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Prioritizing Target Motorcycle Owners to Promote Electric Vehicles Among Motorcycle Taxi Drivers in Bangkok

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ABSTRACT

Governments in many countries have announced their own emission targets and launched several measures to mitigate transport-sourced air pollution, including policies to promote the use of electric vehicles (EVs). However, electrifying a fleet of vehicles requires high investment and it is difficult to fully implement all at once. Therefore, this research aims to develop a framework to help prioritize locations to promote EVs using motorcycle taxis in Bangkok as a case study. The surveyed data was collected from 406 motorcycle taxi drivers around Bangkok. The proposed framework is based on two aspects. One is the impact on CO_2 emission reduction while another is the difficulty of EV deployment. The study's findings yield a potential matrix for EV deployment, which classifies locations into four priority groups. The study concludes that prioritizing locations with high CO2 reduction impact and low deployment difficulty is crucial for efficient EV promotion. Subsequently, recommendations are offered to assist authorities and automobile firms in effectively allocating resources for EV promotion. Policy recommendations highlight the significance of targeted interventions and enhancing public awareness to facilitate the widespread adoption of electric motorcycle. Implications from this study will help the authorities and automobile firms to prioritize areas and allocate budgets for promoting EVs efficiently.

Keywords: electric vehicle, vehicle electrification, motorcycle taxi, Bangkok

INTRODUCTION

Air pollution is one of the major environmental problems around the world, especially in mega cities. One of the main sources of air pollution is the transport sector. In many developing countries, vehicle emissions cause 30%-60% of total air pollution (Shi et al., 2016). Globally, 16.2% of greenhouse gas emissions come from the transport sector (Ritchie et al., 2020). In 2021, the average GHG emission per year in Thailand was 250 Mt while the CO2 emission per capita was 3.68 tons. Almost one-third of these emissions were from the transport sector (Energy Policy and Planning Office [EPPO], 2022). The air pollution problem has been critical issue in Thailand for decades (Phosri et al., 2019). More than 30,000 premature deaths have been caused from ambient air pollution (World Health Organization [WHO], 2022).

Governments around the world have been trying to mitigate transport-source air pollution by adopting various policy initiatives, which can be grouped into two areas (Pew Center, 2008). The first area is policy options related to addressing the amount and type of fuel used for transportation, e.g., renewable fuel policies and low carbon fuel standards (Quirapas et al., 2015). The second area is policy options related to travel distance reduction, e.g., public transport system efficiency improvement, increasing vehicle occupancy rate, and improving land vehicle efficiency and vehicle technology development, including electric vehicles (EVs). This is because EVs are more environmentally-friendly, energy-efficient, and help to reduce noise pollution (Chhikara et al., 2021; Ghosh, 2020).

Although there were barriers to EV adoption in the past, e.g. EV performance (e.g., driving range, speed, etc.), EV technologies, including battery technology has been improved (Hu et al., 2014), which has led to the increasing of EVs in recent years. In addition, with severe environmental concerns and an energy crisis, EVs have become more popular over the last few years. In 2020, EV registration around the world increased by 41% and it is predicted to increase by more than 35.6% each year from 2019 to 2026 (Sathiyan et al., 2022). However, the current EV adoption rate has been relatively slow. To accelerate the replacement of internal combustion vehicles (ICEs) with battery electric vehicles (BEVs) supporting policies are needed. Many countries and cities have announced their own targets to transform from ICE to ZEVs over the next 10 to 30 years (International Energy Agency, 2021). For example, Norway set the challenging target that by 2025, all new vehicles must be zero-emission vehicles (ZEV). Many countries set the target of 100% ZEV by 2030, e.g., Denmark, Netherlands, Sweden and Singapore. Some targeted for 100% ZEV by 2040, e.g., France and Canada. Also, there have been campaigns in order to promote EVs and transform to net-zero emissions target over the next few decades. For example, EV30@30 Campaign which includes 13 countries, such as Canada, China, Germany, the United Kingdom, Japan, and India, participated under the agreement to reach a benchmark target of a 30% sales share for EVs by 2030 (Clean Energy Miniterial, 2017). In Thailand, in reference to the National Energy Plan 2022, the government proposes to achieve carbon neutrality within the period of 2065-2070. To achieve the target, the plan focuses on clean energy and promoting the use of EVs while fading out ICEs in Thailand.

Despite government efforts and policies to promote EV usage, the EV adoption rate is relatively low and still in its early stages (Bijen et al., 2022; Mukherjee and Ryan, 2020; Plötz et al., 2014). For developing countries in particular, with the exception of China, electric cars have yet to gain significant popularity in developing regions (Rajper & Albrecht, 2020). Despite the promotion and encouragement of EVs by governments in developing countries like India, the adoption of EVs appears to be low (Chhikara et al., 2021). Extensive research in developing countries has been conducted by scholars to expand knowledge and gain insights into consumer behavior, attitudes, and factors associated with EV adoption. The existing literature on EVs can be categorized into two main streams. The first stream aims to contribute to and influence the discourse surrounding EVs by highlighting themes and issues that influence consumer behavior towards electric cars in a positive manner. For example, Wang et al. (2018) conducted a survey and found that 18.1% of the respondents are willing to purchase EV to replace conventional vehicles. The authors also found that the technical level, marketing, perceived risks, and environmental awareness significantly influence EV adoption. This result is aligned with the study from Carley et al. (2013) and Coffman et al. (2017) that technical efficiency, such as driving range, impacts on the intention to adopt EVs. Also, the study from (Egbue & Long, 2012) indicated that driving range is ranked as the highest concern compared with other internal factors. The second stream focuses on exploring the perceived barriers that consumers face when considering the purchase of an EV (Dixon et al., 2023; Gupta & Rhoads, 2022). Several barriers to slow down the adoption of EVs are technological, infrastructural, financial, behavioral and external (Bijen et al., 2022). Despite the potential energy and emissions savings offered by EVs, their high purchase cost often renders them unaffordable, particularly for the middle-class population. A study conducted by Jamaludin et al. (2021) highlighted that the substantial upfront expenses associated with EVs are a major hindrance to their widespread adoption in developing regions like ASEAN.

The development of electric motorcycles has gained significant momentum in recent years, driven by advancements in battery technology, increased environmental awareness, and the pursuit of alternative transportation solutions. These vehicles have become popular in urban areas, providing a practical and environmentally friendly mode of transportation for commuters and delivery services. Motorcycles emit CO2 at levels ranging from 64 to 128 grams per passenger kilometer and use 21 to 42 kilowatt-hours per 100 passenger kilometers (Cherry et al., 2009), pose significant environmental concerns. However, recent research by Koossalapeerom et al. (2019) highlights the potential of electric motorcycles, which consume significantly less energy and emit only half the CO2 of traditional gasoline models. These vehicles have become popular in urban areas, providing a practical and environmentally friendly mode of transportation for commuters and delivery services.

Transitioning from conventional gasoline-powered motorcycles to electric models holds the promise of improving local air quality while also addressing a key environmental concern linked with motorcycle usage (Cherry et al., 2009). However, despite their numerous advantages, electric motorcycles face certain challenges, including limited range, charging infrastructure, and rules and regulations. Still, there is a concern among motorcycle riders about performance issues (Liu & Lai, 2020). Additionally, the broader impact on global pollution and fossil fuel consumption hinges upon factors such as power generation sources and the extent of vehicle substitution (Cherry et al., 2009). Nonetheless, embracing electric motorcycles could play a crucial role in advancing initiatives aimed at reducing reliance on fossil fuels. Consequently, prioritizing the promotion of electric two-wheelers in developing nations serves as a promising starting point for advancing sustainable transportation.

As previously mentioned, the electrification of the vehicle fleet is a complex endeavor due to the multitude of factors that influence the adoption of EVs, including both internal factors which manufacturers can control and develop by themselves, e.g., technical efficiency and marketing, (Jain et al., 2022; Wahab & Jiang, 2019; Wang et al., 2018), and external factors, such as fuel pricing, charging networks, and government subsidization (Beresteanu & Li, 2011; Coffman et al., 2017; Gallagher & Meuhlegger, 2011; Ghasri et al., 2019). There are three key policy mechanisms affecting EV adoption, which include 1) financial and non-financial incentives, 2) building up charging stations, and 3) raising public awareness (Coffman et al., 2017). Therefore, electrifying vehicles presents numerous challenges, necessitating reliable technology, sufficient infrastructure, and supportive government incentive policies. However, implementing these policies across an entire area at once can be daunting due to high investment requirements and logistical complexities. Prioritizing areas or zones to promote electric vehicles is one approach to achieve EV transformation, as it requires fewer resources since it is a gradual promotion process.

