FACTORS INFLUENCING EV CHARGING STATION UTILIZATION IN BANGKOK: A STUDY TO SUPPORT THE METROPOLITAN ELECTRICITY AUTHORITY'S MARKET SHARE GROWTH

BY

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ABSTRACT

This study investigates the factors influencing the utilization of electric vehicle (EV) charging stations operated by the Metropolitan Electricity Authority (MEA) in Bangkok. These research have been examined using a mixed-methods approach to synthesize primary data collected from users with secondary data that came from operational records, government reports, and academic literature. It focuses on five critical dimensions: the availability of stations, the price models, proximity to amenities, user demographics, and technological integration to support the market share development of MEA and foster improved sustainable urban mobility within Thailand.

The results show that the availability of stations, speed of charging, and proximity to other amenities are very important in terms of user satisfaction and utilization. The gendered insights show that male users value speed, reliability, and technological advancement, while female users value safety, promotions, and

convenience. Advanced mobile application features such as real-time availability updates and station reservations are also in high demand.

It will be advisable to extend MEA's charging network to remote areas, integrate advanced technologies, and implement user-centric approaches, including targeted promotions and the inclusion of renewable energy sources. This research paper thus gives several managerial implications for policymakers and relevant stakeholders on how best to develop the infrastructure for electric vehicles in accordance with consumer needs for sustainable urban transportation in Bangkok.

Keywords: electric vehicles, charging infrastructure, Metropolitan Electricity Authority, utilization of EVs, urban mobility, sustainable transportation, fast-charging options, renewable energy, gender-specific preferences, Thailand EV market.

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Secondly, I am sincerely thankful to the Metropolitan Electricity Authority (MEA) for their cooperation in providing essential data and insights, which were pivotal for this study. Their contribution significantly enriched the research and enabled a deeper understanding of EV infrastructure development in Bangkok.

Lastly, I extend my heartfelt appreciation to my family, friends, and colleagues for their encouragement and support during this challenging yet fulfilling process. Your belief in me was a constant source of motivation. This accomplishment would not have been possible without your unfailing support.

MS. JINJUTHA MAHAWAN

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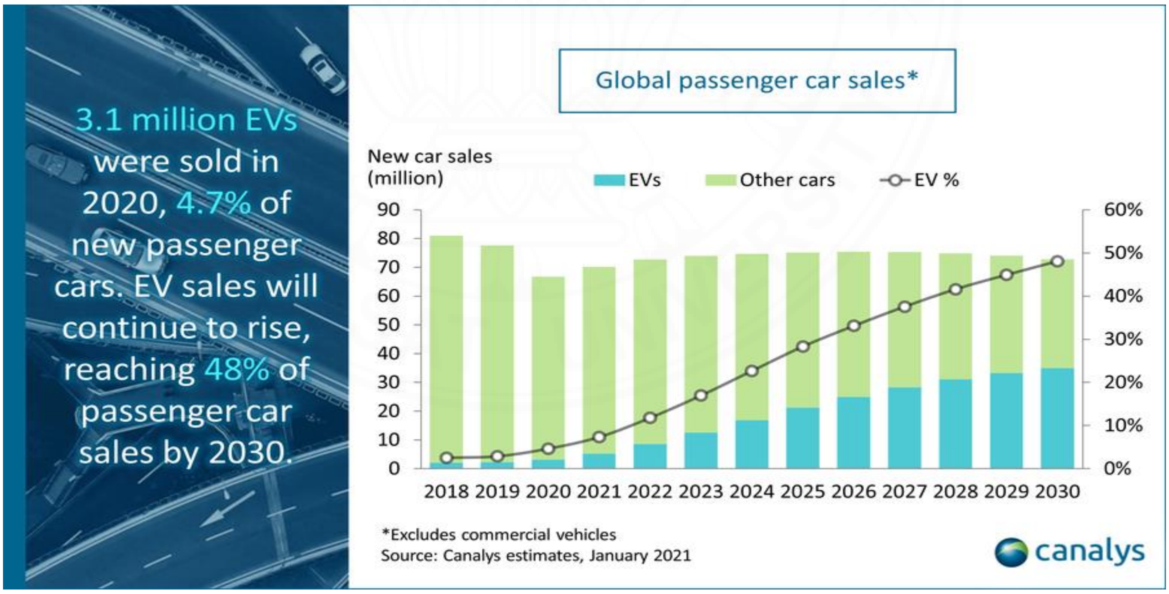
INTRODUCTION

1.1 Global Overview of Electric Vehicle Growth

As countries work to lower their carbon footprint and climate change, the market for electric vehicles (EVs) worldwide has seen substantial growth over the last ten years. The adoption of EV is attributed to various governmental policies, technological development, and transition into green energy. Millions of units were sold in 2023 where EV sales went to a new record level. China, the US, Europe and other prominent markets have encouraged the adoption of EVs through strong policies including tax breaks, subsidies and investment on charging stations.

Figure 1.1

Global Electric Vehicle Growth Trend



Electric vehicles (EVs) penetration in Norway has jumped to over 70% increase in sales of cars through EVs increasing numerous sales throughout EU, while other countries using internal combustion engines (ICEs) struggle. China, being the largest market for EVs, keeps selling the majority of the EVs thanks to the government backing, enormous production capacity, and cutting-edge technologies in batteries. The same trend is observed as well in the European Union – there are strong and strict regulations on emissions which support EVs' development in such markets like Germany, the UK, or France.

One of the reasons, the overall production costs have decreased immensely, and the overall range of these EVs have increased enough to be used by the mass population without restriction over charging time. Additionally, there is a fast expansion of investments into EV charging stations and networks, with new ones appearing in every major city and interstate highways, along with the majority of rural areas.

Even with these promising tendencies, there are still a few barriers that remain. The limited driving ability of some models, the restricted number of charging stations, and the high initial price of the EVs, in general, present common hurdles. And in many developing areas like certain countries of Southeast Asia, EV policies and EV infrastructure still remain at their infancy.

Another issue comes from the ecological damage caused by battery manufacturing and disposal during the battery lifecycle, especially with regards to resource extraction and waste control. Nonetheless, the sector focuses on developing battery recycling techniques and using other materials instead, for instance, lithium iron phosphate and solid-state batteries, as well as minimizing the use of rare minerals. Countries are adopting measures to create recycling infrastructure and promote best practices, which will, amongst other things, play an important role in ensuring that the transition from fossil fuel to electric mobility is as clean as possible.

Part of this wider trend, alongside personal electric vehicles, is in the adoption of electric buses, trucks, and other commercial vehicles. Much of this lies in public transport system electrification being undertaken by cities around the world to help in pollution control. Governments are becoming supportive in introducing e-buses in metropolises like London, Beijing, and New York to reduce emissions from public transit. Likewise, the delivery and logistics industries are using electric trucks and vans in an attempt to achieve corporate sustainability goals and to comply with stricter emissions regulations.

This will only multiply in the years to come, and it has been pegged that in 2030, a large number of vehicle sales on the world will be electric cars. That growth should be underpinned by government regulations around zero-emission vehicle production, corporate commitments to carbon neutrality, and growing consumer interest in sustainability. Now, manufacturers of automobiles around the world are coming out one after another with announcements of changing over to electric-only lines in the coming decades, committing the industry fully to electrification. The countries are setting quite aggressive targets, with some planning on banning the sale of new ICE vehicles within the next 10-15 years, thus speeding up the shift to electric.

In other words, the global EV market has been developing rapidly, supported by strong governmental policies, technological innovations, and increasing commitment from the world to make it sustainable. Challenges around cost, infrastructure, and environmental impact of batteries are still there; however, continuous efforts in technology improvement of the batteries, expansion of charging networks, and installation of eco-friendly practices are making the ecosystem more conducive to the growth of EVs. With these ongoing, EVs have been placed at the forefront to be one of the fundamental levers to reduce global carbon emissions and achieve a genuinely sustainable transportation future worldwide.

1.1.1 Electric Vehicle Growth in Asian

With the continent-wide adoption of EVs as a critical component of countries' strategies to reduce greenhouse gas emissions, improve air quality, and decrease dependency on imported fossil fuels, Asia has emerged as one of the leading players in the global electric vehicle revolution. A confluence of proactive government policies, substantial investment by domestic and international automakers, and burgeoning awareness of both the environmental and economic benefits of electric mobility are behind growth in this segment. Led by major markets like China, Japan, and South Korea, increasingly India and Southeast Asia, their uniqueness—approach and innovations—sets the stage for Asia to lead the way toward sustainable transportation.

1.1.1.1 China: The Epicenter of Asian EV Growth

China leads the Asian EV market, accounting for more than half of global EV sales as of 2023. And in this success, the Chinese government has played a pivotal role by creating a comprehensive set of policies and incentives to drive both supply and demand. The subsidies given to EV buyers, the tax breaks, and even the "dual credit" policy have spurred a very fast expansion of EV production and adoption. With the availability of affordable, locally produced EV models by the likes of BYD, NIO, and Xpeng, together with Tesla's Gigafactory in Shanghai, having catapulted the country to become the global EV powerhouse.

Additionally, China has overly invested in its charging infrastructure; hundreds of thousands of charging stations have been installed across the country. There is a very strong network in place, with further expansion into ultra-fast charging and innovative wireless charging in urban centers. The government also stipulates that all new residential and commercial developments must install EV charging facilities, further easing access for EV users. It also pioneered the electrification of public transport; for example, cities like Shenzhen and Beijing have operated large fleets of electric buses to reduce emissions in populated areas.

1.1.1.2 Japan: Pioneering Hybrid Technology and Transitioning to EVs

Historically a leader in hybrid technology - including class-leading Toyota Prius - Japan has been more reticent in adopting BEVs, but it's now accelerating its effort. Government has underlined plans for carbon neutrality by 2050, a goal which will see ICE vehicle sales start being phased out by the mid-2030s. Japanese manufacturers such as Toyota, Honda, and Nissan ramp up EV manufacturing to keep such targets at bay and competitive. Though slow, the adoption of BEVs has kept Japan invested in hydrogen FCEVs, with main players like Toyota leading from the front in the introduction of models such as Mirai. The policy of the country identifies a series of actions regarding hydrogen infrastructure development and positioning FCEVs for both personal and commercial transports.

While government incentives and investment in both charging and hydrogen refueling infrastructure support Japanese growth in EVs, today, the country has low charging density compared to other Asian countries. The government subsidizes it, therefore, to account for this cost of the private-public effort that's putting up more electric vehicle charging stations, especially in the city and its suburbs, across the country. In that respect, Japan adapted to EV adoption in its unique way: balancing battery electric vehicles with hydrogen fuel cells to realize a diversified, strong, clean transportation system.

1.1.1.3 South Korea: A Battery Manufacturing Hub Fueling EV Growth

With the powerful domestic battery industry-in which giants such as LG Energy Solution, SK Innovation, and Samsung SDI have secured an unrivaled leading position, the country now moves to become an important player in the Asian EV market. Coupled with South Korea's key advantage in battery supply, it has ambitious EV targets: it wants electric and hydrogen cars to make up 33% of new vehicle sales in 2030. The South Korean government offers generous tax rebates, subsidies, and other inducements on purchases of electric vehicles that provide grants for the installation of home charging. Hydrogen, however, is another focus in the EV strategy of South Korea in which Hyundai has been actively developing hydrogen fuel cells for passenger cars and commercial vehicles.

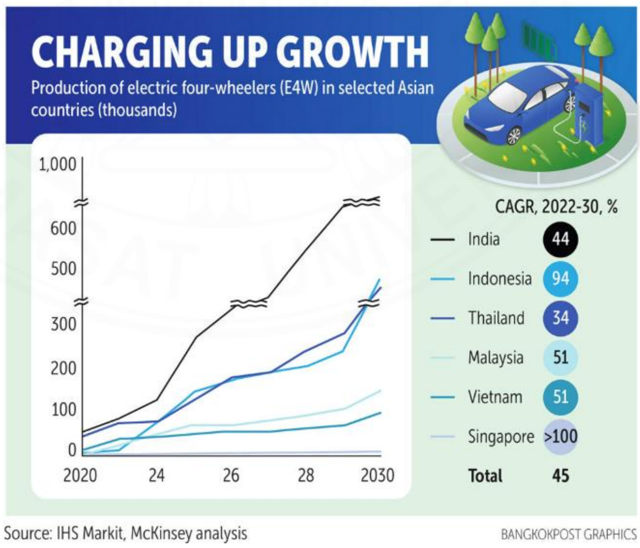
The EV infrastructure has also grown very fast in South Korea, buoyed by heavy investments by the government and private sectors into fast-charging networks and hydrogen-refueling stations. Being one of the powerhouses in battery manufacturing, South Korea is poised to cash in on the global EV boom, with its battery exports driving not only domestic automakers but most world-leading ones. Emphasizing next-generation solid-state batteries among other vanguard battery technologies underlines the seriousness of the country's intent to lead in the EV value chain.

1.1.1.4 Emerging Southeast Asian Markets: Thailand, Indonesia, and Vietnam

Besides, Southeast Asia shows plausible potential for the growth of EVs, with new markets such as Thailand, Indonesia, and Vietnam opening up in the EV ecosystem. For instance, Thailand is aggressively eyeing the target of 30% of its vehicle output to be EVs by 2030, hoping to be established as the EV manufacturing hub for Southeast Asia. The Thai government had given the most aggressive incentives necessary for the EV maker, which included tax breaks and investment grants to attract global automakers. Locally, the infrastructure is getting better; hence, it joined hands with several firms for the building of EV charging stations in major cities and on highways. This again favored Thailand because domestic production reduces its reliance on imported EVs and helps make them cheaper for Thai consumers.

Figure 1.2

Asian Electric Vehicle Growth Trend



Indonesia also hosts large reserves of nickel-a very critical element in lithium-ion batteries. Hence, Indonesia is attracting considerable interest from several large global automakers and battery manufacturers. The Indonesian government leverages this resource advantage through actively encouraging the inflow of foreign investment that will establish local battery production and EV assembly. Indonesia wants to see the number of electric vehicles rise to 600,000 and electric motorcycles to 2.5 million units by 2030-mostly low-cost functional two-wheel EVs-meeting the local demand for commutation. In thrust, too, is a building bloc in the EV sector anchored in companies like VinFast, a homegrown automaker already producing electric vehicles and eyeing expansion overseas. Southeast Asia is equally developing its infrastructure for EVs, although the pace of advancement differs with local policies, budgets by the governments, and regional partnerships.

1.1.1.5 India: An Emerging Giant in Electric Mobility

India’s EV market is at a nascent stage but is showing rapid growth potential, driven by government incentives and a focus on two- and three-wheeler EVs, which make up the majority of vehicles on Indian roads. The Indian government’s Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) initiative provides subsidies and tax breaks for EV purchases, especially for electric scooters, motorcycles, and rickshaws, which are essential for urban and rural mobility. Major Indian automakers like Tata Motors and Mahindra are investing in EV production, while foreign companies such as Tesla and Ola Electric are eyeing India’s vast market. The government’s focus on developing solar-powered charging stations is also an essential part of India’s EV infrastructure strategy, aligning with the country’s renewable energy goals.

