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Long-term trend of electric vehicle sales in Thailand

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ABSTRACT

This research study aims at examining the long-term trend of EV sales in Thailand, utilising the system dynamics (SD) modelling approach. This approach is commonly used to model complex systems with causal relationships among key factors within the system. The developed SD model consists of five key factors affecting electric vehicle (EV) sales, namely, the environment, economy, charging infrastructure, government support, and battery maintenance. The simulation results show the increase in EV sales by ten times in the next 20 years with implementation plans related to the five key factors. The government support factor is the most important in enhancing EV sales in the short term. Several government support plans should be initiated to attract more EV consumers, such as subsidies and tax reductions. The environment and charging infrastructure factors are crucial to increasing EV sales in the long term. The enforcement of the CO_2 tax and the provision of charging stations all around the country should be established to achieve a sustainable EV market in the long term. This research study contributes to the Thai government and automotive industry to better understand the complex relationships among key factors affecting EV sales. The related sectors may use the study results to plan for EV campaigns to promote the use of EVs and achieve a sustainable EV market.

KEY WORDS
electric vehicle, system dynamics modelling, trend, Thailand

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Introduction

Global warming is a critical global issue with transportation as a major contributor. Transport emissions account for 11.9 % of the total global emissions in 2020 (Ritchie & Roser, 2020). Transportation is responsible for carbon dioxide (CO_2) emissions and PM2.5 problems, causing severe harm to human health in the long term. The Thai government has implemented several policies to support alternative energy used in transportation, including electric vehicles

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(EVs). The EV campaign was first launched in 2015 to promote the use and manufacture of EVs in Thailand. A number of charging stations were built by the public and private sectors. Currently, over 230000 EVs represent a 20 % increase from 2020. Out of 700 charging stations, 34 % have fast chargers (EVAT, 2021). By 2030, 750000 EVs are planned to be manufactured in Thailand out of the total of 2.5 million cars, accounting for 30 % of all car sales (BO, 2015; Bangkok Post, 2021).

Although the EV market in Thailand is growing, it is still small compared with the market of internal combustion engine vehicles, as there are several factors affecting consumer purchasing decisions. Thananusak et al. (2017), for example, mentioned five key factors affecting the intention to purchase EVs in Thailand, including vehicle performance, infrastructure, finances, environmental concerns, and price premium factors. The study results revealed the vehicle performance, environmental concerns, and price premium as crucial factors in making EV purchasing decisions. Mendoza (2018) agreed that vehicle performance, financial aspects, and government incentives played major roles in EV purchasing decisions. Key concerns focus on safety issues, maintenance costs, and tax incentives. Dolcharumanee (2018), on the other hand, concluded that technology advancement, information provision, aftersales service, and supportive government policies were the key factors used by Thai consumers in making EV purchasing decisions. Vongurai (2020) examined factors affecting brand preference towards electric vehicles in Bangkok, Thailand, and concluded that social influence has a significant effect on environmental concerns, as well as a positive effect on attitude. The consumer attitude towards environment-friendly products then affected the encouragement of brand preference, which largely depends on individual opinion.

A long-term plan for the EV market requires understanding complex relationships among key factors affecting EV sales in Thailand. Vongurai (2020) stated that the better fuel efficiency of EVs, the lesser harm and better preservation of the environment. This, in turn, leads to a positive attitude towards EVs. Tonpradit (2017) examined causal relationships among key factors affecting EV purchase intention in Thailand using the structural equation modelling approach. The study results revealed that perceived ease of use, perceived usefulness, consumer innovativeness, and consumer's degree of greenness affects the attitude, which influences the purchase intention.

Therefore, this study aims to examine trends of EV sales in the long term utilising the system dynamics (SD) modelling approach. Causal relationships among key EV factors are used as input in the developed SD model to reflect complex relationships of the EV market and the plan for EV strategies to support EV sales in the long term.

This study conducted a literature review to understand the global and Thai EV markets and identify key factors influencing EV sales. SD modelling approach is then reviewed, and relevant data are collected to be used in the SD model development. The developed SD model is separated into five sub-models, representing five key factors affecting EV sales in Thailand. The developed model is simulated and validated using the sensitivity analysis method. The conclusion is finally presented with the contributions and limitations.

1. Literature review

Many research studies attempt to identify key factors affecting the EV purchasing decision and the EV market in Thailand. Mendoza (2018), for example, concluded five key factors involved in the uptake of EVs in Thailand, namely vehicle performance, financial aspects, government incentives, user personality, and buyer demographics. Kumnerdpetch (2020) pinpointed product and price aspects as key marketing factors, while perceived usefulness, perceived ease of use, and perceived risk aspects were indicated as crucial for the technology acceptance factor. Promphat and Deebhijarn (2019) concluded that the customers' purchasing decision was influenced by customer perception, subjective norms, marketing mix, external environment, and attitude. Selvakkumaran et al. (2018) stated four factors affecting the benefits of EV transition in Thailand, namely, economic, social, policy and technological factors. Thananusak et al. (2021) explored the development of EV charging stations in Thailand, as it mainly affects the purchasing decision. It was suggested that the government set up a national EV policy committee to accelerate the EV adoption and EV charging stations in Thailand. According to Bangkok Post (2021), to enhance the EV market in Thailand, the government has to ensure that the drivers have convenient access to power sources, i.e., charging stations.

In this study, five key factors affecting EV sales in Thailand are extracted from the literature and are used in the development of the system dynamics (SD) model. They include 1) environmental, 2) economic, 3) charging infrastructure, 4) government support, and 5) battery performance factors.

