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Original Article

Interrelationships among factors influencing electric vehicle adoption in Thailand

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Abstract

To vitalize the EV market, it is necessary to understand key factors influencing EV adoption and their interrelationships, in order to establish proper strategies and promotion plans. This study utilized exploratory factor analysis (EFA) and structural equation modeling (SEM) approaches to form several EV adoption constructs and examine their directions of relationships. A questionnaire survey was developed based on 24 EV-related variables, extracted from a literature review for use in data collection. The respondents were car manufacturers and EV users in Bangkok and its vicinity, in Thailand. The EFA grouped the 24 variables into four key factors representing Government Support, Battery-related, Vehicle Performance, and Individual Characteristics of EV Adoption. The SEM results prove that government support in, for example, R&D, EV regulation, electric battery- and EV manufacturing-related training, and controlling electricity prices are necessary to stimulate the EV market. Other criteria, such as household income, GDP, and the general trend, should be considered when establishing schemes to promote the EV market in the long term.

Keywords: electric vehicle, interrelationship, structural equation modeling, Thailand

1. Introduction

Air pollution is a big issue in the world, and it is mainly caused by vehicles. IEA (2021) mentioned that carbon dioxide emissions are among the most significant contributors to climate change, of which the transportation sector dominates with its two-thirds share. Therefore, the need to satisfy the vision of energy efficiency, especially in the transportation sector, should draw the concern of every country to embrace fuel-efficient vehicles. Consequently, carmakers need to adopt systems to respond to the challenges of mitigating fuel combustion emissions. Electric vehicles (EVs) are proven to be an alternative to reduce carbon dioxide emissions in the long term.

There are four types of EVs, including battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and fuel-cell electric vehicles (FCEVs) (Egbue & Long, 2012). BEVs run entirely on batteries and electric drive trains. PHEVs, in contrast, run on battery and gasoline. The battery packs provide up to 80 km of driving distance before gasoline engines turn on during longer trips. HEVs have two complementary driving systems: a gasoline engine with a fuel tank and an electric motor with a battery. The battery in HEVs, however, cannot be recharged from the power grid. FCEVs create electricity from hydrogen and oxygen. Because of their efficiency and water-only emissions, some experts consider FCEVs the best electric vehicles, even though they are still under development (CAA, 2020).

The number of new EV registrations and accumulated EVs in Thailand have increased by a half from 2019-2021, with almost 250,000 EVs in 2021 and approaching 300,000 EVs in the first half of 2022 (EVAT, 2022). Among those, 80% are HEVs, 13% are PHEVs, and 7% are BEVs (EVAT, 2022). Thai government targets that 30% of new vehicles produced in Thailand will be zero-emission vehicles by 2030 (e.g., BEVs) and that this will become 100% by 2035 (BOI, 2022; Ploymee, 2021; Utamote, 2021).

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To promote EV adoption, it is essential to understand how consumers perceive EVs and what factors influence consumer intentions to purchase EVs. Moreover, interrelationships among critical factors influencing EV adoption are crucial to effective planning of EV programs and campaigns. This study, therefore, aimed to examine critical factors and their interrelationships affecting EV adoption in Thailand, utilizing exploratory factor analysis (EFA) and structural equation modeling (SEM). The study results are expected to provide insights into consumers' perceptions of EV adoption in Thailand, so that effective plans can be established to vitalize the EV market in the long term.

2. Materials and Methods

In this study, a literature review of EV markets in developed and developing countries, including Thailand, was performed to understand the current situation better. Consumers' perceptions of the EV market were extracted from many sources, such as international journals, company and government reports, and statistical records. They were used in developing a questionnaire survey. The EFA was performed to group the EV adoption attributes into several key factors influencing EV adoption. The SEM was then utilized to examine the relationships, direct and indirect, among those key factors and plan to vitalize the EV market in Thailand.