Hence, the central research question of this paper is: if comprehensive policies cannot be implemented simultaneously, where should governments prioritize their efforts? Which areas warrant immediate focus, and where should attention be directed with less urgency? Prioritizing specific areas or zoning to promote electric vehicles requires a strategic approach to achieving widespread EV transformation. The aim of this research is to develop a framework to help prioritize locations to promote EVs, using motorcycle taxis in Bangkok as a case study. Motorcycle taxis are widely used and are one of the key sources of air pollution in Bangkok. According to the regulation of motorcycle taxi driver registration and service boundary areas, drivers can only pick up passengers from their association stands (Chalermpong et al., 2023). Therefore, each area generates different amounts of CO2 emissions with different levels of difficulty of EV deployment; therefore, prioritizing areas to promote EVs is a good idea for electric motorcycle taxi transformation.

Bangkok is administratively divided into 50 districts and subdivided into 180 subdistricts. However, concerning motorcycle taxi regulation, the city is divided into 5 DLT (Department of Land Transport) districts, with each DLT district encompassing a varying number of Bangkok's subdistricts. Consequently, for data collection in this study, the unit of analysis is Bangkok subdistricts, selected randomly within each DLT subdistrict.

While other commercial motorcycles, like those used for food delivery, lack clear data on registered vehicles or service areas, motorcycle taxis stand out as a widely used mode of transportation and a significant contributor to air pollution in Bangkok. They possess clear service areas and there is a known number of drivers in each location, simplifying the data collection process. Hence, this study exclusively focuses on motorcycle taxis. Nevertheless, the framework developed here can be modified for application to other case studies with clear zone divisions or varying areas.

This paper is organized as follows: The next section describes the study area and the context of motorcycle taxis in Bangkok, followed by our research methodology. The results are then presented in the subsequent section. Finally, the conclusion and discussion are presented in the last section.

LITERARTURE REVIEW

Study Area

Bangkok is the capital of Thailand with an area of 1,569 km2 and has a population of about 5.5 million people as of 2022 (Department of Provincial Administration [DOPA], 2023). In terms of administrative units, Bangkok is divided into 50 districts and subdivided into 180 subdistricts. Bangkok has been facing severe environmental issues, particularly air pollution (Edelman, 2022). In 2021, the city was ranked the 42nd city in terms of the unhealthiest air quality in the world (IQAir, 2021). In that year, the air quality index (AQI) of Bangkok exceeded the Thai air quality regulations for 89 days (Pollution Control Department [PCD], 2022). It is estimated that with current development patterns, emissions will continue to increase during the next 20-25 years (Leong et al., 2001). One of the main sources of air pollution issue in Bangkok is from transport and it is believed that motorcycles are one of the key sources which significantly contribute carbon monoxide as well as hydrocarbon in Bangkok, especially PM10 (Chalermpong et al., 2021; Leong et al., 2001; Phosri et al., 2019).

According to a travel demand survey conducted in 2018, the majority of commuters in Bangkok, accounting for 43.2%, travel by car, followed by motorcycles at 25.5%, and public transport at 20.3% (Office of Transport and Traffic Policy and Planning [OTP], 2018). Given its location along the Chao Phraya River, the city offers three main public transit modes: public buses, mass rapid transit, and boat services. In recent years, rail transit has gained significance as a vital public transportation option, although its coverage remains limited (Thaithatkul et al., 2023). One of the contributing factors to the prevalent use of private cars in Bangkok stems from government policies (Ayaragarnchanakul & Creutzig, 2022), for instance, low fuel prices comparable to car-oriented countries like the US, and higher prices for private off-street parking compared to public on-street parking, ranging from 6 to 20 times higher. Despite efforts to promote non-motorized transportation such as cycling, its success has been hindered by the Bangkok Metropolitan Administration's failure to create the necessary conditions for residents (Panthasen et al., 2021).

One obstacle hindering the use of public transport in Bangkok is its limited coverage and accessibility. Public transport services are primarily available only in densely populated areas. Therefore, many people rely on informal transport, such as motorcycle taxis, especially in a city that has an urban superblock and severe congestion like Bangkok. Referring to the Department of Land Transport (DLT), for on-road vehicles in Thailand, there is more than 22 million motorcycle stocks in 2023, both personal motorcycle and motorcycle taxi, which accounts for more than 50% of all vehicles (Department of Land Transport [DLT], 2023), as shown in Figure 1. Additionally, more than 4 million motorcycles, or one-fifth of the total, were registered in Bangkok, as illustrated in Figure 2.

Figure 1

The Number of Registered Vehicle Stock in Thailand

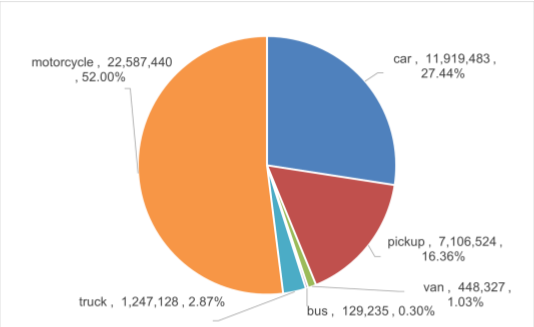
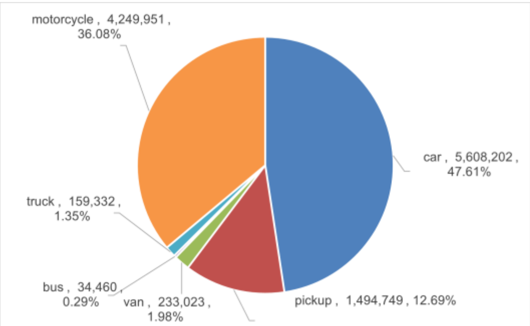


Figure 2

The Number of Registered Vehicle Stock in Bangkok



Motorcycle Taxis in Bangkok

Motorcycle taxi services are organized as a group of drivers, i.e., association, locally known as “win” which also means physical location of motorcycle taxi stands (Ratanawaraha & Chalermpong, 2015). Figure 2 shows the number of motorcycle taxi associations and drivers in 2016-2021. The number of associations, i.e., win, had increased from 2016 to 2017 but the number of registered drivers decreased, which implies that win size decreased during that period. After 2017, the number of associations slightly declined, while the number of drivers increased in 2018 before slightly declining in 2019. At the end of 2021, there were 5,562 associations and 83,398 registered drivers (DLT, 2022).

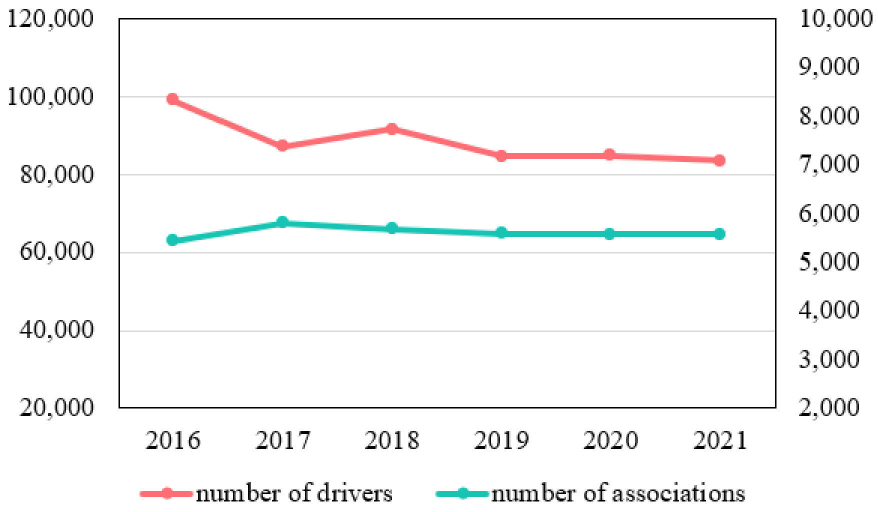
From Figure 3, it can be seen that the number of motor taxi drivers dropped significantly from around 100,000 in 2016 to approximately 80,000 in 2021.This is because in 2016, the National Peace Keeping Council (NPKC) implemented regulations on motorcycle taxis and enforced proper registration according to the law. This resulted in some drivers not registering, causing a significant decrease in the number of drivers during that period. Additionally, after 2019, there was a slight decrease due to the COVID-19 situation at that time, which led to lockdown measures and reduced travel. Consequently, some drivers ceased providing motorcycle taxi services and shifted to other professions. As a result, the number of public motorcycle taxi drivers in Bangkok decreased to approximately 80,000 in 2021.

Even though Bangkok is divided into 50 districts, in terms of motorcycle taxi regulation, the entire area of Bangkok is divided into 5 DLT districts. Each DLT district contains a different number of Bangkok's districts, as shown in Figure 4. Each driver must register in each DLT district, and they usually serve passengers within their registered area. Therefore, each area generates different amounts of CO_2 emissions.

According to the study by Kim (2019), the suggested daily vehicle kilometers per vehicle is 18.03, which equals 6,580.95 km/year/vehicle, with CO_2 emission factors varying depending on the types of engine, as shown in Table 2. The estimated CO_2 emissions per year from motorcycle taxis is 14,348.75 tonnes. Therefore, if the government can motivate drivers to switch to electric motorcycles, CO_2 emissions could be reduced by almost 15 tonnes per year.