- The environmental factor focuses on using EVs to reduce global warming and CO_2 emission. Martz et al. (2021) mentioned that EVs are a promising option for greenhouse gas (GHG) mitigation in the transport sector, especially when the fast decrease in CO_2 emissions from electricity provision is considered. Toyota Motor Corporation (2017) stated that EVs emit less CO_2 than conventional vehicles, with a difference of more than 60 grams/km. This reduces the CO_2 tax the consumers have to pay, leading to a higher EV demand in the future.
- The economic factor focuses on energy saving from the use of EVs (Szkutnik & Jakubiak, 2012; Goncalves et al., 2020). CAA (2021) stated that EVs require less fuel consumption and emit less GHG than conventional vehicles. Controlling electricity prices could stimulate the use of EVs. Mendoza (2018) maintained that electricity cost subsidies could be one of the government policies to stimulate the use of EVs in Thailand.
- The charging infrastructure factor focuses mainly on the availability of charging stations to support the use of EVs. The installation of charging stations is crucial to fulfilling the charging demand at different locations, maintaining the minimum negative impact on the power system (Pal et al., 2020). Thananusak et al. (2017) added that charging stations should be adequately provided as an EV battery still has a low range per charge.
- The government support factor focuses mainly on the vehicle price subsidy for EVs to attract more consumers. According to Shao et al. (2020), government support, especially subsidies, helps expand the EV market. The subsidy scheme in this study follows the first-car scheme implemented in Thailand in 2012, where the consumers were repaid no more than THB 100000 as tax rebates one year after the purchases (Bangkok Post, 2012).
- The battery maintenance factor is reflected by the low maintenance cost of an EV battery. Issues related to the battery cost and its maintenance should be considered individually, as the battery accounts for about half of the EV manufacturing cost (Konig et al., 2021). Krupa et al. (2014) stated that low battery and maintenance costs stimulated the EV market.

Five key factors affecting EV sales are used in the SD model development to examine the trend of the EV market in Thailand in the long term.

2. Research methods

2.1. System dynamics modelling approach

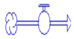
The long-term trend of EV sales in Thailand is examined utilising the SD modelling approach. This method was first introduced for modelling and analysing the behaviour of complex social systems, particularly in the industrial context. It has been widely used in research studies where feedback loops are dynamic and critical to understanding the interrelationships (Rodrigues & Bowers, 1996). SD modelling has the following advantages:

- Both policies and processes can be included in the model to address problems with policies. An example is the subsidy policy from the government to stimulate the EV demand.
- The SD model considers cause and effect interrelationships among system variables, making the outcome realistic. The government's support policies help reduce the vehicle price and increase the EV demand. More EVs reduce CO_2 emissions, raise the environmentally friendly perception, and increase the EV demand. More EVs, however, raise the electricity demand, which may result in high electricity prices. This, in turn, may discourage the use of EVs.
- Qualitative (such as causal loop diagrams) and quantitative (such as flow rates and beginning stock) data can be used as the model input for equations development. Examples include the subsidy policies, the fuel and electricity prices, the increasing rate of the vehicle price, the CO_2 tax, and the EV demand.

The SD methodology provides a good basis for making decisions. It allows the interrelationships among important variables affecting a problem, providing a better understanding and possible solutions.

A number of research studies have been conducted utilising the SD modelling approach. Feng et al. (2013), for example, developed an SD model to examine the future energy demand and CO_2 emissions in Beijing, China. Nhim (2015) developed an SD model to identify sources of drought resilience at household and commune levels and find possible ways to improve it in Cambodia. The results show that access to irrigation is the most important source of resilience at both household and community levels as it can help maintain stability and continuous development of rice production over time. Doan & Chinda (2016) exam-

Tab. 1. SD model components

Component	Icon	Explanation
Stock		A stock represents a part of a system whose value at any given instant in time depends on the system's past behaviour that accumulates
Flow		A flow represents the rate at which the stock is changing at any given instant. It either flows into a stock (causing it to increase) or out of stock (causing it to decrease)
Converter		A converter is used to take input data and convert it into output
Connector		A connector is used to transmit input and information

ined the feasibility of a construction and demolition waste recycling programme in Bangkok, Thailand, using the SD modelling technique. The results revealed that the investment return for the recycling programme takes 14 years. Nghia & Chinda (2018) examined the profit of residential projects in Ho Chi Minh City, Vietnam, in the long-term using five key profit factors, including the urban population, buyer capacity, housing supply, housing economics, and housing finance. Simulation results revealed that the average profit of residential projects in Ho Chi Minh City, Vietnam, in the next 20 years is 35 %, with a minimum and maximum profit of 19 % and 41 %, respectively.

This study utilises the Structural Thinking Experimental Learning Laboratory with Animation (STELLA) software in the SD model development. It provides a graphically oriented front end for the development of SD models. The stock and flow diagrams used in the SD model development are directly supported with a series of tools supporting model development. Equations are written using dialogue boxes accessible from the stock and flow diagrams. The graphical depictions of the SD model, and the ability to quickly adjust a model and run it on the software, have proven to be an excellent discussion medium for model enhancement (Isee Systems, 2021). The model consists of four key components: stock, flow, converter, and connector, see Table 1 (Tang & Vijay, 2001).

