Chapter 4

Investment in and Planning of Charging Infrastructure

August 2019

This chapter should be cited as

ERIA (2019), 'Investment in and Planning of Charging Infrastructure', in Suehiro, S. and A.J.Purwanto (eds.), *Study on Electric Vehicle Penetrations' Influence on 3Es in ASEAN.* ERIA Research Project Report FY2018 no.6, Jakarta: ERIA, pp.48–62.

CHAPTER 4

Investment in and Planning of Charging Infrastructure

1. Introduction

Several ASEAN countries have strategies for low‑emission mobility, with decreasing oil import dependency as a main objective. The strategies emphasise, amongst others, removing obstacles to electrification of transport to promote market development of road PEVs, especially cars, powered two-wheelers, and light-duty vehicles or vans.

Removing obstacles means that ASEAN countries must secure critical technological system requirements: road EV manufacturing and its supporting or supplier industries, and the corresponding EV charging infrastructure.

Only two countries in ASEAN produce and commercialise PEVs – Thailand and Malaysia.

Thailand's first EV development roadmap, the Electric Vehicle Promotion Plan, was approved by the government in March 2015. In 2017, the Board of Investment (BoI) approved incentive measures for manufacturers of BEVs, HEVs, and PHEVs, mostly in the form of corporate tax exemptions for 5 to 8 years. The project to develop next-generation automotive vehicles with a focus on EVs was included in the Eastern Economic Corridor, approved in February 2018, to spur investment. In March 2019, the BoI agreed to renew the investment package for HEVs to lure more investment in EVs. Interested investors are required to submit their applications for HEVs in 2019 and to assemble BEVs within 3 years. HEV and PHEV sales rose by 24.7% in 2017 to 11,945 units whilst BEV sales reached 165 units (Nicholls et al., 2018). All vehicles sold in that year totalled 870,748 units. By 2036, Thailand targets having1.2 million electric cars in its streets and setting up 690 charging stations.

Malaysia started its EV programme earlier than Thailand. In 2011, the government exempted from excise duties and import taxes completely built-up, fully imported hybrid cars to encourage manufacturers to invest in EV production in the country. After the policy failed to boost foreign investment, the government abandoned it in 2014 and extended it only for completely knocked-down models assembled in Malaysia. The government now prefers to deal with manufacturers individually, a strategy that appears to work with several foreign original equipment manufacturers.

A recent tripartite agreement between TNBES, PetDag, and GreenTech Malaysia has resulted in the installation of 100 charging stations across the country in 2018. As of end 2018, EV charging stations amount to 251 units located across the Peninsular (Weng, 2019) GreenTech Malaysia is under the purview of the Ministry of Energy, Science, Technology, Environment and Climate Change to spearhead the development and promotion of green technology as a strategic engine for socio-economic growth in line with Green Technology Master Plan 2017–2030. The number of new registered hybrid vehicles, including conventional HEVs and, in the recent years, PHEVs, has increased from 138 in 2010 to more than 9,000 in 2017. Malaysia aims to build 125,000 charging stations by 2020.

Since January 2018, the ASEAN Free Trade Agreement has dropped import duties for vehicles originating in other ASEAN countries to 0%. Investment in the domestic EV manufacturing industry might benefit the countries if the final purchasing price of the vehicles can compete with those of imported vehicles.

Whilst EV manufacturing and its support industries might rely mostly on integration with global value chains, developing charging points needs significant domestic public and private investment. This chapter focuses on building the decision-making framework for charging infrastructure investment to encourage EV deployment.

We start with a brief introduction on the state of charging technology development, including the different charging technologies and modes, and the need for standardisation to ensure interoperability. We then discuss the costs of the different charging technologies, followed by a synthesis of the 'chicken and egg' relationship between charging infrastructure and the EV penetration rate. The most-used indicator is the number of PEVs per charging point. Some argue that developing more charging infrastructure will stimulate PEV penetration, but it is often the electric car manufacturers that encourage deploying the infrastructure (Li et al., 2016).

