, energy storage systems can be adopted to mitigate intermittency, support grid stability, and lowering energy costs [4]. Furthermore, electricity is stored in the energy storage system.

The current problem in adopting electric vehicles in Taiwan is that the EV transition will need government support to succeed with the master plan for charging infrastructure development. Subsidies and other incentives are required to spur private investment in charging infrastructure and urge consumers to purchase EVs [5]. In addition, energy storage systems (ESS) require subsidies because they can be costly to install and operate [6]. Several strategies are implemented to increase the adoption of EVs. Li et al. [7] consider the R&D subsidy from the government and purchase subsidy for EVs and charging stations. However, most of the previous studies only considered one subsidy policy without evaluating various policies that the government could implement by considering the electricity supply relationship with the ESS to be connected to the charging station. Meanwhile, the previous research [8] with the transdisciplinary concept focuses on batteries in EVs. It considers mobile energy storage for EVs [9], not the electricity supply or battery in a central or whole energy storage system.

Therefore, this study develops a model using a system dynamics approach that provides an overview and causal relationships between the ESS electricity supply infrastructure and charging stations for electric vehicles. This study also aims to investigate electricity supply from ESS to charging stations that can increase the adoption of electric vehicles and reduce carbon emissions by considering in subsidy for ESS, R&D subsidies, EV purchase subsidies, and charging station subsidies. Transdisciplinary engineering can be used with a dynamic systems approach when developing electric vehicles (EVs) and energy storage systems. From the perspective of transdisciplinary engineering, it can assist in considering a variety of variables and viewpoints that influence the development of EVs and ESS. Also, from the perspective of the system dynamics method, it can encourage simulating changes in various scenarios over a long period and modeling interactions between variables. A suitable policy suggestion for the Taiwanese government in the development of electric vehicles (EV) and ESS is the final result of this research, which was based on the outcomes of the model scenario simulation.

1. Literature Review

Several strategies are implemented to increase the adoption of EVs. Li et al. [10] and Li et al. [7] consider the R&D subsidy from the government and purchase subsidy for EVs and charging stations. Meanwhile, Liu and Xiao [11] explore the financial support of EV manufacturers. Esmaeili et al. [12] found that renewable energy capacity incentives can support EV deployment. However, on the charging station/pile manufacturing side, Yu and Chou [13] examine the proportional ratio of EVs and charging piles in China. Considering the ESS for renewable energy, Liu et al. [14] simulate the installed capacity and installed cost of ESS under the mandatory policy in China. Meanwhile, Liu et al.

[15] researched lithium battery supply and demand as the most common ESS type for storing energy from renewable energy with a system dynamics approach. Furthermore, Volan et al. [16] and Quinteros-Condoretty, et al. [17] evaluate the investment in ESS.

Therefore, our study employs system dynamics methods for model development and scenario simulations like previous research. However, this study specifically investigates the impact of electricity supply from energy storage systems (ESS) to charging stations on electric vehicle adoption and carbon emissions reduction, considering subsidies for ESS, R&D, electric vehicle purchases, and charging stations.

Table 1. Promotion Policy for Taiwan's Electric Vehicle Industry.

BEFORE 2010		
2009.04	Green Energy Industry Sunrise Solution	
2009.08	Electric Motorcycle Industry Development Promotion Plan	
2010 - 2015		
2010.04	Smart Electric Vehicle Development Strategy and Action Plan: Forming the Foundation"	
2014.05	Smart Electric Vehicle Development Strategy and Action Plan Phase II "Level Up"	
SINCE 2015		
2016.07	Promotion Program of Smart Machine Industry	Among "Five Innovative Industrial Policies"
2017.12	Air Pollution Prevention and Control Action Plan (APPCAP)	Fuel electrification of official vehicles and city buses by 2030
2019.09	Taiwan's Sustainable Development Goals	Ban fuel-powered scooters by 2035
		Ban fuel-powered cars by 2040
		35% of new scooters sold being electric by 2030.

Table 2. Incentives for Electric Buses in Taiwan.

Incentive Item	Subsidy
Replace one bus and buy an eBus	49% of a vehicle's body
	Type I bus: NT$ 35.58 M (upper limit)
	Type II bus: NT$ 2 M (upper limit)
Operating a new route	80% of a vehicle's body
	Type I bus: NT$ 5.2 M
	Type II bus: NT$ 2.5 M

Countries like China, South Korea, Japan, Norway, the United States, and Canada have implemented various subsidies to promote electric vehicle (EV) adoption and energy storage system (ESS) development, including public charging infrastructure, vehicle purchase subsidies, charging equipment funding, and direct incentives to ban fossil fuel vehicles [7, 10, 11]. Furthermore, the Taiwanese government offers direct investment and applies various purchase subsidies to promote EV projects and strengthen the industry chain [18]. The Taiwanese government stated that all buses must be electric vehicles by 2030, and electric bus operators must request a value-added tariff of between 30% and 70% from the national government [19]. Taiwan's government established a policy promoting the electric vehicle industry, as shown in Table 1, and an incentive for the electric bus in Table 2.

