sustainability

MDPI

Article

Electric Vehicle Adoption Barriers in Thailand

Jung-Fa Tsai [1], Sheng-Che Wu [1], Pajaree Kathinthong [1], Thu-Hien Tran [2] and Ming-Hua Lin [3,*]

1 Department of Business Management, National Taipei University of Technology, No.1, Sec. 3, Zhongxiao E. Rd., Taipei 106344, Taiwan
2 Department of Industrial Engineering and Management, National Taipei University of Technology, No.1, Sec. 3, Zhongxiao E. Rd., Taipei 106344, Taiwan
3 Department of Urban Industrial Management and Marketing, University of Taipei, No.101, Sec. 2, Zhongcheng Rd., Shilin District, Taipei 111036, Taiwan
* Correspondence: mhlin@utaipei.edu.tw

Abstract: Adopting electric vehicles (EVs) is a potential solution to reduce emissions and protect the environment. Although countries encourage people to use EVs to replace gasoline and diesel vehicles, the application of EVs still needs to overcome many barriers, especially in developing countries such as Thailand. This study aims to identify critical barriers that hinder the adoption of EVs not only among EV owners but also among non-EV owners. First, two rounds of the modified Delphi method were used to identify significant barriers through expert opinions. The decision-making trial and evaluation laboratory (DEMATEL) method was then applied to determine their relationship. Among financial, technical, infrastructure, and policy dimensions, industrial experts agree about 14 significant barriers to the adoption of EVs. The results show that the long charging duration, limited driving range, and lack of charging stations are the most critical barriers affecting Thai customers adopting EVs. This study's findings will help manufacturers and policymakers understand customer requirements and develop appropriate strategies to improve the adoption of EVs.

Keywords: electric vehicle; barriers analysis; modified Delphi method; decision-making trial and evaluation laboratory (DEMATEL) method

check for updates

Citation: Tsai, J.-F.; Wu, S.-C.; Kathinthong, P.; Tran, T.-H.; Lin, M.-H. Electric Vehicle Adoption Barriers in Thailand. *Sustainability* **2024**, *16*, 1642. https://doi.org/10.3390/su16041642

Academic Editors: Tunmin (Catherine) Jai and Ruirui Zhang

Received: 13 January 2024
Revised: 10 February 2024
Accepted: 13 February 2024
Published: 16 February 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The primary reason for global warming is widely acknowledged to be the release of greenhouse gases (GHGs), primarily from the combustion of fossil fuels [1]. The transportation sector alone contributes to 14% of global carbon dioxide (CO_2) emissions [2], mainly using fossil energy for roads, rail, air, and marine transport. Transportation is one of the essential functions of human activity and is projected to increase over time. The continued use of fossil energy directly impacts global CO_2 emissions. Governments worldwide have set CO_2 emission targets for the transportation sector to reduce emissions. However, current technology still relies on internal combustion engines (ICEs), and meeting this target is not feasible. New electric vehicles (EVs) are one way to establish a sustainable emission reduction strategy for fleet CO_2 emissions.

There are various EVs on the market. Hybrid electric vehicles (HEVs) combine an ICE with an electric motor and use regenerative braking to recharge their batteries, removing the need for plug-in charging. Second, plug-in hybrid electric vehicles (PHEVs) have an ICE and a battery-powered electric motor. Third, battery electric vehicles (BEVs) do not have ICEs and rely solely on battery power. Therefore, BEVs do not require gasoline or diesel fuel and can be charged using a plug-in charger. The term "EVs" has become a catch-all phrase for any vehicle that runs on electricity, at least in part. However, since BEVs rely entirely on battery power, they are commonly referred to as EVs. For this study, BEVs will also be referred to as EVs.

Adopting EVs has emerged as an essential solution to reduce CO2 emissions and mitigate the effects of climate change. As more countries plug into electric power, governments are ramping up their efforts to promote EVs to reduce pollution, save consumer fuel, and encourage industrial development. To counteract the expansion of the EV market, Thailand's government has designated the next-generation automotive development and offered various incentives to attract investors into the EV industry [3]. While the growing interest in EVs in Thailand demonstrates the potential for widespread adoption, it is essential to note that the total number of EVs registered is still relatively low compared to internal combustion engine vehicles (ICEVs). In fact, according to Thailand's Department of Land Transport, there are currently only 32,081 registered EVs in Thailand, compared to 43,362,023 ICEVs in 2022 [4]. This report suggests that obstacles exist to hinder the widespread adoption of EVs in the country. In light of Thailand's prominent position in the Southeast Asian automobile industry and its leading sales rate in the region, the Thai government has recognized the global potential of EVs. Positioned to establish itself as a critical player in the Southeast Asian EV market, the government is proactively fostering the growth of the EV industry. Introducing various incentives to attract investors has resulted in the establishment of EV manufacturing facilities by renowned brands such as BYD, GWM, MG, NETA, and others. As a result, this study specifically focuses on Thailand, delving into the unique barriers that impact each factory's decision to invest in the country. Therefore, it is crucial to study and identify the barriers that most influence the slow adoption of EVs in Thailand. Addressing significant barriers to the adoption of EVs will contribute to the government's goal of speeding up Thailand's adoption of EVs, which is crucial to reducing carbon emissions and dependence on fossil fuels in the transportation sector. This study aims to investigate the critical barriers to the adoption of EVs in Thailand and the differences in awareness of barriers to EV adoption between non-EV and EV owners. Suggestions for eliminating barriers to the adoption of EVs in Thailand are also discussed in this study. The research results show that the long charging duration, limited driving range, and lack of charging stations are the most critical barriers affecting Thai customers adopting EVs.

The Thailand EV adoption study benefits academia and industry. This study offered the following contributions:

- This research analyzes barriers to EV adoption in Thailand. The study strengthens academic and practical awareness of the complexity by identifying and examining these barriers.
- The analytical results help policymakers and stakeholders prioritize barriers and strategize effective methods to overcome them.

The remaining sections follow. Section 2 reviews EV adoption barriers discussed in the literature. Section 3 summarizes the research method, and Section 4 presents the analytical results. In Section 5, the research findings are discussed. Finally, Section 6 concludes and plans further work.

2. Literature Review

2.1. Literature Review on EV Adoption

To reduce greenhouse gas emissions that contribute to climate change, several governments have established particular goals to promote the use of EVs in their countries. Despite the benefits, industry and governments must overcome several obstacles and constraints before EVs can be widely adopted [3]. Numerous studies have been conducted to investigate possible barriers to the adoption of EVs. For example, the research by Hosseinpour et al. [5] revealed that the limited driving range and long charging times made the EVs less appealing. The lack of public charging stations, the high purchasing cost, and the social acceptance of behavior change are the major obstacles to the adoption of EVs, and strict regulations and aggressive legislation have been identified to impact the adoption of EVs positively. Adhikari et al. [6] found that a higher purchase price, the absence of charging stations, and long-term strategic planning on the part of the government were the top three barriers to EV adoption using the analytical hierarchical process (AHP) to prioritize these barriers.