We go on to present possible policy measures to facilitate the rolling out of charging infrastructure based on practices in several PEV front-runner countries, and the different charging scheme strategies to ensure that PEV deployment objectives are achieved. We close with recommendations for ASEAN governments.

2. Charging Infrastructure: An Introduction

ICEV users would benefit from refuelling station networks being located nearly everywhere. But PEV charging infrastructure is in its early development stage, especially in ASEAN countries.

In principle, a PEV can simply be plugged into a home wall-mounted box, which is the simplest EV service equipment, but home-charging is not as simple as it seems and the long charging time is its main inconvenience. Increasing grid pressure is a risk as home-charging takes place mainly in the late afternoon after working hours, when household electricity demand is peaking. These are the main reasons for developing different types of chargers and installing them in public spaces such as parking lots, workplaces, pump stations, and motorway rest areas.

2.1. Charger Types

Chargers on the market can, in principle, be divided into slow and fast. Slow chargers use an alternating current (AC) under 400 volts whilst fast chargers use a direct current (DC) of 400 volts and above. Most charging stations are slow and more than 88% have 22 kW power or lower. This category includes 2.3 kW household plugs that take about 9 hours to completely recharge a common PEV. Most PEVs can be home-charged via an AC outlet of 3.3–11 kW.

Slow chargers are level 1 (120 volts) and level 2 (200–240 volts) and suitable for short trips, whilst DC fast chargers, most often found in public locations such as motorway rest areas, are best for longer journeys (Hall and Lutsey, 2017). Both recharging times are significantly longer than ICEV refuelling time.

Table 4.1 classifies chargers into four modes, each corresponding to a specific charging speed, required voltage, electric current, and level of communication between vehicle and power outlet.

Slow chargers are also often grouped into slow and semi-fast. It takes 6–8 hours to fully charge a pure BEV using slow chargers with a single-phase 3.3 kW of power and 120–240 volts. This practice corresponds to home-charging using share circuit without any safety protocol.

With slow to semi-fast chargers, charging time should be reduced from 4 hours to 1. Facilities with power greater than 3.3 kW but less than 22 kW can be found in households, workplaces, and public spaces. Chargers with power lower than 22 kW allow a maximum speed up to 2 hours of charging and can be applied to shared or dedicated circuits with safety protocols. Facilities with power higher than 22 kW reduce charging time down to 1 hour. Semi-fast chargers are installed mostly in public charging facilities often equipped with an active communication line between the charging point and the vehicle.

Finally, the DC fast chargers allow BEVs to be fully charged in less than an hour. They are often installed in motorway service areas or in urban dedicated charging stations where long charging time is less tolerated.

Table 4.1: Different Modes of Plug-in Electric Vehicle Charging

Mode	Name	Power (kilowatt)	Current	Phase	Charging time	Place	Voltage (volt)	Power range (ampere)	Communication level	Further description
1	Slow	3.3	AC	Single	6–8 hours	Household, workplace wall box	120–240	Up to 16	N/A	Shared circuit without safety protocols
2	Slow, semi-fast	7.4	AC	Single	3–4 hours	Household, workplace wall box and public charging poles	120–240	Over 16 and up to 32	Semi-active connection to vehicle to communicate for safety purpose	Shared or dedicated circuit with safety protocols, including grounding detection, overcurrent protection, temperature limits, and a pilot data line
3	Slow, semi-fast or fast	10	AC	Three	2–3 hours		240	Any	Active connection between charger and vehicle	Wired-in charging station on a dedicated circuit, mode-2 safety protocols, active communication line with the vehicle, i.e., smart charging suitability
		22	AC	Three	1–2 hours	Mostly public charging poles				
4	Fast	50	DC	–	20–30 minutes	Motorway service area or dedicated charging stations in urban areas (current standard)	400		Active connection between charger and vehicle	Mode-3 features with more advanced safety and communication protocols
		120	DC		10 minutes	Motorway service area or dedicated charging stations in urban areas (future standard)				

AC = alternating current, DC = direct current.