2.1 EV adoption attributes

Several research studies have been conducted to understand better consumers' perceptions of EV adoption in developed and developing countries. Rezvani, Jansson, and Bodin (2015), for example, reported that they found four key factors, namely technical, contextual, cost, and individual and social factors, with several associated attributes, such as recharging time, range, speed, carbon emissions, and charging infrastructure. Goswami and Sadhu (2021) mentioned that battery performance, safety, and reliability are crucial in the adoption of EVs. Thananusak, Rakthin, Tavewatanaphan, and Punnakitikashem (2017) studied factors affecting the intention to buy EVs in Thailand and summarized five key factors: performance, infrastructure, financial, environmental, and price premium factors.

This study lists 24 variables affecting EV adoption, sourced from several pieces of literature (Table 1). They were used in developing the questionnaire survey to collect data for the analyses.

2.2 Exploratory factor analysis (EFA)

The EFA method is often used in the early stages of data analysis to gather information about interrelationships among a set of variables. It is a precursor to structural equation modeling (SEM). It is used to extract from attributes

Table 1. Variables affecting the EV adoption

Variable	Abbreviation	Explanation
Battery cost	BTC	EV battery is more expensive than the normal battery.
Battery life	BTL	Recently, EV batteries are designed for extended life to attract more EV customers.
Battery warranty	SLP	Manufacturers offer longer battery's warranty period and wider coverage to attract more EV customers.
Brand preference	BPF	Brand reputation may guarantee the quality of its products.
Change in electricity price	CEP	If the electricity price decreases, EV adoption may increase.
Charging station	CHS	Market share of EVs is explained by the number of charging stations.
Charging time	CHT	Factors related to EV purchasing include driving range, speed, and charging time.
Driving comfort	DCF	One main argument against EVs is the low driving comfort.
Environmental concern	ENC	Environmentalism is a consumer characteristic with positive effects on EV adoption.
EV background	EVB	Barriers to EV adoption include lack of knowledge, low consumer risk tolerance, and high initial production cost.
EV knowledge	EVK	Knowledge sharing is a strategy to stimulate EV market.
GDP	GDP	The country GDP is utilized as a measure of EV penetration rate.
Income	INC	Income is a consumer characteristic with positive effects on EV adoption.
Maintenance cost	MTC	Lower maintenance cost of EVs may incentivize consumers to adopt this new technology.
Petroleum price	PTI	High fuel price raises EV competitiveness.
Range per charge	RPC	Range per charge is a criterion influencing EV purchasing decision.
R&D	RAD	Strengthening R&D investment is the long-term development strategy of EV market.
Regulation	REG	EV regulation should be established to support EV-related activities.
Resale price	SHP	Resale anxiety reflects concern that value of used EV may deteriorate quickly.
Risk of explosion	ROE	When EV battery experiences extreme operating conditions, it can eject sparks, which can lead to jet flames or a gas explosion.
Tax reduction	TRD	Tax incentive system should be implemented to attract EV consumers.
Technology innovation	EVI	Innovation could be used to differentiate the company's products from competitors.
Trend	TRN	EVs have become a part of a globally emerging industry, setting up a new development trend for the automobile industry.
Vehicle size	SEV	Limited EV size affects consumers' purchasing decision.

Note: References include Barton and Schütte (2017); Cheong, Song, and Hu (2016); Krupa *et al.* (2014); Lim, Mak, and Rong (2014); Malmgrem (2016); Masiero, Ogasavara, Jussani, and Risso (2016); Morton, Anable, and Nelson (2016); Soltani-Sobh, Heaslip, Stevanovic, Bosworth, and Radivojevic (2016); Thananusak *et al.* (2017); Tu and Yang (2019); Wager, Whale, and Braunl (2016); Yong and Park (2017) several factors that represent the interrelations among those attributes. It has been used in the context of various industries, such as construction, agriculture, manufacturing, real estate, and automotive. Chinda and Mohamed (2008) utilized EFA to confirm the proposed factor structure of the safety culture model in the Thai construction industry. On the other hand, Tu and Yang (2019) explored vital factors influencing consumers' purchase of EVs in China, utilizing EFA.