Figure 3

The Number of Motorcycle Taxi Driver Associations (Win) and Drivers in Bangkok



Note. Adapted from Motorycle taxis in Bangkok as of 31 December 2021, by Department of Land Transport, 2022, https://web.dlt.go.th/statistics/. Copyright 2018 by Groups of Transportation Statistics, Planning Division, Department of Transport.

Figure 4

Map of DLT District in Bangkok

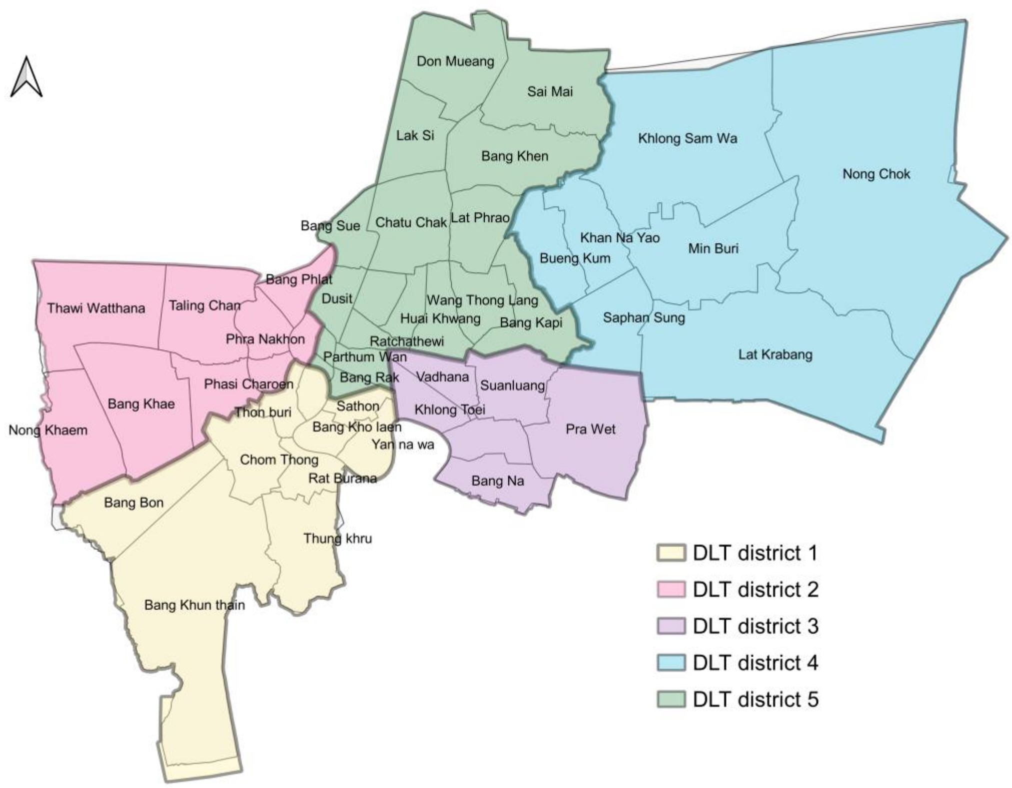


Table 1

Descriptive Statistics of Motorcycle Taxis Based on the Area Offices of DLT in Bangkok in 2021

DLT district	Number of districts	Number of associations	Number of drivers	Average driver per association
1	10	1,001	18,097	18
2	9	821	11,230	14
3	6	744	13,259	18
4	7	639	7,620	12
5	18	2,357	33,192	14
Total	50	5,562	83,398	15

Table 2

Estimated CO2 Emission From Motorcycles Registered in Bangkok

	Fraction of sub-category[1]	**CO2 emission factor (g/km)**	**Estimated number of motorcycles in Bangkok** (c)		**CO2 emission (Tonnes)** (a) x (b) x (c) x yearly VKT	
	(a)	(b)	Private motorcycle	Motorcycle taxi	Private motorcycle	Motorcycle taxi
Gasoline 2-stroke (uncontrol)	0.002	98.271	8,482	138	10.97	0.18
Gasoline 4-stroke (uncontrol)	0.014	79.955	59,376	962	437.39	7.09
Gasoline 4-stroke (catalyst)	0.125	84.811	530,140	8,594	36,986.34	599.58
Gasohol 2-stroke	0.030	37.544	127,234	2,062	943.09	15.28
Gasohol 4-stroke	0.829	44.146	3,515,888	56,994	846,777.90	13,726.62
Total					885,155.69	14,348.75

Note. CO2 emission factor adapted from *PCD-AIT Emission Inventory Database Workbook version 1.0,* by Kim, O., 2019, Copyright 2019 by Pollution Control Department and Asian Institute of Technology*.* Estimated number of motorcycles in Bangkok adapted from *The number of registered vehicle stock in Bangkok,* by Department of Land Transport, 2023, https://web.dlt.go.th/statistics/. Copyright 2018 by Groups of Transportation Statistics, Planning Division, Department of Transport.

METHODOLOGY

Research Framework

Since EV deployment requires many resources, it should be ensured that promoting EVs is worth the investment. The idea of prioritizing locations for EV promotion in this research is based on two aspects. Firstly, prioritizing should focus on the impact of EV deployment. To promote EVs, the area which currently causes high CO2 emission should be the first option. Secondly, prioritizing should focus on the difficulty of EV deployment. In other words, an area that not only has a high tendency of drivers to shift to EVs but also is an area not difficult for EV deployment should be selected first. Figure 3 illustrates the research framework. For the first aspect of prioritizing, we used daily vehicle kilometers travelled (VKT) as the representative of the impact of EV deployment, since longer distances contribute higher CO2 emission. For the second aspect, the possibility of shifting is represented by the driver's attitude on shifting intention for electric motorcycle adoption. Both data were obtained from the survey. Then, the data was transformed to total VKT and average intention to shift in subdistrict level by combining the data with Bangkok's motorcycle taxi data obtained from DLT. The next step was to standardize data. Since both data have different scales, we needed to standardize data to rescale in comparable units. In this research we used z-score to standardize data. Finally, we combined those two assumptions and proposed an EV reduction potential matrix.

As depicted in Figure 5, the potential matrix is classified into four groups. The first group comprises areas or zones with a high impact on CO2 emission reduction and a high possibility of switching to electric motorcycles. The second group consists of areas or zones with a high impact on CO2 emission reduction but face difficulty in transitioning to electric motorcycles. The third group includes areas with a low impact on CO2 emission reduction but are not difficult to transition to electric motorcycles. The final group encompasses areas with both a low impact on CO2 emission reduction and difficulty in transitioning to electric motorcycles.