Source: Bakker (2013), Hall and Lutsey (2017), and Spöttle (2018).

The situation is, however, complicated. Compatibility between PEVs and charging point technology standards is an issue as there are at least five technology standards or connector types:

- Type-1 AC. Amongst the most popular PEV connectors in this category are some produced by the Japanese manufacturer Yazaki, following the North American SAE J1772 standard. They are mostly slow chargers and can be found in North America and Japan.
- Type-2 AC. Most are fabricated by the German company Mennekes, following the AC charging technology standard gaining market share in Europe and China. This type is compatible with most PEVs and AC chargers and can facilitate not only single-phase but also three-phase AC charging.
- Type-3 AC. Built by the PEV Plug Alliance, mostly in Italy and in France, and used only up to 2012, when the Type-2 AC became dominant in Europe.
- Type-4 DC. Also known as the Japanese standard, CHAdeMO. It was the first widespread technical standard for DC fast charging developed by a Japanese consortium. This type is found not only in Japan but also in European countries, mostly in France.
- CCS or combined charging system. The combined AC and DC fast-charging plugs are CCS Combo 1, preferred by US car manufacturers, and CCS Combo 2, preferred by Germans.
- Tesla supercharger infrastructure. This DC fast charger is used mostly in North America.

2.2. Standardisation and Interoperability

Charging stations are considered interoperable if they can serve a large variety of PEV models and offer payment methods accessible to all PEV drivers (Spöttle et al., 2018). Standardisation guarantees interoperability, provides clarity to manufacturers, allows for economies of scale, and ensures compliance with safety standards. PEV charging interoperability means that PEV users can charge their cars at any charging point using their usual choice of authorisation and payment method.

Charging infrastructure – at least the physical equipment, payment systems, and charging protocol – must be standardised. Section 2.1 shows how different charging equipment types can coexist in one country or region. In Europe, for example, Type-2 AC and Type-3 AC coexisted, as did CHAdeMO and CCS Combo 2. In 2014, European Commission Directive 2014/94/EU required that all providers of public chargers include a Type-2 AC connector where level-2 or fast AC charging is available, and a CCS connector where level-3 charging is provided. In Southeast Asia, the rolling out of charging infrastructure is still in its development phase, but some trends are visible: Type-2 connectors are available for AC charging, and CCS Combo connectors are also available for DC charging in Thailand, Malaysia, and Singapore. CHAdeMO is available in Thailand and Malaysia.

Many charging station network operators in the early years of PEV penetration developed their own payment systems. PEV users normally subscribe to a charging station operator and cannot always charge or pay at a station belonging to another operator. A simple solution is for the user to subscribe to more than one operator. A more sophisticated solution is to allow roaming between operators as mobile phone network operators have been doing for years.

Finally, charging activity needs protocols that standardise the communication interface between the car, the charging stations, and the system that oversees monitoring and managing of the charging station, including the roaming platforms. That system is usually referred to as the charge point operator (CPO) or charging service operator (CSO). For example, Europe has the open clearing house protocol (OCHP) supported by national charging infrastructure providers in Belgium, Germany, the Netherlands, Luxembourg, Austria, Ireland, and Portugal; open charge point protocol (OCPP), initiated by ElaadNL, which is also involved in OCHP; and open charge point interface (OCPI), supported by European operators.

2.3. Cost of Charging Infrastructure

Simple home charging can compete with more efficient gasoline cars and are even significantly cheaper when a time-of-use (TOU) electricity tariff with lower prices in off-peak periods is in place. More powerful home charging is sensitive to capital cost but competitive with moderately efficient ICEVs and would be substantially cheaper under a TOU regime (Lee and Clark, 2018).