Three criteria are relevant when performing the EFA: an assessment of the suitability of the data, the factor extraction, and the factor rotation (Hair, Anderson, Tatham, and Black, 1998). In this study, Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) tests were applied to assess the factorability of the data. Bartlett's test of sphericity should be significant ($p < 0.05$), and the KMO index should be at least 0.6 to be considered appropriate for the EFA (Tabachnick & Fidell, 2007).

The principal component analysis and the varimax rotation were applied for factor extraction and rotation, respectively. Moreover, an 0.4 cut-off level for loadings was used to screen out the variables that are weak indicators of the constructs (Hair *et al.*, 1998).

2.3 Structural equation modeling (SEM)

SEM is a multivariate statistical analysis technique used to analyze structural relationships. It allows examinations of mutual influences among variables, either direct, or indirect through other variables as intermediaries (Nguyen & Chinda, 2018). Researchers prefer this method because it estimates the multiple and interrelated dependences in a single analysis. For example, Nguyen and Chinda (2018) examined interrelationships among key profit factors of Vietnamese residential projects using SEM. Tiwari, Aditjandra, and Dissanayake (2020) utilized SEM to analyze public attitudes towards EVs and explore barriers to EV adoption in the UK.

SEM comprises two main tests: the measurement model and the structural model. Measurement models work as confirmatory factor analyses to specify how well observed variables represent factors. Structural models, on the other hand, explore relationships among key factors (Nguyen & Chinda, 2018). To assess the model fit, this study utilized the chi-squared to the degrees of freedom (χ^2/DF), comparative fit index (CFI), and root mean square error of approximation (RMSEA). The values of χ^2/DF, CFI, and RMSEA of less than two, at least 0.8, and less than 0.08 indicate a good model fit (Nguyen & Chinda, 2018).

Model refinement may also be performed to achieve a better model fit by 1) eliminating paths with low correlations and 2) removing observed variables shown by the computed modification indices (MI) as having multicollinearity (Kline, 2005).

2.4 Data collection

A questionnaire survey is used for data collection in this study. The target group is car manufacturers with existing EV models and experienced EV users. The survey asks the respondents to rank their perceptions of EV adoption in Thailand using the 5-point Likert scale, where 1 = strongly disagree and 5 = strongly agree. The surveys were distributed to 10 car manufacturers and experienced EV users in January-February 2020. Respondents in car manufacturers range from management to operational positions to reflect various perspectives of EV adoption in Thailand.

3. Results

3.1 Data collection results and data screening

Three hundred survey questionnaires were distributed, with 150 responses returned, representing 50% total response rate. Among those, 72% were car manufacturers, and 43% were in management positions, such as executives, managers, and senior staff. 28% of the respondents were experienced EV users of HEVs, PHEVs, and BEVs, such as Honda HRV, MG VS, MG HS, Toyota Corolla Cross, Nissan Kicks, Mitsubishi Outlander, Hyundai Kona Electric, MG ZS EV, and Nissan Leaf models.

The collected data were then screened using normality and outlier tests. Skewness and kurtosis measure normality of distribution, while the z-score can reveal outliers. Skewness and kurtosis values in the range of ±2.00 and ±7.00, respectively, are typically distributed; in contrast, z-scores higher than 3.29 indicate potential outliers (Vitharana & Chinda, 2019). The analysis results revealed two records as potential outliers; thus, they were removed from the data file, leaving 148 data records for further analysis.