Figure 5

Research Framework

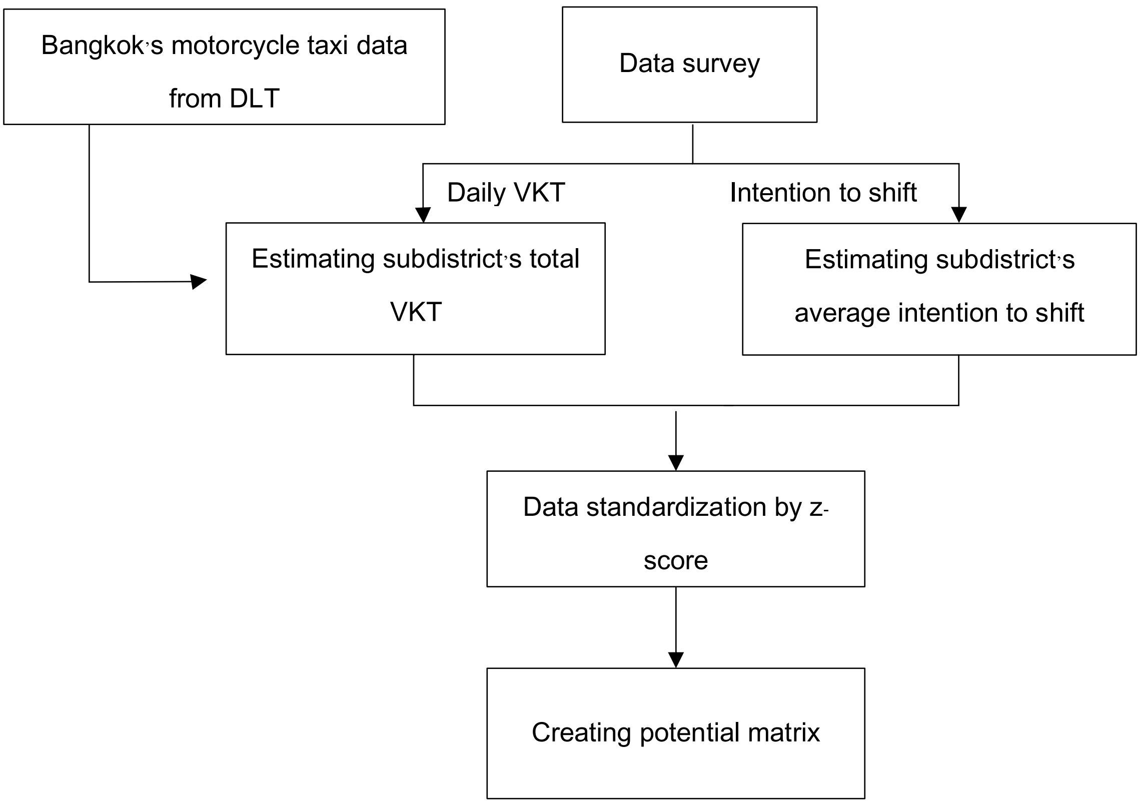
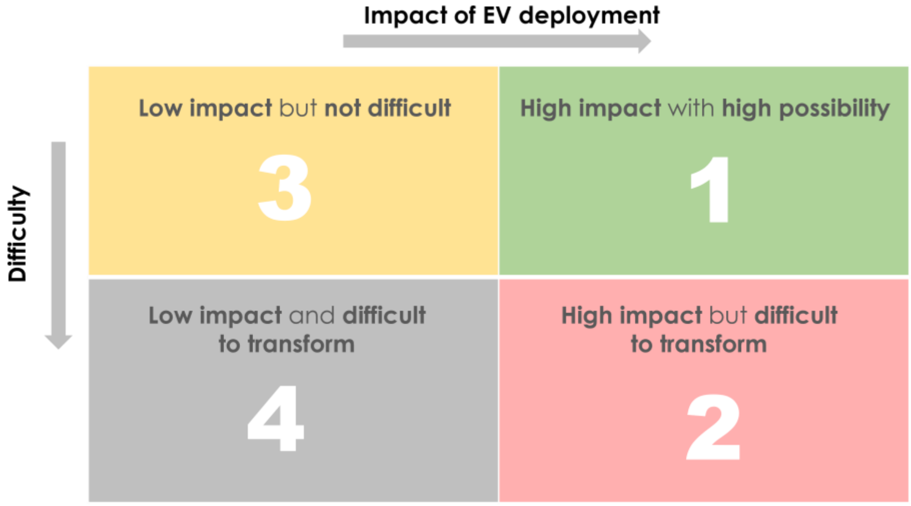


Figure 6

Potential Matrix



Data collection

Since this research focuses on the transformation of motorcycle taxis to electric motorcycle taxis, the target group of the survey was motorcycle taxi drivers in Bangkok. Firstly, Bangkok was classified into five zones referring to the five area offices of the Department of Land Transport, as explained in section 3. The sample size can be calculated using equation (1) (Daniel, 1988).

$$n = \frac{NZ^2p(1-p)}{d^2(N-1)+Z^2p(1-p)} \quad (1)$$

Where N is the population size, Z is the critical value of the Normal distribution at a/2 (1.96), p denotes sample proportion, and d is the margin of error. Since N is the number of drivers, which equals 83,398 according to Table 1, z = 1.96, p = 0.5 (since we did not know p, we set p = 0.5 because it yields the maximum value of n (Daniel, 1988)), and d = 5%. Therefore, the minimum sample size calculated is equal to 383. Finally, we decided to collect samples of 400.In each area, we randomly selected subdistricts to conduct surveys. The survey was conducted during September 2022 by trained surveyors. As a result, there were 433 respondents in 72 subdistricts out of 180 subdistricts who participated. After cleaning the data, e.g., removing suspicious or incomplete data, 406 observations remained. Along with personal information, respondents were asked about driving behavior, i.e., daily VKT, and their attitude towards shifting to EVs, i.e., intention to shift to an electric motorcycle using rating scale from 1-5 (1= least likely to shift, 5 = most likely to shift) with questions shown in Table 3.

Regression analysis model for intention to shift to electric motorcycle

To indicate factors which impact on the intention to shift to electric motorcycles, regression analysis was also performed. The dependent variable is the average rating of the intention to shift from the three questions shown in Table 3. The possible number of the average intention to shift is a continuous number between 1 to 5. Therefore, OLS model was selected. We modelled the intention to shift to electric motorcycles as a function of socio-demographic characteristics, i.e., age, monthly income, education, age of motorcycle, and attitude towards switching to electric motorcycles, i.e., technical efficiency, external factors, perceived usefulness, environmental awareness, and knowledge about EV. The relationship to be modeled can be written in equation (2):

$$Y_i = \alpha + \beta X_i + \gamma M_i + \delta A_i + \varepsilon_i \quad (2)$$

Where Y_i is the intention to shift to an electric motorcycle of respondent i, X_i is the vector of socio-demographic of subdistrict i, M_i is the age of the current motorcycle of respondent i, A_i is the vector of attitude towards switching to an electric motorcycle of respondent i,and ε_i is the disturbance term.

RESULTS

Descriptive statistics

After data cleaning, a total of 406 completed observations remained and the participants' characteristics are presented in Table 4. Approximately 95% are male drivers. Ages range from 20 to 72 years. The age group of 40-49 years has the highest proportion followed by 50-59 and 30-39 years, with percentages of 35.7%, 31.0% and 18.5%, respectively. Work experience varies from less than one year to more than 30 years. In terms of education levels, the majority of respondents finished high school (79.6%). Most respondents (35.7%) have a monthly income between 15,001 – 20,000 baht, followed by 10,001-15,000 baht (36.2%). The average motorcycle age is 4.8 years with the longest motorcycle age of 20 years, and the minimum less than one year. The daily VKT varies between 10 to 200 kilometers per day, with an average of 77 kilometers per day as shown in Table 5.

Table 3

Questionnaire Items and Intention to Shift to Electric Motorcycle

	Questions	References
Intention to shift to electric motorcycle	I intend to purchase an EV in the future.	
	I will try to consider buying an EV.	(Bhutto et al., 2021)
	I plan to switch my ICE to an EV.	

Table 4

Demographic Characteristics of Respondents (N=406)

Sample characteristics		n	%
Sample size by the Office of Bangkok Land Transport	DLT district 1	94	23.2
	DLT district 2	57	14.0
	DLT district 3	58	14.3
	DLT district 4	38	9.4
	DLT district 5	159	39.2
Gender	Male	387	95.3
	Female	19	4.7
Age (years)	20-29	16	4
	30-39	75	18.5
	40-49	145	35.7
	50-59	126	31
	60-69	42	10.3
	≥70	2	0.5

Table 4 (Continued)

Sample characteristics		n	%
Education	High school Graduate	323	79.6
	Vocational degree	58	14.3
	Bachelor’s degree	24	5.9
	Other	1	0.2
Monthly Income (THB, 1 THB = 0.03 USD, as of 11 March 2023)	≤10,000	16	3.9
	10,001 – 15,000	147	36.2
	15,001 – 20,000	154	37.9
	20,001 – 30,000	79	19.5
	≥ 30,001	10	2.5
Work experience (years)	<5	90	22.2
	5-10	139	34.2
	10-15	73	18.0
	15-20	67	16.5
	20-25	15	3.7
	25-30	16	3.9
	>30	6	1.5

Table 5

Summary of Continuous Variables

Variables	Min	Max	Mean	SD
Daily VKT (km)	10	200	77	26.1
Age of motorcycle (years)	0.8	20	4.8	3.1

OLS model results for the intention to shift to electric motorcycles

In order to achieve a successful and efficient deployment of electric vehicle (EV) transition, it is essential to consider various factors, such as socio-demographic, socio-economic, and drivers’ attitude towards EVs. This research also employs regression analysis to examine the factors that influence the intention to switch to EVs. The results are shown in Table 6.

The result indicates that drivers with higher incomes are less inclined to transition to electric motorcycles, as income has a negative impact on their intention to make the shift. In other words, drivers with higher incomes exhibit less interest in switching to EVs compared to those with lower incomes. Since for the most part, promoting or encouraging people to switch to using electric vehicles often hinges on the reduced energy costs compared to gasoline, this is typically the first factor people consider. However, since electric motorcycles are relatively new for motorcycle taxi drivers in Thailand, those who feel they have sufficient income might not pay much attention to the potential cost savings of switching to electric motorcycles, especially regarding fuel costs, as it might not seem worthwhile compared to the concerns or difficulties of adapting to something unfamiliar. Conversely, those with lower incomes might be more interested because it helps to reduce expenses. Furthermore, other socio-demographic factors such as age and education do not significantly influence the intention to shift to electric motorcycles.

According to the respondents' attitude towards adopting electric motorcycles, external factors, such as the presence of supporting infrastructure, exert a positive influence on their intention to make the switch. This suggests that a greater availability of external support, such as battery charging or swapping stations, as well as government incentive policies, will enhance drivers' inclination to transition to electric motorcycles. Furthermore, the findings also indicate that individuals who possess knowledge about electric vehicles are more inclined to shift to electric motorcycles.