2.2. Data collection

Data related to five key factors affecting the EV demand are collected using several literature sources as input in the SD model development (Table 2). For example, EV maintenance costs amount to around THB 26731 for 100000 kilometres (Best Auto Sales,

Tab. 2. Data used in the SD model development

Factor	Data	Reference
Environment	• CO_2 tax: 483 Baht/ton CO_2, • CO_2 reduction: 205871.083 tonnes CO_2 per 1 % increase in EVs/total vehicles ratio, • Initial EVs: 231682 units, • Initial total vehicles: 10.5 million units, • The maximum increasing rate of total vehicles in Thailand: 6.39 % per year, • The minimum increasing rate of total vehicles in Thailand: 1.83 % per year, • The increasing rate of EV sales in Thailand: 5.46 % per year, • Average EV price: THB 2.48 million/unit (THB 33.75 = USD 1)	Doan & Chinda (2016); EPPO (2021); EVAT (2021); Thananusak et al. (2021); Kaeo-tad et al. (2021)
Economy	• Average fuel consumption: THB 1.68 /kilometre, • Average electricity consumption for EVs: THB 0.85 /kilometre, • Average driving distance: 20000 kilometres/year	BCP (2021); Hearst Autos (2021)
Charging infrastructure	• The number of EVs per charging station: 1739, • The initial number of charging stations: 276, • Consumer purchasing decision based on charging stations: 7 %	Sutabutr (2019); Kaewtatip (2019); ITL (2020); EVAT (2021); GPSC (2021); F&L Asia (2021); Thananusak et al. (2021)
Government support	• EV increasing rate following the first-car scheme: 18.2 % until 2023 and 16.1 % until 2026	Svasti (2012); Department of Land Transport (2019); CEIC (2021); Statista (2021)
Battery maintenance	• Maintenance cost of an EV: 50 % of a conventional vehicle, • Average maintenance cost of an EV: THB 5346/year	Best Auto Sales (2020); Consumer Reports (2021)

2020). Hearst Autos (2021) stated that the average mileage of an EV per year is 20 000 kilometres. This leads to average EV maintenance costs of THB 5346 per year. Consumer Reports (2021) stated that EV drivers save an average of 50 % on maintenance and repairs over the vehicle's life compared to owners of gas-powered cars.

This results in the maintenance cost savings of THB 5346 per year for an EV. The initial number of charging stations in Thailand is 276 (without shopping centres, restaurants, and property developers). It is expected to reach 690 stations with a total of 1.2 million EVs by 2036 (Sutabutr, 2019; Kaewtatip, 2019). This brings an average of 1739 EVs required for a charging station location. EVs have about half lower electricity costs and higher motor efficiency than conventional vehicles.

2.3. SD model of EV sales in Thailand

The SD model of EV sales in Thailand consists of six sub-models, namely, the environment, economy, charging infrastructure, government support, battery performance, and total EV sub-models (Fig. 1). Details are provided below.

2.3.1. Environment sub-model

Every 1 % increase in EVs/total vehicles ratio brings the reduction of 205871.083 tonnes in CO_2 emissions (Sutabutr, 2019; EPPO, 2021). Less CO_2 emission results in a lower CO_2 tax, thus attracting more green consumers to purchase EVs. In this study, the increase in the EV demand based on the environmental factor (EVEN) is achieved by dividing the savings of CO_2 tax (SVCO) with the average selling price of an EV of THB 2.48 million (Eqs. 1–3).

$$RTEV = IF\ CTY > 0$$
$$THEN\ (HISTORY(RATIO_{EV}, CTY) - -HISTORY(RATIO_{EV}, CTY-1))\ ELSE\ 0 \quad (1)$$

$$SVCO = RTEV \times 205871.083 \times 483 \quad (2)$$

$$EVEN = ROUND(SVCO/2480000) \quad (3)$$

Where

RTEV = Increase in EVs/total vehicles ratio

CTY = Count year

$RATIO_{EV}$ = Ratio of EVs/total vehicles each year

SVCO = Savings of CO_2 tax (THB/year)

EVEN = Increase in the EV demand from the environment factor (vehicles/year)