India’s transition to EVs is driven by the need to combat severe air pollution in cities and reduce dependence on imported oil. As EV adoption grows, India’s automotive sector is expected to create a strong domestic supply chain for battery production, recycling, and assembly. Challenges such as charging infrastructure, cost sensitivity, and consumer awareness persist, but India’s large population and government commitment present a significant opportunity for the country to become a major player in the global EV landscape.

1.1.1.6 Challenges and Opportunities Across Asia

The EV market in Asia is highly promising; however, there are a lot of challenges to overcome for sustainable growth. Charging infrastructure, being one of the biggest hurdles in most countries apart from major cities, reduces convenience for rural and long-distance drivers. While the initial cost of EVs is going down, it remains a major issue for many consumers, especially in economies where affordability holds primary importance. Similarly, there are a number of consumer perceptions-things that make possible buyers cautious about long life and performance compared to conventional vehicles. Government incentives in Asia, as a result of the subsidies, growing charging networks, and public awareness campaigns, try to break these barriers by educating consumers about the advantage of EVs.

It thus gives Asia a strategic hold on batteries with respect to the EV market and leads in the production of lithium-ion batteries with countries such as China, South Korea, and Japan. This is because batteries form a big portion of the cost in an EV. Hence, much investment is being carried out in the areas of battery recycling, solid-state technology, and other technologies for making EVs more ecological and economical. There is a huge scope of integration with the latest renewable energy installations across Asia and to make the ecosystem of electric mobility greener.

1.1.1.7 Future Outlook: Asia's Role in the Global EV Landscape

With capability and resourceful support for adherence to electrical mobility, surely, the continent of Asia is going to be a future leader in the EV industry. Most probably, China, Japan, and South Korea would continue holding the rein, while Southeast Asia and India can be counted as emerging markets with enormous growth potential. Infrastructure getting better and prices of EVs being more reasonable would see wide-scale adoption in Asia for passenger vehicles, public transportation, and commercial fleets.

The efforts put in by Asia, towards a strong EV ecosystem in the near future, mark the future of human transportation. With sustained government support, continuous technological innovation, and investment in infrastructure, chances are that it will be Asia that leads the world toward a sustainable, zero-emission future and will set an example for other regions that seek decarbonization of their transport sectors..

1.1.2 Electric Vehicle Growth in Thailand

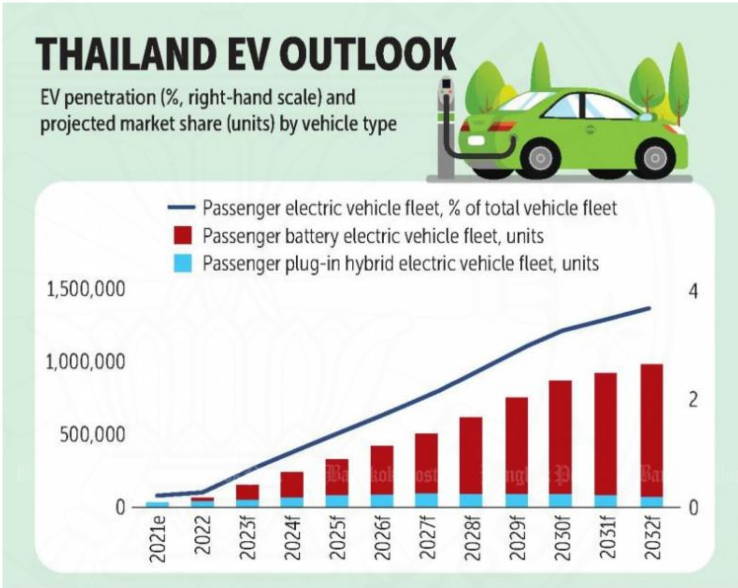
Following the trend in the world, Thailand has joined the revolution in electric vehicles, especially in its capital city of Bangkok. In 2023, EV sales in Thailand posted a significant growth of 684% at about 90,000 units, thus accounting for about 12% of all vehicle sales and an indication that the country was turning into cleaner options for transportation. In line with that, it dares to stretch and reach to become the leading production hub of EVs in Southeast Asia, a dream supported by the ambition of the government to have 30% of all vehicles made in the country be electric cars by 2030. The goal also aligns with the broader strategy of the country to be the top manufacturing hub for EVs in Southeast Asia.

The Thai government has established a number of incentives to spur this growth manifold and diversified on both consumer and manufacturer levels. The measures are mainly tax reductions, subsidies on domestically produced batteries, and lowered import duties for EV components and finished vehicles. Besides that, policies like EV 3.0 call for the foreign direct investment of Thailand's EV sector in getting big international automakers and technology companies to set up a manufacturing plant or research facility in the country. While companies such as Toyota, Honda, and Nissan, which have long had relationships with the country, are expanding their EV production lines to supply the local market, there are some new entrants in the market fray, including BYD and MG. That adds a competitive element.

Infrastructure Development: The development of the infrastructure is another thrust area for the growth of EVs in Thailand. Joint investments by the government and the private sectors are being made in the expansion of the EV charging network, especially in urban areas like Bangkok. State-owned enterprises like MEA take leading roles in installing public charging stations throughout the country to ease range anxiety and make EVs more convenient for daily usage. By 2023, hundreds of charging points had become available nationwide; new stations are currently under construction on a regular basis and also include fast and ultra-fast chargers to minimize charging time. These are important in overcoming some of the main diffusions barriers of electric vehicles: the actual scarcity of reliable charging infrastructures.

Figure 1.3

Thailand Electric Vehicle Growth Trend



Source: Department of Land Transport, BMI BANGKOK POST GRAPHICS

This interest in EVs has been sparked by the increasing expansion in the infrastructure of EVs apart from the government support. Electrically powered public transport is progressively common in the cities, and electric buses and taxis help to clean the air of urban agglomerations and reduce noise. Ride-sharing services and couriers have joined the bandwagon to increase their margins through economizing on operational costs and meeting their commitments toward greening their operations. This is further extending into the public and commercial sectors to raise consumer awareness and show the benefits and practicality of EVs in daily transport.

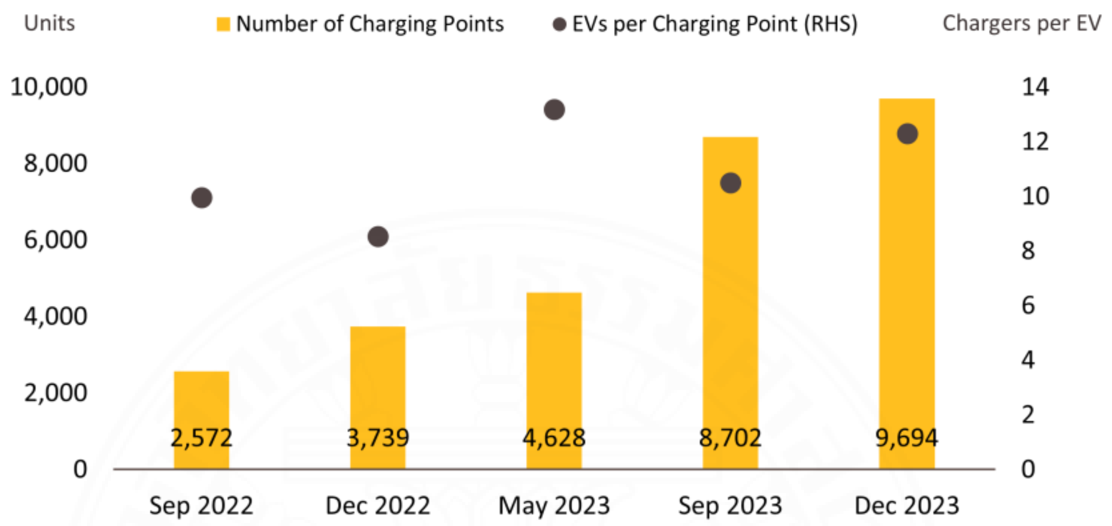
Going forward, Thailand's EV market is well-placed for further growth. Government commitment coupled with private sector investment has shaped generally conducive surroundings for consumer interest in EVs. The better infrastructure and gradual slashing of EV prices could mean a remarkable turn in the tides faced by Thailand's automotive market, where EVs would always be on the center stage for personal, public, and even commercial transportation. Besides the development of natural resources, such a focus by the country to emerge as an EV manufacturing hub could also enable it to strengthen its economy through job creation, foreign investment, among other avenues, and develop technological innovation. Success by Thailand in scaling up its EV ecosystem over the next couple of years may serve as a model for other Southeast Asian countries in the transition to sustainable transportation.

1.1.2.1 Challenges in EV Infrastructure Development

However, with such rapid growth, the country is seriously faced with daunting challenges in the building of the needed infrastructure for wide usage of EVs. Charging infrastructure remains concentrated in urban cities, while the countryside is severely lagging in filling and charging stations for EVs. The big difference in disparity results in "range anxiety" among EV users who take a long drive outside the city's metropolitan areas. Most of the stations currently operating in Bangkok have operational hours usually confined to daytime only; that is, the flexibility of the service for users cannot go through the night or off-peak times.

Figure 1.4

Number of Charging Points and the Ratio of Charging Points to EVs (BEVs & PHEVs)



Source: EVAT, DLT, Krungsri Research

It has included insufficient charging points available, especially outside metropolitan areas like Bangkok. So far, it has only seen a gradual investment from both MEA and private companies to implement the installation of charging networks in high-demand urban areas while leaving those areas with low demand without the service. This inaccessibility creates "charging deserts" that render EV ownership more unrealistic than ever for the people who reside outside of major cities. They add to the range anxiety among would-be EV buyers, too, since there could be a perceived deficiency in infrastructure to ensure that reliable charging options are available with long-distance drives across provinces.

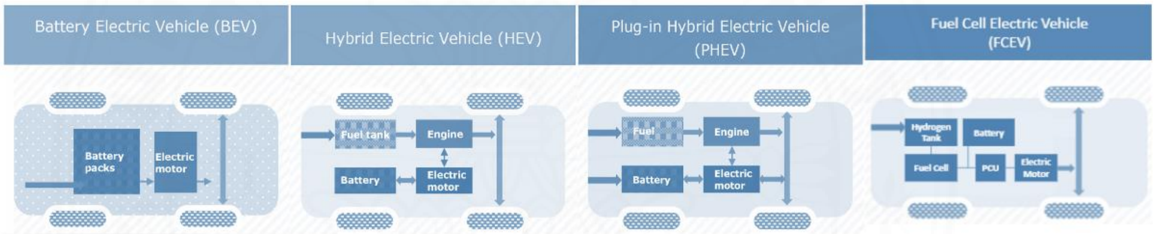
Another major constraint is the high cost of infrastructure. Very high investments are required, especially for DC fast chargers and ultra-fast chargers, in establishing EV charging stations, as both need higher power capacity and more complicated installation processes. The underlying cost of the land itself, equipment, and grid upgrades that support these high-demand stations is quite high, while returns on investment are not immediate, given the relatively low EV penetration in Thailand.

1.2 Types of Electric Vehicles (EVs)

Electric vehicles encompass various types, each differing by propulsion method and level of dependence on electricity. These types include Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Hybrid Electric Vehicles (HEVs)

Figure 1.5

System Architecture of 4 types of electric cars



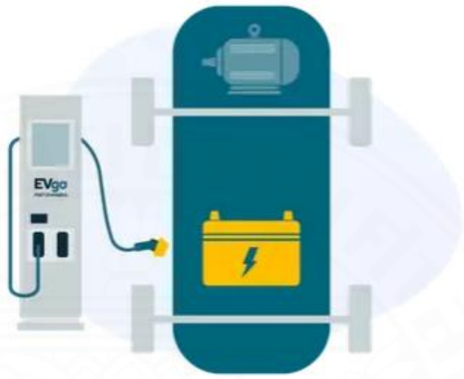
1.2.1 Battery Electric Vehicles (BEVs)

BEVs are fully electric cars powered solely by electricity stored in rechargeable battery packs and, therefore, independent of any internal combustion engine. Since the power in BEVs directly reaches the electric motor(s) from the battery, there are no tailpipe emissions; thus, they go a long way in helping reduce urban pollution and combating climate change. Their nature is so eco-friendly and goes well with transport's sustainable goals. These electric cars can be combined with renewable sources of energy to bring about zero-emission forms of travel altogether.

BEVs have become known especially for instant torque and rapid acceleration, making for a very smooth ride. Electric motors are very efficient, with efficiencies up to 85-90%, as opposed to the 20-30% efficiency of ICEs, hence making BEVs quite energy-efficient. To make them even more energy-efficient, onboard regenerative braking systems in most BEVs will recapture energy during braking. This helps extend the driving range of the vehicle and reduces overall energy loss.

Figure 1.6

Battery Electric Vehicles (BEVs)



BEVs need to be recharged regularly for them to operate. This undertaking can be made from different kinds of charging stations, including Level 1 home outlets, Level 2 either public or home installations, and DC fast chargers. Driving ranges vary from about 150 to over 500 kilometers on a single charge, depending on the size of the battery, the vehicle model, and driving conditions. The only anxiety some drivers might feel is with longer journeys, but this again is not as much of an issue, as the technology in batteries is constantly improving and further structure is being built.

While they are more expensive to buy, the BEV still saves enough operationally to justify long-term savings further sweetened by government incentives. These savings come from lower operation costs: there is minimal maintenance to be performed on a BEV, with no oil changes and fewer moving parts. BEVs are also much more economical to fuel up-especially for those that can charge them at home during off-peak hours. These savings generally drive down the overall cost of ownership, over the life of a vehicle, compared to that of a more conventionally technologically equipped vehicle.

Most of the salient features of BEVs are based on lithium-ion batteries that bring in the spirit of high energy density, durability, and capacity retention over a couple of years with considerable performance. With new innovations like solid-state batteries, BEVs would be expected to improve their range, lifespan, and safety in the near future, thus making them even more desirable.

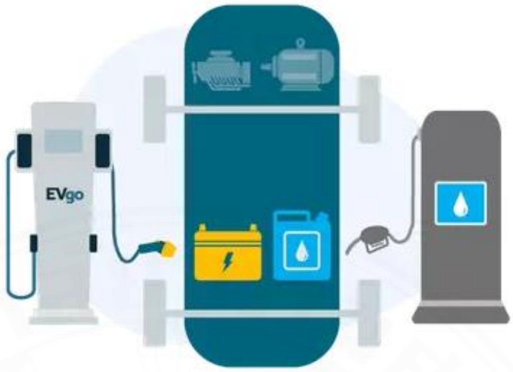
The most popular BEVs, like Tesla Model 3, Nissan Leaf, and Chevrolet Bolt, become more and more ordinary on the roads. Traditional car manufacturers also joined this trend: BMW, Audi, Hyundai present their electric car versions. This means that the BEV market-powered by improving battery technology, wider charging infrastructure, and low-emission policy pressure around the world-is growing fast. The only things standing in the way now are battery costs, charging availability, and greater consumer education. With global investments continuing to pace infrastructure and technology improvement, BEVs are certain to become one of the leading modes of personal and commercial transportation, forging the pathway toward a cleaner, more sustainable future.