For post-estimation analysis of the model, firstly, the variance inflation factors (VIF) were tested to check multicollinearity among independent variables. There is no concrete cut-off of VIF to identify serious multicollinearity, but normally it is accepted that VIF exceeding 10 implies that independent variables are correlated (Freund et al., 2010). The result of VIF in Table 5 shows that there is no significant multicollinearity among independent variables. Therefore, all variables remained in the model. Then, the assumption of homoskedasticity was performed by Breusch-Pagan test. The null hypothesis of Breusch-Pagan test is that the residuals have constant variance, i.e., homoskedasticity. The Breusch-pagan test statistics is 17.291 with a p-value of 0.4435. Since the p-value is greater than 0.05, therefore, we accept the homoscedasticity assumption for our model. The last important issue that should be of concern is testing the assumption of linearity. We performed the Ramsey RESET test by adding the squared term of fitted value as one more explanatory variable. The result shows that there is linearity since the squared term of fitted value is insignificant.

Table 6

Regression Analysis Results

	Estimate	**SE**	**p-value**		**VIF**
(Intercept)	3.2857	0.3567	<0.0000	***	1.143
Age	-0.0035	0.0050	0.4785		1.139
Monthly Income	-0.1259	0.0534	0.0189	*	1.153
Education	0.0383	0.0843	0.6493		1.051
Age of motorcycle	-0.0107	0.0148	0.4718		1.749
Technical efficiency	0.0906	0.0583	0.1211		1.825
External factor	0.3305	0.0596	<0.0000	***	1.562
Perceived usefulness	0.0603	0.0551	0.2742		1.157
Environmental awareness	0.0388	0.0474	0.4134		1.137
Knowledge	0.3555	0.0470	<0.0000	***	1.143
Residual standard error		0.8873			
Degree of freedom		396			
Multiple R-squared		0.331			
Adjusted R-squared		0.3158			

Note. +, *, **, and *** denote significance at the 10%, 5%, 1%, and 0.1% level, respectively

Subdistrict's total VKT and intention to shift to electric motorcycles

To develop the framework to prioritize the locations to promote electric motorcycle taxis, the drivers' survey data was used to estimate average VKT and average potential to shift to electric motorcycles in a subdistrict level. These represent the impact of EV deployment and the difficulty for EV deployment in each subdistrict, respectively. The subdistrict estimation was calculated by combining the data of respondents within the same subdistrict. The average score of intention to shift obtained from the questionnaire of drivers in the same subdistrict was calculated to represent the average potential to shift to electric motorcycles. To estimate the average daily VKT of a subdistrict, firstly, the average daily VKT of all drivers in each subdistrict was calculated, then multiplied by the number of motorcycle taxi drivers in each subdistrict obtained from DLT. The calculation is presented in equation (3).

$$Total\ daily\ VKT_i = average\ daily\ VKT_i \times number\ of\ driver_i \quad (3)$$

Total daily VKT_i denotes the daily VKT of subdistrict I, average daily VKT_i is the average daily VKT of a driver in subdistrict i, and number of $driver_i$ is the the number of drivers in subdistrict i. Since the survey was conducted in 72 out of 180 subdistricts, 102 subdistricts have no data and will not be included in the analysis, as shown in Figures 7 and 8.

From Table 7, the total daily VKT in subdistrict varies between 33,600 kilometers to over 200,000 kilometers with an average of 66,907.14 kilometers. The average intention to shift to electric motorcycles varies from one to five with the average of 2.82, indicating that drivers are slightly leaning towards being less likely to shift. In other words, this implies a mild reluctance or hesitation towards shifting compared to a neutral position. Since data of daily VKT and intention to shift have different scales, in order to create potential matrix with the combination of both variables, both data need to be standardized. In this research we used z-score to standardize both data. The standardized results are shown in Table 7.

The interpretation of the z-score is illustrated in Figure 9. A positive z-score means that the data point lies above the mean. For example, a subdistrict with a positive z-score of total daily VKT, i.e., the impact on CO2 emission reduction, indicates a subdistrict that belongs to the group with a high impact on CO2 emission reduction. Conversely, a subdistrict with a negative z-score implies a low impact.

Table 7

Summary of Subdistrict's Total VKT and Intention to Shift to Electric Motorcycles

		Min	**Max**	**Mean**	**SD**
Total daily VKT (km)	Unstandardized	33,60.00	246,903.75	66,907.14	48,627.94
	Standardized	-0.52	4.89	0.89	1.08
Intention to shift	Unstandardized	1.00	5.00	2.83	0.76
	Standardized	-2.41	2.86	0.01	1.01

Figure 7

Total Daily VKT in Each Subdistrict

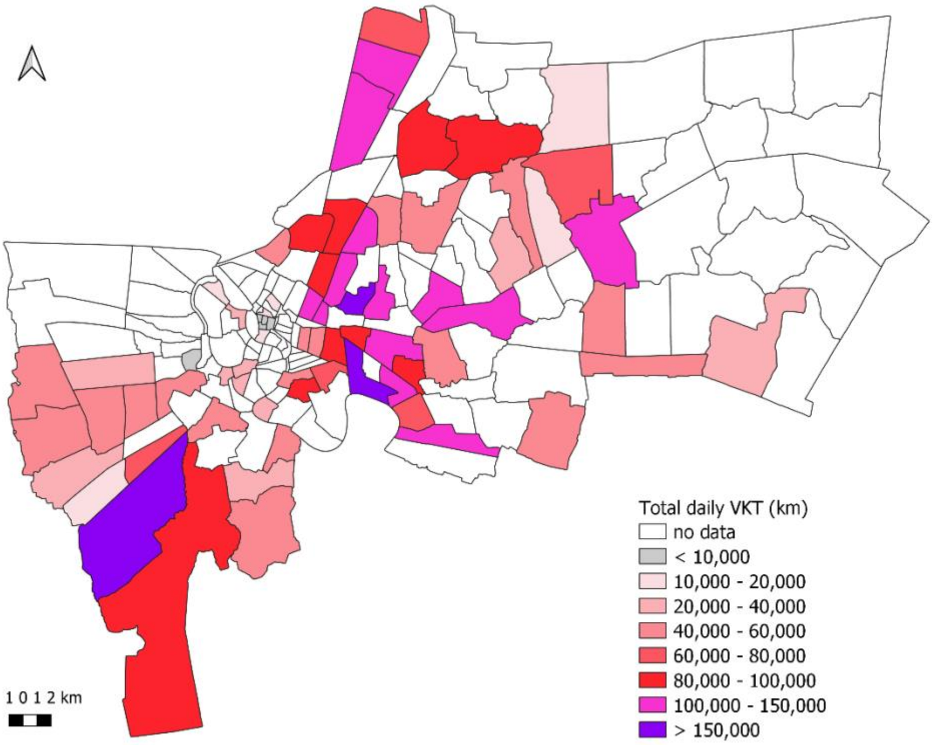


Figure 8

Spatial Distribution of Intention to Shift to Electric Motorcycles

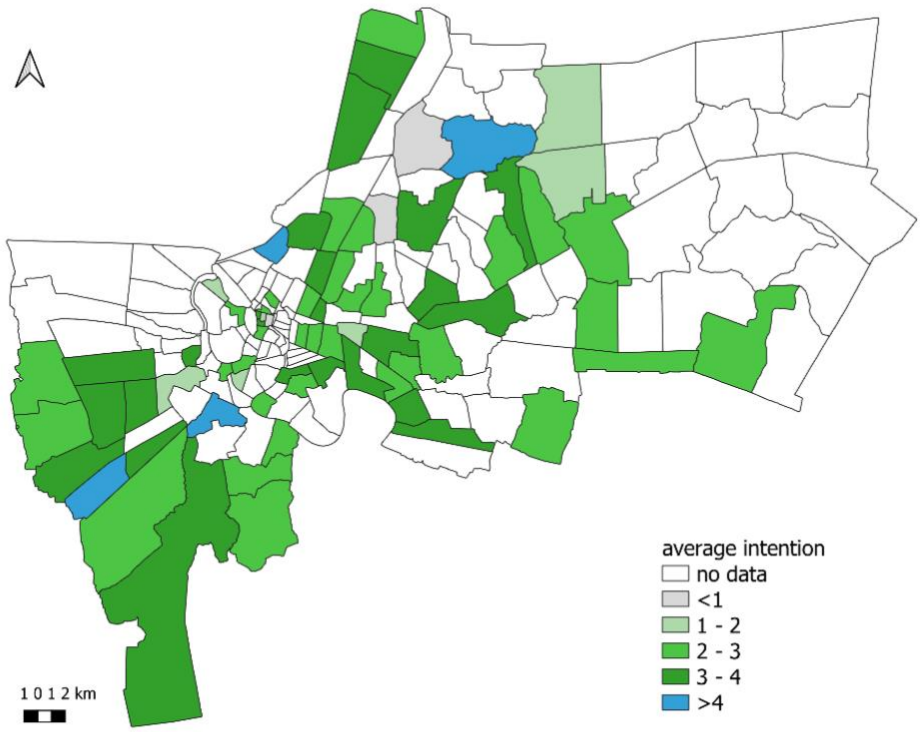
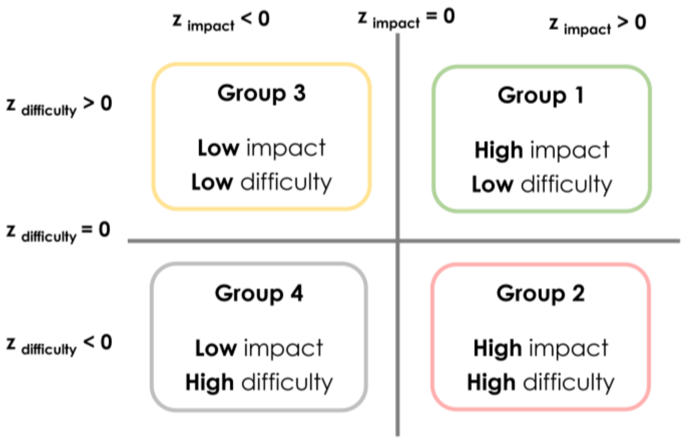