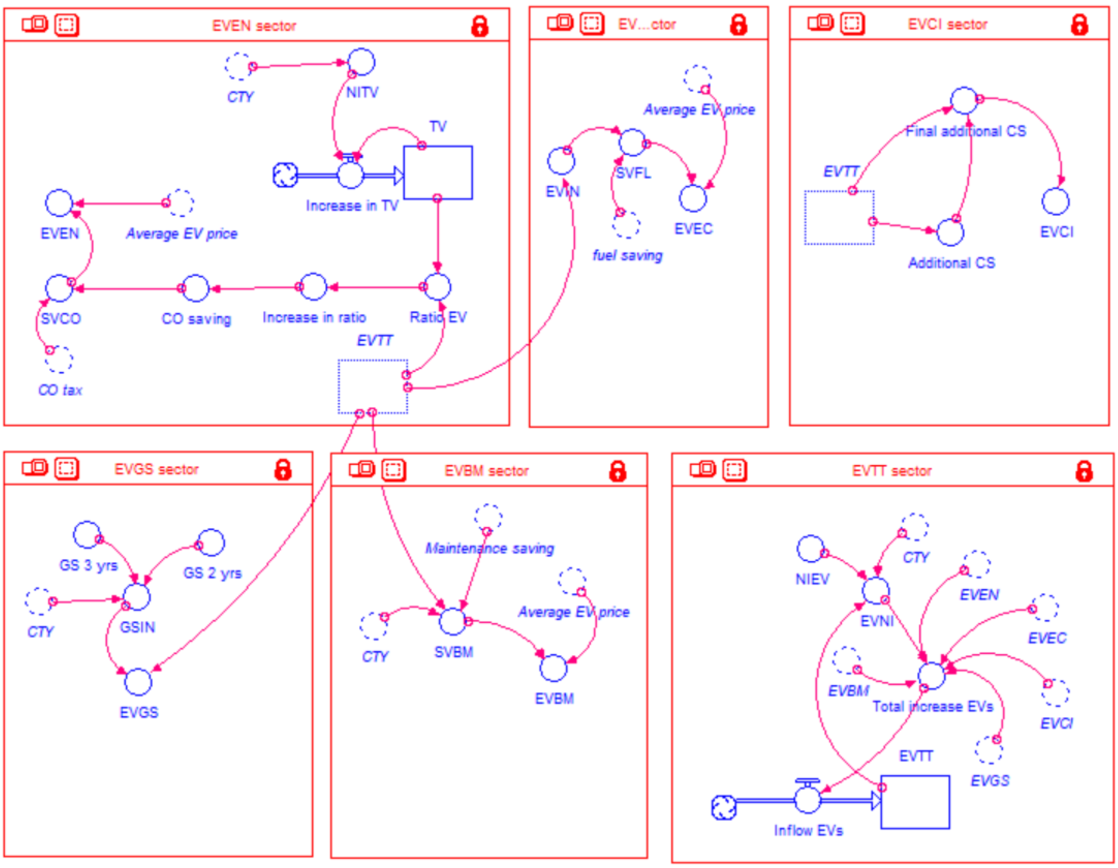


Fig. 1. SD model of EV sales in Thailand

2.3.2. Economic sub-model

The average fuel consumption of conventional vehicles is 1.68 THB/kilometre, while EVs cost about 0.85 THB of electricity/kilometre (BCP, 2021; Hearst Autos, 2021). This results in the saving of 0.83 THB/kilometre. With an average driving distance of 20000 kilometres/year, this yields the saving of 16600 THB/EV/year. The increase in the EV demand based on the economic factor (EVEC) is achieved by dividing the savings of fuel consumption (SVFL) by the average selling price of an EV (Eqs. 4–6).

$$EVIN = EVTT - DELAY(EVTT, 1) \quad (4)$$

$$SVFL = 16600 \times \text{EVIN} \quad (5)$$

$$EVEC = ROUND(SVFL/2480000) \quad (6)$$

Where
EVIN = Increased number of EVs (vehicles/year)
EVTT = Total EVs (vehicles/year)
SVFL = Savings of fuel consumption (THB/year)
EVEC = Increase in the EV demand from the economic factor (vehicles/year)

2.3.3. Charging infrastructure sub-model

Thailand currently has 276 charging station locations with a capacity to service up to 479964 EVs (1739 EVs require one charging station). One additional charging station could attract 7 % of green consumers to purchase EVs (Kaewtatip, 2019; Thananusak et al., 2021). The increase in EV demand based on the charging infrastructure factor (EVCI) is then achieved, as shown in Eqs. 7–8.

$$CIAD = IF\ EVTT < 479964\ THEN\ 0\ ELSE\ ROUND((EVTT - DELAY(EVTT, 1))/1739) \quad (7)$$

$$EVCI = CIAD \times 1739 \times 0.07 \quad (8)$$

Where
CIAD = Additional charging stations (stations/year)
CHTT = Total charging stations (stations)
EVCI = Increase in the EV demand from the charging infrastructure factor (vehicles/year)

2.3.4. Government support sub-model

It is expected that the government policy to subsidise the first-car to be an EV will help increase the share of EVs by 18.2 % in the next two years (until 2023) and by 16.1 % three years after, i.e., until 2036 (Svasti, 2012; Department of Land Transport, 2019). The increase in the EV demand based on the government support factor (EVGS) is achieved by multiplying the increasing rate from the government support (GSIN) with the total number of EVs each year (EVTT) (Eqs. 9–10).

$$GSIN = IF\ CTY \leq 2\ THEN\ 0.182\ ELSE\ (IF\ 3 \leq CTY \leq 5\ THEN\ 0.161\ ELSE\ 0) \quad (9)$$

$$EVGS = GSIN \times EVTT \quad (10)$$

Where
GSIN = Increasing rate of EVs from the government support
EVGS = Increase in EV demand from the government support factor (vehicles/year)

2.3.5. Battery maintenance sub-model

EV battery maintenance costs comprise only half of the maintenance costs of conventional vehicles (Consumer Reports, 2021). This is equivalent to the savings in maintenance costs of 5346 THB/EV/year. The increase in the EV demand based on the battery maintenance factor (EVBM) is then achieved, as shown in Eqs. 11–12.

$$SVBM = 5346 \times \text{EVIN} \quad (11)$$

$$EVBM = ROUND(SVBM/2480000) \quad (12)$$

Where SVBM = Savings of battery maintenance costs (THB/year)
EVBM = Increase in the EV demand from the battery maintenance factor (vehicles/year)

2.3.6. Total EV sub-model

The average increase of the EV number amounts to 14.45 % per year (EVAT, 2021). The additional EV demand from five key factors, i.e., the environment, economy, charging infrastructure, government support, and battery maintenance factors, are also added to achieve the total EVs (EVTT), see Eqs.13–15.

$$EVIN = EVEN + EVEC + EVCI + {} + EVGS + EVBM + EVNI \quad (13)$$

$$EVNI = DELAY(EVTT, 1) \times 0.0546 \quad (14)$$

$$EVTT = EVIN + DELAY(EVTT, 1) \quad (15)$$

Where
EVNI = Increase in the EV demand from the normal increasing rate (vehicles/year)

3. Research results

3.1. Simulation results

The SD model of EV sales is simulated for a 20-year period to examine the trend of EV sales in the long term. The simulation results are shown in Fig. 2 and Table 3.