2. System Dynamics Modeling

System dynamics modeling represents real-world systems with an engineering and system thinking approach that can facilitate understanding and solving complex problems related to EVs and ESS adoption. The dynamic system methodology also includes mathematical models and interactions across disciplines such as economics and government policy investigating subsidies provided for EVs and ESSs that affect EV purchase willingness, green energy, and transportation discipline to assess environmentally friendly EVs and carbon emission reduction in the transportation sector.

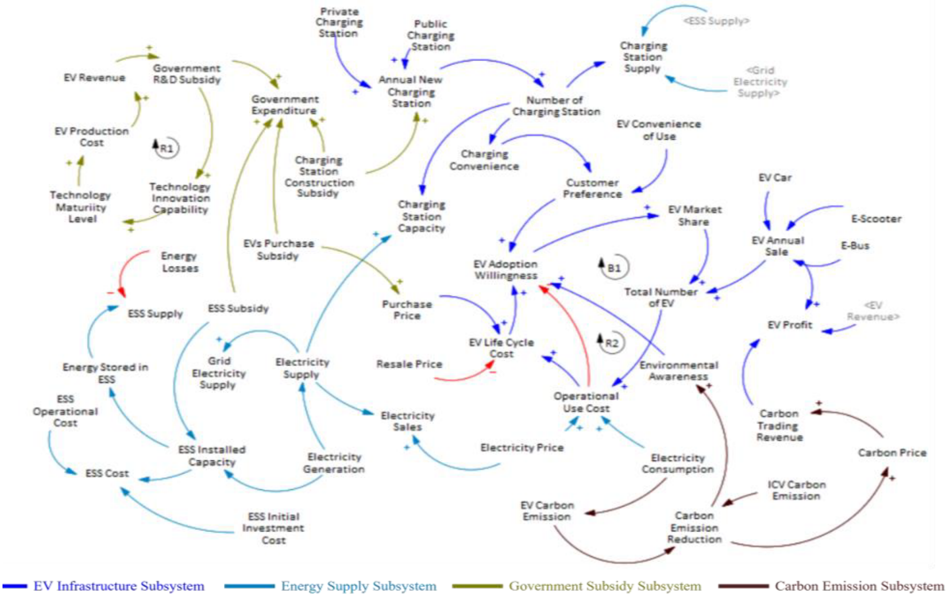

Figure 1. System Dynamics Model of EV and ESS.

The EV system dynamics model is developed based on the literature on previous studies that cover the purchase willingness of EV adoption and ESS development as well as analysis and depiction of government policies related to EV development and subsidies for purchase, research, and innovation, and supporting EV facilities such as charging station construction such as EVs Roadmap from National Development Council and Taiwan net zero pathway 2050 from Environmental Protection Administration (行政院環境保護署). The causal loop diagram of the EVs and ESS system is shown in Figure 1, including EV infrastructure, energy supply, and government subsidy, and it can impact the reduction of carbon emissions.

2.1. EV Infrastructure Subsystem

A stable electricity supply can increase EV demand and production [12], which can help increase the number of EVs [10]. An increase in EVs and EV production can trigger an expansion in the number of charging stations [11] and the other way around [13]. Customers can charge at home (private charging stations) or at public charging stations. Several factors influence the level of EV adoption, including considering the convenience of using EVs based on the distance that EVs can travel and the convenience of charging EVs considering charging speed and distance between charging station locations. In addition, EV adoption is strongly influenced by Life Cycle Cost (LCC) in the form of EV purchase and usage costs [7]. The Taiwanese government charges a monthly fee for charging at home and an additional fee for charging at public charging stations. To increase the number of charging stations, the government can implement subsidies for charging station construction [17, 20]. The stock and flow diagram of EV infratructure, including the charging station infratructure is shown in **Figure 2**.