The issue, however, is how to develop non-home-based charging points or stations as home charging has limitations. Developing such stations needs significant investment, supporting regulations, an adequate business model, and, in many places, central government intervention or initiatives.

China's central government has funded a programme in 88 pilot cities, led by Shanghai, Beijing, and Shenzhen, to provide one charging point for every eight PEVs. The charging points are grouped into stations, which must be no more than 1 km from any point within the city centre (NDRC [2015], quoted by Hall and Lutsey [2017]).

The 13th Five-Year Plan (2016–2020) states that China shall build a nationwide charging-station network that will fulfil the power demand of 5 million EVs by 2020 (Xin, 2017). State Grid Corp of China, the state-owned electric utility monopoly, had built more than 40,000 charging stations by 2016 and was planning to build a network of 120,000 public-individual charging points for electric cars by 2020, throughout major regions in China (Chen, 2018).. China's National Energy Administration says that the country had a total of 450,000 stationary charging points in 2017, including around 210,000 publicly accessible units (Ying and Xuan, 2018).

Singapore's Land Transport Authority announced in 2016 it would install 2,000 charging points, and in 2017 reached an agreement with a private company, BlueSG Pte Ltd., to launch a nationwide car-sharing programme with a fleet of 1,000 PHEVs. The company planned to install and operate the charging points. Singapore Power Group, the state-owned electricity and gas distribution company, plans to roll out 1,000 charging points by 2020, of which 250 would be 50 kW fast DC chargers able to fully charge a car in 30 minutes. Normal slow chargers cost around US$3,700 whilst fast chargers cost US$48,000. By September 2018, HEVs made up 4.3% of the total of around 615,000 registered vehicles, PHEVs 0.06%, and BEVs 0.08% (Tan, 2018). Many industrial players think the lack of charging facilities has been a main cause of slow PEV penetration.

In Japan, the government created the massive Next Generation Vehicle Charging Infrastructure Deployment Promotion Project to fund charging stations around cities and highway rest stations in 2013 and 2014 (CHAdeMO Association, 2016). The nationwide Nippon Charge Service, a joint project of the state-owned Development Bank of Japan with Nissan, Toyota, Honda, Mitsubishi, and Tokyo Electric Power Company, operates almost 7,500 stations.

In the US, by 2017, around 47,000 charging outlets had been built all over the country, the General Services Administration had installed EV charging stations for federal employees and other authorised users, and more than 10 states were offering rebates and tax credits to commercial customers and homeowners for installing charging stations (Lu, 2018).

In several PEV front-runner countries in Europe, the public sector and private investors financed early charging infrastructure when the use of chargers was not yet high enough to be profitable. Public subsidies will be phased out in 2020–2025. Technological acceptance and spread and economies of scale should stimulate similar developments in other European countries (Transport & Environment, 2018) (see section 3 of this paper).

What follows is a summary of public charging facility costs in PEV front-runner countries. We focus on the top priority for ASEAN countries, which is to develop slow or semi-fast level-2 charging facilities, and on fast-charging infrastructure, whose installation will be much more limited, depending on mobility purposes and needs.

Slow to Semi-fast AC Charging Facility Costs

Table 4.2 shows that the hardware costs of slow to semi-fast charging facilities are comparable, even between the US and Europe and India.