The results show that the number of EVs will increase from 231682 vehicles to over 2 million vehicles in the next 20 years with the implementation of the five key factors affecting EV sales. This represents an average increasing rate of EVs of 41.4 % per year.

These simulation results are consistent with Sutabutr (2019), claiming that the number of EVs are expected to be over 1.2 million vehicles in 2036.

Closer examination (Fig. 3) reveals that the EV demand mainly increased due to the government support factor (EVGS) in the first five years of simulation. The increase followed the first-car scheme implemented in 2012, resulting in more than 100000 new registered vehicles (Svasti, 2012; Statista, 2021). Therefore, the government may offer a subsidy programme to attract more EV consumers, such as a tax rebate of up to THB 100000 per vehicle per person. This programme, however, should be implemented for a short period to promote the use of EVs. Fig. 3 also shows that the additional EV demand from the environmental factor (EVEN) is crucial in enhancing EV sales in Thailand by reducing the CO_2 tax that attracts more green consumers.

The EV demand from the charging infrastructure (EVCI) is zero in the first four years of simulation. This is because the current number of charging stations (276) is adequate to service up to 479964 EVs. As the number of EVs increases, more charging stations are built, reflecting the availability of charging stations and attracting more EV consumers.

Tab. 3. Numerical results of the SD model of EV sales in Thailand

Simulation time	Year	Total EV (vehicles/year)	Increased EV demand (vehicles/year)
Initial	2021	231682	0
1	2022	286998	55316
2	2023	369540	82542
3	2024	471176	101636
4	2025	598404	127228
5	2026	767012	168608
6	2027	860148	93136
7	2028	929786	69638
8	2029	994393	64607
9	2030	1060424	66031
10	2031	1130180	69756
11	2032	1204536	74356
12	2033	1284028	79492
13	2034	1369012	84984
14	2035	1459818	90806
15	2036	1556789	96971
16	2037	1660412	103623
17	2038	1771105	110693
18	2039	1889294	118189
19	2040	2015429	126135
20	2041	2150114	134685