3.2 EFA results

One hundred forty-eight screened data records were subjected to EFA. In this study, the EFA was performed using SPSS software version 27. The results extracted from 24 variables affecting EV adoption four factors that explained 50.7% of variance (Table 2). The four factors are named the Individual Characteristics of EV Adoption (IND), Battery-related (BAT), Government Support (GOV), and Vehicle Performance (PER) factors, with respectively seven, six, six, and five associated variables. In the Individual Characteristics of the EV Adoption factor, for example, the petroleum price (PTI), GDP, and resale price (SHP) variables are the most important criteria when making the EV adoption decision, with high factor loadings of 0.712, 0.709, and 0.616, respectively. These are consistent with Soltani-Sobh, Heaslip, Stevanovic, Bosworth, and Radivojevic (2016) in that rising fuel costs may encourage the EV market. The battery life (BTL), maintenance costs (MTC), and battery cost (BTC) are, on the other hand, significant variables in the Battery-related factor (with factor loadings of 0.803, 0.723, and 0.677, respectively). Low battery and maintenance costs may stimulate the EV market (Krupa *et al.*, 2014).

These four extracted factors were assessed for their reliability by use of Cronbach alpha. According to Nguyen and Chinda (2018), an alpha of at least 0.7 is considered acceptable. The analysis results (Table 3) revealed alpha values ranging from 0.7 – 0.82, thus confirming the suitability of the four extracted factors for use in SEM.

3.3 SEM results

The four factors extracted in EFA and their associated variables form the baseline model of EV adoption in Thailand were subjected to a measurement test to confirm

Table 2. EFA results

Variable	Extracted factor			
	IND	BAT	GOV	PER
PTI	0.712			
GDP	0.709			
SHP	0.616			
INC	0.544			
TRN	0.520			
ENC	0.479			
ROE	0.473			
BTL		0.803		
MTC		0.732		
BTC		0.677		
CHT		0.644		
RPC		0.58		
SLP		0.47		
TRD			0.725	
CHS			0.632	
EVK			0.575	
REG			0.520	
RAD			0.503	
CEP			0.401	
DCF				0.751
EVI				0.618
SEV				0.601
BPF				0.571
EVB				0.547

Table 3. Reliability test results

Extracted factor	Cronbach alpha
IND	0.78
BAT	0.82
GOV	0.74
PER	0.70

the correlations among them. A total of six two-headed arrows are assumed to represent the correlations among the four key EV adoption factors (Figure 1). The measurement model was tested, and the results (Table 4) show that all fit indices are in acceptable ranges. Correlation coefficients among the four key factors (ranging from 0.5 – 0.72) are considered vital (Figure 1). Chinda (2020) stated that the correlation or path coefficients of more than 0.5 show strong relationships, while the path coefficients between 0.3 – 0.5, 0.1 – 0.3, and less than 0.1 show moderate, weak, and no relationships, respectively. These lead to the best-fit measurement model of EV adoption.

Having established confidence in the measurement model, a structural model is next tested to examine the directions of relationships among the four key factors. Six confirmed correlations among the four key factors, represented by two-headed arrows in the measurement model, are now replaced with the one-headed arrow to test the directions of the relationships. The hypothesized directions were extracted from the literature and were tested with the structural model (Figure 2). For example, the Government Support factor is assumed to influence the Vehicle Performance factor (H1). This is supported by Hirst, Winnett, and Hinson (2021), suggesting that government support is needed to improve EV performance and innovation. On the other hand, the Battery-related factor is assumed to influence

Table 4. Fit index results

Fit index	Acceptable value	Best fit measurement model	Best fit structural model
χ^2/DF	≤ 2	1.78	1.61
CFI	≥ 0.8	0.83	0.87
RMSEA	≤ 0.08	0.07	0.06