1.2.2 Plug-in Hybrid Electric Vehicles (PHEVs)

PHEVs are a unique combination of electric and classic gasoline power, making them one of the most versatile options for drivers. Unlike conventional hybrids, PHEVs contain a larger battery that can be externally charged by plugging in and allows the car to drive as an electric vehicle, within a limited range, typically from 20 to 50 kilometers. When the battery runs out of its charge, it switches over to the gasoline engine, thus giving flexibility for longer drives without the need to stop and recharge. It is this dual nature capability that makes PHEVs especially appealing to people desiring to experience electric driving of shorter commutes yet still need the assurance of a gasoline engine for longer trips.

Figure 1.7

Plug-in Hybrid Electric Vehicles (PHEVs)



With its decreased fuel consumption and emission in electric mode, the environmental benefit of a PHEV is considerable. This becomes more useful in urban areas where the motor will be able to handle low-speed travels independent of the combustion motor at zero emission, minimizing pollution. Because PHEVs still have to use their gasoline engine, they do emit some fumes when the vehicle switches from electric mode into hybrid mode-meaning they are not completely emission-free. However, for drivers not ready to go fully into electric vehicles yet, PHEVs represent a step toward sustainability by lowering overall carbon emissions compared with traditional ICEs. PHEVs, regarding performance, can deliver a refined and responsive drive; the electric motor provides instant torque for rapid acceleration in electric mode.

They also incorporate regenerative braking systems that capture energy normally lost during braking and store it in the battery. This energy-saving feature not only increases electric driving range but also enhances fuel efficiency. Several PHEVs offer an option to choose between electric/gasoline mode so a driver could choose between electric, gasoline, and hybrid modes according to his needs and the conditions of the road. One of the major benefits of PHEVs is flexibility in terms of charging.

For drivers, they are less concerned with the availability of charging infrastructure than would be the case with a BEV, since they can run on gasoline.

Additionally, owners of PHEVs have the flexibility in charging the battery at home with Level 1 charging-a standard outlet-or a Level 2 charger at home or public stations. However, charging frequency depends on usage; regular recharging is ideal for maximum electric miles and minimum gasoline consumption. Looking from a cost point of view, PHEVs mostly fall under the category of higher purchase prices because of the dual powertrain system, but they receive incentives and tax credits from the government in many regions, making them very affordable.

While the operating cost is usually lower compared to conventional ICE vehicles, drivers who can rely mostly on electric power pay even less. Besides, reduced fuel consumption automatically means that over the lifetime of a vehicle, refueling will cost less. Maintenance costs are lower too, relative to traditional vehicles, since the electric motor reduces the wear on the gasoline engine, which translates into fewer wear-and-tear repairs over time. As the automobile industry races toward greener alternatives, PHEVs reflect a transition technology which perhaps more concretely and tangibly marries the best of the electric and gasoline worlds.

PHEVs have further combined in a very attractive blend issues of sustainability, range flexibility, and cost savings for those not quite ready to make a full switch into an electric vehicle. This makes them a strong candidate for the eco-conscious driver who still needs the reliability of a gasoline engine on occasion for extended travel. And with ongoing developments in battery technology, further charging infrastructure, PHEVs are very likely to remain one of the popular choices on the way to complete electric car adoption.

1.2.3 Hybrid Electric Vehicles (HEVs)

The HEVs combine the traditional ICEs with an electric motor. The net result is that it involves higher fuel economy and lower emission compared to conventional gasoline-only vehicles. The difference is that, unlike PHEVs, HEVs do not have to be plugged in-they recharge their batteries from regenerative braking and by drawing power from the onboard ICE. Since this is a self-sustaining battery system, HEVs can also run in electric power in concert with the gasoline engine to optimize fuel efficiency and minimize emissions during low-speed driving.

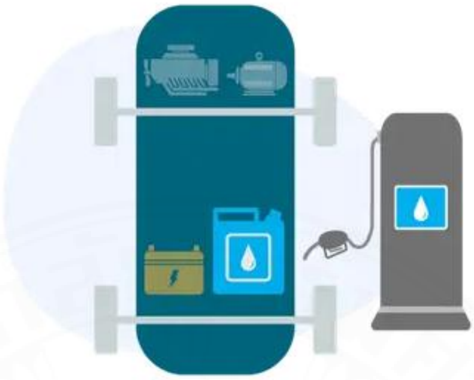
From the environmental point of view, especially, HEVs sound quite tempting to people who want to reduce emissions but cannot switch to an electric vehicle. In conventional gasoline engines, the electric motor supplements and cuts fuel consumption and emissions, especially in stop-and-go city driving. The carbon dioxide emissions that HEVs produce mean they burn gasoline; thus, they also represent real improvement over traditional ICE vehicles in helping bring down air pollution and greenhouse gas emissions in urban areas.

HEVs are efficient, especially in the city. At low speeds or during idling, they run completely electric and hence are quiet and smooth on the road. During higher power requests, such as acceleration or highway speeds, the gasoline engine automatically kicks in to assist the electric motor. This transition, between the electric and gasoline modes, is done seamlessly by the onboard computer system through continuous monitoring of the driving conditions for optimum efficiency.

Some of the major advantages of HEVs include fuel economy savings. Due to the fact that HEVs are able to utilize their electric motor during lower-speed driving and minimize usage of their ICE, they achieve significantly superior fuel economy relative to conventional vehicles. In the process, the regenerative braking system captures energy that is typically lost during braking and converts it into electrical energy that recharges the advanced battery. This feature saves energy and extends the driving range of the vehicle; hence, HEVs are very suitable for daily drives and town trips characterized by many stops.

Figure 1.8

Hybrid Electric Vehicles (HEVs)



HEVs are also convenient, easy to operate independent of external charging infrastructure; hence, very attractive to motorists in areas where charging options still remain scanty. They can be quite practical for those interested in more sustainable transportation that is not quite ready to go fully electric or plug-in hybrid yet. This flexibility allows HEV drivers to have many of the advantages of electric power without having to change their refueling habits, and thus, makes HEVs reachable and easy to use by the widest range of customers.

Cost-wise, generally speaking, HEV usually has a higher initial purchase price compared with traditional ICE vehicles, because the additional electric motor and battery add up to the cost. Most of the time, such offsets in the initial cost are recovered in gains from fuel over a certain period, especially for those drivers who always deal with stop-and-go traffic. Besides, HEVs require less maintenance compared to ICE-only vehicles, since the electric motor reduces the load on the engine, which means fewer repairs and longer engine life. And the more carmakers invest in the technology, the spate of HEV models burgeons to span vehicle categories from sedans and SUVs to even some trucks.

HEVs are an on-ramp to fully electric vehicles in the broader market. They provide a practical, non-disruptive way to orient consumers to electric power. With that in mind, many drives find HEVs offer a good balance of environmental benefits, cost savings, and range flexibility without the range anxiety associated with BEVs. With fuel efficiency standards continuing to tighten and a growing population beginning to look at options for greener choices, HEVs will more than likely be holding their own within the automobile market for the future, continuing to play a significant role in the overall movement toward greener and more efficient transportation.

1.2.4 Fuel Cell Electric Vehicles (FCEVs)

Fuel-cell electric vehicles represent the newest generation in the field of green transportation, fusing the best features of electric vehicles with the huge energetic density of hydrogen fuel. Whereas BEVs derive their propulsion from pre-stored batteries, FCEVs generate their electricity onboard from a fuel cell using hydrogen as its principal feedstock. In the fuel cell, hydrogen is used in a chemical reaction with oxygen to produce the electricity feeding the electric motor, with the only emission being water vapor. This particular mechanism makes FCEVs have the advantages of both being emission-free at the tailpipe and possessing extended driving ranges, often comparable to gasoline-powered vehicles

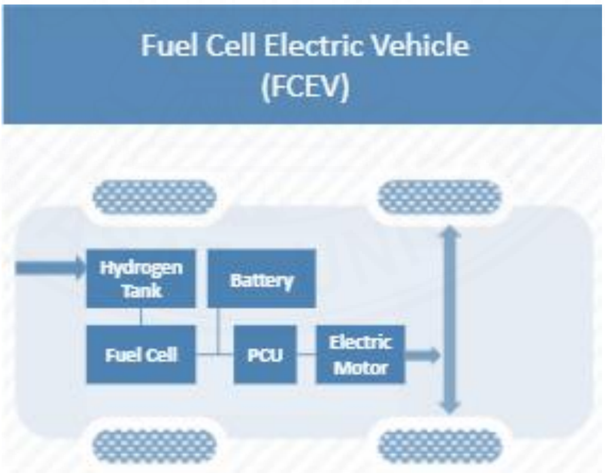
On the other hand, perhaps the most striking feature of FCEVs has been their refueling time, long considered on par with conventional gasoline cars. Indeed, a full hydrogen tank is refueled in approximately 5-10 minutes, or less than a fraction it takes to charge most BEVs-a feature that also has made FCEVs appealing for distances farther apart and for commercial or public transportation applications where any form of downtime should be minimal. Besides that, most FCEVs can normally provide ranges from 300 up to 500 kilometers per tank and can be used for any application without any "range anxiety," including highway use. From an ecological point of view, FCEVs provide zero-emission transportation.

They only produce water vapor and heat as byproducts, so it reduces pollutants and greenhouse gases in urban areas, making air cleaner and more free from dependence on fossil fuels. Hydrogen manufacturing can be absolutely ecological, obtained as it is from renewable resources, for example, through electrolysis powered by wind or solar energy, since these will greatly increase the environmental advantages of

FCEVs. In any case, where hydrogen production depends on natural gas, the carbon footprint of FCEV will be much higher, which underlines another very relevant issue-that of developing green hydrogen infrastructure. Notwithstanding these advantages, there have been many challenges affecting the broad diffusion of FCEVs. The infrastructure is still very scarce, with most of the existing refueling stations confined to a few geographically limited regions that include California in the United States and parts of both Europe and Japan. Building hydrogen refueling stations requires huge investment, and it is logistically complicated in itself, as hydrogen needs to be stored at high pressure and distributed safely. Besides that, hydrogen production as such is an expensive process so far, and in most cases, it involves energy-intensive procedures, though research and investments are being directed toward reducing costs and improving production efficiency, particularly through renewable sources. From the safety viewpoint, hydrogen is a highly flammable gas, and that fact has raised apprehensions regarding storage and handling-particularly at high pressure.

Figure 1.9

Fuel Cell Electric Vehicles (FCEVs)



They did, however, equip the FCEVs with numerous safety features including strong tanks for storing hydrogen at high pressure and strict standards concerning its enclosure and preventing leakage. With the development of technology, FCEVs have gone through all kinds of rigorous testing to meet even the most hard-nosed safety standards, and studies carried out to date show that they are no less safe than other types of vehicles where these protocols have been followed. The production of FCEVs has been expensive so far, as the parts required for fuel cell technologies and hydrogen storage are still more expensive than their counterparts in BEVs or hybrid vehicles.

However, the costs are gradually coming down with the development of better materials and manufacturing processes, and economies of scale are expected to improve even further with more entrants in the hydrogen market. Many countries are targeting FCEVs in their national energy strategy, considering the wide applications hydrogen is seen covering: aside from transportation, its usage in industry and energy storage is an idea that is gaining popularity. This may allow a wider integration with hydrogen, reducing costs and accelerating the adoption of FCEVs. The models launched so far have ranged from the early adopter-bought Toyota Mirai to the Hyundai Nexo for fleet operators.

These carmakers are working closely with governments and energy companies to install hydrogen infrastructure with the aim of making FCEVs a mainstream option for environmentally sensitive consumers. As this technology continues to evolve, so will the possibility of FCEVs acting not only at the level of personal transportation but also playing a serious role in heavy-duty applications, from trucks and buses down to even trains, where batteries make BEVs less practical due to size and capacity limitations. In summary, Fuel Cell Electric Vehicles could be superior to battery electric and internal combustion vehicles for sustainable development by offering those applications-long range-quick refueling that may have special needs.

Where hydrogen production and refueling infrastructure continue to develop, FCEVs could be part of a big deal in the future of clean mobility-particularly in those segments where, up to today, battery solutions have shown limited reach. In a world moving toward renewable energy and carbon reduction, FCEVs represent an exciting pathway to zero-emission transportation for the future across a broad use case spectrum.

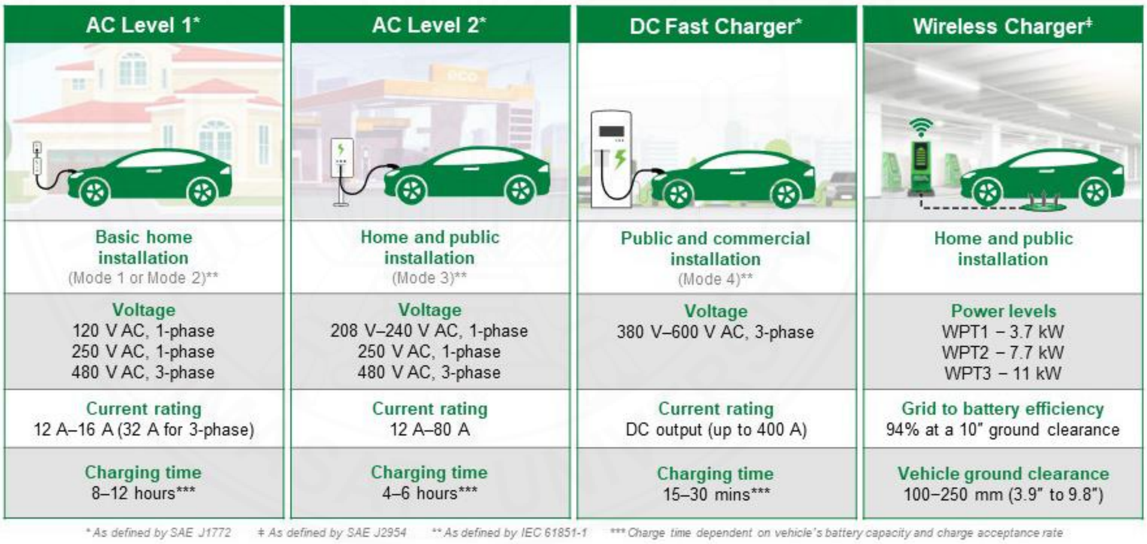
1.3 Types of EV Charging Stations

Electric Vehicle (EV) charging stations are categorized based on the speed and method of charging they offer, meeting the varying needs of EV drivers for home, workplace, and public charging. Each type of charging station uses different power levels and infrastructure, influencing the time it takes to recharge the vehicle.

1.3.1 Level 1 Charging Stations (Standard Home Outlet)

Figure 1.10

Comparison table of each type of EV Charging Stations



Level 1 charging stations are the most basic type of EV charger, and they use the same 120-volt AC plug common to most residential circuits. Such types of chargers provide an extremely slow charge rate, adding approximately 2 to 5 miles of range per hour. Of course, this would mean that Level 1 charging is best used at times when an electric vehicle will be parked for considerable lengths of time, such as overnight. While this may take 8 to 20 hours with the typical 40-60 kWh batteries common in many EVs, Level 1 charging could be sufficient for drivers with a short daily commute or for driving plug-in hybrid electric vehicles with smaller batteries. Arguably, the major advantages of Level 1 chargers are inexpensiveness and ease of access, since no special equipment is required other than a standard outlet. However, this could be a disadvantage to the owners of the EV in that they may require faster charging options. The level 1 voltage chargers will, therefore, be ideal for the low-mileage drivers or for complementary reasons rather than being used as a mainstream option.