Table 4.2: Examples of Slow and Semi-fast Charging Facility Purchase and Installation Costs

Countries (Currency)	Application	Costs	Included Items	Report
United States (US$, 2017)	L2 – home	450–1,000 (50–100)	Charging station hardware (additional electrical material costs in parentheses)	RMI (2017)
	L2 – parking garage	1,500–2,500 (210–510)		
	L2 – curb side	1,500–3,000 (150–300)		
France, Germany, Italy, Netherlands, Spain, UK (euro, 2017)	3.7 kW new residential building	1,170	Materials (for installation, including cables); wall-box (hardware of charging station, excluding cables); and labour (around 20% of total costs)	CREARA Analysis (2017)
	3.7 kW operating residential building	1,280		
	7.4 kW new nonresidential building	1,760		
	7.4 kW operating nonresidential building	2,025		
Germany (euro, 2017)	>3.7 kW – one charging point	1,200	Complete hardware, including communication and smart meter	NPE (2018)
	11 kW or 22 kW – two charging points	5,000		
India (US$, 2019)	Bharat charger AC 001-1 point(s)-3 phase 415 volt-3 x 3.3 kW	980	Approximate cost, including goods and services tax at 18%	ISGF (2018)
	Type-2 AC Charger-1 point(s)-7.2 kW	1,050		
	CCS-2-1 point(s)-3 phase 415 volt-25 kW	9,800		
European Union 28 average (euro, 2018)	AC mode 2 – home (up to 11 kW)	< 800	Purchase cost for a single charging point, not installation, grid connection, or operational costs	Spöttle et al. (2018)
	AC mode 2 – commercial (up to 19.4 kW)	< 2,000		
	AC mode 3 – fast (22 kW of 43 kW)	1,000 – 4,000		

Source: Authors' compilation

In the US, a simple home 3.7 kW charger costs only around US$500, whilst a 7.2 kW charger that can fully charge a PEV in around 4 hours costs around US$1,000 – almost the same as in Europe and India, which shows that local content of charger production in India is low. For chargers of 22 kW or more, costs in India are much higher than in the US or Europe, which means India still does not enjoy economies of scale for charging hardware production.

The charger’s power, electric power phases, and number of charging points are amongst the factors that determine the cost of PEV charger hardware and material.

Home installations are used less intensively and have lower safety requirements and are, therefore, less costly than public stations, which are much more sophisticated and might include liquid-crystal display (LCD) screens, advanced payment and data tracking communication, and dual-port power routing capabilities (RMI, 2017).

Installation methods significantly affect total installation costs: installation from scratch is always cheaper than from partially make-ready facilities such as those that are pre-piped or pre-cabled. Several European governments stimulate development of partially make-ready charging facilities by the private sector, e.g., building or utility owners (CREARA Analysis, 2017).

Fast DC Charging Facility Costs

DC level-3 charging stations reduce charging time but they cost significantly more than a level-2 charger because of two factors: expensive equipment and the frequent need to install a 480 V transformer. Fast-charger hardware is significantly more expensive than level 2, and in the US a transformer might cost another US$10,000–US$20,000 (Cleantechnica, 2018). Installing DCFC in the US typically costs as much as US$50,000. Inclusion of project development, design, permits, and system upgrades can rise the total cost of DCFC deployment as high as US$300,000 each (Fitzgerald, 2018).

Table 4.3: Examples of Fast-Charging Facility Purchase and Installation Costs

Countries (Currency)	Application	Costs	Included items	Report
United States (US$, 2017)	DC fast charging	12,000–35,000 (300–600)	Charge station hardware (plus extra electrical materials)	RMI (2017)
Germany (euro, 2017)	50 kW	25,000	Complete hardware, including communication and smart meter	NPE (2018)
European Union 28 average (euro 2018)	DC fast – standard (20 kW–50 kW)	20,000	Purchase cost for a single charging point, not installation, grid connection, or operational costs	Spöttle et al. (2018)
	DC high power – fast (100 kW–400 kW)	40,000–60,000		

Fast-charging stations need to achieve a sufficiently high utilisation ratio to compensate for the high total cost of installation and operation where grid impact will be low. DC fast-charging hubs should serve high-usage fleets and ride-hailing vehicles, ideally along high-usage corridors and commuting routes around major cities, and rest areas for interurban trips on major highways (Lee and Clark, 2018).

3. Correlation between Plug-In Electric Vehicles and Charging Infrastructure

Since 2011, we have witnessed the unprecedented growth of PEV sales and the number of charging infrastructure points in different parts of the world.