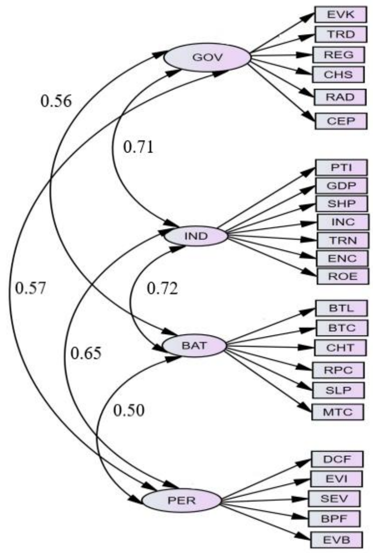

Figure 1. Best fit measurement model of EV adoption

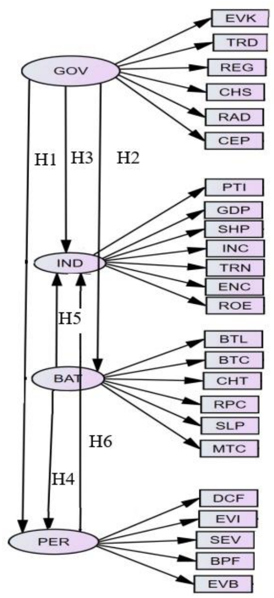

Figure 2. Hypothesized directions of relationships among the four key factors

the Individual Characteristics of the EV Adoption factor (H5). According to Soltani-Sobh *et al.* (2016), the electric battery in EVs helps reduce fuel consumption and is environmentally friendly.

The structural model was tested, and the MI results (Table 5) suggest some variables to be correlated to improve the model fit. According to Vitharana and Chinda (2019), correlations with high MI values should be added. As a result, four correlations were added to the structural model, including RPC ←→ DCF, MTC ←→ ROE, BTL ←→ RPC, and CHS ←→ RPC. These are consistent with, for example, Masiero, Ogasavara, Jussani, and Risso (2016), in that proper battery maintenance reduces the chances of a battery explosion. Thananusak, Punnakitikashem, Tanthasith, and Kongarcha patara (2021) mentioned that charging stations should be available as EV battery still has a low range per charge.

After the modifications, the structural model was retested, and the best fit structural model (Figure 3), i.e., the final model of EV adoption (Figure 4), was achieved with all modification indices falling in the acceptable ranges (Table 4).

The results reveal weak, moderate, and strong relationships among the four key factors influencing EV adoption. The strong relationship between Government Support and Battery-related (GOV → BAT) factors (with a path coefficient of 0.57) is supported by Kaewtatip (2019) in that the government initiates various policies, such as import and excise taxes reduction, charging infrastructure, and EV battery production and end-of-life management, to promote the use of EVs in Thailand. Kumnerdpetch (2020) mentioned that the Thai government should focus on battery performance, especially in the driving range and charging time, to attract more EV consumers who usually travel a long distance daily. Masiero *et al.* (2016) mentioned that government support in the R&D of electric batteries enhances battery performance in terms of battery life. Tax reduction could also help reduce the battery costs, thus encouraging EV adoption in the long term.

Moderate relationships were found between Government Support and Vehicle Performance (GOV → PER), Battery-related and Individual Characteristics to EV Adoption (BAT → IND), Vehicle Performance and Individual Characteristics to EV Adoption (PER → IND), and Government Support and Individual Characteristics to EV Adoption (GOV → IND) factors, with path coefficients of 0.48, 0.39, 0.35, and 0.3, respectively. These confirm the importance of government support, battery performance, and vehicle performance in encouraging EV adoption. Promotion of EVs, increase of charging stations, improved driving range with battery power and battery life, enhanced driving comfort, and increase of vehicle varieties may, for instance, help motivate EV adoption and increase EV use in Thailand (Masiero *et al.*, 2016; Thananusak *et al.*, 2017; Wager, Whale, & Braunl, 2016).

The results show a weak relationship between the Battery-related and Vehicle Performance (BAT → PER) factors with a path coefficient of 0.17. This may be because EV batteries are mainly imported from other countries. Battery production in Thailand still requires high support from the government in various areas, such as R&D and skill training, to improve the battery performance (Kaewtatip, 2019; Maksiri & Tresirichod, 2019). The end-of-life management of batteries through remanufacturing, recycling, and reprocessing is required to minimize long-term environmental effects on air, soil, and water contamination from lithium-ion battery disposal (Poosuwan, 2022).