1.3.2 Level 2 Charging Stations (Public and Home Installations)

Level 2 Charging Stations: Level 2, higher than the previous option Level 1, runs on 240 volts and provides a faster charge. They can give out about 10-25 miles of range per hour, which could serve most the EVs in 4 to 8 hours with a full charge, considering the size of the battery. Level 2 chargers are installed almost everywhere-publicly and privately-in parking garages, shopping centers, and workplaces. Especially attractive to drivers who may need to charge midday or between errands, they can greatly reduce charging time versus Level 1. Most Level 2 home chargers require a dedicated 240-volt circuit-the same power supply large appliances use-and often require professional installation. While Level 2 is more than the installation cost, the faster charge rate and added convenience provided by Level 2 chargers make it a very popular choice for daily EV users since it offers a great balance between charging speed and accessibility.

1.3.3 DC Fast Charging Stations (Level 3 or DCFC)

DC Fast Charging stations, also called Level 3 chargers, supply direct current, DC, directly to the electric vehicle to the battery at very high power output. This bypasses the onboard charger generally used for AC charging and can greatly reduce charging times. For its part, a DC Fast Charger can add up to 80% of a full charge in just 20-40 minutes, which again makes it very suitable for long-distance travelers and drivers in need of a quick charge on the go. Such chargers are typically installed along highways and at other high-traffic spots, such as shopping centers and rest stops, whose primary function is to allow EVs to replenish their batteries efficiently on the road. At the opposite end of the convenience spectrum, DC Fast Charging is significantly more expensive to install and maintain, and consequently often passes a bigger bill to the end-user. Besides, not all the models of electric vehicles can take on the input of high power that the DC Fast Chargers have to give; therefore, the premises of availability and compatibility do exist when counting on this charging method for frequent travel.

1.3.4 Ultra-Fast Charging Stations (Superchargers and Hyperchargers)

Ultra-fast charging stations are also occasionally described as superchargers or hyperchargers, representing today the most powerful kind of charging station. These would be normally stations running over 350 kW power, which can give an additional range of 200-300 miles in 10-15 minutes depending on the vehicle make and battery capacity. Ultra-fast chargers are placed along highways and popular travel routes to support long-distance EV travel with very minimal downtime. Ultra-fast chargers are targeted mainly towards luxury and high-performance EVs that can take in such a high-power input, making the commute with EVs more convenient in cases when a user has to charge it quickly during their long commutes. This is because not all the EV models are fit with ultra-high-power station availability; therefore, their installation cost remains high, confined to high-demand locations only. Despite such limitations, the ultra-fast charging station is of essence, allowing for long-distance EV travel and dismissing range anxiety.

1.3.5 Wireless (Inductive) Charging Stations

Wireless or inductive charging stations introduce a no-cable charging experience with the use of electromagnetic fields, transferring energy from a ground-mounted charging pad to a receiver coil in the EV. The EV only has to be parked over the charging pad, where it will get electricity wirelessly transmitted. While their charging speeds at present are slower—gaining 10 to 15 miles of range per hour—wireless chargers provide a very high level of convenience, as no action from the user is required to connect or disconnect cables. Wireless charging has good applicability to residential situations and also some public transit applications such as buses that can charge during some stops. But for now, it is less efficient compared to the wired means and higher installation costs, making it not quite practical to apply for EVs traveling long ranges. Again, this would change as soon as research and development lead to quicker and more feasible wireless charging technologies that will open up the possibility of dynamic-charging lanes allowing Evs to charge while traveling.

1.3.6 Battery Swapping Stations

While traditional charging is the conventional means, a swapping station gives EV drivers the chance to get a fully charged battery in place of a depleted one in just a couple of minutes. In this way, it eliminates the waiting time involved with charging, therefore allowing for an instant recharge experience similar to refueling a gasoline car. In reality, it is only being deployed in any significant number in China and India, where companies such as NIO and Gogoro have installed networks to swap batteries in passenger EVs, two-wheelers, and fleet vehicles. The true value of swapping is with commercial fleets and high-usage vehicles, for which any reduction in idle time is most valuable. While it does offer an extremely fast and convenient way of replenishing range, the aforementioned requirements-meaning standardized battery sizes across different models-can be quite limiting to more widespread adoption. Moreover, the inventory of millions of batteries is prohibitively expensive, as is the establishment of special stations. However, for ultra-high-demand applications-in particular, in markets with sparse charging infrastructure-this system remains an innovative solution.

1.4 Charging Price During On-peak and Off-peak Periods

These will, therefore, give price mechanism incentives toward efficient use of energy while reducing strain on the electricity grid during peak demand periods. In Thailand, EGAT and MEA have an important role in implementing the TOU rate that manages electricity costs for EV users and promotes off-peak charging.

Table 1.1

Time of Use Rate EV Charging Station in Thailand

Time of use rate	Energy charge (Baht/kWh)		Service charge (Baht/Month)
	Peak	Off Peak	
22 - 33 kV	4.5827	2.1495	312.24
Below 22kV	5.2674	2.1827	38.22 (Residential) 46.16 (Small business)

Note: Peak — The time from 09:00 - 22:00 Mon. - Fri. and Royal Ploughing Day
Off Peak — The time from 22:00 - 09:00 Mon. - Fri. and Royal Ploughing Day and the time from 00:00 - 24:00 Sat. - Sun., Labor Day, Royal Ploughing Day which falls on Sat. and Sun., and Official Holidays (Not include Compensatory Holiday)

1.4.1 On-Peak Charging in Thailand

Peak demand calls for the peak rate when demand for electricity is at its zenith and falls between 9 in the morning and 10 at night on all weekdays. During these peak hours, electricity becomes very expensive because the demand arising from residential, commercial, and industrial consumers of that resource is very high. It can be a great deal more expensive per kilowatt-hour to charge an electric car during an on-peak period; it can be in the region of 4.10-5.50 THB, which is determined by the utility provider and charging station location.

On-peak pricing discourages times-of-day charging when demand is busy, shifting owners of EVs to off-peak hours where rates are lowest. For those few drivers who have to charge midday, using DC fast chargers especially, on-peak higher rates may be relevant given the higher capacity of the vehicle's battery. Using the example of a 50 kWh full charge, this would come on-peak at 5.50 THB/kWh, approximately 275 THB further than if it were charged off-peak

1.4.2 Off-Peak Charging in Thailand

For the most part, off-peak charging in Thailand is much cheaper and usually kicks in from 10 pm through to 9 am during the week, over weekends, and during public holidays. These are normally off-peak hours when the demand for electricity is low, hence owners can have a leading edge in taking such reduced rates for charging their

EV. In Thailand, rates in the off-peak period are usually between 2.60 to 3.10 THB per kWh, thus substantially discounted from the on-peak price. With such a drastically reduced rate, significant savings can be accrued, especially since most drivers should be able to schedule their EV charging at this low rate overnight or early in the morning.

This would mean that charging a 50 kWh battery would see it charged at just 2.60 THB during off-peak hours, a charge of only 130 THB-less than half for the same amount charged at peak times. This would surely be a disincentive in behavioral modification for the owners, who would not only want to minimize their charges but also lighten the country's power grid during peak hours.

Apart from the usual on- and off-peak rates, Thailand is also studying dynamic pricing, in which prices would also move with real-time demand.

1.4.3 Dynamic and Time-of-Use (TOU) Pricing Models

This would allow for the adjustment of electricity rates to immediate grid conditions, thereby allowing EV owners to have the opportunity to charge at the cheapest times of the day. For drivers who can afford some flexibility in their charging times, dynamic pricing offers some advantages when they change or adjust to real-time pricing signals. This model, however, requires an advanced metering infrastructure that is at its development stage in most areas of Thailand. Due to the high growth in the number of EVs in the Thai market recently, TOU pricing became very popular.

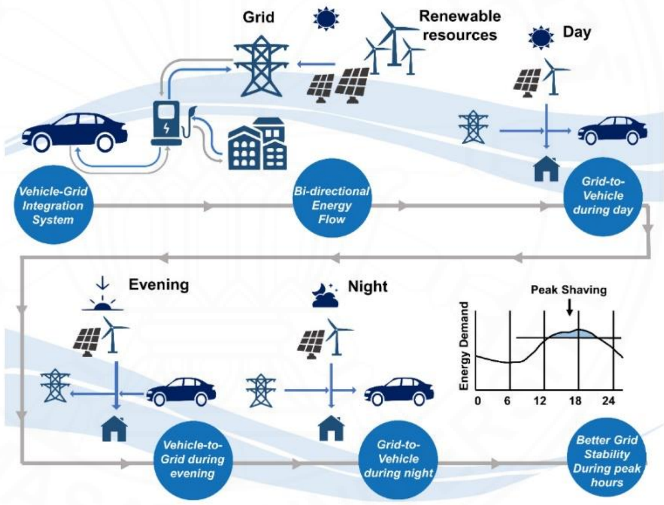
In this model, the day is divided, as it is in the on-peak and off-peak pricing model, into differently priced time periods. The prices are higher during those times of the day when demands are at their peak and low at times of low demand. TOU pricing can thus be most effective for an EV owner who has a home charging system preset in advance for charging during off-peak hours, often through automated smart-charging systems. With the TOU rate, that indeed has happened: in Thailand electric vehicle owners already experienced reduced recharging cost, while helping to smooth out demand on the utility grid to mutual advantage of consumer and utility alike. And all this will only get better in the future when the vehicle-to-grid technology, also called V2G, is put into operation. This technology means that an electric vehicle will feed back stored energy into the grid during peak usage periods, hence serving like mobile energy storage units.

1.4.4 vehicle-to-grid (V2G)

For example, in such a system, electric vehicle owners are granted certain incentives by discharging their batteries into the grid at peak hours in return for recharging during off-peak hours when electricity is supplied at lower rates. The V2G technology allows EV owners to add another revenue stream by selling electricity back to the grid, while the utilities are assured of a more resilient grid with distributed energy resources

Figure 1.11

Vehicle-to-Grid technology



1.5 Government Incentives and Policy Support in Thailand

The Thai government has introduced a range of incentives to encourage the adoption of EVs from subsidies on domestically produced batteries to less stringent import and excise taxes, as well as the promotion of foreign investment in the EV sector. The Thai government's long-term policy of attracting an investment of US$28 billion in the next four years through foreign investors aims to reinforce its EV industry. The fact that such inducements have created competition-not only within local but also foreign vehicle assemblers-means that highly developing EV market competition arises

Table 1.2

Measure to Support Purchases and Production Compensation for Import Under EV 3.0

EV 3.0	Passenger Car		Pick-up Truck	Motorcycle
Specification	Price ≤ 2 Mn THB **Battery Capacity :** **1-30 kWh**	Price ≤ 2 Mn THB **Battery Capacity :** **≥ 30 kWh**	Price ≤ 2 Mn THB **Battery Capacity :** **≥ 30 kWh**	Price ≤ 0.15 Mn THB
Cash Subsidy	**70,000** THB/Unit	**150,000** THB/Unit	**150,000** THB/Unit	**18,000** THB/Unit
Specification	Price ≤ 2 Mn THB **Battery Capacity :** **≥ 10 kWh**	Price **2-7 Mn THB** **Battery Capacity :** **≥ 30 kWh**	Price ≤ 2 Mn THB **Battery Capacity :** **≥ 30 kWh**	Price ≤ 0.15 Mn THB **Battery Capacity ≥ 50 kWh**
Excise Tax	2% (reduced from 8%)		0% (reduced from 10%)	1%
Import Tariff	Up to 40% Reduction	Up to 20% Reduction	No reduction	No Reduction
BEV Import : BEV Production in Thailand	**1 : 1** for the production by 2024 **1 : 1.5** for the production by 2025 (Production compensation must be the same model as imported for passenger cars with price between 2-7 Mn THB)			

Source : BOI

Table 1.3

Excise Tax Structure by Type Effective 2026 Onwards

Type	CO_2	Passenger Cars – Excise Tax Rate									
		At least 2 out of 6 Advanced Driver – Assistance Systems (ADAS) must be installed						Not in compliance			
		Effective from 2026		Effective from 2028		Effective from 2030		Effective from 2026		Effective from 2030	
		ICE	HEV	ICE	HEV	ICE	HEV	ICE	HEV	ICE	HEV
Engines ≤ 3,000 cc.	≤ 100 g/km	13%	6%	14%	8%	15%	10%	25%	15%	30%	20%
	101-120 g/km	22%	9%	24-27%	11%	26%	13%	25%	15%	30%	20%
	121-150 g/km	25%	14%	27%	16%	29%	18%	25%	15%	30%	20%
	151-200 g/km	29%	19%	31%	21%	33%	23%	35%	25%	40%	30%
	> 200 g/km	34%	24%	36%	26%	38%	28%	35%	25%	40%	30%
Engines > 3,000 cc.	Indefinitely	Effective from 2026									
		ICE						HEV			
		50%						40%			
	Electric Range and Oil tank	At least 2 out of 6 ADAS must be installed		At least 4 out of 6 ADAS must be installed		Not in compliance					
		PHEV		BEV	FCEV	PHEV		BEV		FCEV	
		Effective from 2026		Effective from 2022	Effective from 2026	Effective from 2026	Effective from 2030	Effective from 2022	Effective from 2026	Effective from 2026	
Engines ≤ 3,000 cc.	Electric Range≥ 80 km and Oil tank ≤ 45 L	5%		2%	1%	15%	20%	8%	10%	5%	
	Electric Range< 80 km and Oil tank > 45 L	10%									
Engines > 3,000 cc.	Indefinitely	PHEV		BEV	FCEV	PHEV		BEV		FCEV	
		30%		2%	1%	30%		8%	10%	5%	

1.6 Metropolitan Electricity Authority (MEA) Background

In the year 1958, it was established as a state enterprise under the Ministry of Interior, Government of Thailand, and named the Metropolitan Electricity Authority of Thailand. The mandate given to MEA was efficient, safe, and reliable services concerning distribution for both residential and commercial consumers in Bangkok, Nonthaburi, and Samut Prakan Provinces.

During Thailand's rapid urbanization and the metropolitan city of Bangkok, MEA has always played an important role in modernizing the country's electrical infrastructure in keeping up with energy stability and economic development within the country.

With the sustained development of Thailand's electric vehicle market, MEA has been instrumental in developing the charging infrastructures that have obtained urban electric mobility. MEA is aware of the need for accessible EV charging; thus, it installed a network of public EV charging stations inside the Bangkok Metropolitan Area such that it has both Level 2 AC chargers and DC fast chargers, enabling a great variety of models and types of user needs.