Figure 9

Z-score Interpretation



Potential matrix

Figure 10 illustrates subdistrict's EV deployment potential in each DLT district in Bangkok. DLT district 3 seems to be the best location to promote EVs since all surveyed subdistricts have a high environmental impact and most of them have a low difficulty of EV deployment. Similar to DLT district 3, all surveyed subdistricts in DLT district 5 contribute high CO2 emissions but half of them are difficult to transform to electric motorcycles. The results also show that implementing electric motorcycles for motorcycle taxis in DLT district 4 seems to be the most difficult as subdistricts in this DLT district have a lower intention to shift to EVs than subdistricts in other DLT districts. However, if the government can persuade drivers to change their minds, it would highly affect CO2 emission reduction since most subdistricts in this DLT district contribute high CO2 emission.

Figure 11 presents a potential matrix for EV deployment. The x-axis represents the impact on CO2 emission reduction, which is measured by standardized total daily VKT in a subdistrict. The y-axis represents the difficulty of EV deployment in each subdistrict, which is measured by standardized intention to shift. With low intention to shift, it is difficult to promote electric vehicles. All subdistricts are classified into four groups. The first group is subdistricts in which standardized intention to shift and standardized total daily VKT are higher than the average values. It implies that this category has the highest impact on CO2 emission reduction. Also, with the current state of high level of CO2 emissions inferred from a high level of subdistrict's daily VKT, drivers in these subdistricts have a high possibility of switching to electric motorcycles or willingness to shift to electric motorcycles. Therefore, EV deployment is not too difficult or too challenging. In other words, motorcycle taxi electrification is highly possible with a high impact in these subdistricts. Therefore, subdistricts in this group should be the first priority to promote EVs.

The second category is the group of subdistricts which also have a high impact on CO2 emission reduction but are difficult to transform to electric motorcycles since drivers have a low intention to shift to EVs. However, if the government can motivate drivers in these subdistricts to shift to electric motorcycles, there would be as high an impact on reducing CO2 emission as the first group. Therefore, these subdistricts should be the second priority to promote electric motorcycles because they also contribute to high levels of CO2 emissions (high impact) but may need more encouragement and support to shift to electric motorcycles.

Unlike the first and second group, EV promotion in subdistricts in the third and fourth group may not have a high environmental impact since both contribute low CO2 emissions, i.e., the standardized total daily VKT is lower than the average values. However, for subdistricts in the third group, drivers in this group already have a positive attitude towards shifting to electric motorcycles. i.e., the difficulty of EV deployment is low; therefore, these subdistricts should be the third priority to promote EVs after the first and second group.

Figure 10

Map of EV Deployment's Potential

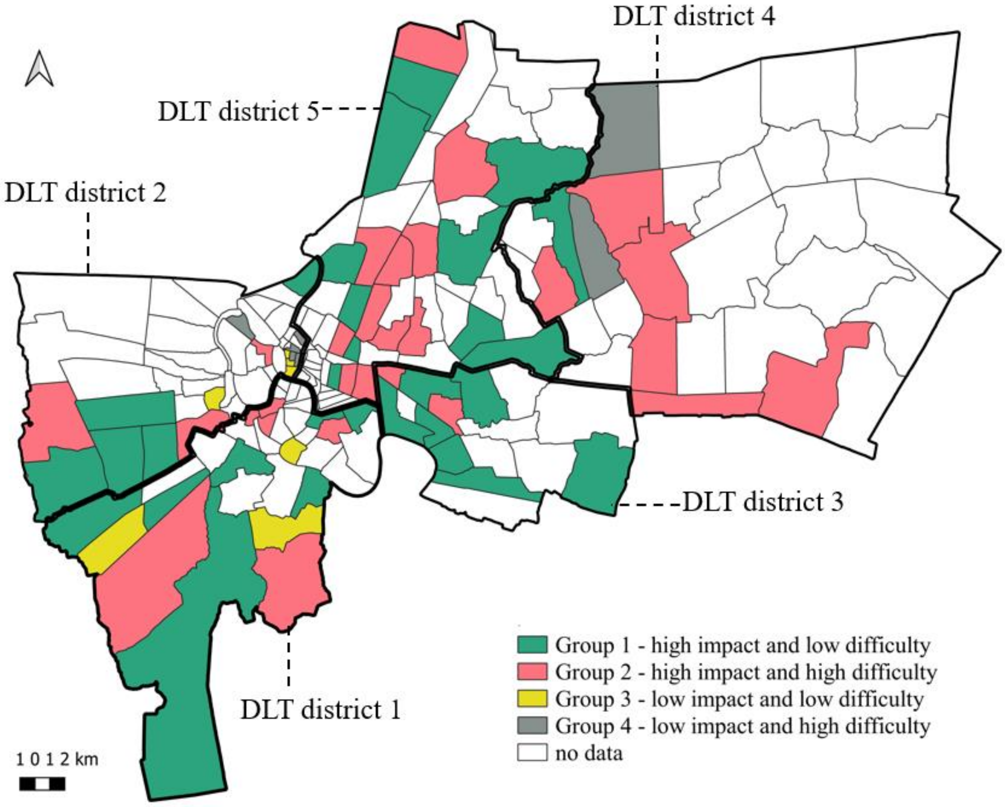
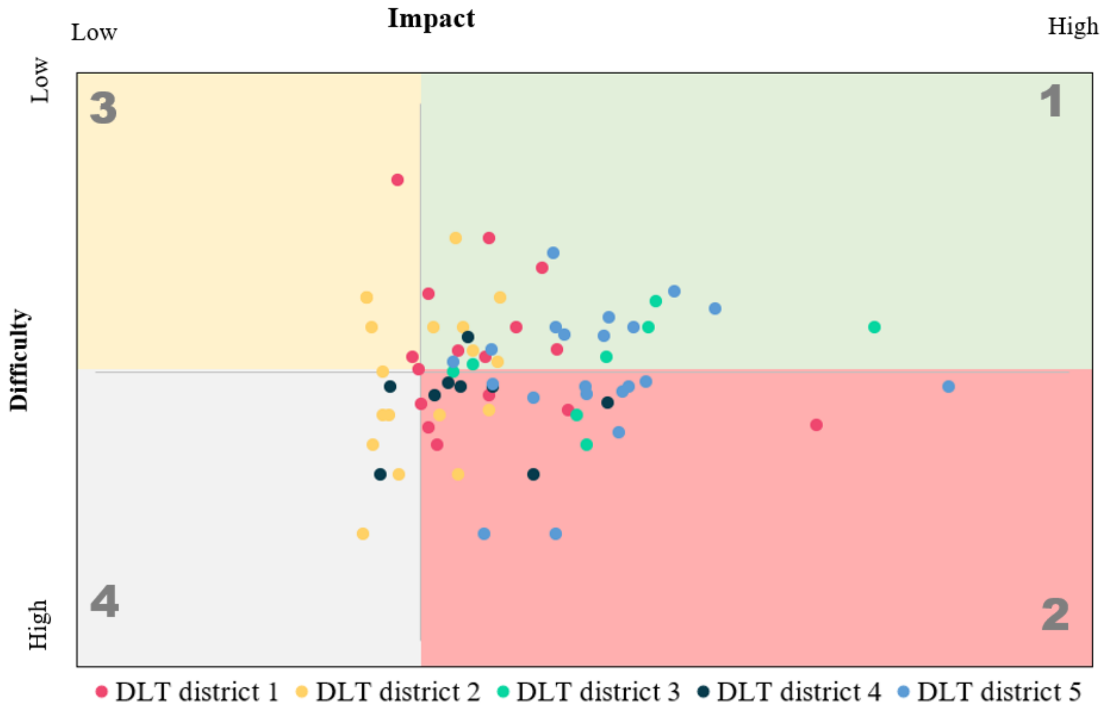


Figure 11

Potential Matrix for EV Deployment



DISCUSSION AND CONCLUSION

Air pollution has been a critical issue all over the world for decades. Bangkok is one of the cities facing severe air pollution problems. One of the main sources of air pollution issue in Bangkok is from transport. Transforming to electric vehicles can help mitigate the problem by reducing CO2 emissions. Yet, electrifying vehicles needs a huge number of resources and support, especially external factors including support from the government, which requires high investment and hard to invest all at once.