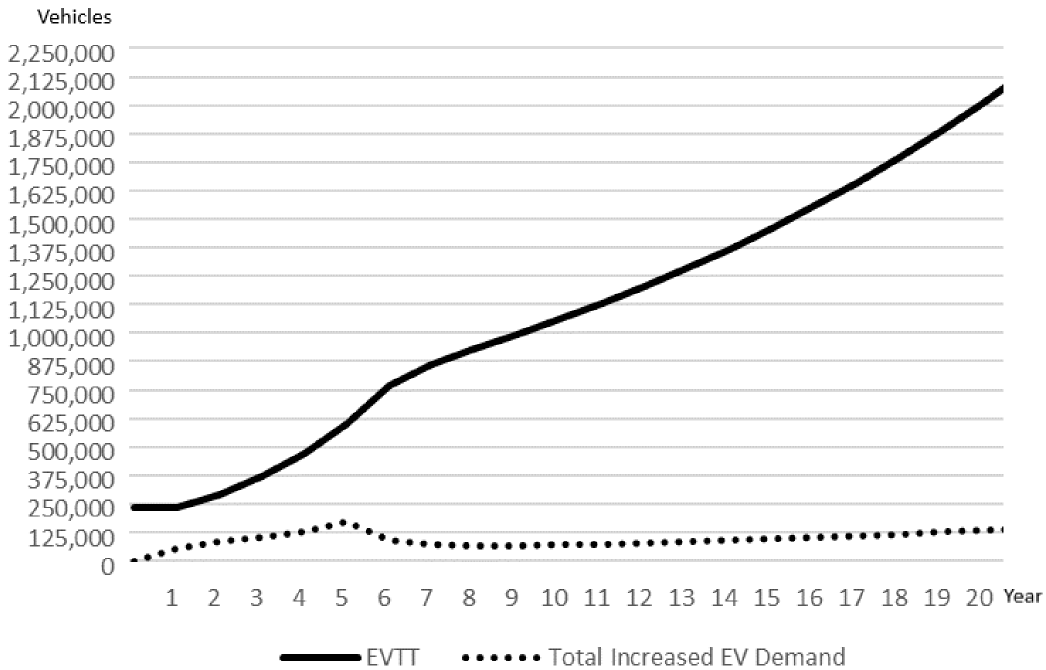


Fig. 2. Graphical results of the SD model of EV sales in Thailand

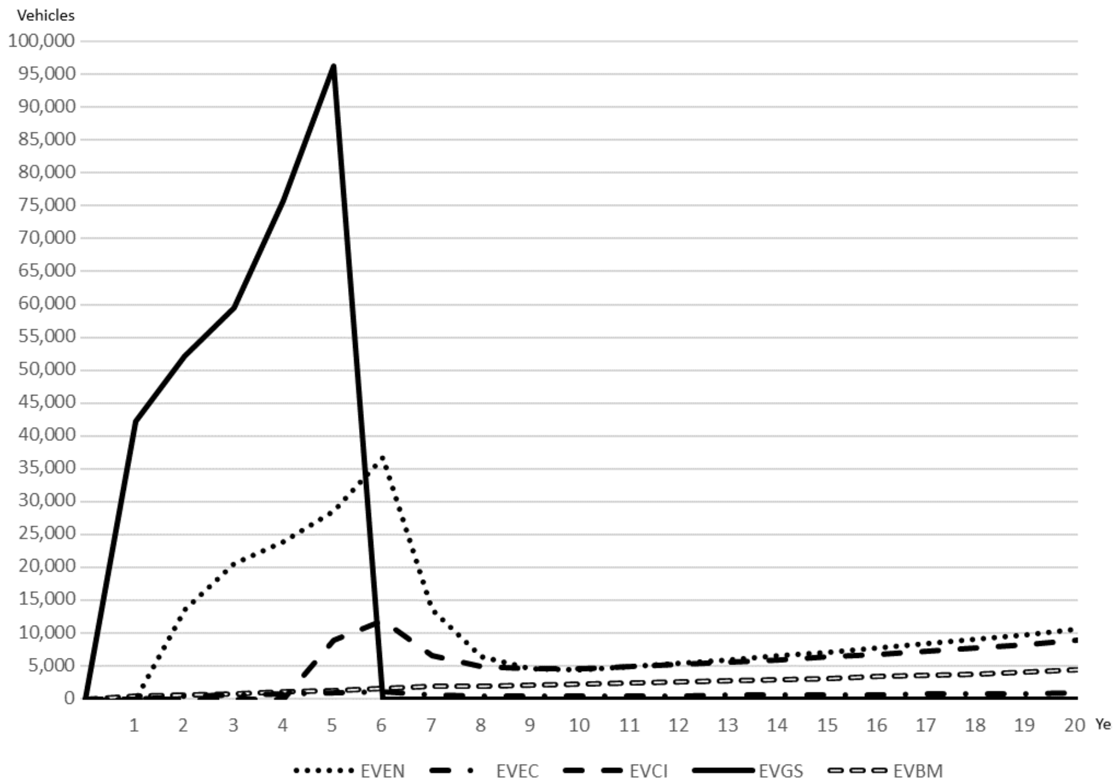


Fig. 3. Increased EV demand from five key factors affecting EV sales

3.2. Model validation

The developed SD model of EV sales in Thailand must be validated to ensure its use in practice and ascertain whether plausible shifts in model parameters can cause the model to fail behaviour tests that were passed previously (Balas et al., 2007). One of the common model validation tests is sensitivity analysis, or so-called policy analysis. It is used to reveal the degree of robustness of the model behaviour and indicate the degree to which policy recommendations may be influenced by uncertainty in parameter values.

This study performed the sensitivity analysis by varying the values related to government support, environment, and charging infrastructure factors, representing the highest additional EV demand (Fig. 3). In the government support factor, the increasing rate of EV sales from year 3 to year 5 (the last three years of the government subsidy programme) varied from 16.1 % to 18.2 % (Svasti, 2012; Statista, 2021). The simulation results (Fig. 4) show that the developed SD model of EV sales is robust, as the model

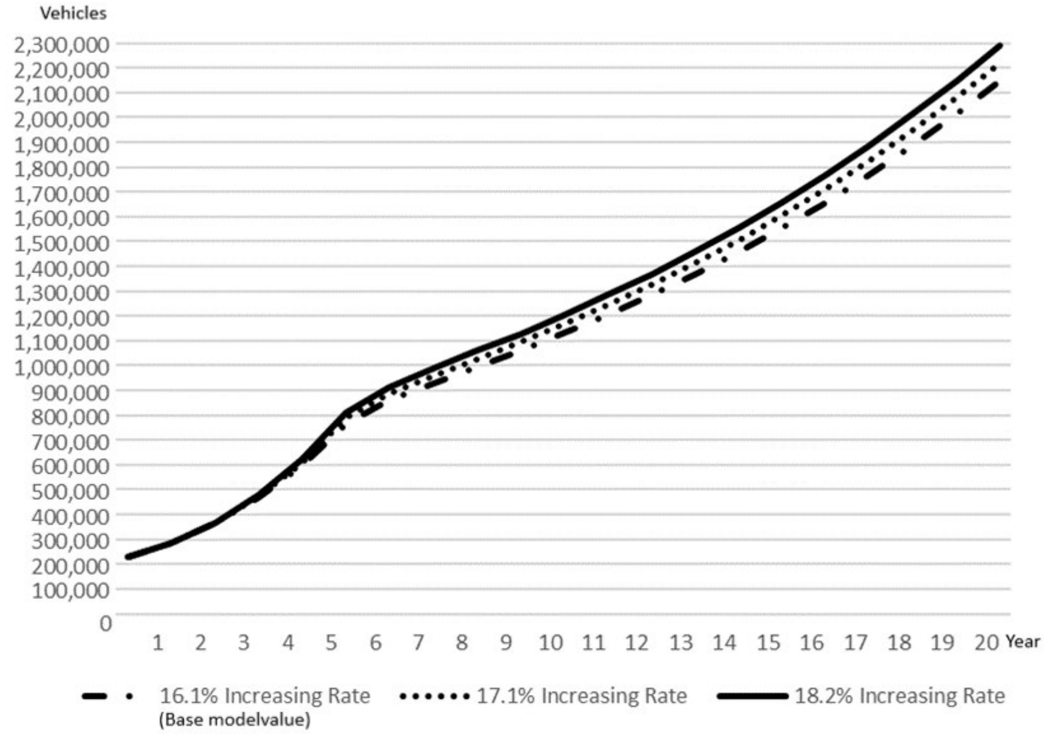


Fig. 4. Sensitivity analysis results when the increasing rate of the EV sales from the government support factor is changed