MEA operates over dozens of charging stations across the area but is going further, in keeping with increasing numbers of EVs on Thailand's roads. Besides that, this would be important not only for MEA's commitment to sustainable transport but also to help overcome range anxiety-one of the major barriers that holds back possible potential adopters. Finally, MEA is considering the possibility of Vehicle-to-Grid technology; an electric vehicle could act like a sort of mobile energy storage. In a V2G system, an electric vehicle can feed electricity back into the grid during periods of peak use and help stabilize the load on the grid while saving extra generation demand. Also, this will give owners extra sources of income against the power fed into the grid. Mechanisms for V2G meet MEA's vision for the distributed energy network whereby electric vehicles can be coupled with Distributed Renewable Energy Resources and Smart Grid Technology in further building a robust and productive electricity ecosystem. A major player in the development of the infrastructure for electric vehicles in Bangkok is the Metropolitan Electricity Authority or MEA. By the end of 2023, there were 72 EV charging stations, which housed 223 charging points, as illustrated in Figure 3. Compared to private operators like PTT, it is highly small and plans to expand up to 1,000 stations by the end of 2024. MEA provides both normal and fast charging services. However, the pricing model gives its customers a big burden, coupled with the limited operating hours of its stations. That is a huge drawback. Compared to competitor apps, which allow finding and reservation at charging stations, it is still less advanced via the MEA mobile application.

1.6.1 Role of the MEA in EV infrastructure development

The MEA is one of the major participants in developing Bangkok's EV infrastructure. MEA operates 72 EV charging stations equipped with 223 charging points at the beginning of 2023, as shown in figure 3. However, the network of MEA is very small compared to the networks formed by private operators such as that of PTT, which plans to reach 1000 stations by the end of 2024. MEA has different sub-networks allowing both normal and fast-charging services but its pricing model and operating hours per station are limited and hence very burdensome to its users. Also, the mobile application of MEA for searching and booking charging points is not as advanced as some competitors' apps, which can also provide other functionalities.

Figure 1.12

Number of Electric Vehicle Charging Stations in Thailand in 2024

Service Providers ผู้ให้บริการ	Number of Locations จำนวนแห่ง	DC CCS 2	DC CHAdeMO	AC TYPE 2	TOTAL
EV	919	1,717	1	861	2,579
EA Anywhere	538	1,515	-	1,824	3,339
PEA	423	694	316	171	1,181
R	412	404	60	673	1,137
evolt	263	86	15	624	725
EleX	142	174	7	144	325
ALTERVIM	118	240	-	102	342
ESPRO	86	3	3	218	224
mea ev	72	87	9	127	223
on ion	70	25	1	462	488
HAUP	45	4	4	63	71
Galvanic	36	28	1	54	83
GWM	28	60	-	-	60
CHOSEN	19	2	2	49	53
PUMP CHARGE	5	-	-	16	16
TOTAL	3,175	5,039	419	5,388	10,846

Notes: Not including public charging stations that serve only specific EV owners e.g., Tesla Supercharger, MG Super Charge, etc.

1.7 Opportunities in the EV Sector

Despite such setbacks, however, the prospect for electric vehicles does look bright within the Thai automotive market. Advances in battery technology further support investment interest in the EV sector, together with growing environmental awareness among consumers. Development of charging infrastructure remains yet another priority, with earnest efforts of the public-private sectors in reducing service gaps. Understanding those factors influencing the use of its EV charging stations will be important for MEA in terms of competitiveness and growth of market share in this fast-changing market.

1.8 Study Objective

The study is necessary to identify the various factors that affect the consumption of the electric vehicle charging station operated by MEA in Bangkok. The current research will underline some aspects, including user behavior, the location of stations, pricing models, and technology integration, in which MEA can further develop its services to capture a larger market share. The findings from this study also contribute to the general effort of developing sustainable urban mobility and overcoming several challenges of EV adoption in Thailand.

Thus, specific objectives of the current study are as follows:

1. To identify the main influential characteristics determining the usage of EV charging stations of MEA in Bangkok.

2. The usage of the charging station assessment in respect to customer demographics, preference, and behavioral pattern

3. To establish impacts of a location, station type, availability of amenities within surroundings, pattern of use, pricing model, and technology on station utilization.

4. To give strategic recommendations based on research findings to MEA, with respect to EV charging infrastructure and related services.

CHAPTER 2
LITERATURE REVIEW

2.1 Global Perspectives on EV Charging Infrastructure

The adoption of electric vehicles (EVs) worldwide has catalyzed the rapid development of charging infrastructure, a critical component for ensuring the sustainability and scalability of the EV ecosystem. Borlaug et al. (2022) explored public charging station utilization in the United States and identified several factors influencing infrastructure efficiency. Urban areas with higher traffic volumes benefit from denser networks, enabling quicker access to charging services and higher station turnover rates. Conversely, rural regions often struggle with underutilized infrastructure due to sparse EV adoption and limited connectivity.

International case studies provide valuable insights into best practices. For instance, Norway's EV policies, as outlined by Figenbaum (2017), demonstrate how financial incentives, combined with targeted infrastructure investments, can drive adoption. Norway’s fast-charging networks and stringent emissions regulations have made it a global leader in EV penetration. Similarly, Funke et al. (2019) conducted a comparative analysis of EV infrastructure adequacy in Europe and Asia, highlighting that population density, economic factors, and government policies significantly influence charging station deployment and utilization.

The global surge in EV sales, as reported by Canalys (2021), underscores the growing need for comprehensive charging networks. In 2020 alone, EV sales increased by 39%, despite the decline in overall automotive markets due to the COVID-19 pandemic. This trend underscores the urgency for investments in charging infrastructure to support the growing EV population, especially in emerging markets where infrastructure development remains nascent.

2.2 Consumer Preferences and Barriers

Consumer behavior is a cornerstone of successful EV charging infrastructure planning. Hardman et al. (2018) reviewed consumer interactions with EV charging networks and identified key preferences, such as the availability of fast-charging options, proximity to frequent destinations, and ease of payment. The study emphasized that consumer satisfaction is closely tied to the seamless integration of charging stations into daily routines, making location and accessibility paramount.

EV Connect (2023) reinforced these findings, outlining six key locations where EV users prefer charging stations: retail centers, workplaces, highways, residential neighborhoods, public transit hubs, and tourist attractions. These locations cater to diverse user needs, from daily commuters to long-distance travelers, highlighting the importance of strategic placement in maximizing utilization.

Despite these advancements, significant barriers persist. ABeam Consulting (2022) highlighted the inadequacy of residential charging infrastructure in Thailand, where limited availability in multi-story condominiums hampers EV adoption. Similarly, Mastoi et al. (2022) emphasized that range anxiety—the fear of running out of battery before finding a charging station—remains a critical deterrent. Addressing these barriers requires not only infrastructural investments but also public awareness campaigns to educate consumers about the availability and benefits of EVs.

Additionally, Sukkasem (2023) identified pricing models and station reliability as key concerns among Bangkok residents. Dynamic pricing strategies, which offer lower rates during off-peak hours, can alleviate cost concerns while optimizing grid usage. However, inconsistent station performance and limited fast-charging options often undermine consumer confidence, necessitating technological and operational improvements.

2.3 Technological Innovations in Charging Infrastructure

Advancements in technology have revolutionized the EV charging landscape, enabling more efficient and user-friendly systems. Bacancy Systems (n.d.) provided a detailed classification of EV chargers, ranging from Level 1 home chargers to high-speed DC fast chargers and emerging wireless systems. These advancements cater to diverse user needs, from overnight residential charging to quick stops during long-distance travel.

Wireless charging, though still in its nascent stages, represents a significant leap forward. Bacancy Systems (n.d.) described how electromagnetic fields can transfer energy between a ground-mounted pad and the vehicle, eliminating the need for physical connectors. This technology not only enhances convenience but also reduces wear and tear on charging equipment, promising long-term benefits for both users and providers.

Lyu et al. (2024) explored the integration of dual-incentive mechanisms that promote grid stability by enabling EVs to discharge electricity during peak demand periods. This vehicle-to-grid (V2G) technology transforms EVs into mobile energy storage units, enhancing grid resilience and reducing reliance on traditional power sources. EV Engineering Online (n.d.) also highlighted the potential of smart grids and dynamic pricing models in optimizing energy distribution and reducing operational costs.

Furthermore, Harper et al. (2019) emphasized the importance of sustainable practices in EV adoption, particularly the recycling of lithium-ion batteries. Developing closed-loop recycling systems can mitigate environmental impacts and ensure a steady supply of raw materials, aligning EV infrastructure development with broader sustainability goals.

2.4 The Thai Context: EV Infrastructure and Utilization

Thailand's EV market has witnessed substantial growth, driven by supportive government policies and increasing consumer awareness. The EV 3.0 initiative by the Thai Ministry of Energy (2023) aims to position Thailand as a regional hub for EV manufacturing and adoption. This policy includes tax incentives, subsidies for domestic battery production, and relaxed import duties for EV components, creating a conducive environment for market expansion.

Evat (2023) reported a significant increase in charging stations nationwide, particularly in urban centers like Bangkok. However, rural areas remain underserved, exacerbating range anxiety and limiting EV adoption outside metropolitan regions. Addressing this imbalance requires targeted investments and public-private partnerships to extend infrastructure to less-populated areas.

Krungsri Research (2024) highlighted the importance of aligning Thailand's EV infrastructure with ASEAN trends, noting that regional collaboration can accelerate technology transfer and investment flows. The study also emphasized the growing demand for home-based charging solutions, which can alleviate pressure on public networks and enhance consumer convenience.

Sukkasem (2023) identified several factors influencing charging station utilization in Bangkok, including location, pricing, and technological features. The study recommended leveraging mobile applications to provide real-time information on station availability and integrating renewable energy sources to enhance sustainability. Additionally, prioritizing high-traffic areas for fast-charging stations can significantly improve utilization and consumer satisfaction.

2.5 Consumer Expectations for EV Charging Infrastructure in Thailand

Greater demand for EVs in Thailand also means rising consumer expectations for charging infrastructure. In July 2024, Milieu Insight researched what users of electric vehicles wanted to see in EV-charging infrastructure over the next five years. All 200 respondents were current owners or lessees of EVs, and a number of key findings really came into sharp focus, particularly those to do with the needs of different age groups.

Accordingly, the two most pivotal wishes across all of the age brackets were increasing the total number of charging stations by 39% and the speed at which charging will happen by 41%. A desire to increase the number of charging stations was felt most in both the 45-54- and 55+ year-old segments, where 56% and 50% of those respectively marked this as a key priority. Indeed, this might even insinuate that middle-aged and older EV users consider charging-point inaccessibility even in suburban and less crowdy areas.

Disregarding this infrastructure expansion, the speed of charging is an area of concentration mainly in the age group of 25-34 years at 49% and that of 16-24-year-olds at 41%, with more and more users starting to embed EVs into their routine, definitely for quicker ways to get things charged. The demand comes in line with the global trend, whereby fast-charging networks will be highly instrumental in reducing waiting times and further improving ownership experiences of an EV.

Figure 2.1

Breakdown of the Survey Results by Age Group

What improvements would you like to see in the EV charging infrastructure over the next five years?

		Age group				
	Overall	16-24	25-34	35-44	45-54	55+
Increase in the number of charging stations	39%	31%	36%	40%	56%	50%
Faster charging speeds	41%	41%	49%	38%	33%	30%
Increase in the reliability of existing charging stations	11%	11%	11%	13%	4%	20%
Lower cost of charging	24%	19%	28%	21%	26%	40%
Integration of renewable energy sources in charging stations	22%	24%	18%	21%	22%	30%
Enhanced safety features at charging stations	20%	30%	18%	19%	7%	20%
Improved real-time information on charging station availability	18%	6%	20%	29%	22%	0%
Other(s) not listed here	2%	4%	3%	0%	0%	0%
Sample Size (N)	200	54	61	48	27	10

The quantitative study was conducted via Milieu Insight's proprietary survey community with N=200 in Thailand. The data is representative of Thailand residents aged 18 and above who currently own or lease an electric vehicle. Fieldwork was conducted 17th to 19th July 2024.

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Other priorities that follow involve increasing the reliability of the existing charging stations at 11% and decreasing the cost of charging at 24%. This latter factor was especially important to respondents aged 55 and above, at 40%. These results show that while expanding the infrastructure is key, making the existing network more affordable and more reliable also plays a significant role in improving user satisfaction and further facilitating EV adoption.

Other valid information is that, in general, 22% of the interviewees were interested in the inclusion of renewable energy sources into the charging stations, in other words, the ecologically-sensitive user seeks more green sources of energy to complete their EV experience.

This data reinforces the importance of addressing both quantitative (number of stations) and qualitative (speed, reliability, sustainability) aspects of EV charging infrastructure development in Thailand, which is critical to meeting consumer needs and supporting the growth of the EV market.

2.6 International Comparisons and Lessons for Thailand

Global case studies offer valuable lessons for Thailand's EV infrastructure development. Norway's comprehensive approach, as detailed by Figenbaum (2017), demonstrates the effectiveness of integrating financial incentives with robust infrastructure planning. The country's widespread fast-charging networks and universal access policies have significantly boosted consumer confidence and adoption rates.

In the United States, Borlaug et al. (2022) identified regional disparities as a major challenge. Rural areas often face underutilization due to limited infrastructure, while urban centers grapple with congestion at popular charging stations. Mastoi et al. (2022) suggested that public-private partnerships can effectively address these issues by pooling resources and expertise to expand coverage.

Bitencourt et al. (2021) proposed a multi-objective optimization model for charging station placement, balancing factors such as accessibility, environmental impact, and economic viability. This approach can guide Thailand's infrastructure planning, ensuring that investments meet diverse user needs while minimizing environmental footprints. Additionally, integrating renewable energy into charging networks can align infrastructure development with Thailand's sustainability goals.

2.7 Research Gaps and Future Directions

Despite substantial progress in the development of EV infrastructure, several gaps persist in addressing the unique challenges faced in Thailand. Key areas for further exploration include urban versus rural dynamics, which involve investigating how differences in urban density and rural disparities influence infrastructure utilization and consumer behavior. The integration of advanced technologies, such as wireless charging and vehicle-to-grid (V2G) systems, also warrants evaluation to understand their adoption and impact within the Thai context. Additionally, the effectiveness of government policies, including subsidies and infrastructure investments, remains an area of interest to assess their long-term outcomes and contribution to the EV ecosystem. Understanding the preferences, expectations, and pain points of Thai EV users is another critical aspect that could inform targeted interventions aimed at enhancing user satisfaction and adoption rates.

Future research should take a holistic approach, incorporating environmental, economic, and social considerations into infrastructure planning. Bitencourt et al. (2021) highlighted the value of multi-objective optimization models in achieving balanced and sustainable development. Such models can help policymakers address competing priorities while ensuring equitable infrastructure expansion. Furthermore, cross-regional collaborations can play a pivotal role in facilitating knowledge sharing and accelerating the adoption of best practices. These collaborative efforts can position Thailand as a leader in the EV transition within the ASEAN region, fostering innovation and sustainable growth in the sector.

CHAPTER 3
METHODOLOGY

3.1 Research Design

This study adopts a mix-method approach, where data collection strategies are combined, both quantitative and qualitative. Most of this paper is devoted to discussing the factors that affect the utilization of the EV charging stations operated by the MEA in Bangkok. It integrates both primary data from user surveys and secondary data from operational records of the MEA, government reports, and academic literature.