Table 5. MI values

Suggested correlation			MI
RPC	<-->	DCF	16.60
MTC	<-->	ROE	12.80
BTL	<-->	RPC	9.06
CHS	<-->	RPC	8.37
PTI	<-->	TRD	5.70
ROE	<-->	RAD	5.29
CHT	<-->	EVK	4.59
BPF	<-->	EVB	4.29
PTI	<-->	RAD	4.18
SHP	<-->	TRN	4.07

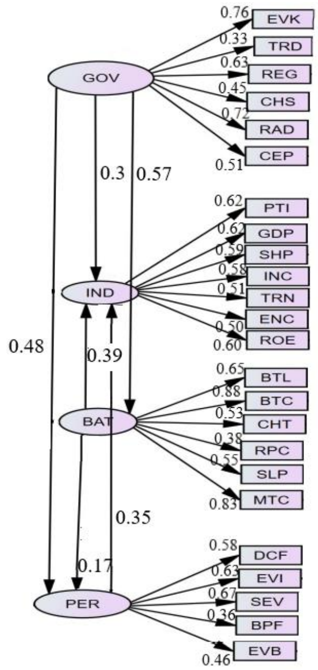

Figure 3. Best fit structural model of EV adoption

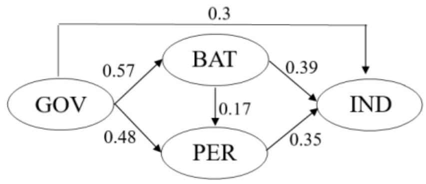

Figure 4. The final model of EV adoption

Summary of relationships among the four key factors influencing EV adoption is shown in Table 6.

4. Discussion and Conclusions

The EV market in Thailand receives little attention, although it was introduced in 2015. To support EV adoption, it is crucial to examine critical factors influencing EV adoption so that the government and related parties can develop suitable strategies to promote the EV market in the long term.

Table 6. Summary of relationships among the four key factors influencing EV adoption

Hypothesis	Path coefficient	Hypothesis testing result	Degree of relationship
H1	0.48	Supported	Moderate
H2	0.57	Supported	Strong
H3	0.3	Supported	Moderate
H4	0.17	Supported	Weak
H5	0.39	Supported	Moderate
H6	0.35	Supported	Moderate

This study utilized the EFA and SEM methods to extract critical factors influencing EV adoption and to examine their interrelationships. The EFA extracted four key factors influencing EV adoption: Government Support, Battery-related, Vehicle Performance, and Individual Characteristics of EV Adoption. The SEM results further revealed interrelationships among the four key factors. It was found that government support is key to stimulating the EV market. Support to R&D and EV knowledge provision are needed to improve manufacturing efficiency. Specific skills related to EV manufacturing, battery, vehicle performance, and innovation in EV technology should be provided through, for example, training and short courses (Maksiri & Tresirichod, 2019). Issues related to battery cost and maintenance should be explicitly considered, as battery accounts for almost 50% of the EV manufacturing cost (Kaewtatip, 2019; Konig *et al.*, 2021). Control of electricity prices could also stimulate the use of EVs. Before purchasing, consumers also consider various vehicle criteria, such as vehicle size, driving comfort, and brand. Promotion schemes to match consumers' requirements could help enhance EV adoption in the long term.

Further improvements to support EV adoption could be associated with the variables that had low factor loadings (Figure 3). They include an increase in charging stations (in the GOV factor), the environmental concerns (in the IND factor), the battery warranty (in the BAT factor), and the EV background (in the PER factor). Thananusak *et al.,* (2021) mentioned that charging stations affect the EV purchasing decision. Poosuwan (2022) stated that research on recycling and disposal of EV batteries should be encouraged to address the environmental concerns with EVs in Thailand. Manufacturers may offer more extended battery warranty periods and reduce battery maintenance costs to attract more EV customers (Konig *et al.*, 2021).

This study has some limitations. The variables used in the survey questionnaire were sourced and consolidated from literature in developed and developing countries. A pilot test could be performed before launching a questionnaire survey to increase the confidence in the variables used in the analysis. Data were also collected from a limited target set of car manufacturers and EV users, mainly in Bangkok, Thailand. Increasing the sample size might provide better analysis results.

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