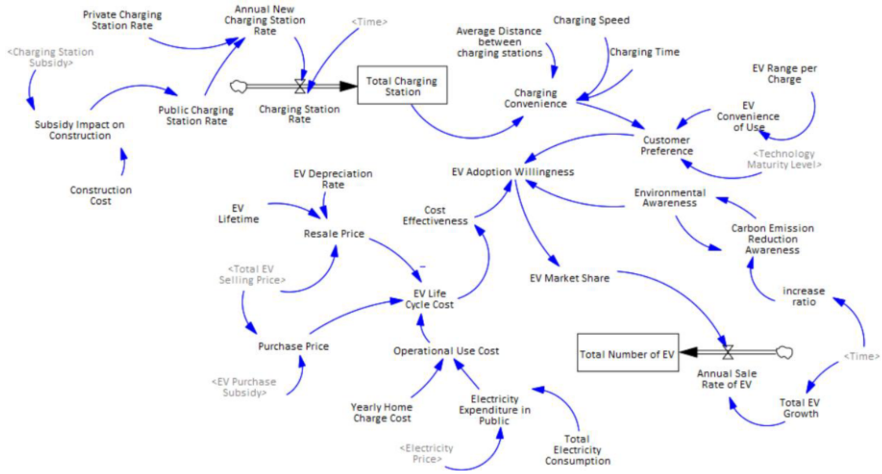

Figure 2. EV Infrastructure Subsystem.

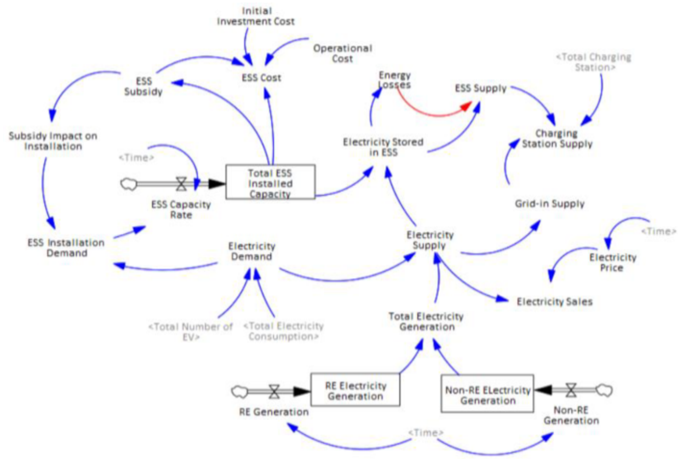

Figure 3. Energy Supply Subsystem.

2.2. Energy Subsystem

A critical issue with EVs is that high penetration leads to branch and transformer congestion and high electricity demand on the power grid [15]. Electricity sources can be derived from renewable and non-renewable energy [21] and supplied to the EV charging infrastructure [12]. The generated electricity will be transmitted to the grid [22] and provided to charging stations. However, with the instability of RE or reducing the impact of intermittency of renewable energy generation [23], ESS can be implemented to store extra generations for use during peak load hours. ESS is recommended for electric vehicle charging stations to support the increasing diffusion of electric vehicle charging loads [11]. However, the total electricity stored in the ESS cannot be fully supplied to the charging station due to energy losses. Energy losses will reduce 10% of the total energy stored in the ESS [24]. The stock and flow diagram of the energy subsystem that includes the ESS supply is shown in Figure 3.

2.3. Government Subsidy Subsystem

Several subsidies provided by the government to increase the adoption of EVs that benefit customers are subsidies on the purchase of EVs, be it e-scooters, EV buses, or EV cars. One of the government subsidies is the R&D subsidy [10]. This subsidy can support manufacturers in reducing the high production cost of EVs [11]. With R&D subsidy, the innovation and technology maturity level will increase and reduce the cost coefficient of EVs [17], resulting in lower production [7]. Then, this can positively increase revenue and continued investment from the government [12] [10]. Another subsidy the government provides is subsidizing the construction of charging stations to increase the number of charging stations according to EV demand [20]. The stock and flow diagram of the government subsystem is shown in Figure 4.

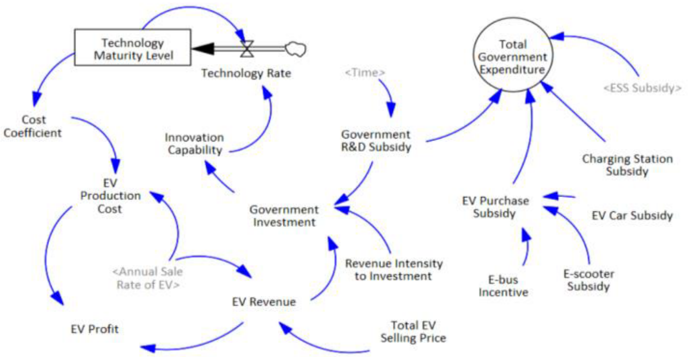

Figure 4. Government Subsidy Subsystem.