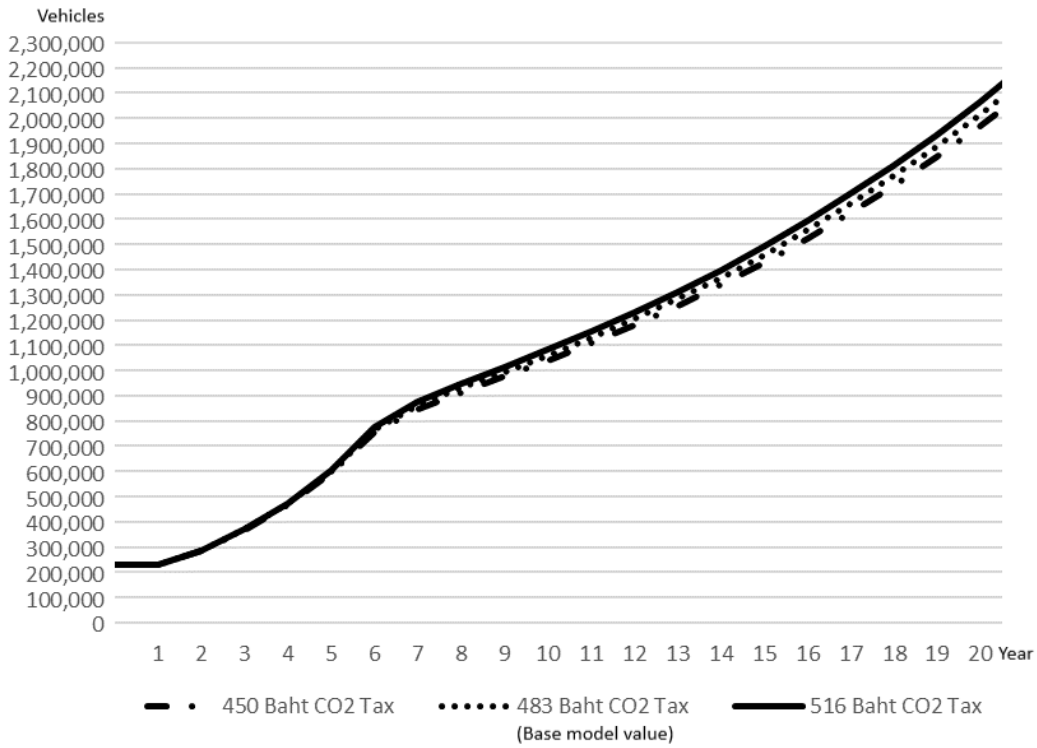


Fig. 5. Sensitivity analysis results when the CO_2 tax from the environment factor is changed

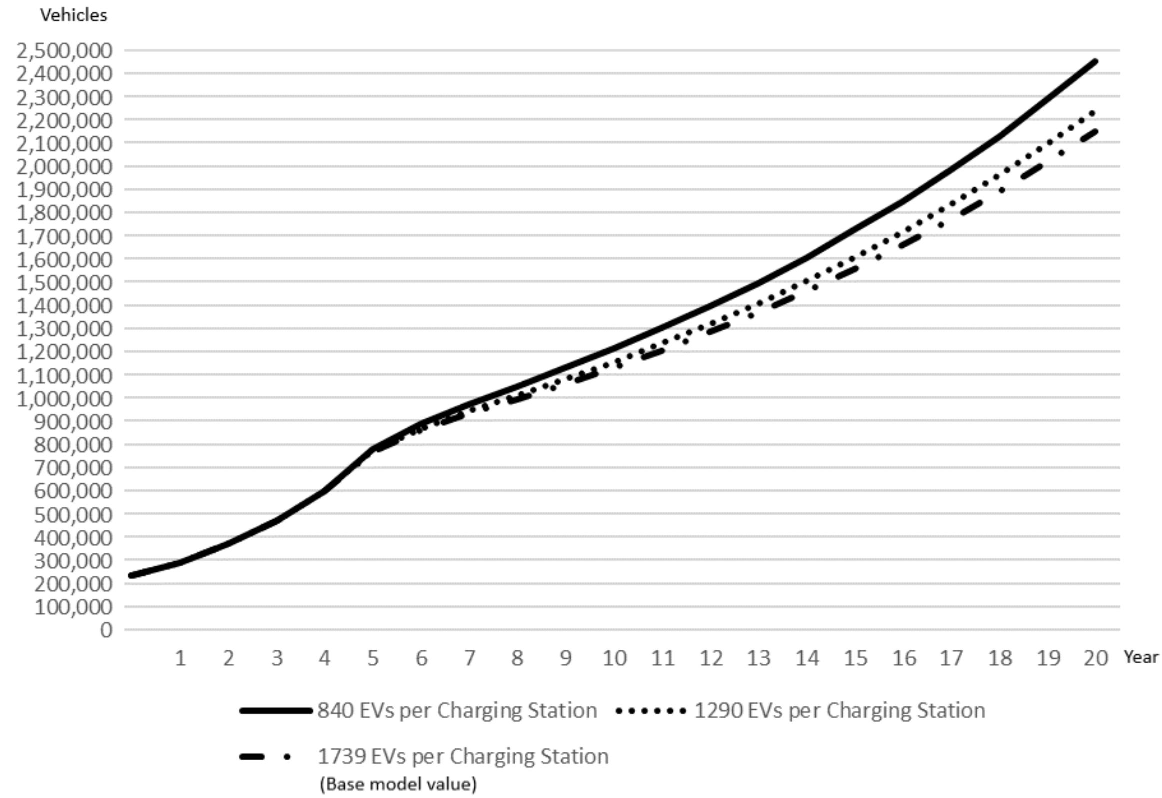


Fig. 6. Sensitivity analysis results when the number of EVs per charging station from the charging infrastructure factor is changed