A mixed-method approach will be suitable since it allows numerical data collection for statistical analysis and investigation of personal user experiences, attitudes, and preferences about EV charging stations. One will definitely acquire insight into what affects utilization of electric vehicle charging infrastructure in Bangkok that way.

3.2 Data Collection

3.2.1 Primary Data Collection: Surveys

The data will be collected through an online structured survey from the owners and users of EVs in Bangkok. The questionnaires will be forwarded using e-mail, social media platforms, and online communities of users of electric vehicles with the help of a purposive sampling method in order to make sure that the population segment of interest uses the EV charging stations. The purposive sampling technique will be highly applicable because only the respondents who are active users of EVs and charging stations in Bangkok will be selected.

The survey will be divided into a number of parts:

Demographics: there will be the demography that assures data about age, sex, income level, occupation, and type of residence-for example, condominium or house

EV Ownership and Usage Patterns: EV ownership and use patterns would involve questions about the kind of EV owned, time period of ownership, and frequency of use of a public charging station

Charging Behavior and Preferences: This section shall delve into the favorite types of charging stations, that is Level 1, Level 2, or DC fast chargers; the frequency and time taken for a charge; and preference for charging station location.

Perception of Charging Stations: The level of satisfaction of the respondents regarding the availability and accessibility of charging stations, and charging behavior with respect to charging station proximity to the place of interest like a shopping centre or workplaces.

Key Factors Influencing Utilization: The drivers include locational characteristics, vicinity to high-traffic areas, time-of-use patterns, pricing models, and available government incentives.

Certain factors that affect the use of charging stations are drawn from a 5-point Likert scale: "Not Important" to "Most Important." This would make it possible to quantify the attitudes and behavior of users.

Barriers to Utilization: On this question, the respondent will also be asked to identify which factor, according to him or her, hinders them the most from using an EV charging station, such as not enough charging points, too long a wait, or too expensive.

Satisfaction with Current MEA Charging Stations: Respondents were asked to rate their overall satisfaction with MEA charging stations on a scale of 1 to 5, covering aspects such as station availability, accessibility, charging speed, and security.

Recommendations for MEA Improvements: Respondents were prompted to identify specific improvements they would like to see at MEA charging stations, including suggestions for expanding the network, integrating advanced technologies, and enhancing customer experience.

3.2.2 Secondary Data Collection

Data will be collected from various sources, which can give contextual support to the research work. It includes operational data from MEA like historical usage records at charging stations, energy consumption at different locations, and pattern variations with respect to time factor. The secondary sources of the data also include government reports, industry publications, and academic studies relevant to the EV infrastructure in Thailand and globally.

Secondary data will serve two purposes:

1. Cross-referencing with Primary Data: Data triangulation is achieved by cross-referencing primary data to validate the results for their validity and accuracy.

2. Providing Contextual Insights: The secondary analysis informs the study about the greater trends in the utilization of the EV charging stations and their infrastructural development.

3.3 Sampling Strategy

This would ensure the results of the survey are reasonably reliable and representative; hence, targeting a sample size ranging between 150 and 250 respondents is appropriate. As such, this range of sampling size is right, considering the relatively small population of EV owners in Bangkok. This will be sufficiently large to assure high statistical analysis representative for the majority of different user demographics: age, income class, and area of residence.

It will adopt a purposive sampling method whereby the respondents either own EVs or habitually use public charging stations. That is to say, in this study, direct experience and relevant insights sought from participants will provide valuable data, hence only they shall be able to contribute towards shedding light on relevant factors that influence utilization of MEA's electric vehicle charging stations.

3.4 Statistical Analysis

3.4.1 Descriptive Analysis

Summary statistics will describe the demographic characteristics of the respondents, their ownership, and the charging behavior of EVs. The summary statistics, such as the mean, median, and standard deviation, and frequency distributions for these variables will be calculated to provide an overview.

3.4.2 Exploratory Data Analysis (EDA)

Hence, EDA will be done in such a way as to bring out patterns, trends, and even relationships within the data. Some EDA techniques would include the following visualizations: a histogram, a bar chart, and a scatter plot that may expose any possible intervariable correlations between location, station type, and user satisfaction. Further statistical tests will be highlighted in the paper once these key insights have been obtained.

3.4.3 Multiple Regression Analysis

The present study shall apply multiple regression to the dependent variable of interest, which is the usage of charging stations for electric vehicles, against a range of independent variables: demographic factors, station attributes, pricing models, and proximity to amenities. In this way, using multiple regression can determine which independent variables are significant and can, therefore, be used as predictors of charging station use and thus give complete insight into which factors weigh the most in user behavior.

The regression model will take the following form:

$$\begin{aligned} &Charging\ Station\ Utilization \\ &\qquad = \beta_0 + \beta_1(Location) + \beta_2(Station\ Type) \\ &\qquad + + \beta_3(User\ Demographics) + + \beta_4(Pricing\ Model) \\ &\qquad + \beta_5(Other\ Factors) + \varepsilon \end{aligned}$$

$Where$:

- β_0 $is\ the\ intercept,$
- $\beta_1, \beta_2, \beta_3, \beta_4, \beta_n$ $are\ the\ coefficients\ for\ each\ factor,$
- ε $is\ the\ error\ term.$

The model will, therefore, help estimate the relative importance of various factors affecting utilization and will help MEA prioritize the improvements based on statistical evidence.

3.5 Expected Deliverables

The key deliverables from this study would be as follows:

1. A comprehensive report on the findings of the analysis performed based on the primary and secondary data.

2. Charts and graphs depicting patterns of usage and demographics broken down by key factors that affect the use of the EV charging stations.

3. Recommendations, actionable by MEA, on improving its electric vehicle-charging infrastructure and user satisfaction in order to improve market share.

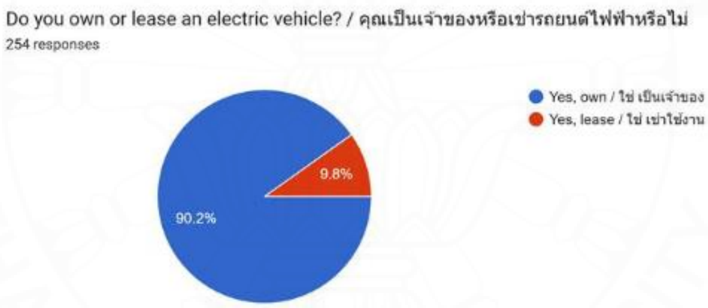
CHAPTER 4
DATA ANALYSIS AND FINDING

By conducting a survey through multiple channels, including customers who use services at MEA Charging Stations, customers who use services at other charging stations, and respondents from Facebook Groups and Line, a total of 254 surveys were collected, categorized into the following usage types:

4.1 EV Ownership

Figure 4.1

EV Ownership

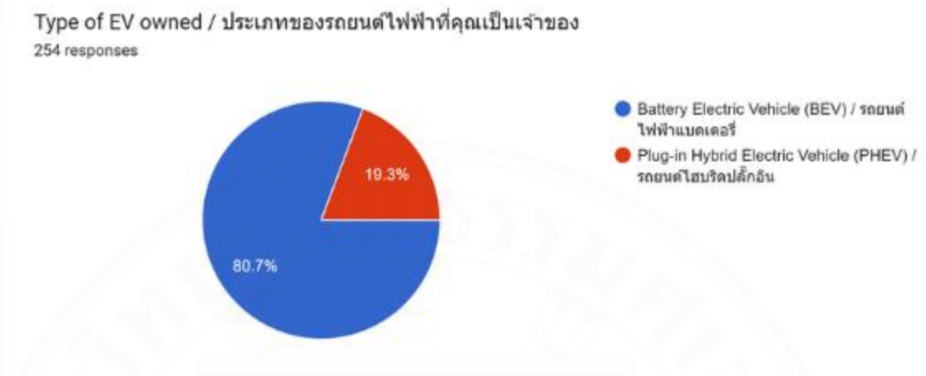


According to Figure 6, 90.2% of respondents own their EVs, while 9.8% lease them, showing a strong preference for ownership. This indicates that most EV users prioritize the long-term benefits and control that come with owning a vehicle, compared to the flexibility offered by leasing.

4.2 Type of EV Owned

Figure 4.2

Type of EV Owned

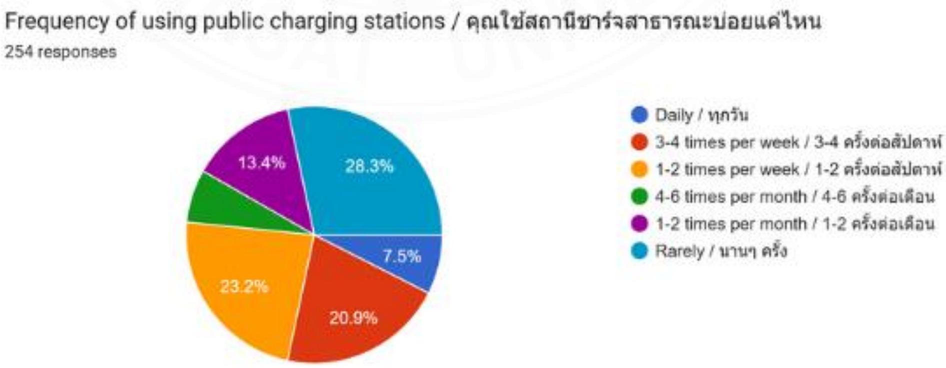


According to Figure 7, 80.7% of respondents own Battery Electric Vehicles (BEVs), while 19.3% own Plug-in Hybrid Electric Vehicles (PHEVs), highlighting a strong shift toward fully electric vehicles over hybrids.

4.3 Frequency of Using Public Charging Stations

Figure 4.3

Frequency of Using Public Charging Stations



According to Figure 8, 28.3% of respondents charge their EVs rarely, 23.2% use public charging stations 1-2 times per week, and 20.9% use them 3-4 times per week, demonstrating a wide range of charging habits among users.

4.4 Average Time Spent at a Charging Station

Figure 4.4

Average Time Spent at a Charging Station

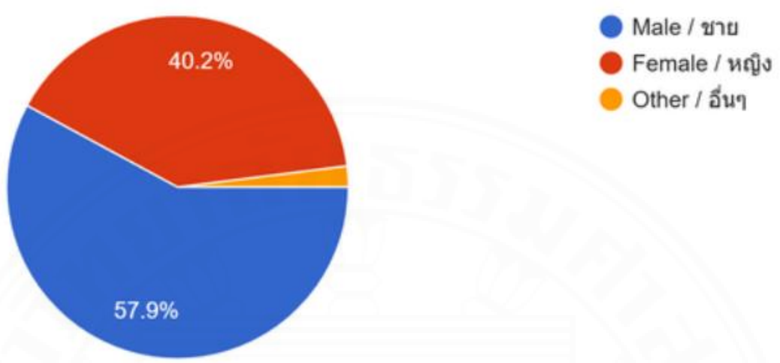
According to Figure 9, 59.4% of respondents spend 30-60 minutes per charging session, while 20.5% take less than 30 minutes, emphasizing the importance of charging time as a key consideration for EV users.

Transitioning to the demographic analysis, this section delves into key variables such as gender, age group, and income level of EV users in Bangkok. Understanding these demographic characteristics is essential for identifying patterns and preferences that influence EV charging station utilization, thereby providing insights to support the Metropolitan Electricity Authority's strategies for market share growth.

4.5 Gender Distribution and Its Implications for EV Adoption Trends

Figure 4.5

Gender Distribution

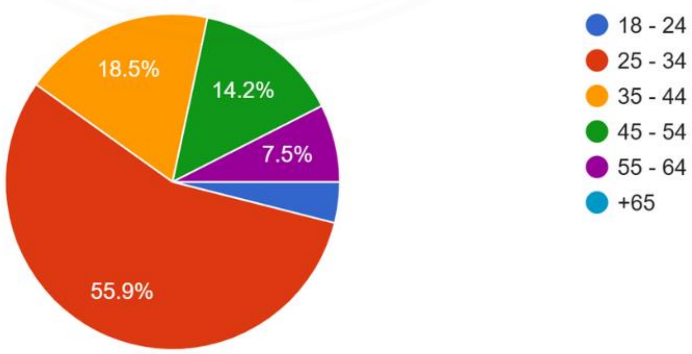


According to figure 10, among the respondents, 57.9% are male, while 40.2% are female. A small percentage (1.9%) identify as other. The male majority indicates a possible gender skew in EV ownership and charging station usage, which may reflect broader market trends in EV adoption

4.6 Age Group

Figure 4.6

Age Group

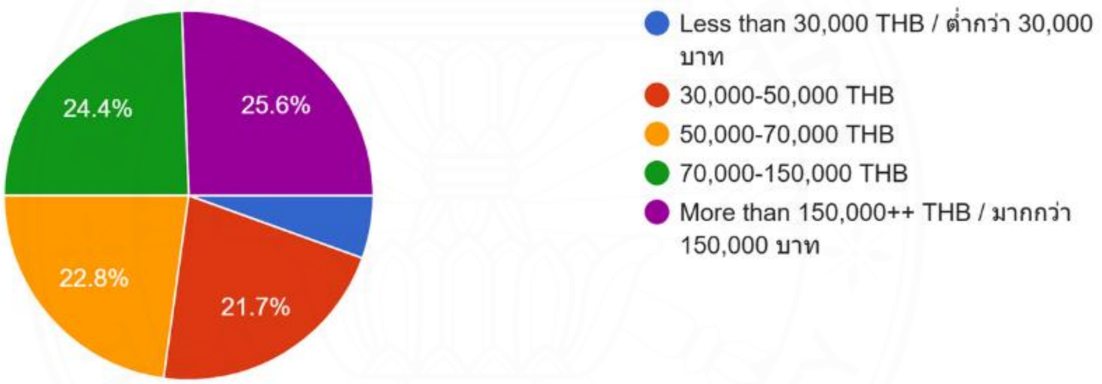


According to figure 11, the largest age group among respondents is 25-34 years, making up 55.9% of the total. This is followed by the 35-44 age group at 18.5%, while the younger (18-24) and older (45-54) groups constitute 14.2% and 7.5%, respectively. The dominance of the 25-34 demographic highlights that younger working professionals are the primary users of EV charging infrastructure.

4.7 Monthly Income Level

Figure 4.7

Monthly Income Level



According to figure 12, the majority of respondents (25.6%) fall into the income bracket of greater than 150,000 THB per month, followed by 24.4% earning more than 70,000 THB. The middle-income brackets, 30,000-50,000 THB and 50,000-70,000 THB, account for 21.7% and 22.8%, respectively. This income distribution suggests a wide range of users, with higher-income groups possibly driving the demand for premium EV charging services

4.8 Perception of EV Charging Stations

The analysis aimed to identify the most significant factors influencing users' overall satisfaction with EV charging stations in Bangkok. To achieve this, multiple linear regression analysis was employed to assess the relationship between various independent variables and overall satisfaction, the dependent variable.