In Thailand, Aungkulanon et al. [3] employed the fuzzy analytical hierarchy process (FAHP) to rank a list of obstacles and sub-hindrances to the adoption of EVs. The results showed that the infrastructure policy barrier was the most significant barrier to adopting EVs, followed by technological and market barriers. Thananusak et al. [7] used partial least squares structural equation modeling (PLS-SEM) to test the relationships between financial factors, infrastructure, performance, environmental concerns, and price premiums and the intention to buy EVs in Thailand. Their findings suggested that Thai car buyers paid attention to the performance factor of EVs, while little attention was paid to the infrastructure and financial factors of EVs. Kongklaew et al. [8] conducted 454 surveys of Thai customers to investigate barriers and motivations for the adoption of EVs. The results indicated that the public infrastructure and vehicle performance in terms of charging range and battery life are concerns of Thai customers when they decide to buy EVs. Chinda [9] used exploratory factor analysis (EFA) and structural equation modeling (SEM) approaches to develop several EV adoption constructs and investigate their connection directions.

2.2. Literature Review on Delphi and DEMATEL Methods

Multi-criteria decision making (MCDM) is a technique to tackle complicated problems involving many criteria. It considers opinion-based decision making, an assessment of options, and the impacts each alternative produces [10]. This study applies two MCDM methods (i.e., the Delphi and the decision-making trial and evaluation laboratory (DEMATEL) methods) described below to investigate the research topic.

Delphi method: The Delphi method was first proposed by Dalkey and Helmer [11] and is an organized and iterative procedure that gathers expert opinions from various domains through systematic improvement and anonymous evaluation [12]. The Delphi method offers four main benefits that are believed to be vital to obtaining the thoughtful input of experts [13]. (i) Experts in the subject are involved in group decision-making processes, which are more valid than those made by an individual [14]. (ii) Participants' anonymity and the use of questionnaires prevent issues that are frequently related to group interviews, such as phony persuasion or "deference to authority, impact of oral facilities, reluctance to modify publicized opinions, and bandwagon effects" [15]. (iii) Due to the Delphi process's requirement that group members analyze the issue under study logically and submit written answers, the group's consensus reflects well-reasoned perspectives. (iv) Expert opinions are obtained through the Delphi technique, which can come from a group of people who may live far apart [16]. In particular, the Delphi method is a useful MCDM tool for verifying crucial factors before evaluating them. To prevent uncertainty and difficulty in obtaining the consensus of experts in the iterative open survey process of the traditional Delphi method, Murry Jr. and Hammons [16] presented a modified Delphi method to accelerate opinion convergence by using literature collection to replace the open surveys to construct the evaluation prototype. Therefore, this study utilized the modified Delphi method to obtain the consensus of the experts. Moreover, Kharat et al. [17] used the fuzzy Delphi method to obtain crucial criteria for selecting landfill sites. Nguyen [18] applied the fuzzy Delphi method to acquire valid and reliable attributes through qualitative information.

DEMATEL method: One of the most widely used approaches to establish relationships between criteria is the DEMATEL method. This method divides elements into two quadrants based on two fundamental criteria: cause and effect [19]. The DEMATEL method is an effective tool in the MCDM model due to its advantages. When comparing DEMATEL with other techniques such as the AHP, Best Worst Method, VIKOR (VIekriterijumsko KOmpromisno Rangiranje), and TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), it becomes clear that DEMATEL is superior because it not only identifies the connection between the components but also separates them into two groups: causes and effects. Meanwhile, the remaining techniques ignore the connection between variables [20]. To represent components in a hierarchical sequence, interpretive structural modeling (ISM) and DEMATEL approaches are useful tools for structural modeling. Although DEMATEL measures the effect level on a Likert scale (e.g., 0–4), the ISM classifies variables into four hierarchies [21]. DEMATEL is a better solution than ISM because it analyzes heterogeneous components and illustrates the degree of influence of the elements. Although ISM can identify a structural relationship between elements, this method cannot measure the strength of the correlations. When looking at relationships in a complex structural model, the DEMATEL methodology is recommended [21]. Bhatia et al. [22] adopted the grey-DEMATEL approach to examine external barriers to remanufacturing. Liu et al. [23] applied the fuzzy DEMATEL technique to quantify the cause-and-effect correlations between the various obstacles to China's production and consumption of sustainable food. DEMATEL was used to determine the cause-and-effect link between barriers to the adoption and expansion of food banks in India in the research of Dubey and Tanksale [24].

2.3. MCDM on EV Adoption

Generally, problems related to EVs were considered from an MCDM perspective. Therefore, many researchers have applied the MCDM method to solve research objects. Tarei et al. [25] developed a two-phase hybrid multi-criterion decision-making tool (Best-Worst Method and Interpretative Structural Modeling) to investigate five barriers that hinder the adoption of EVs, including technical barriers, infrastructure barriers, financial barriers, behavioral barriers, and external barriers. The study by Patel et al. [26] provided comparative research on the multi-criteria decision-making techniques CRITIC-COPRAS (Criterion Importance Through Inter-criteria Correlation—Complex Proportional Assessment) and CRITIC-TOPSIS (Criterion Importance Through Inter-criteria Correlation—Technique for Order Preference by Similarity to an Ideal Solution) for the best selection of electric motorcycles. Palevičius et al. [27] employed four MCDM methods (EDAS (Evaluation based on Distance from Average Solution), SAW (Simple Additive Weighting), TOPSIS, and PROMETHEE II (Preference Ranking Organization Method for Enrichment of Evaluations II)) to evaluate the perception of infrastructure by electric car owners. In the context of Malaysia, Asadi et al. [28] used the DEMATEL method to identify environmental concerns, trust in EVs, personal norms, price value, attitudes towards EVs, and subjective norms are the most critical factors influencing the adoption of EVs. For other recent research articles related to EV adoption, please refer to Patil and Majumdar [29], Murugan and Marisamynathan [30], and Pradhan et al. [31].

2.4. Research Gaps

Adopting EVs is an essential method for governments to cut emissions and ensure sustainable transportation; however, research on them has significant gaps:

- Recent quantitative and qualitative research may overlook the validity of barriers due to their interaction. Factors vary by setting and topic of research. Thus, this study employed Delphi to identify Thailand's key EV adoption barriers.
- Previous studies have only examined the challenges of EV adoption from the perspective of experts or owners. However, the perspectives of EV and non-EV owners must be assessed in studies to comprehend the actual scenario.

Despite the widespread use of MCDM methodologies in EV research, few studies in Thailand have identified impediments to EV adoption. This study examines the main challenges to EV adoption in Thailand from the perspectives of EV and non-EV owners. For this, the study focused on the following objectives:

- Identify key barriers to EV adoption in Thailand.
- Utilize the DEMATEL approach to analyze the interrelationships and categorize EV adoption barriers in Thailand into cause-and-effect groups.
- Provide practical feedback on significant impediments for the business and public sectors to build strategy and support policies effectively.

3. Research Method

3.1. Barriers to EV Adoption

She et al. [32] investigated the barriers to the widespread adoption of EVs in the Chinese market and classified them according to vehicle performance, infrastructure, and finances. Similarly, Tarei et al. [25] determined the barriers to the adoption of EVs in India with four barriers: technical, infrastructure, financial, behavioral, and external barriers. In the research by Hosseinpour et al. [5], the authors explored the barriers to widespread adoption of EVs from multiple perspectives, such as technology, social, economic, and political. The five categories Adhikari et al. [6] used to classify the challenges of EVs were technical, social, economic, infrastructure, and policy. Based on an extensive literature review, the authors have identified four aspects and 15 potential barriers significantly hindering customers when purchasing EVs, as summarized in Table 1.

Table 1. Description of EV adoption barriers.