In order to effectively transition towards a more sustainable mobility system, such as an electric vehicle (EV) society, stakeholders must carefully consider the benefits associated with this transition. On the one hand, investments should prioritize the environmental impact, focusing on reducing emissions as the primary objective of EV adoption. However, given the limitations of resources, it is crucial to consider the feasibility of implementation in comparison to other measures. Therefore, the development of a framework or tools to assist authorities and automobile firms in making decisions regarding area prioritization and budget allocation for promoting EVs should be able to balance these two considerations. The objective of this research is to create a practical framework that can be easily applied to real-world cases, aiding decision-makers in efficiently allocating resources and prioritizing efforts towards promoting EVs. Therefore, this research develops a framework to help policy makers prioritize the locations to promote electric motorcycles for motorcycle taxis in Bangkok based on two aspects. One is the impact on CO2 emission reduction, i.e., promoting should focuses on the locations with high CO2 emissions. Another one is the difficulty of EV deployment, which is related to the possibility of drivers shifting to EV.

The proposed potential matrix for EV deployment was developed based on both aspects. Implications from this study can help the authorities as well as automobile firms to prioritize locations and allocate budgets on promoting EV efficiently. The potential matrix for EV deployment can classify locations to promote EVs into four groups. The first group, which is the first priority to promote EVs, is subdistricts with a low difficulty of EV deployment but a high impact on CO2 emission reduction. The second group is subdistricts with a high impact on CO2 emission reduction but which face greater difficulty in transforming to electric motorcycles, and these should be the second priority to promote EVs since they contribute high level of CO2 emission. The third and fourth groups are subdistricts with a low impact on CO2 emission reduction. Therefore, promoting EVs in these subdistricts should be considered as the last priority since they may not be worth investing.

According to the DLT districts, the results show that there are two DLT districts which have high potential. One is a DLT district in which almost all subdistricts have a high impact on CO2 emission reduction and a high possibility of drivers switching to electric motorcycles. Another one is DLT district 5 where all subdistricts have a high impact on CO2 emission reduction, although half of them are difficult to transform to EVs. DLT districts 1 and 2 have moderate potential, while DLT district 4 has the lowest potential of EV deployment.

Besides the impact on CO2 emission reduction and the willingness of drivers to shift to electric motorcycles, this research also explores factors affecting intentions to shift to EVs. The results indicate that income has a detrimental impact on the willingness to transition to electric motorcycles. This suggests that individuals with higher or adequate income levels are not actively pursuing the reduced cost of ownership offered by electric vehicles (EVs) in comparison to internal combustion engine (ICE) vehicles.

In addition to drivers' economic capacity, such as income, several external factors play a role in enhancing their inclination to transition to electric motorcycles. These factors include the presence of supportive infrastructure, government incentives, and knowledge about electric vehicles (EVs). This implies that effective government policies are crucial for promoting and motivating individuals to switch to EVs. Moreover, enhancing drivers' knowledge about EVs, including the benefits of using them over ICE vehicles, proper maintenance practices, and optimal EV usage, can further encourage them to adopt electric motorcycles.

The findings from this research indicate several policy recommendations to facilitate the transition towards electric motorcycle adoption in Bangkok. Firstly, the government should prioritize the development of supportive infrastructure such as charging or battery swapping stations, particularly in areas identified as having high potential for EV deployment based on the proposed matrix. Secondly, offering financial incentives and subsidies to both consumers and automobile firms can alleviate the initial cost barrier associated with purchasing EVs and implementing charging infrastructure. Furthermore, implementing educational campaigns to increase public awareness and knowledge about EVs, their benefits, and proper usage and maintenance practices can enhance drivers' confidence and willingness to transition to electric motorcycles. By implementing these policies in a coordinated manner, the government can promote the widespread adoption of electric motorcycles, ultimately contributing to the reduction of air pollution and CO2 emissions in the city.

This research has some limitations. Since the sampling did not cover all subdistricts, the results might change if all subdistricts are included. Nevertheless, the proposed framework will still be applicable if data of all subdistricts are included. The second limitation is this research only focuses on driver's intention to shift to electric motorcycles. Future research should be studied in deeper detail, e.g., considering factors related to the intention to shift. It is important to note that this research specifically focuses on the transition to electric vehicles, and therefore, only considers the impact on CO2 emissions in the transport sector. While the transport sector is indeed a significant contributor to CO2 emissions, it is crucial to acknowledge that emissions can arise from various sources, including open mass burning, industrial sectors, and power generation. In order to establish efficient and sustainable strategies for CO2 emission reduction, it is imperative to consider all relevant emission sources comprehensively.

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REFERENCES

Ayaragarnchanakul, E., & Creutzig, F. (2022). Bangkok's locked-in traffic jam: Price congestion or regulate parking? *Case Studies on Transport Policy*, *10*(1), 365–78. https://doi.org/10.1016/j.cstp.2021.12.016

Beresteanu, A., & Li, S. (2011). Gasoline prices, government support, and the demand for hybrid vehicles in the United States. *International Economic Review*, *52*(1), 161–182. http://www.jstor.org/stable/23016626

Bhutto, M. H., Shaikh, A. A., & Sharma, R. (2021). Factors affecting the consumers' purchase intention and willingness-to-pay more for electric-vehicle technology. *Proceedings of the 21st International Conference on Electronic Business* (pp. 583–594). https://aisel.aisnet.org/iceb2021/4/

Bijen, M., Shrestha, A., Chapagain, A., Bishwokarma, R., Kumar, P., & Conzalez-Longatt, F. (2022). Challenges in the penetration of electric vehicles in developing countries with a focus on Nepal. *Renewable Energy Focus*, *40*(1), 1–12. https://doi.org/https://doi.org/10.1016/j.ref.2021.1 1.003 1

Carley, S., Krause, R. M., Lane, B. W., & Graham, J. D. (2013). Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cites. *Transportation Research Part D: Transport and Environment*, *18*(1), 39–45. https://doi.org/10.1016/j.trd.2012.09.007

Chalermpong, S., Ratanawaraha, A., & Anuchitchanchai, O. (2023). Motorcycle taxis' varying degrees of complementarity and substitution with public transit in Bangkok. *Journal of Transport Geography*, *108*, Article 103557. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2023.103557

Chalermpong, S., Thaithatkul, P., Anuchitchanchai, O., & Sanghatawatana, P. (2021). Land use regression modeling for fine particulate matters in Bangkok, Thailand, using time-variant predictors: Effects of seasonal factors, open biomass burning, and traffic-related factors. *Atmospheric Environment*, *246*, Article 118128. https://doi.org/10.1016/j.atmosenv.2020.118128

Cherry, C. R., Weinert, J. X., & Xinmiao, Y. (2009). Comparative environmental impacts of electric bikes in China. *Transportation Research Part D: Transport and Environment*, *14*(5), 281–290. https://doi.org/10.1016/j.trd.2008.11.003

Chhikara, R., Garg, R., Chhabra, S., Karnatak, U., & Agrawal, G. (2021). Factors affecting adoption of electric vehicles in India: An exploratory study. *Transportation Research Part D: Transport and Environment*, *100*(October), Article 103084. https://doi.org/10.1016/j.trd.2021.103084

Clean Energy Ministerial (2017). *EV30@30 Campaign*. CleanEnergyMinisterial. https://www.cleanenergyministerial.org/initiatives-campaigns/ev3030-campaign/

Coffman, M., Bernstein, P., & Wee, S. (2017). Electric vehicles revisited: A review of factors that affect adoption. *Transport Reviews*, *37*(1), 79–93. https://doi.org/10.1080/01441647.2016.1217282

Daniel, W. W. (1988). Biostatistics: A foundation for analysis in the health sciences. *Biometrics* , *44*(1), 317–318. https://doi.org/10.2307/2531929

Department of Provincial Administration, 2023. *Population statistics from civil registration records.* https://stat.bora.dopa.go.th/stat/statnew/#/

Dixon, J., Zhou, Z., Phommachanh, S., Kythavone, S., Inthavongsa, P., & Hirmer, S. A. (2023). Plugging into green growth: Towards e-mobility and renewable energy integration in Lao PDR. *Energy Strategy Reviews*, *48*, Article 101099. https://doi.org/10.1016/j.esr.2023.101099