behaviour has not changed. This validates the developed SD model to be used in real situations.

Fig. 4 shows that a higher increasing rate from the government support factor gives higher EV sales. Therefore, the government may support the EV manufacturers and consumers with various subsidy programmes, such as tax reduction and incentives and start-up programmes to encourage the EV production and EV market in Thailand in the long term.

The sensitivity analysis is also performed with the environmental factor by varying the CO_2 taxes from 450 to 500 THB/ton CO_2 (Doan & Chinda, 2016). Fig. 5 shows that a higher CO_2 tax results in higher savings from the CO_2 tax and more EVs purchased. This finding is consistent with Thananusak et al. (2017) that reduction in CO_2 emission helps enhance the EV sales in Thailand in the long term.

The sensitivity analysis in the charging infrastructure factor is performed by varying the number of EVs from 840 to 1739 vehicles per charging station (EVAT, 2021). The simulation results in Fig. 6 confirm that more charging stations attract more EV consumers and enhance the EV market in the long term.

4. Discussion of the results

The SD model of EV sales in Thailand is simulated for 20 years to examine the long-term trend of EV sales in Thailand. The simulation results reveal that the number of EVs increases from about 0.23 to 2.1 million vehicles in 20 years, representing an average increasing amount of about 100000 vehicles per year or an average increasing rate of 44 % per year.

These results follow the previous Thai government's first-car scheme that produced more than 100000 new registered vehicles per year (or a 50 % increase in the rate per year) (Statista, 2021). Therefore, it is crucial that the Thai government provides a number of supporting campaigns to enhance the EV market in the long term, as follows:

- Set up the subsidy campaign following the first-car campaign of 2012. The campaign provides EV consumers with a tax rebate through EV purchases. It could be implemented at the early stage to boost the EV market in Thailand (Bangkok Post, 2012). Based on the simulation results, this campaign could grow the number of EVs by over 300000 vehicles in the next five years.

- Enforce the CO_2 tax regulation to reduce the CO_2 emission and control the global temperature increase to not exceed 1.5 °C following the Conference of the Parties (COP) 26 (BBC, 2021). The simulation results reveal that the reduction of CO_2 emission could enhance the EVs by almost 240000 vehicles in the next 20 years.
- Have an adequate number and distribution of charging stations. Private companies may cooperate in providing charging stations at specific locations, such as supermarkets, shopping centres, and restaurants (EVAT, 2021). In this study, adequate charging stations could raise the number of EVs by almost 120000 vehicles in the next 20 years.
- Control electricity prices to motivate the use of EVs.
- Provide skills training for EV battery manufacturing to reduce production and maintenance costs. A comprehensive set of incentives should be provided to cover all major aspects of the EV supply chain, focusing on battery EVs and local production of critical parts (BOI, 2017).

Conclusions

EVs are a possible solution in response to the increasing concerns for climate change and global warming. The SD model of EV sales is developed based on five key factors, namely, the environment, economy, charging infrastructure, government support, and battery maintenance factors, to examine the trend of EV sales in Thailand in the long term. The simulation results revealed that strategies and campaigns related to the five key factors could help raise the number of EVs by almost ten times in the next 20 years. Some strategies are suggested to be implemented in the early years, while others aim at a longer period. The government support through tax rebates, for instance, could be established at the early stage to promote the use of EVs. Import taxes for key EV components, especially the electric battery, should be subsidised to support the local EV manufacturing.

The government should also have a long-term plan to increase the number of charging stations to cover the charging demand of the country. Electricity costs for vehicle charging should be controlled to attract more EV consumers. Moreover, the government should add electric battery and EV manufacturing modules in vocational study programmes to supply an adequate number of skilled workers in the market in the long term.

Short- and long-term plans related to the five key factors could help stimulate the EV demand and enhance EV sales. The public and private sectors should cooperate to achieve a sustainable EV market in Thailand in the long term.

This research study contributes to the government and automotive industry as follows:

- It considers the long-term trend of EV sales in Thailand utilising the SD modelling approach.
- Five key factors affecting EV sales, their complex relationships and the link with the EV demand. The developed SD model clearly depicts these relationships to better understand the EV sales trend in the long term.
- The Thai government plays a vital role in successfully growing the EV market in Thailand. Various supports should be initiated, both short-and long-term, to enhance EV sales. Such supports are tax reduction, subsidies, charging infrastructure provision, skills training, and promotion campaigns.

This research study has some limitations. Data used in the SD model development have been obtained from the literature on developed and developing countries and are not specific to the Thai context. Expert interviews may be performed to collect specific data, such as CO_2 emissions, energy consumption, and related-infrastructure plans for the SD model development. The EV sales achieved from the developed SD model should be compared with the real data when available.

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