Dimensions	Sub-Barriers	Definition	References
Financial Barriers	F1—High purchase price	Compared to the price of vehicles on the market, the cost of purchasing EVs is higher.	[25,33]
	F2—High maintenance cost	The cost of repair and maintenance of an EV is higher compared to an ICEV.	[6,8]
	F3—High battery replacement cost	The cost of an EV battery is high and must be paid by EV owners.	[6,34]
	F4—Resale value concerns	Concern about an aggressive drop in resale value once used cars are sold.	[8,29]
Technical Barriers	T1—Limited driving range	The limited range on a single charge.	[5,34]
	T2—Long duration of charging	It takes a long time to fully charge an EV.	[8,34]
	T3—Reliability concerns	Fear of the reliability and consistency of EV technology.	[6,8]
	T4—Battery lifespan concerns	Deterioration concerns the battery lifespan.	[8,29]
	T5—Safety concerns	Safety concerns of the battery or electrical component.	[8]
	T6—Lack of available styles and models	Limited availability of different sizes and styles of EVs in the market.	[6,34]
Infrastructure Barriers	I1—Lack of charging station availability	The limited availability of public charging stations.	[8,25]
	I2—Limited charging conditions at the residence	Limited charging conditions in the community due to restrictions.	[8]
	I3—Lack of service and maintenance centers	The limited availability of service and maintenance centers.	[5,6]
Policy Barriers	P1—Lack of government support	Lack of effective government policy to meet customer needs and attract investors.	[5,6]
	P2—Lack of EV awareness	Lack of awareness and understanding of customers of EVs.	[6]

3.2. Research Framework and Methodology

This study aims to examine the barriers to the adoption of EVs by employing a multi-criteria decision-making problem that combines qualitative and quantitative methods to identify critical barriers to EV adoption in Thailand.

Phase 1: The modified Delphi method is implemented in two rounds of qualitative questionnaires.

In Round 1, a group of 4 experts from the Thai automobile industry ranked the importance of barriers that may or may not affect the adoption of EVs in Thailand using a five-level Likert scoring scale. The experts were asked to suggest modifications, additions, or insertions of the criteria mentioned in the questionnaire.

In Round 2, the revised questionnaire based on expert comments was sent to experts along with a summary and analysis of Round 1 responses to finalize the barriers to EV adoption in Thailand.

Following two rounds of surveys, the barriers to EV adoption are identified for further evaluation in the next stage, and the main survey questionnaires are created based on expert consensus.

Phase 2: In this study, the systematic procedure of the DEMATEL method was used to identify critical barriers to EV adoption in Thailand.

Step 1: Each participant was instructed to score the level of direct influence between two factors using a score ranging from 0 to 4; 0 means no influence, 1 means weak influence, 2 means moderate influence, 3 means strong influence, and 4 means very strong influence. The notation x_{ij} indicates the extent to which factor i affects factor j. An $n \times n$ nonnegative matrix denoted as $x^k = \left[x_{ij}^k\right]$ can be created for each respondent, where n represents the number of factors, and k denotes the participant number with $1 \leq k \leq H$. Therefore, $x^1,\ x^2,\ x^3, \ldots,\ x^H$ are the matrices obtained from H participants. To synthesize all the responses from H participants, the average matrix $A = \left[a_{ij}\right]$ can be formulated as follows:

$$a_{ij} = \frac{1}{H}\sum\nolimits_{k=1}^{H} x_{ij}^k \tag{1}$$

Step 2: Calculate the normalized initial direct-relation matrix (D)

$$D = A \times S \tag{2}$$

$$S = \frac{1}{max_{1 \leq i \leq n}\sum\nolimits_{j=1}^{n} a_{ij}}$$

Step 3: Calculate the total relation matrix $T = \left[t_{ij}\right]$

$$T = D(I \times D)^{-1}, \text{ is an identity matrix} \tag{3}$$

The total relation matrix (T) is represented as shown below:

$$T = \begin{bmatrix} t_{11} & \cdots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{n1} & \cdots & t_{nn} \end{bmatrix}_{n \times n}$$

Step 4: Calculate the degree of influence strength. The row summation R_i and column summation C_j can be computed using the following equations.

$$R_i = \sum\nolimits_{j=1}^{n} t_{ij},\ (i = 1,\ 2,\ 3,\ \ldots,\ n) \tag{4}$$

$$C_j = \sum\nolimits_{i=1}^{n} t_{ij},\ (j = 1,\ 2,\ 3,\ \ldots,\ n) \tag{5}$$

The interaction matrix is used to compute the significant indexes $\left(R_i + C_j\right)$ and causal indexes $\left(R_i - C_j\right)$. The value of $\left(R_i + C_j\right)$ illustrates all the effects that are generated and received by factor "i", which indicates the influence of both factor "i" on the entire system and the influence of other system factors on factor "i". On the other hand, the $\left(R_i - C_j\right)$ indicator reveals the net effect that factor "i" has on the system. If the corresponding value of $\left(R_i - C_j\right)$ for factor i is positive, it means that the factor is a cause factor.

4. Research Results

4.1. The Results of Modified Delphi Method

After two rounds of the modified Delphi questionnaire, the dimensions and sub-barriers in the prototype framework are revised and confirmed by the selected panel of automobile panelists in Thailand.

During Round 1, among 15 potential barriers, only "lack of availability of style and model" was evaluated as non-important by over half of the experts. "High purchase price" and "lack of EV awareness" were evaluated as important by 75% of the experts. The other 12 potential barriers were evaluated as important by all experts. The result shows that the average degree of agreement on the "lack of availability of style and model" is lower than the threshold of Round 1 at 55%. Panelists indicated that the customer perception of the style and model of ICEVs and EVs in the Thai market is nearly identical. Therefore, "lack of availability of style and model" should be eliminated.

In Round 2, the survey was revised based on Round 1 results and sent to the same panelists for re-evaluation. All panelists agreed to keep the four dimensions of barriers and fourteen sub-barriers. Table 2 shows the final evaluation results of the expert questionnaire for the EV adoption barrier obtained from the modified Delphi method.

Table 2. The results of the modified Delphi method.

Dimension of Barriers	Sub-Barriers	Agreement	Dimension of Barriers	Sub-Barriers	Agreement
Financial Barriers	F1	80%	Technical Barriers	T1	100%
	F2	80%		T2	75%
	F3	95%		T3	85%
	F4	80%		T4	80%
Infrastructure Barriers	I1	95%		T5	80%
	I2	85%	Policy Barriers	P1	75%
	I3	85%		P2	80%

4.2. The Results of the DEMATEL Method

Based on the modified Delphi method, a pairwise interrelationship comparison questionnaire was distributed to 10 non-EV owners and 10 EV owners in Thailand. Table A1 of Appendix A presents the demographics of the respondents.

After collecting the questionnaires, the response evaluations were used to build the average relationship matrices according to Equation (1) and are shown in Table A2 (Appendix A) for non-EV owners and Table A3 (Appendix A) for EV owners. Then, the normalized direct-relation matrix was constructed by Equation (2). Lastly, we converted the normalized direct relation matrix into a total relation matrix based on Equation (3). The total relation matrices of non-EV owners and EV owners are shown in Table A4 (Appendix A) and Table A5 (Appendix A), respectively. Finally, Equations (4) and (5) were applied to compute the $\left(R_i + C_j\right)$ values and $\left(R_i - C_j\right)$ values. The results are shown in Table 3.