Table 4.1

Means Score of Each Specific Questions

Topics	Survey Questions	Mean
Overall Satisfaction (Dependent Variable)	Please rate your overall satisfaction with EV charging stations in Bangkok on a scale of 1 to 5	3.59
Convenience of Location	Charging stations are conveniently located near my home or workplace	3.93
Station Availability	I am satisfied with the availability of charging stations in my area	3.74
Proximity to Amenities	Charging stations near amenities (e.g., shopping centers) encourage me to use them more often	3.93
Real-Time Availability Information	I prefer charging stations that are equipped with real-time availability information	4.6
Security Concerns	I am concerned about the security of EV charging stations, especially at night	3.63
Cost Concerns	I am concerned about the cost of EV charging stations	3.12

Table 4 summarizes the topics assessed, the corresponding survey questions, and the mean scores obtained from respondents. These findings provide insights into user perceptions and the key factors contributing to their satisfaction

4.8.1 Correlation Matrix Analysis

To identify potential multicollinearity issues among the independent variables, a correlation matrix was constructed. All correlation coefficients were below 0.6, indicating a low risk of multicollinearity as shown in figure 13. This confirms that each factor contributes uniquely to explaining overall satisfaction, enabling a robust regression analysis.

Figure 4.8

Correlation Matrix

	Convenience of Location	*Station Availability*	*Proximity to Amenities*	*Real-Time Availability Information*	*Security Concerns*	*Cost Concerns*	*Overall Satisfaction*
Convenience of Location	1.000						
Station Availability	0.502	1.000					
Proximity to Amenities	0.279	0.269	1.000				
Real-Time Availability Information	0.334	0.242	0.226	1.000			
Security Concerns	-0.011	-0.054	0.066	0.104	1.000		
Cost Concerns	-0.013	-0.021	0.124	0.009	0.347	1.000	
Overall Satisfaction	0.308	0.426	0.261	0.222	-0.057	-0.057	1.000

4.8.2 Multiple Regression Analysis

The multiple regression analysis was conducted to determine the most significant factors influencing users' overall satisfaction with EV charging stations in Bangkok. Key findings from the analysis include:

- **Model Summary**:
  - The F-statistic (11.85, $p < 0.001$) demonstrates that the model is statistically significant overall.

- The adjusted R-squared value indicates that 20% of the variance in user satisfaction is explained by the independent variables included in the model.

Figure 4.9

Multiple Regression Result

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.472813106
R Square	0.223552234
Adjusted R Square	0.204691154
Standard Error	0.6663074
Observations	254

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	31.57279241	5.262132069	11.85256842	1.1082E-11
Residual	247	109.6594911	0.443965551		
Total	253	141.2322835			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.9499	0.3108	6.2740	0.0000	1.3378	2.5620	1.3378	2.5620
Convenience of Location	0.0472	0.0432	1.0925	0.2757	-0.0379	0.1324	-0.0379	0.1324
Station Availability	0.2304	0.0467	4.9291	0.0000	0.1383	0.3225	0.1383	0.3225
Proximity to Amenities	0.0893	0.0381	2.3457	0.0198	0.0143	0.1643	0.0143	0.1643
Real-Time Availability Informatior	0.0932	0.0621	1.5008	0.1347	-0.0291	0.2155	-0.0291	0.2155
Security Concerns	-0.0222	0.0353	-0.6299	0.5294	-0.0917	0.0473	-0.0917	0.0473
Cost Concerns	-0.0322	0.0353	-0.9096	0.3639	-0.1018	0.0375	-0.1018	0.0375

The analysis identified Station Availability as the most influential factor affecting overall satisfaction with EV charging stations. This finding highlights the critical importance of increasing station density and ensuring accessibility, particularly in high-demand and underserved areas. To address this, it is recommended that infrastructure expansion be prioritized, focusing on strategic locations where user demand is greatest.

Additionally, Proximity to Amenities was found to support user satisfaction, though it remains secondary to station availability. Amenities such as shopping centers and leisure facilities enhance the user experience by providing added convenience during charging sessions. It is recommended that future charging station developments incorporate or be co-located with such amenities to improve user satisfaction further.

On the other hand, Security and Cost Concerns were found to have minimal impact on satisfaction, suggesting that these factors may not require immediate attention in strategic planning. However, basic safety measures and fair pricing models should still be maintained to avoid dissatisfaction among users. Lastly, while Convenience of Location showed moderate correlation with satisfaction, it was deemed less critical in the regression model. This implies that while proximity to residential or workplace areas is beneficial, it is not as pressing as other factors and can be addressed as a secondary priority.

4.9 Impact of Time Spent on Amenity Preferences

To further explore user preferences, an ANOVA (Analysis of Variance) was conducted to test the hypothesis that respondents who spend longer durations at EV charging stations exhibit a greater preference for locations with more amenities. The analysis was designed to evaluate whether the time spent at charging stations significantly influences preferences for additional services and facilities.

Table 4.2

Means Score of Impact of Time Spent on Amenity Preferences

Average time spent at a charging station per visit	**Charging stations near amenities (e.g., shopping centers) encourage me to use them more often**					**Mean**
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	
Less than 30 minutes	9.6%	5.8%	23.1%	19.2%	42.3%	3.79
30 minutes to 1 hour	4.0%	11.3%	17.2%	29.8%	37.7%	3.86
More than 1 hour	3.9%	2.0%	15.7%	21.6%	56.9%	4.25
Grand Total	**5.1%**	**8.3%**	**18.1%**	**26.0%**	**42.5%**	**3.93**

The null hypothesis (H_0) stated that there is no significant relationship between the duration respondents spend at EV charging stations and their preference for locations with more amenities. In contrast, the alternative hypothesis (H_1) proposed that respondents spending longer durations at EV charging stations demonstrate a significant preference for such locations.

Figure 4.10

Impact of Time Spent on Amenity Preferences ANOVA Result

```
Group Statistics:
                              Frequency Group      Mean  Count  Variance
0  30 minutes to 1 hour / 30 นาทีถึง 1 ชั่วโมง  3.860927    151  1.347196
1      Less than 30 minutes / น้อยกว่า 30 นาที  3.788462     52  1.738688
2         More than 1 hour / มากกว่า 1 ชั่วโมง  4.254902     51  1.113725

ANOVA Results:
     Statistic     Value
0  F-statistic  2.586488
1      P-value  0.077290
Reject the null hypothesis: There is a significant difference between the group means.
```

The findings from the ANOVA revealed a statistically significant difference in amenity preferences among respondents with varying durations of charging station usage, at a 10% significance level. Respondents who spent more than one hour at charging stations exhibited the highest preference for amenities, followed by those who spent 30 minutes to one hour. Respondents spending less than 30 minutes displayed the lowest preference for amenities. Employing a 10% significance level allowed the analysis to uncover meaningful trends that might have been undetected under stricter thresholds (e.g., 5%). This approach was suitable for exploratory purposes and informed strategic decision-making.

Based on these findings, two key recommendations emerge. First, to enhance user experience, charging stations catering to users with extended charging durations (more than one hour) should prioritize amenities such as coffee shops, shopping areas, and productivity-enhancing services. These facilities can make the waiting period more productive and enjoyable, thus improving user satisfaction. Second, the Metropolitan Electricity Authority (MEA) should focus its investment on high-amenity charging stations located in high-traffic areas where prolonged charging times are common. Aligning infrastructure development with user preferences will not only enhance satisfaction but also strengthen the overall appeal of EV charging services.

4.10 Preference for Fast Charging: Impact of EV Ownership Type

To investigate the relationship between the type of EV owned and preferences for fast or ultra-fast charging options, an ANOVA (Analysis of Variance) was conducted. The objective was to assess whether owners of specific types of EVs, such as Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs), exhibited differing preferences for fast or ultra-fast charging options.

Table 4.3

Means Score of Preference for Fast Charging and EV Owned

Type of EV owned	Availability of fast or ultra-fast charging options					Mean
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	
Battery Electric Vehicle (BEV)	1.5%	3.4%	11.7%	16.6%	66.8%	4.44
Plug-in Hybrid Electric Vehicle (PHEV)	4.1%	8.2%	22.4%	20.4%	44.9%	3.94
Grand Total	**2.0%**	**4.3%**	**13.8%**	**17.3%**	**62.6%**	**4.34**

The null hypothesis (H_0) posited that there is no significant relationship between the type of EV owned and the preference for fast or ultra-fast charging options. Conversely, the alternative hypothesis (H_1) suggested that respondents who own specific types of EVs, particularly fully electric vehicles, demonstrate a significant preference for fast or ultra-fast charging options.

Figure 4.11

Preference for Fast Charging and EV Ownership Type ANOVA Result

```
Group Statistics:
                                   Frequency Group      Mean  Count  \
0  Battery Electric Vehicle (BEV) / รถยนต์ไฟฟ้าแบ...  4.439024    205
1  Plug-in Hybrid Electric Vehicle (PHEV) / รถยนต...  3.938776     49

   Variance
0  0.865136
1  1.392007

ANOVA Results:
     Statistic      Value
0  F-statistic  10.250370
1      P-value   0.001542
Reject the null hypothesis: There is a significant difference between the group means.
```

The results of the ANOVA analysis revealed a statistically significant difference in charging preferences, with a p-value of 0.001542 (below the 0.05 significance level). BEV owners exhibited the highest preference for fast or ultra-fast charging options, reflected by a mean score of 4.439, compared to PHEV owners, who had a mean score of 3.939. These findings underscore the critical role of fast and ultra-fast charging infrastructure in meeting the needs of BEV owners, who rely heavily on quick charging solutions to minimize inconvenience and enhance their overall satisfaction.

Based on these findings, it is recommended to enhance user experience by focusing on the installation of fast and ultra-fast charging options at stations frequently used by BEV owners. Meeting the high demand for such facilities can significantly improve user satisfaction and reduce waiting times. Furthermore, the Metropolitan Electricity Authority (MEA) should strategically prioritize the deployment of fast and ultra-fast chargers in areas with a high concentration of BEVs. This targeted approach aligns with user preferences, supports the adoption of sustainable energy solutions, and advances MEA's strategic goals for the development of EV infrastructure.

4.11 Impact of Charging Frequency on Mobile App Feature Preferences

To explore the relationship between the frequency of public charging station usage and preferences for mobile application features, an ANOVA (Analysis of Variance) was conducted. This analysis aimed to determine whether frequent users of public charging stations exhibit a greater preference for mobile application features, such as station reservation and payment functionalities, compared to less frequent users.

Table 4.4

Means Score of Impact of Charging Frequency on Mobile App Feature Preferences

Frequency of using public charging stations	**Mobile application features for station reservation and payment**					**Mean**
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	
Frequently used more than 15 times per month	1.4%	6.9%	16.7%	26.4%	48.6%	4.14
2-5 times per month	5.3%	5.3%	17.1%	22.4%	50.0%	4.07
Less than 2 time per month	2.8%	6.6%	5.7%	12.3%	72.6%	4.45
Grand Total	**3.1%**	**6.3%**	**12.2%**	**19.3%**	**59.1%**	**4.25**

The null hypothesis (H_0) stated that there is no significant relationship between the frequency of using public charging stations and the preference for mobile application features. In contrast, the alternative hypothesis (H_1) proposed that respondents who frequently use public charging stations have a significant preference for these features.

The results of the ANOVA revealed a statistically significant difference in preferences for mobile application features among respondents with varying frequencies of public charging station usage, with a p-value of 0.036782 (below the 0.05 significance level). Interestingly, respondents who used public charging stations less than two times per month exhibited the highest preference for mobile application features (mean = 4.453). This was followed by frequent users who charged more than 15 times per month (mean = 4.139), and those using public stations 2-5 times per month (mean = 4.066).

Figure 4.12

Impact of Charging Frequency on Mobile App Feature Preferences ANOVA Result

```
Group Statistics:
                          Frequency Group      Mean  Count  Variance
0                      2-5 times per month  4.065789     76  1.368947
1  Frequently used more than 15 times per month  4.138889     72  1.050861
2                 Less than 2 time per month  4.452830    106  1.107278

ANOVA Results:
     Statistic     Value
0  F-statistic  3.346581
1      P-value  0.036782
Reject the null hypothesis: There is a significant difference between the group means.
```

These findings highlight the importance of mobile applications in enhancing user convenience, particularly for infrequent users who may perceive app-based functionalities as essential to overcoming potential challenges, such as locating available stations or streamlining payment processes. Frequent users also benefit from advanced features that align with their consistent charging patterns, such as quick reservations, loyalty rewards, or integration with routine scheduling tools.

To address these insights, it is recommended to focus on attracting infrequent users by emphasizing the convenience and efficiency of mobile application features like station reservations and payment. For frequent users, enhancing app functionalities with advanced features such as loyalty programs or seamless scheduling tools can foster greater user satisfaction and retention. Strategically, the Metropolitan Electricity Authority (MEA) should prioritize promoting mobile application adoption among infrequent users, as they demonstrate the strongest preference for these features, thereby broadening the appeal of its charging infrastructure and strengthening overall user engagement.

4.12 Gender-Based Satisfaction with MEA's EV Charging Stations

To explore the relationship between gender and satisfaction with MEA's EV charging stations, an ANOVA (Analysis of Variance) was conducted. This analysis aimed to identify whether user satisfaction levels significantly differ across gender groups, providing insights to tailor services and improvements accordingly.

Table 4.5

Means Score of Gender-Based Satisfaction with MEA's EV Charging Stations

Gender	How satisfied are you with MEA's EV charging stations?					Mean
	Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied	
Female	2.0%	5.9%	50.5%	31.7%	9.9%	3.42
Male	9.9%	12.7%	47.2%	23.2%	7.0%	3.05
Other	20.0%	0.0%	60.0%	20.0%	0.0%	2.80
Grand Total	**6.9%**	**9.7%**	**48.8%**	**26.6%**	**8.1%**	**3.19**

The null hypothesis (H_0) stated that there is no significant relationship between gender and satisfaction with MEA's EV charging stations. Conversely, the alternative hypothesis (H_1) proposed that a significant relationship exists between gender and satisfaction levels.

Figure 4.13

Gender-Based Satisfaction with MEA's EV Charging Stations ANOVA Result

```
Group Statistics:
                          Frequency Group      Mean  Count  Variance
0                      2-5 times per month  4.065789     76  1.368947
1  Frequently used more than 15 times per month  4.138889     72  1.050861
2                 Less than 2 time per month  4.452830    106  1.107278

ANOVA Results:
     Statistic     Value
0  F-statistic  3.346581
1      P-value  0.036782
Reject the null hypothesis: There is a significant difference between the group means.
```

The analysis revealed a statistically significant difference in satisfaction across gender groups, with a p-value of 0.008549 (below the 0.05 significance level). Female respondents reported the highest satisfaction (mean = 3.416), followed by male respondents (mean = 3.049), and those identifying in the "other" category (mean = 2.800). These findings suggest that gender-specific preferences and experiences play a role in shaping user satisfaction with EV charging services.

Understanding these differences is critical for enhancing the user experience. For female users, MEA should focus on further improving features that already resonate well, such as safety measures, ease of access, and user-friendly designs. For male and other users, it is essential to identify specific needs or barriers impacting satisfaction, such as charging speed or station accessibility, and address them through targeted improvements.