Department of Land Transport. (2022). *Motorycle taxis in Bangkok as of 31 December 2021*. https://web.dlt.go.th/statistics/

Department of Land Transport. (2023). *Thailand statistics on number of vehicle stocks in 2023*. https://web.dlt.go.th/statistics/

Edelman, D. J. (2022). Managing the urban environment of Bangkok, Thailand. *Current Urban Studies* , *10*(1), 73–92. https://doi.org/10.4236/cus.2022.101005

Egbue, O., & Long, S. (2012). Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy*, *48*, 717–729. https://doi.org/10.1016/j.enpol.2012.06.009

Energy Policy and Planning Office. (2022). *Energy satistics of Thailand 2021*. https://www.eppo.go.th/index.php/th/informationservices/ct-menu-item-56

Freund, R. F., Wilson, W. J., & Mohr, D. L. (2010). Chapter 8 : Multiple regression. *Statisticsl Methods* (pp. 375–471). Elsevier. https://doi.org/10.1016/B978-0-12-374970-3.00008-1

Gallagher, K. S., & Meuhlegger, E. (2011). Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. *Journal of Environmental Economics and Management*, *61*(1), 1–15. https://doi.org/https://doi.org/10.1016/j.jeem.2010.05.004

Ghasri, M., Ardeshiri, A., & Rashidi, T. (2019). Perception towards electric vehicles and the impact on consumers' preference. *Transportation Research Part D: Transport and Environment*, *77*(November), 271–291. https://doi.org/10.1016/j.trd.2019.11.003

Ghosh, A. (2020). Possibilities and challenges for the inclusion of the electric vehicle (EV) to eeduce the carbon footprint in the transport sector: A review. *Energies*, *13*(10), Article 2602. https://doi.org/10.3390/en13102602

Gupta, A., & Rhoads, J. (2022). Barriers and drivers for electric vehicle adoption in developing countries. *International Journal of Social Analytics*, *7*(12), 1–10. https://hcommons.org/deposits/item/hc:55989

Hu, Y., Sun, J., Li, W., & Pan, Y. (2014). A scientometric study of global electric vehicle research. *Scientometrics , 98*(2), 1269–1282). https://doi.org/10.1007/s11192-013-1067-8

International Energy Agency. (2021). *Global EV outlook 2021-Accelerating ambitions despite the pandemic*. https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf

IQAir. (2021). *2021 World air quality report: Region and city PM2.5 ranking*. https://www.iqair.com/world-air-quality-report

Jain, N. K., Bhaskar, K., & Jain, S. (2022). What drives adoption intention of electric vehicles in India? An integrated UTAUT model with environmental concerns, perceived risk and government support. *Research in Transportation Business and Management*, *42*, Article 100730. https://doi.org/10.1016/j.rtbm.2021.100730

Jamaludin, N. F., Hashim, H., Ho, W. S., Lim, L. K., Binti Sulaiman, N. S., Demoral, A., Tirta, A., Kresnawan, M. R., Safrina, R., & Rosalia, S. A. (2021). Electric vehicle adoption in ASEAN; prospect and challenges. *Chemical Engineering Transactions , 89*, 625–630. https://doi.org/10.3303/CET2189105

Kim, O. (2019). *PCD-AIT emission inventory database workbook version 1.0*. Asian Institute of Technology.

Koossalapeerom, T., Satiennam, T., Satiennam, W., Leelapatra, W., Seedam, A., & Rakpukdee, T. (2019). Comparative study of real-world driving cycles, energy consumption, and CO2 emissions of electric and gasoline motorcycles driving in a congested urban corridor. *Sustainable Cities and Society*, *45*, 619–627. https://doi.org/10.1016/j.scs.2018.12.031

Leong, S. T., Muttamara, S., & Laortanakul, P. (2001). Evaluation of air pollution burden from contribution of motorcycle emission in Bangkok. *Water, Air, and Soil Poluution*, *131*, 41–60. https://doi.org/10.1023/A:1011908724706

Liu, Y., & Lai, I. K. W. (2020). The effects of environmental policy and the perception of electric motorcycles on the acceptance of electric motorcycles: An empirical study in Macau. *SAGE Open*, *10*(1), 1–14. https://doi.org/10.1177/2158244019899091

Mukherjee, C. S., & Ryan, L. (2020). Factors influencing early battery electric vehicle adoption in Ireland. *Renewable and Sustainable Energy Review, 118*, Article 109504. https://doi.org/https://doi.org/10.1016/j.tra.2014.06.006

Office of Transport and Traffic Policy and Planning. (2018). *Bangkok travel demand survey report 2018*. https://www.otp.go.th/edureport/view?id=147

Panthasen, T., Lambregts, B., & Leopairojana, S. K. (2021). Bangkok's bumpy road to sustainable Urban mobility: governance challenges in the promotion of cycle-friendliness. *Nakhara: Journal of Environmental Design and Planning*, *20*(1), Article 106. https://doi.org/10.54028/NJ202120106

Pollution Control Department. (2022). *Report on the situation and management of air pollution and noise situation and management in Thailand in 2021*. Air4Thai. http://air4thai.com/tagoV2/tago_file/books/book_file/3870c44c5ad9bef4736b9fb4fd90b1f8.pdf

Pew Center. (2008). *Policies to reduce emissions from the transportation sector*. Center for Climate and Energy Solution. https://www.c2es.org/wp-content/uploads/2017/09/policies-reduce-emissions-transportation-sector.pdf

Phosri, A., Ueda, K., Phung, V. L. H., Tawatsupa, B., Honda, A., & Takana, H. (2019). Effects of ambient air pollution on daily hospital admissions for respiratory and cardiovascular diseases in Bangkok, Thailand. *Science of the Total Environment*, *651*, 1144–1153. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.09.183

Plötz, P., Schneider, U., Globisch, J., & Dütschke, E. (2014). Who will buy electric vehicles? Identifying early adopters in Germany. *Transportation Research Part A*, *67*, 96–109. https://doi.org/10.1016/j.tra.2014.06.006

Quirapas, M. A. J. R., Lin, H., Abundo, M. L. S., Brahim, S., & Santos, D. (2015). Ocean renewable energy in Southeast Asia: A review. *Renewable and Sustainable Energy Reviews*, *41*, 799–817. https://doi.org/https://doi.org/10.1016/j.rser.2014.08.016

Rajper, S. Z., & Albrecht, J. (2020). Prospects of electric vehicles in the developing countries: A literature review. *Sustainability*, *12*(5), Article 1906. https://doi.org/10.3390/su12051906

Ratanawaraha, A., & Chalermpong, S. (2015). Monopoly rents in motorcycle taxi services in Bangkok, Thailand. *Transportation Research Record: Journal of the Transportation Research Board*, *2512*(1), 66–72. https://journals.sagepub.com/doi/pdf/10.3141/2512-08

Ritchie, H., Roser, M., & Rosado, P. (2020). *CO_2 and greenhouse gas emissions*. OurWorldInData. https://ourworldindata.org/co2-and-greenhouse-gas-emissions

Sathiyan, S. P., Pratap, C. B., Stonier, A. A., Peter, G., Sherine, A., Praghash, K., & Ganji, V. (2022). Comprehensive assessment of electric vehicle development, deployment, and policy initiatives to reduce GHG emissions:Opportunities and chanllenges. *IEEE Access*, *10*, 53614–53639. https://doi.org/10.1109/ACCESS.2022.3175585

Shi, X., Wang, S., Yang, J., & Sun, Z. (2016). Electric vehicle transformation in Beijing and the comparative eco-environmental impacts: A case study of electric and gasoline powered taxis. *Journal of Cleaner Production Journal*, *137*, 449–460. https://doi.org/10.1016/j.jclepro.2016.07.096

Thaithatkul, P., Sanghatawatana, P., Anuchitchanchai, O., & Chalermpong, S. (2023). Effectiveness of travel demand management policies in promoting rail transit use and reducing private vehicle emissions: A stated preference study of Bangkok, Thailand. *Nakhara: Journal of Environmental Design and Planning*, *22*(1), Article 303. https://doi.org/10.54028/NJ202322303

Wahab, L., & Jiang, H. (2019). Factors influencing the adoption of electric vehicle: The case of electric motorcycle in northern Ghana. *International Journal for Traffic and Transport Engineering*, *9*(1), 22–37. https://doi.org/10.7708/ijtte.2019.9(1).03

Wang, N., Tang, L., & Pan, H. (2018). Analysis of public acceptance of electric vehicles: An empirical study in Shanghai. *Technological Forecasting and Social Change*, *126*, 284–291. https://doi.org/10.1016/j.techfore.2017.09.011

World Health Organization. (2022). *Ambient air pollution attributable deaths*. https://www.who.int/data/gho/data/indicators/indicator-details/GHO/ambient-air-pollution-attributable-deaths