For non-EV owners, barriers with a positive value have a cause feature that influences the effect factors. These cause barriers include P1, F1, T2, I1, I2, I3, and T1. T2 has the highest $\left(R_i + C_j\right)$ values (3.513), followed by T1 and I1. However, effect barriers include T4, F2, F3, P2, T3, T5, and F4. Then, the average value 3.362 of $\left(R_i + C_j\right)$ and the value 0 of $\left(R_i - C_j\right)$ divide the barriers into four quadrants (as shown in Table 4). The first quadrant includes the cause factors $\left(R_i - C_j > 0\right)$ with higher $\left(R_i + C_j\right)$ values. The second quadrant includes the cause factors $\left(R_i - C_j > 0\right)$ with lower $\left(R_i + C_j\right)$ values. The third quadrant contains the effect factors $\left(R_i - C_j < 0\right)$ with lower $\left(R_i + C_j\right)$ values. The fourth quadrant includes the effect factors $\left(R_i - C_j < 0\right)$ with higher $\left(R_i + C_j\right)$ values. Therefore, decision-makers must pay attention to the core factors T2, I1, and T1, then the driving factors P1, F1, I2, and I3.

Table 3. Final results of DEMATEL analysis.

	Non-EV Owners					EV Owners				
	R_i	C_j	$R_i + C_j$	$R_i - C_j$	Class	R_i	C_j	$R_i + C_j$	$R_i - C_j$	Class
					Financial Barriers					
F1	1.805	1.233	3.038	0.573	Cause	1.846	1.381	3.227	0.465	Cause
F2	1.621	1.743	3.365	−0.122	Effect	1.922	1.905	3.827	0.018	Cause
F3	1.627	1.917	3.545	−0.290	Effect	2.245	2.023	4.268	0.222	Cause
F4	1.414	2.374	3.788	−0.960	Effect	1.495	2.764	4.259	−1.269	Effect
					Technical Barriers					
T1	1.844	1.594	3.438	0.251	Cause	1.920	1.838	3.758	0.082	Cause
T2	2.019	1.494	3.513	0.525	Cause	2.032	1.848	3.880	0.185	Cause
T3	1.749	2.227	3.975	−0.478	Effect	1.807	2.339	4.146	−0.532	Effect
T4	2.078	2.080	4.157	−0.002	Effect	2.118	2.735	4.853	−0.616	Effect
T5	1.431	2.056	3.487	−0.626	Effect	1.498	1.749	3.247	−0.252	Effect
					Infrastructure Barriers					
I1	1.891	1.512	3.402	0.379	Cause	2.144	1.551	3.695	0.593	Cause
I2	1.481	1.231	2.712	0.250	Cause	1.676	1.228	2.904	0.448	Cause
I3	1.650	1.405	3.056	0.245	Cause	2.191	1.484	3.675	0.706	Cause
					Policy Barriers					
P1	2.174	1.002	3.176	1.172	Cause	2.057	1.107	3.164	0.949	Cause
P2	1.181	1.591	2.772	−0.410	Effect	1.310	1.890	3.200	−0.580	Effect

Table 4. Results of the four quadrants.

Quadrant	Non-EV Owners	EV Owners	Class	Order Priority
I	T2, I1, T1	I3, I1, F3, T2, T1, F2	Core Factor	First
II	P1, F1, I2, I3	P1, F1, I2	Driving Factor	Second
III	P2	T5, P2	Independent Factor	Fourth
IV	F2, F3, T3, T5, F4, T4	T3, T4, F4	Impact Factor	Third

Similarly, for EV owners, cause barriers to the perception of EV owners include P1, I3, I1, F1, I2, F3, T2, T1, and F2. Among these, F3 has the highest $(R_i + C_j)$ value (4.268), followed by T2 and F2. However, barriers with an effect characteristic included T5, P2, T3, T4, and F4. Furthermore, the average value 3.665 of $(R_i + C_j)$ and the value 0 of $(R_i - C_j)$ divide the barriers into four quadrants, as displayed in Table 4. Therefore, decision-makers must first pay attention to I3, I1, F3, T2, T1, and F2.

5. Discussion

5.1. Discussion of the Results

A complete Delphi and DEMATEL framework is employed to examine EV adoption barriers in Thailand. A survey of four experts found that the most critical obstacles to the adoption of EVs by individuals were financial, technical, infrastructure, and policy. Based on the customer's perspective, the study's findings concluded that technical criteria are the most critical barriers that hinder customer adoption of EVs (Table 5). Specifically, T2 and T1 were cause barriers in both EV and non-EV owners. Furthermore, this study found that I1 was a crucial barrier for both groups of customers. As a result, both groups of customers had a similar perception of the adoption barriers of EVs in Thailand. Our results align with much research that emphasizes long charging duration, limited driving range, and lack of charging stations as crucial barriers to EV adoption [25,30,35].

Table 5. Significant barriers for both groups.

Significant Cause Barriers	Non-EV Owners	EV Owners
T2—Long duration of charging	✓	✓
T1—Limited driving range	✓	✓
I1—Lack of charging station availability	✓	✓
F2—High maintenance cost		✓
F3—High battery replacement cost		✓
I3—Lack of service and maintenance centers		✓

Meanwhile, EV owners worry not only about T2, T1, and I1 but also about F2, F3, and I3, which makes them concerned when using EVs. EV owners pay more attention to maintenance costs, battery replacement costs, and service and maintenance centers than non-EV owners since these barriers directly impact the ownership of an EV, making these barriers more important for the EV owner's perception. Compared to other studies conducted in the context of Thailand, the findings of this research differ slightly. Kongklaew et al. [8] indicated that the top three concerns of the respondents about EVs in Thailand were public infrastructure and vehicle performance, such as public infrastructure availability, highway infrastructure availability, public infrastructure range on charge, battery life, and safety. According to the research by Adhikari et al. [6], Thai customers' primary concern regarding the adoption of EVs was not just the lack of charging spots but also impediments to price and government policy. The results of the research by Thananusak et al. [7] revealed that Thai auto consumers focus more on the performance characteristics of EVs, such as speed, range, and safety, than on infrastructure, such as charging stations, and financial considerations, such as the cost of acquisition, maintenance, and eventual resale value. Differences in context, time, and research subjects can explain the discrepancy.

5.2. Comparisons with Research in Other Markets

Haddadian et al. [36] discussed significant economic, societal, technological, and political barriers to the large-scale adoption and deployment of EVs. Although many barriers are region-specific, innovative business models are critical to encourage private investments along with public sector policies and incentives to create a growing EV market [36]. Kuo et al. [37] investigated the relationship between EV adoption barriers from an automotive industry perspective. The highest-weighted barrier was battery capacity and lifespan, followed by government support, the impacts of tax and subsidy policies, and high costs. Their research indicated that battery capacity and lifespan not only had the highest weighting but also the highest influence on other barriers according to the DEMATEL result.

By the end of 2022, the electric vehicle market in the United States was only 8% [38]. Pamidimukkala et al. [38] investigated how customers perceived electric vehicles and the potential technological, environmental, financial, and infrastructure barriers to EV adoption in the United States. The results indicated that the high purchase price, insufficient public stations, and high battery replacement cost were of most concern. Most respondents were concerned about the EV price and public infrastructure. The high purchase price ranked number one, in line with other studies [39,40].

She et al. [32] classified the barriers to EV adoption in the context of China into three categories: financial, vehicle performance, and infrastructure. Safety, reliability, and range per charge were the top three concerns, and high battery cost was the main technological barrier to widespread EV adoption. The respondents concerned with vehicle performance had a significantly lower EV acceptance. Recently, Shen et al. [41] identified the restricting factors for promoting EVs in China. The results indicated that the top five factors are security issues, limited driving range, long charging time, improper distribution of charging stations, and lack of sharing between charging piles.