Strategically, MEA should leverage these insights to create a more inclusive EV charging experience by addressing the diverse needs of all user groups. By enhancing satisfaction across genders, MEA can foster broader adoption of EV infrastructure and build stronger loyalty among its users, ultimately supporting its mission of sustainable and user-centered development.

4.13 Gender Differences in Preferences for MEA Expanding Charging Infrastructure

An ANOVA (Analysis of Variance) was conducted to explore the relationship between gender and the preference for increasing the number of MEA charging stations as a strategy to improve utilization. The analysis aimed to determine whether preferences for network expansion varied significantly across gender groups.

Table 4.6

Means Score of Gender Differences in Preferences for MEA Expanding Charging Infrastructure

Gender	Increase the number of charging stations					Mean
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	
Female	0.0%	1.0%	16.8%	23.8%	58.4%	4.40
Male	0.0%	0.0%	8.3%	16.6%	75.2%	4.67
Other	0.0%	0.0%	40.0%	20.0%	40.0%	4.00
Grand Total	**0.0%**	**0.4%**	**12.4%**	**19.5%**	**67.7%**	**4.55**

The null hypothesis (H_0) proposed that there is no significant relationship between gender and the preference for expanding the number of charging stations. In contrast, the alternative hypothesis (H_1) suggested a significant relationship between these variables.

Figure 4.14

Gender Differences in Preferences for MEA Expanding Charging Infrastructure ANOVA Result

```
Group Statistics:
  Frequency Group      Mean  Count  Variance
0   Female / หญิง  4.396040    101  0.641584
1      Male / ชาย  4.668966    145  0.389655
2   Other / อื่นๆ  4.000000      5  1.000000

ANOVA Results:
     Statistic     Value
0  F-statistic  5.941469
1      P-value  0.003017
Reject the null hypothesis: There is a significant difference between the group means.
```

The results revealed a statistically significant difference in preferences across gender groups, with a p-value of 0.003017 (below the 0.05 significance level). Male respondents expressed the highest preference for increasing the number of charging stations (mean = 4.669), followed by female respondents (mean = 4.396). These findings highlight gender-specific priorities in enhancing EV charging infrastructure and emphasize the importance of tailoring initiatives to meet these needs.

To enhance the user experience, MEA should focus on implementing and effectively communicating plans to expand the charging station network, particularly targeting male users who show the strongest preference for this improvement. Strategically, MEA should prioritize infrastructure expansion in areas where male users constitute the primary demographic, while ensuring the needs of female users are also met. This approach will optimize resource allocation, address diverse user priorities, and support increased utilization of EV charging stations.

4.14 Gender-Based Preferences for MEA Mobile App Enhancements at EV Stations

A statistical analysis using ANOVA (Analysis of Variance) was performed to investigate the relationship between gender and preferences for enhancing mobile application features to improve the utilization of EV charging stations. The objective was to determine if user preferences for app functionalities, such as station reservations and real-time availability, varied significantly by gender.

Table 4.7

Means Score of Gender-Based Preferences for MEA Mobile App Enhancements at EV Stations

Gender	**Enhance the mobile application features (e.g., station reservation, real-time availability)**					**Mean**
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	
Female	1.0%	2.0%	17.0%	30.0%	50.0%	4.26
Male	1.4%	2.7%	10.3%	17.8%	67.8%	4.48
Other	0.0%	0.0%	0.0%	20.0%	80.0%	4.80
Grand Total	**1.2%**	**2.4%**	**12.7%**	**22.7%**	**61.0%**	**4.40**

The null hypothesis (H_0) posited that there is no significant relationship between gender and the preference for enhancing mobile application features. Conversely, the alternative hypothesis (H_1) proposed that such a relationship exists.

Figure 4.15

Gender-Based Preferences for MEA Mobile App Enhancements at EV Stations ANOVA Result

```
Group Statistics:
  Frequency Group      Mean  Count  Variance
0   Female / หญิง  4.260000    100  0.780202
1      Male / ชาย  4.479452    146  0.789230
2   Other / อื่นๆ  4.800000      5  0.200000

ANOVA Results:
     Statistic     Value
0  F-statistic  2.371408
1      P-value  0.095463
Reject the null hypothesis: There is a significant difference between the group means.
```

The analysis revealed a statistically significant difference at the 10% significance level, with a p-value of 0.095463, indicating that preferences for mobile application enhancements vary across gender groups. Male respondents demonstrated a higher preference for app features emphasizing reliability, speed, and accurate updates. These findings suggest that gender-specific considerations are essential when designing and enhancing mobile applications for EV charging station users.

To address these insights, MEA should emphasize app features such as reliability, speed, and real-time updates, aligning with male users' higher preference for these functionalities. Additionally, mobile app development efforts should prioritize inclusivity, addressing the unique preferences of all gender groups. This approach will ensure a user-friendly and efficient digital experience, improve satisfaction, and ultimately drive higher adoption and utilization of MEA's EV charging infrastructure.

4.15 Gender-Based Preferences for MEA Promotions and Incentives at EV Charging Stations

An ANOVA (Analysis of Variance) was conducted to assess the relationship between gender and the preference for MEA conducting more promotions or providing incentives as a strategy to improve EV charging station utilization. The analysis aimed to determine whether promotional preferences differed significantly across gender groups.

Table 4.8

Means Score of Gender-Based Preferences for MEA Promotions and Incentives at EV Charging Stations

Gender	Conduct more promotions or provide incentives					Mean
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	
Female	3.0%	1.0%	25.3%	30.3%	40.4%	4.04
Male	3.4%	8.2%	31.5%	17.8%	39.0%	3.81
Other	0.0%	20.0%	60.0%	20.0%	0.0%	3.00
Grand Total	**3.2%**	**5.6%**	**29.6%**	**22.8%**	**38.8%**	**3.88**

The null hypothesis (H_0) stated that there is no significant relationship between gender and the preference for promotions or incentives to enhance utilization. In contrast, the alternative hypothesis (H_1) proposed that a significant relationship exists between these factors.

Figure 4.16

Gender-Based Preferences for MEA Promotions and Incentives at EV Charging Stations ANOVA Result

```
Group Statistics:
  Frequency Group      Mean  Count  Variance
0   Female / หญิง  4.040404     99  0.977943
1      Male / ชาย  3.808219    146  1.314691
2   Other / อื่นๆ  3.000000      5  0.500000

ANOVA Results:
     Statistic     Value
0  F-statistic  3.068562
1      P-value  0.048264
Reject the null hypothesis: There is a significant difference between the group means.
```

The analysis revealed a statistically significant difference at the 5% significance level, with a p-value of 0.048264, indicating that gender influences preferences for promotional strategies. Female respondents exhibited the highest preference for promotions and incentives, with a mean score of 4.040, followed by male respondents with a mean score of 3.808. These results underscore the importance of understanding gender-specific promotional preferences to design effective and engaging campaigns.

To enhance the user experience, MEA should focus on creating personalized promotions and attractive incentives, such as discounts, reward programs, or free charging hours, that align with the stronger preferences expressed by female users. Strategically, MEA should design gender-sensitive promotional campaigns that address the diverse needs of all user groups, ensuring inclusivity and maximizing the effectiveness of such initiatives. This approach will not only increase EV charging station usage but also build loyalty across different demographics.

4.16 What MEA should improve to increase EV charging station utilization?

Based on user feedback, key areas for improvement in MEA's EV charging infrastructure have been identified and prioritized according to preference scores. The highest priority is to **increase the number of charging stations**, with a mean score of 4.55. Expanding the network to underserved and high-traffic areas is essential to address user demand. Collaborations with commercial establishments, such as shopping malls and supermarkets, can further enhance accessibility. Additionally, extending the network to residential and workplace areas will improve convenience for a wider range of users.

Table 4.9

Mean Score of Key Areas that user Feedback for MEA Improvement

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Mean
Increase the number of charging stations	0.0%	0.4%	12.4%	19.5%	67.7%	4.55
Provide more fast or ultra-fast charging options	0.4%	0.8%	9.9%	25.0%	63.9%	4.51
Improve the visibility and accessibility of stations	0.4%	0.8%	13.9%	27.5%	57.4%	4.41
Enhance the mobile application features (e.g., station reservation, real-time availability)	1.2%	2.4%	12.7%	22.7%	61.0%	4.40
Extend operating hours	0.8%	1.2%	19.0%	27.8%	51.2%	4.27
Lower the cost of charging	1.6%	5.2%	28.2%	19.0%	46.0%	4.03
Increase the number of amenities (e.g., shopping centers)	2.4%	5.6%	27.5%	26.7%	37.8%	3.92
Conduct more promotions or provide incentives	3.2%	5.6%	29.6%	22.8%	38.8%	3.88

Another critical area is to **provide more fast or ultra-fast charging options**, with a mean score of 4.51. Upgrading existing stations with fast-charging capabilities can significantly reduce waiting times and improve efficiency, especially in high-demand locations. MEA should also promote the adoption of advanced fast-charging technologies and ensure compatibility with various EV models to cater to diverse user needs.

Lastly, efforts to **improve the visibility and accessibility of charging stations** are also important, with a mean score of 4.41. Clear signage and navigation aids should be installed near stations to make them easier to locate. Additionally, ensuring that stations are situated in accessible locations, such as main roads, highways, and public spaces, will enhance convenience and usability for EV users. By implementing these prioritized improvements, MEA can significantly enhance user satisfaction, drive higher utilization of its EV charging infrastructure, and support the broader adoption of electric vehicles.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Tendencies from this study clearly indicate that Bangkok is gravitating towards full electric vehicles, as 90.2% of the respondents have EVs and 80.7% consider BEV as their preferred vehicle choice. These facts are indicative of the rise in consumer confidence in EV technology and the demand for accessible and sufficient charging infrastructure. Daily charging habits of 28.3% and session durations of 30-60 minutes at 59.4% indicate that the dependency on public charging stations is huge, requiring fast, reliable, and strategically located facilities. The availability of the stations was pointed out as the most critical factor affecting satisfaction, with a mean of 3.74; the users prefer convenience and proximity to amenities like shopping centers and workplaces.

The preferences were also biased toward gender specifics: The male respondents insisted on infrastructure development and qualitative application in order to make the procedure of charging as fast and reliable as possible, whereas female respondents believe in safety first and appreciation for promotion and stimulus - that means improvements should be complex. The revealed gender-based gaps prove that design solutions should satisfy diverse user needs - ensure inclusivity:.

While cost and security concerns have been rated as less critical than the factors of convenience and reliability, these are yet crucial aspects which ensure user trust and engagement; MEA therefore needs to clearly address them for broad appeal and long-term satisfaction of its users. In the end, the results underline pressing demands on MEA to extend and upgrade the charging network, increase the functionality of the mobile app, and develop focused approaches to engage with users in support of Bangkok's emerging EV market.

5.2 Recommendations

To address the findings and enhance user satisfaction, the following recommendations are proposed:

5.2.1 Expand Charging Infrastructure

MEA should focus on expanding the charging station base, giving greater importance to the hitherto under-served suburban areas and high-traffic destinations like shopping malls, workplaces, and residential areas. Greater station density would alleviate range anxiety and meet the ever-growing demand for charging services. Furthermore, fast and ultra-fast charging options must be installed in order to fulfill the needs of 59.4% of users whose session duration lies between 30-60 minutes and can help reduce the queueing period by improving the experience for users.

5.2.2 Enhance Mobile Applications

The integration of innovative mobile app functionalities is key. These features are real-time tracking, the ability to smoothly reserve the stations, dynamic pricing, and smooth payment alternatives. Infrequent users, which hold a high preference for the aforementioned feature features (mean = 4.453), are substantially benefited through this. Apart from that, features in an application should also be designed to be specific to the requirements based on gender: speed and reliability for males and user-friendliness and safety for females.

5.2.3 Improve Visibility and Accessibility

The only way this can be addressed is by ensuring that the stations are highly visible and accessible. MEA should invest more in better signage to ensure that finding the stations is easy. Integrating station locations into navigation apps such as Google Maps will assist users in planning their routes. Furthermore, awareness drives should be created to educate the users on the availability and features of the MEA stations. This will, in particular, help the new EV users who are unaware of existing infrastructure.

5.2.4 Offer Targeted Incentives and Promotions

MEA should design targeted incentive programs to increase user engagement. Personalized promotions, especially those for female users (mean = 4.040), can be highly effective. Collaboration with local businesses can enhance value by providing discounts or rewards to customers for using MEA's charging services. These incentives encourage not only more frequent use but also user loyalty.

5.2.5 Enhance Amenities and Safety

Charging stations should be fitted out with facilities that enhance the user experience, especially for those users who would be on-site for extended periods of time (>1 hour). Amenities such as restrooms, coffee shops, seating areas, and Wi-Fi increase comfort and productivity while waiting. Safety, including improved lighting and surveillance, would also attract those users who may have security concerns, especially at night or in remote areas.

5.2.6 Promote Sustainability and Partnerships

MEA should incorporate renewable energy sources, such as solar-powered charging stations, aligning with Thailand's sustainability goals and appealing to environmentally conscious users. Roaming capabilities through partnerships with other charging providers will help ensure a seamless user experience across networks. The partnership will reinforce MEA's competitive advantage in the market.

5.3 Limitation

This study has several limitations that must be considered. The research sample was predominantly composed of respondents from Bangkok, which may not fully reflect the challenges and preferences of EV users in suburban and rural areas. These regions often face distinct infrastructure limitations and user behaviors that differ significantly from urban settings. Additionally, the focus on MEA-operated charging stations limits the scope of the findings, as it does not account for the experiences of users who rely on competing networks or private charging facilities.

The study also did not extensively explore the potential of emerging technologies, such as wireless charging, battery swapping, and Vehicle-to-Grid (V2G) systems, which could significantly impact the future of EV infrastructure. Moreover, the reliance on self-reported data introduces the potential for response bias, as users may overstate or understate their preferences and satisfaction levels. Addressing these limitations in future research will provide a more comprehensive understanding of the EV charging ecosystem in Thailand.

5.4 Future Research

Limitations will be acknowledged in future research over these limitations and further dimensions that need to be considered for a better understanding of the development of EV charging infrastructures. Studies about urban-rural dynamics will have to be informative with regard to the special difficulties of the non-metropolitan users and also facilitate the framing of strategies on infrastructure inclusivity. The study of the adoption and impact of new technologies, such as wireless charging, battery swapping, and V2G systems, may give further insights into next-generation solutions. Longitudinal studies are also recommended to assess the long-term effectiveness of MEA's improvements in user satisfaction and EV adoption rates.

It also deserves to be a particular area of focus: the future research on cross-sector collaboration, studying how partnerships between energy providers, car manufacturers, and urban planners set the pathway to integrated EV ecosystems for a variety of user needs. Finally, studies on consumer education and engagement will help bridge this awareness-availability gap so that users are fully informed about the benefits and features of charging services provided by MEA. Addressing these facets will help MEA solidify its leading position within Bangkok's EV Market and contribute to the transition of Thailand toward sustainable urban transportation.

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