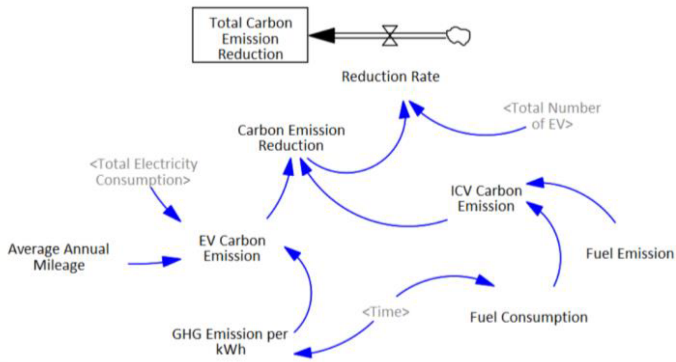

Figure 5. Carbon Emission Subsystem.

2.4. Carbon Emission Subsystem

Variable carbon emission reduction and the total number of EVs influence total emission reduction—the total EV usage, the higher the carbon emission reduction [10]. The EV and ICV emission variables will affect carbon emission reduction by considering total electricity consumption, average annual mileage, fuel consumption, and fuel emission [11]. The higher the portion of EV carbon emission, the higher the carbon emission reduction because it will reduce ICV carbon emission [25]. The stock and flow diagram of the carbon emission subsystem is shown in Figure 5.

3. Model Verification and Validation

Verification is essentially a check that the model is built correctly and error-free. Validation involves examining the substance of the model following the objectives of the model to be achieved [26]. Behavior validity tests compare the simulation result with actual data (error rate or mean absolute percentage error). The model is valid if the Mean Absolute Percentage Error (MAPE) is below 5% [27]. The comparison of historical and simulation data for validation is shown in Table 3.

Table 3. Comparison of Historical and Simulation Data.

Year	Total Number of EV (Units)			Charging Station (Units)			Electricity Generation (GWh)		
	Data	Simulation	Error	Data	Simulation	Error	Data	Simulation	Error
2010	3114	3114	0.0%	80	80	0.6%	243997.9	243998.0	0.0%
2011	7399	7406	0.1%	102	104	1.6%	249264.9	244257.0	2.0%
2012	8049	8755	8.8%	130	122	6.3%	247436.5	250744.0	1.3%
2013	7101	7613	7.2%	166	156	5.8%	249153.7	248365.0	0.3%
2014	5273	5660	7.4%	211	200	5.2%	256842.8	250634.0	2.4%
2015	11176	11302	1.1%	269	256	4.7%	255107.0	260342.0	2.1%
2016	27787	28787	3.6%	342	328	4.2%	260814.0	258915.0	0.7%
2017	49547	47055	5.0%	435	420	3.6%	266922.7	261387.0	2.1%
2018	88847	81059	8.8%	554	537	3.1%	272174.4	268993.0	1.2%
2019	203512	190325	6.5%	706	688	2.5%	270980.6	276513.0	2.0%
2020	141621	134779	4.8%	898	880	2.0%	276819.2	275317.0	0.5%
2021	217229	211416	2.7%	1143	1127	1.4%	287752.0	282078.0	2.0%
2022	370914	377598	1.8%	1388	1442	3.9%	292444.1	292612.0	0.1%
MAPE		**4.4%**			**3.4%**			**1.3%**	

4. Result and Discussion

Government subsidies for charging stations can increase charging station construction as it helps with construction costs. The Ministry of Economic Affairs promoted the public charging station plan in 2021, which states that the first-stage goal is to build 7,800 charging stations by 2025, including 600 fast charging stations. Assuming the Ministry of Economic Affairs (MOEA) keeps the NT$300,000 subsidy provided by the Industrial Development Bureau as it is today with similar construction costs for the next few years. Based on the developed model in this study, the target number of charging stations will be achieved in 2028-2029 with a predicted number of 6,342 to 8,118 charging stations. By 2030, the number of charging stations will reach 10,392 units, and 122,689 charging stations in 2040, as shown in Figure 6.

As the Taiwan government declared in the plan to ban fossil fuel vehicles and as stated in 2050 Net-zero Pathway in 2040, all vehicle sales should be 100% EVs. Therefore, EV purchase subsidies can help increase the transition from internal combustion engine vehicles (ICEVs) to EVs. Currently, the MOEA subsidizes the purchase of e-scooters at NT$7,000, extending to 2026. For the purchase of EV cars, the subsidy is NT$15,000, and NT$2.5 million for electric buses as public transportation.