Consumers in various markets have different considerations in EV acceptance. Stakeholders could initiate changes to EVs, which would help overcome the adoption barriers and attract increasing consumers.

5.3. Managerial Implications

This research found that T2, T1, and I1 were critical barriers to EV adoption in Thailand for EV and non-EV owners. Therefore, stakeholders must pay attention to these barriers to improve customers' adoption of EVs. To address the long charging time barrier, EV companies should invest in high-power charging infrastructure, such as DC fast charging stations, research and develop ultra-fast charging technologies, and improve battery thermal management systems. Additionally, Vehicle-to-Grid technology enables bidirectional charging, allowing EVs to consume energy and feed energy back to the grid. Additionally, the use of efficient battery management systems helps optimize the use of battery capacity and improve overall energy efficiency. By providing accurate and transparent information to customers, educating consumers about the actual range of driving of electric vehicles minimizes range anxiety, establishes realistic expectations, and builds customer confidence.

Charging infrastructure is a very complex part of EV planning. Hatt et al. [42] revealed that charging station availability issues significantly impact EV adoption, reinforcing our strategic considerations for improving charging infrastructure. Due to the lack of an existing charging infrastructure in Thailand, electric vehicle sales are low. Governments, utilities, and private companies should collaborate to invest in developing charging infrastructure, particularly in urban areas, highways, commercial centers, and residential areas. They should install fast charging stations along major transportation routes and in key destinations such as shopping centers, restaurants, and tourist attractions. Standardizing charging protocols, connector types, and payment systems is crucial to ensure compatibility and ease of use for EV owners. Smart charging solutions should be implemented that consider grid load, renewable energy availability, and time-of-use pricing to schedule charging sessions when electricity demand is low or renewable energy generation is high.

Since EVs are still being developed in Thailand, the long charging duration and limited driving range are significant barriers with causal elements for both customer groups, demonstrating that both groups have worries about EV technology's reliability. The car industry and related industries must improve EV technology by increasing the availability of charging stations and home charging conditions. The industry might also actively develop battery materials and energy storage technologies to meet driving range and charging time demands. Substantial investment in research and development is imperative to enhance EV battery technology. This entails improving charging time, enabling faster and more convenient charging experiences. Advancements in battery energy density and capacity will also address concerns regarding limited driving range, providing potential buyers with reassurance. Geny's [43] research aligns with our identified barriers, limited driving range and long duration of charging, emphasizing the critical role of pricing and charging infrastructure in influencing consumer purchase decisions, thus supporting our strategic considerations. The government can play a pivotal role by implementing regulations and incentivizing automakers to invest in battery technology research and development. Such measures may include tax incentives, grants, or subsidies, which will foster innovation, drive down battery costs, and ultimately increase the affordability of EVs for consumers. Drawing on Jabbari et al. [44], we substantiate our strategy-related discussions by highlighting consumer dissatisfaction as a barrier to EV adoption, particularly emphasizing the impact of policy, in accordance with our identified barrier, impediments to government policy. Moreover, the lack of charging stations in Thailand hinders EV adoption. Hence, the government and related sectors should prioritize charging infrastructure support programs to increase the adoption of EVs and consumer satisfaction and make EVs a better alternative to ICEVs.

In order to enhance the attractiveness of EVs as a sustainable mode of transportation, it is paramount to address the significant barriers identified in this study. Collaboration between the government and the automobile industry is crucial for improving EV infrastructure, for instance, expanding the existing charging station network and establishing a comprehensive system of service and maintenance centers dedicated to EVs. By strategically locating charging stations in urban areas and along major highways, customers will have convenient access to charging facilities, alleviating concerns regarding the limited availability of charging stations. Additionally, specialized service and maintenance centers will reduce maintenance costs and offer reliable and efficient services to customers, thereby instilling confidence in EV technology.

The widespread adoption of EVs in Thailand can be fostered by undertaking these necessary measures, leading to a cleaner and more sustainable transportation system. The availability of accessible charging infrastructure, reliable service and maintenance centers, improved battery technology, and supportive government policies will collectively enhance the appeal of EVs, positioning them as an attractive and viable choice for consumers seeking environmentally friendly transportation options.

Furthermore, recycling becomes crucial when electric vehicles are retired, especially for larger batteries with higher material costs. Contrary to being considered waste, these batteries, with a lifespan of over ten years, can be repurposed as second-hand batteries and utilized as backup power sources. The Thai government is currently working on establishing standards for second-hand batteries, determining their classification as waste or as a product. This approach aligns with environmentally friendly practices, avoiding a waste stream more burdensome than carbon dioxide emissions during disposal and recycling. The Thai government actively supports the establishment of battery recycling factories, encouraging entrepreneurs through incentives and other measures to contribute to responsible and sustainable disposal practices in Thailand.

5.4. Theoretical Implications

Governments worldwide are promoting the adoption of electric vehicles to reduce greenhouse gas emissions, reduce dependence on fossil fuels, and highlight the growing importance of electric vehicles in national transportation policy. Many other approaches are being taken in all countries to promote the use of electric cars, but this process faces many challenges. This research contributes to improving understanding of the multifaceted nature of EV adoption barriers and their interdependence in policy and decision-making. First, our findings provide empirical support for the existing theoretical framework for the adoption of EVs. This study confirms that there are financial, technical, infrastructure, and policy barriers to the adoption of EVs. Second, this research extends the understanding of EV adoption by investigating the perception of non-EV owners and EV owners. The results show that both groups are concerned about charging time, driving range, and lack of availability of charging stations as barriers that prevent them from adopting EVs. Furthermore, our study provides a set of verified barriers to EV adoption and the interrelationship between them in Thailand.

6. Conclusions

The adoption of EVs is of great significance for environmental protection. The present study used the modified Delphi method to confirm the barriers to the adoption of EVs in the context of Thailand. This study proposes an initial set of attributes of four aspects and 15 barriers. The results show that 14 barriers have been accepted, and four dimensions remain. The DEMATEL method was then applied to classify barriers into cause and effect groups. Furthermore, this method also determined the interrelationship between these barriers and prioritized the four group barriers. The findings revealed that among the four aspects, the significant cause barriers assigned by both EV owners and non-EV owners were T2—Long duration of charging, T1—Limited driving range, and I1—Lack of charging station availability. This highlights the importance of the technical aspect in the EV customers' perceptions.

To promote EVs as sustainable transportation, the auto industry and government must deal with the primary obstacles found in this study. Increasing EV adoption in Thailand will create a greener, more sustainable transportation system. EVs will appeal to environmentally conscious consumers due to accessible charging infrastructure, reliable service and repair centers, improved battery technology, and support for government legislation.

This study primarily focuses on uncovering barriers to EV adoption in Thailand, providing valuable insights into the specific challenges within the local context. While this targeted approach allows for a detailed analysis of Thailand's EV market, future research could explore broader global comparisons for a more comprehensive understanding of how global manufacturers navigate challenges in different regions. Notably, the Thai EV market is relatively small compared to global counterparts such as China and USA. However, the Thai government's strong commitment and guidelines for developing the EV industry and fostering EV adoption in Thai society indicate a proactive stance towards overcoming barriers and promoting sustainable transportation practices. For future research, it would be beneficial to delve deeper into factors unique to Thailand's context and conduct comparative studies with other regional countries, focusing on issues such as customers' changing behavior and specific barriers within Thailand's EV market. Exploring these aspects can provide a more nuanced understanding of the challenges. Additionally, incorporating insights from a diverse group of experts in both the EV and combustion fields would enrich the research, bringing varied perspectives and fostering a comprehensive analysis of the factors influencing EV adoption in Thailand.

Author Contributions: Conceptualization, J.-F.T., S.-C.W. and P.K.; methodology, J.-F.T., S.-C.W. and P.K.; software, P.K., T.-H.T. and M.-H.L.; validation, J.-F.T., P.K., T.-H.T. and M.-H.L.; formal analysis, P.K., T.-H.T. and M.-H.L.; investigation, J.-F.T., S.-C.W., T.-H.T. and M.-H.L.; resources, P.K., T.-H.T. and M.-H.L.; data curation, P.K. and T.-H.T.; writing—original draft preparation, P.K., T.-H.T. and M.-H.L.; writing—review and editing, J.-F.T. and M.-H.L.; supervision, J.-F.T. and M.-H.L.; project administration, J.-F.T.; funding acquisition, J.-F.T. and M.-H.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported in part by the National Science and Technology Council in Taiwan under Grants NSTC 111-2410-H-027-006, NSTC 112-2410-H-027-005-MY2, and NSTC 111-2410-H-845-012-MY2.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available on request due to privacy restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Participant demographics.

		Non-EV Owners	EV Owners			Non-EV Owners	EV Owners
Gender	Men	70%	80%	Age	21–30	20%	40%
	Woman	30%	20%		31–40	30%	40%
Educational level	Bachelor	80%	70%		41–50	40%	20%
	Master	20%	30%		51–60	10%	0%

Table A2. Average direct relation matrix of non-EV owners.

	F1	F2	F3	F4	T1	T2	T3	T4	T5	I1	I2	I3	P1	P2
F1	0	2.500	2.750	2.875	2.625	1.123	0.875	1.250	1.500	1.750	1.250	2.250	2.000	2.500
F2	2.000	0	2.750	3.000	0.375	1.125	2.250	2.250	1.875	0.750	0.500	2.250	1.000	1.250
F3	2.875	3.500	0	2.500	0.750	0.875	2.125	2.500	1.750	0.375	0.375	1.250	1.000	1.875
F4	1.000	1.875	1.125	0	0.625	0.625	2.625	2.375	1.875	1.000	0.875	1.500	0.375	1.225
T1	1.120	0.875	1.750	2.625	0	2.750	3.000	2.750	1.875	3.000	1.500	1.000	0.875	1.250
T2	1.125	1.000	2.125	3.250	2.250	0	2.625	3.500	1.821	2.875	2.250	1.375	0.875	1.625
T3	0.875	1.500	1.350	3.875	1.875	1.429	0	3.000	3.500	1.125	1.000	1.000	0.625	1.250
T4	1.375	1.250	1.375	3.500	3.625	3.125	3.250	0	2.500	1.250	1.250	0.875	0.625	1.875
T5	1.000	1.875	1.500	2.125	1.250	1.000	3.500	1.000	0	0.250	1.250	1.625	1.125	1.500
I1	0.625	0.625	1.000	2.875	2.875	2.500	1.875	1.500	1.375	0	1.975	1.750	2.125	1.875
I2	0.250	0.625	0.875	1.375	2.875	2.750	1.725	2.500	1.250	2.000	0	0.875	0.625	0.750
I3	0.625	2.750	2.875	3.250	1.250	0.875	2.125	1.750	2.500	1.250	1.125	0	0.625	1.250
P1	3.250	3.000	3.125	1.175	1.125	1.125	1.520	0.875	1.875	3.500	1.750	2.750	0	3.250
P2	0.125	2.500	0.125	1.750	0.500	0.625	1.951	1.875	1.925	0.750	1.125	0.375	1.625	0

Table A3. Average direct relation matrix of EV owners.

	F1	F2	F3	F4	T1	T2	T3	T4	T5	I1	I2	I3	P1	P2
F1	0	2.250	2.625	3.000	1.375	1.125	0.625	1.500	0.750	1.125	1.000	1.625	1.500	2.125
F2	1.625	0	3.000	3.375	0.625	0.875	1.750	3.125	1.075	0.625	0.625	1.875	1.125	1.250
F3	3.750	3.625	0	3.625	0.500	0.625	2.250	3.375	0.875	0.500	0.500	1.250	1.000	2.125
F4	0.625	1.500	1.375	0	0.750	0.750	2.250	2.750	2.000	0.750	0.625	1.250	0.500	1.125
T1	0.750	0.875	1.325	2.625	0	2.375	2.625	2.750	1.000	2.500	1.000	0.875	1.000	1.250
T2	0.500	0.875	1.125	3.000	1.750	0	2.375	3.375	1.300	2.500	1.750	1.250	0.750	1.625
T3	0.750	1.375	1.400	2.750	1.625	1.375	0	2.875	2.625	1.375	1.000	1.000	0.625	1.125
T4	0.875	1.325	1.425	3.375	1.550	1.325	2.875	0	1.750	1.125	1.250	0.875	0.625	1.575
T5	0.750	1.625	1.250	1.875	1.250	1.000	3.625	1.250	0	0.375	0.875	1.250	1.125	1.120
I1	1.000	0.875	1.125	2.875	3.250	3.250	1.625	1.625	0.750	0	1.500	1.375	1.375	1.875
I2	0.375	0.625	1.000	1.375	3.000	3.375	1.550	2.000	0.875	2.250	0	0.875	0.625	0.625
I3	0.875	3.625	3.375	3.125	1.125	1.000	2.375	1.875	2.125	1.125	1.000	0	0.625	1.000
P1	3.000	1.625	2.625	0.875	0.875	0.875	1.250	0.875	1.125	3.250	1.000	2.125	0	2.875
P2	0.500	0.500	0.625	2.625	0.875	0.750	2.250	2.250	2.125	1.000	1.375	0.750	1.250	0

Table A4. Total relation matrix of non-EV owners.

	F1	F2	F3	F4	T1	T2	T3	T4	T5	I1	I2	I3	P1	P2
F1	0.062	0.153	0.167	0.205	0.116	0.101	0.142	0.135	0.119	0.114	0.092	0.129	0.103	0.144
F2	0.109	0.081	0.159	0.197	0.077	0.092	0.164	0.150	0.120	0.078	0.065	0.121	0.070	0.104
F3	0.133	0.172	0.089	0.187	0.087	0.087	0.162	0.158	0.105	0.070	0.062	0.098	0.072	0.121
F4	0.075	0.118	0.113	0.105	0.078	0.074	0.163	0.143	0.118	0.077	0.069	0.093	0.048	0.094
T1	0.090	0.107	0.119	0.203	0.082	0.149	0.198	0.178	0.118	0.150	0.103	0.095	0.073	0.111
T2	0.096	0.120	0.160	0.232	0.150	0.085	0.202	0.207	0.116	0.153	0.128	0.112	0.078	0.129
T3	0.083	0.113	0.102	0.228	0.120	0.109	0.118	0.178	0.191	0.097	0.084	0.093	0.063	0.108
T4	0.106	0.101	0.117	0.243	0.182	0.166	0.223	0.122	0.183	0.114	0.103	0.102	0.072	0.137
T5	0.075	0.118	0.116	0.162	0.092	0.083	0.185	0.110	0.083	0.061	0.079	0.097	0.068	0.101
I1	0.075	0.098	0.119	0.203	0.153	0.140	0.167	0.143	0.119	0.072	0.120	0.113	0.103	0.125
I2	0.055	0.083	0.101	0.147	0.145	0.138	0.097	0.154	0.117	0.114	0.052	0.078	0.056	0.083
I3	0.074	0.152	0.163	0.205	0.101	0.089	0.165	0.141	0.160	0.092	0.082	0.063	0.061	0.103
P1	0.158	0.181	0.195	0.098	0.120	0.115	0.109	0.145	0.113	0.172	0.118	0.157	0.062	0.180
P2	0.043	0.062	0.066	0.120	0.066	0.065	0.118	0.116	0.109	0.065	0.070	0.055	0.074	0.050

Table A5. Total relation matrix of EV owners.