Therefore, the subsidy can reduce the expenditure cost of purchasing EVs. However, the life cycle cost of the purchase price may be reduced, but the cost of EV usage remains high in the electricity expenditure. Therefore, the life cycle cost of EVs can influence customer willingness to purchase to reach 20-30% in 2040, shown in Figure 7, which is 0.17% this year. Therefore, the adoption willingness percentage can influence the increase in EVs to approximately 13 million in 2040, remaining at 45% of Taiwan's total vehicles, as shown in Figure 8.

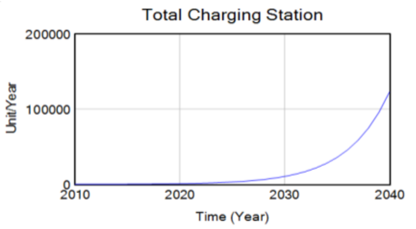

Figure 6. Total Charging Station 2010 – 2040.

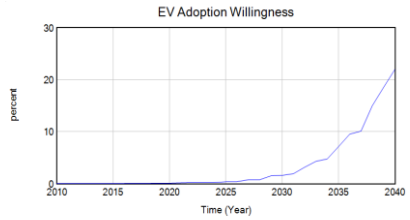

Figure 7. EV Adoption Willingness 2010-2040.

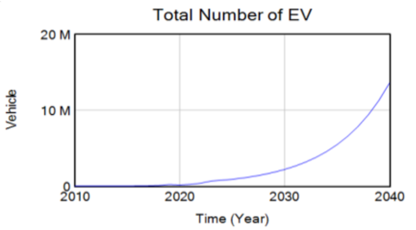

Figure 8. Total Number of EVs Taiwan 2010-2040.

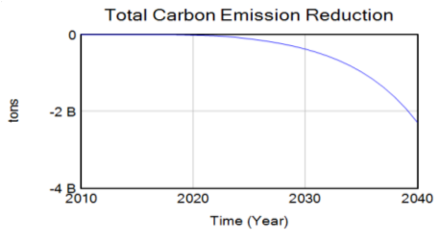

Figure 9. Total Carbon Emission Reduction.

R&D subsidy of EVs influences the level of technology maturity in EV production and reduces the cost of EV production. The level of EV technological maturity can drive the adoption willingness factor in customer preference and the influence of EV range per charge to overcome customer range anxiety. NT$2-5 billion is provided to improve EV development in manufacturing. R&D subsidy has the most significant influence on government expenditure to drive EV adoption into the future. In the developed model, R&D subsidy can meet the needs of EV technology maturity development in 2025.

The government established an ESS subsidy that can help reduce the cost of ESS and increase the number of ESS installations. By 2030, the ESS subsidy may increase to NT$13 million with an initial value of NT$15,000 per KW. The increase in ESS can help supply electricity for charging stations, especially renewable energy. With the amount of electricity provided to EVs, electricity consumption will increase in the transportation sector. However, because the increase in EVs can lead to a decrease in the number of ICEVs that produce more carbon emissions, the contribution to reducing carbon emissions in transportation from EV adoption is as much as 2 billion tons of carbon emissions, as shown in Figure 9.

5. Conclusion

Significant factors influencing the increase in adoption willingness are EV life cycle cost, customer preference, charging convenience, and environmental awareness. Subsidies can be one way for the government to increase EV adoption. Purchase subsidies can increase EV adoption by reducing EV life cycle costs. ESS Subsidy and Charging station construction subsidy through charging convenience by increasing charging stations, the closer distance between charging stations, and optimal electricity supply. R&D subsidy drives EV adoption through customer preference for EVs. Increasing EV adoption by replacing vehicles with ICEVs can reduce carbon emissions in the transportation sector. The subsidy that requires more attention is the charging station subsidy to reduce customer anxiety about charging distance and purchase subsidy. ESS subsidy can also be considered to optimize the electricity supply for EVs and charging station upgrades in the future. The valid model results provide a representative overview of EV adoption factors, especially in Taiwan. It supports government decision-making regarding economic (subsidy) and environmental (carbon emission reduction), and this system dynamics model can also help in energy management by considering the adoption of ESS for EV charging station electrical infrastructure.

Future research can consider electricity supply for charging stations from renewable energy to reduce electricity supply from non-RE and consider customer demographics as a factor in EV adoption willingness. In addition, optimizing the period of subsidy provision and termination can be regarded as using optimization methods.

Acknowledgment

This work was supported by the Center for Smart Manufacturing Innovation from the Featured Areas Research Center Program within the Higher Education Sprout Project framework by the Ministry of Education (MOE) in Taiwan.

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