	F1	F2	F3	F4	T1	T2	T3	T4	T5	I1	I2	I3	P1	P2
F1	0.051	0.130	0.144	0.191	0.099	0.092	0.107	0.139	0.083	0.085	0.070	0.097	0.080	0.121
F2	0.096	0.072	0.155	0.204	0.081	0.087	0.139	0.183	0.108	0.070	0.060	0.104	0.069	0.099
F3	0.158	0.177	0.086	0.226	0.085	0.087	0.161	0.202	0.097	0.073	0.062	0.095	0.072	0.131
F4	0.056	0.095	0.095	0.089	0.073	0.072	0.135	0.152	0.106	0.063	0.052	0.075	0.044	0.081
T1	0.068	0.090	0.106	0.184	0.069	0.133	0.163	0.174	0.093	0.126	0.073	0.076	0.066	0.099
T2	0.062	0.093	0.105	0.199	0.122	0.074	0.163	0.195	0.105	0.128	0.096	0.088	0.061	0.111
T3	0.068	0.104	0.101	0.183	0.104	0.102	0.092	0.174	0.133	0.091	0.070	0.078	0.055	0.093
T4	0.075	0.106	0.102	0.215	0.101	0.106	0.182	0.113	0.120	0.096	0.084	0.082	0.060	0.099
T5	0.061	0.101	0.096	0.144	0.087	0.080	0.173	0.118	0.055	0.057	0.060	0.078	0.063	0.083
I1	0.077	0.093	0.106	0.196	0.159	0.160	0.142	0.151	0.089	0.064	0.090	0.093	0.079	0.119
I2	0.052	0.075	0.090	0.140	0.146	0.157	0.106	0.146	0.082	0.118	0.042	0.071	0.052	0.075
I3	0.082	0.176	0.173	0.210	0.099	0.096	0.166	0.163	0.128	0.088	0.074	0.058	0.060	0.097
P1	0.137	0.120	0.150	0.146	0.094	0.093	0.128	0.128	0.097	0.147	0.075	0.115	0.044	0.148
P2	0.051	0.066	0.074	0.158	0.078	0.074	0.136	0.138	0.111	0.073	0.073	0.062	0.065	0.050

References

1. Sakashita, W.; Miyahara, H.; Yokoyama, Y.; Aze, T.; Nakatsuka, T.; Hoshino, Y.; Ohyama, M.; Yonenobu, H.; Takemura, K. The Physical Science Basis. In *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2023; Volume 455, pp. 1–7.
2. Khalili, S.; Rantanen, E.; Bogdanov, D.; Breyer, C. Global Transportation Demand Development with Impacts on the Energy Demand and Greenhouse Gas Emissions in a Climate-Constrained World. *Energies* **2019**, *12*, 3870. [CrossRef]
3. Aungkulanon, P.; Atthirawong, W.; Luangpaiboon, P. Fuzzy Analytical Hierarchy Process for Strategic Decision Making in Electric Vehicle Adoption. *Sustainability* **2023**, *15*, 7003. [CrossRef]
4. Next-Generation Automotive Research Center. MReport Newly Registered Electric Vehicles (XEV) in March 2022. Available online: https://www.mreport.co.th/en/news/statistic-and-ranking/320-new-electric-vehicles-registration-2022-march (accessed on 10 December 2023).
5. Hosseinpour, S.; Chen, H.; Tang, H. Barriers to the Wide Adoption of Electric Vehicles: A Literature Review Based Discussion. In Proceedings of the Portland international conference on management of engineering and technology (PICMET), Portland, OR, USA, 2–6 August 2015; pp. 2329–2336.
6. Adhikari, M.; Ghimire, L.P.; Kim, Y.; Aryal, P.; Khadka, S.B. Identification and Analysis of Barriers against Electric Vehicle Use. *Sustainability* **2020**, *12*, 4850. [CrossRef]
7. Thananusak, T.; Rakthin, S.; Tavewatanaphan, T.; Punnakitikashem, P. Factors Affecting the Intention to Buy Electric Vehicles: Empirical Evidence from Thailand. *Int. J. Electr. Hybrid Veh.* **2017**, *9*, 361–381. [CrossRef]
8. Kongklaew, C.; Phoungthong, K.; Prabpayak, C.; Chowdhury, M.S.; Khan, I.; Yuangyai, N.; Yuangyai, C.; Techato, K. Barriers to Electric Vehicle Adoption in Thailand. *Sustainability* **2021**, *13*, 12839. [CrossRef]
9. Chinda, T. Interrelationships among Factors Influencing Electric Vehicle Adoption in Thailand. *Songklanakarin J. Sci. Technol.* **2023**, *45*, 476–482.
10. Ashok, B.; Kannan, C.; Usman, K.M.; Vignesh, R.; Deepak, C.; Ramesh, R.; Narendhra, T.M.V.; Kavitha, C. Transition to Electric Mobility in India: Barriers Exploration and Pathways to Powertrain Shift through MCDM Approach. *J. Inst. Eng. Ser. C* **2022**, *103*, 1251–1277. [CrossRef]
11. Dalkey, N.; Helmer, O. An Experimental Application of the Delphi Method to the Use of Experts. *Manag. Sci.* **1963**, *9*, 458–467. [CrossRef]
12. Linstone, H.A.; Turoff, M. Delphi: A Brief Look Backward and Forward. *Technol. Forecast. Soc. Change* **2011**, *78*, 1712–1719. [CrossRef]
13. Shen, Y.C.; Lin, G.T.R.; Tzeng, G.H. Combined DEMATEL Techniques with Novel MCDM for the Organic Light Emitting Diode Technology Selection. *Expert Syst. Appl.* **2011**, *38*, 1468–1481. [CrossRef]
14. Brooks, K.W. Delphi Technique: Expanding Applications. *North Cent. Assoc. Q.* **1979**, *53*, 377–385.
15. Martorella, P.H. Consensus Building among Social Educators: A Delphi Study. *Theory Res. Soc. Educ.* **1991**, *19*, 83–94. [CrossRef]
16. Murry, J.W., Jr.; Hammons, J.O. Delphi: A Versatile Methodology for Conducting Qualitative Research. *Rev. High. Educ.* **1995**, *18*, 423–436. [CrossRef]
17. Kharat, M.G.; Kamble, S.J.; Raut, R.D.; Kamble, S.S. Identification and Evaluation of Landfill Site Selection Criteria Using a Hybrid Fuzzy Delphi, Fuzzy AHP and DEMATEL Based Approach. *Model. Earth Syst. Environ.* **2016**, *2*, 1–13. [CrossRef]
18. Nguyen, P.H. Spherical Fuzzy Decision-Making Approach Integrating Delphi and TOPSIS for Package Tour Provider Selection. *Math. Probl. Eng.* **2022**, *2022*, 4249079. [CrossRef]
19. Gardas, B.B.; Raut, R.D.; Narkhede, B. Modelling the Challenges to Sustainability in the Textile and Apparel (T&A) Sector: A Delphi-DEMATEL Approach. *Sustain. Prod. Consum.* **2018**, *15*, 96–108. [CrossRef]

20. Sonar, H.; Belal, H.M.; Foropon, C.; Manatkar, R.; Sonwaney, V. Examining the Causal Factors of the Electric Vehicle Adoption: A Pathway to Tackle Climate Change in Resource-Constrained Environment. *Ann. Oper. Res.* **2023**, 1–27. [CrossRef]
21. Farooque, M.; Jain, V.; Zhang, A.; Li, Z. Fuzzy DEMATEL Analysis of Barriers to Blockchain-Based Life Cycle Assessment in China. *Comput. Ind. Eng.* **2020**, *147*, 106684. [CrossRef]
22. Bhatia, M.S.; Srivastava, R.K. Analysis of External Barriers to Remanufacturing Using Grey-DEMATEL Approach: An Indian Perspective. *Resour. Conserv. Recycl.* **2018**, *136*, 79–87. [CrossRef]
23. Liu, Y.; Wood, L.C.; Venkatesh, V.G.; Zhang, A.; Farooque, M. Barriers to Sustainable Food Consumption and Production in China: A Fuzzy DEMATEL Analysis from a Circular Economy Perspective. *Sustain. Prod. Consum.* **2021**, *28*, 1114–1129. [CrossRef]
24. Dubey, N.; Tanksale, A. A Study of Barriers for Adoption and Growth of Food Banks in India Using Hybrid DEMATEL and Analytic Network Process. *Socio-Econ. Plan. Sci.* **2022**, *79*, 101124. [CrossRef]
25. Tarei, P.K.; Chand, P.; Gupta, H. Barriers to the Adoption of Electric Vehicles: Evidence from India. *J. Clean. Prod.* **2021**, *291*, 125847. [CrossRef]
26. Patel, A.; Jha, S.; Soni, R.; Fuse, K. Comparative Study of MCDM Techniques COPRAS and TOPSIS for Selection of Electric Motorcycles. In Proceedings of the 2020 IEEE 7th International Conference on Industrial Engineering and Applications (ICIEA), Bangkok, Thailand, 16–21 April 2020; pp. 16–21.
27. Palevičius, V.; Podviezko, A.; Sivilevičius, H.; Prentkovskis, O. Decision-Aiding Evaluation of Public Infrastructure for Electric Vehicles in Cities and Resorts of Lithuania. *Sustainability* **2018**, *10*, 904. [CrossRef]
28. Asadi, S.; Nilashi, M.; Iranmanesh, M.; Ghobakhloo, M.; Samad, S.; Alghamdi, A.; Almulihi, A.; Mohd, S. Drivers and Barriers of Electric Vehicle Usage in Malaysia: A DEMATEL Approach. *Resour. Conserv. Recycl.* **2022**, *177*, 105965. [CrossRef]
29. Patil, M.; Majumdar, B.B. Prioritizing Key Attributes Influencing Electric Two-Wheeler Usage: A Multi Criteria Decision Making (MCDM) Approach—A Case Study of Hyderabad, India. *Case Stud. Transp. Policy* **2021**, *9*, 913–929. [CrossRef]
30. Murugan, M.; Marisamynathan, S. Analysis of Barriers to Adopt Electric Vehicles in India Using Fuzzy DEMATEL and Relative Importance Index Approaches. *Case Stud. Transp. Policy* **2022**, *10*, 795–810. [CrossRef]
31. Pradhan, P.; Shabbiruddin; Pradhan, S. Selection of Electric Vehicle Using Integrated Fuzzy-MCDM Approach with Analysis on Challenges Faced in Hilly Terrain. *Energy Sources A Recovery Util. Environ. Eff.* **2022**, *44*, 2651–2673. [CrossRef]
32. She, Z.Y.; Sun, Q.; Ma, J.J.; Xie, B.C. What Are the Barriers to Widespread Adoption of Battery Electric Vehicles? A Survey of Public Perception in Tianjin, China. *Transp. Policy* **2017**, *56*, 29–40. [CrossRef]
33. Kumar, R.; Jha, A.; Damodaran, A.; Bangwal, D.; Dwivedi, A. Addressing the Challenges to Electric Vehicle Adoption via Sharing Economy: An Indian Perspective. *Manag. Environ. Qual. Int. J.* **2021**, *32*, 82–99. [CrossRef]
34. Moeletsi, M.E. Socio-Economic Barriers to Adoption of Electric Vehicles in South Africa: Case Study of the Gauteng Province. *World Electr. Veh. J.* **2021**, *12*, 167. [CrossRef]
35. Muzir, N.A.Q.; Mojumder, M.R.H.; Hasanuzzaman, M.; Selvaraj, J. Challenges of Electric Vehicles and Their Prospects in Malaysia: A Comprehensive Review. *Sustainability* **2022**, *14*, 8320. [CrossRef]
36. Haddadian, G.; Khodayar, M.; Shahidehpour, M. Accelerating the Global Adoption of Electric Vehicles: Barriers and Drivers. *Electr. J.* **2015**, *28*, 53–68. [CrossRef]
37. Kuo, T.-C.; Shen, Y.-S.; Sriwattana, N.; Yeh, R.-H. Toward Net-Zero: The Barrier Analysis of Electric Vehicle Adoption and Transition Using ANP and DEMATEL. *Processes* **2022**, *10*, 2334. [CrossRef]
38. Pamidimukkala, A.; Kermanshachi, S.; Rosenberger, J.M.; Hladik, G. Evaluation of barriers to electric vehicle adoption: A study of technological, environmental, financial, and infrastructure factors. *Transp. Res. Interdiscip. Perspect.* **2023**, *22*, 100962. [CrossRef]
39. Giansoldati, M.; Monte, A.; Scorrano, M. Barriers to the adoption of electric cars: Evidence from an Italian survey. *Energy Policy* **2020**, *146*, 111812. [CrossRef]
40. Noel, L.; de Rubens, G.Z.; Kester, J.; Sovacool, B.K. Understanding the sociotechnical nexus of Nordic electric vehicle (EV) barriers: A qualitative discussion of range, price, charging and knowledge. *Energy Policy* **2020**, *138*, 111292. [CrossRef]
41. Shen, L.; Chen, Z.; Dou, X.; Xu, X.; Cao, Z.; Liao, S. Restricting factors for promoting electric vehicles: Evidence from China, Transp. *Policy* **2024**, *148*, 234–245. [CrossRef]
42. Hatt, K.; Wilson, B.; Butt, P. *Benefits and Barriers to Electric Vehicle Adoption in the City of Guelph*; University of Guelph: Guelph, ON, Canada, 2020.
43. Geny, V. Key factors influencing Electric Vehicles adoption: A multidimensional meta-analysis. Master's Thesis, Blekinge Institute of Technology, Karlskrona, Sweden, 2021.
44. Jabbari, P.; Chernicoff, W.; MacKenzie, D. Analysis of Electric Vehicle Purchaser Satisfaction and Rejection Reasons. *Transp. Res. Rec. J. Transp. Res. Board* **2017**, *2628*, 110–119. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.