The European Alternative Fuels Observatory (2019) database shows that in European Union (EU) 28 and in four non-EU countries (Iceland, Norway, Switzerland, Turkey), PEV sales have increased from only 11,500 units in 2011 to nearly 386,000 in 2019. The database reveals that recharging infrastructure points in Europe have increased from 3,200 in 2010 to 161,000 in 2019 – nearly five-fold per year.

PEV ownership and public charging infrastructure data was collected from 14 countries[4] that have the highest EV uptake, because the data was available for local EV uptake and public charging infrastructure. These national markets include about 90% of global EV sales (Hall and Lutsey, 2017).

Public charging infrastructure is key to EV market growth. Rough apparent patterns are observed between EV uptake and charging infrastructure availability, with substantial variability across markets. The development of a robust charging infrastructure network is a key requirement for large-scale transition to electromobility, but there is no universal benchmark for the number of EVs per public charge point (Hall and Lutsey, 2017).

Table 4.4 shows that the average ratios of PEVs to charging station in EV front-runners vary greatly between or even within regions.

Table 4.4: Indicated Average Ratios of Electric Vehicles per Public Charge Point

Country	Region	Electric vehicle/Public charge point ratio	Source
China	China average	8 (pilot cities) 15 (other cities)	NDRC (2015)*
World	Worldwide	8 (2015), 15 (2016)	IEA Electric Vehicle Initiative (2016, 2017)*
United States	United States average	7-14	Cooper and Schefter (2017); EPRI (2014)*
		24	Wood et al. (2017)*
	California	27	CEC and NREL (2017)*
European Union	European Union average	10	European Parliament (2014)*
	The Netherlands	3.6	Spöttle et al. (2018)
	Norway	15.2	
	Germany	6.7	
	The UK	9.7	
	France	7.6	

* From Hall and Lutsey (2017).

[4] Austria, Belgium, Canada, China, Denmark, Finland, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland, the United States, and the United Kingdom.

EU data shows that the PEV market share of new registrations rises as the vehicle to charging point ratio drops from 25 to 5. A low ratio would benefit PEV uptake but infrastructure coverage denser than 1 charging point per 10 PEVs would be inefficient: sales numbers become insensitive with a decreasing ratio. The high costs of additional charging infrastructure, therefore, do not justify high investments (Harrison and Thiel, 2017).

A study on the relationship between the number of PEVs and the publicly accessible charging points in Europe (EU 28 + Norway) demonstrate two interesting findings. First, with some variation in the countries' national context, the density of charging infrastructure generally correlates positively with PEV adoption. A range of other factors are proven or suspected to be correlated with PEV uptake, such as model availability, financial incentives, urban density, etc. Charging infrastructure is necessary but not enough for PEV adoption. Most front-runner countries have applied a demand-oriented approach to rolling out charging infrastructure. Second, the ideal ratio of PEVs per charging point will, in the long run, lie between 10 and 16 (Spöttle et al., 2018).

The rollout of charging infrastructure may be oriented towards demand or coverage. The demand-oriented approach assumes that charging infrastructure should be constructed where existing and future demand can be determined and aims for optimal allocation and utilisation of all charging points and avoids redundancies. The coverage-oriented approach is premised on public infrastructure guaranteeing a minimum standard of service to the widest possible public by minimising the distance between the charging points. None of the front-runner countries take the coverage-oriented approach, except the US, with its designated alternative fuel corridors; China, which has required 88 pilot cities to install a charging network with charging points positioned no farther than 1 km from any point within the city centre; and Norway, where the government financed the deployment of at least two fast-charging stations every 50 km on all main roads by 2017 (Figenbaum, 2019).

3.1. Facilitating Charging Infrastructure Investment

Developing charging infrastructure needs significant investment. The public sector cannot bear the total burden and needs to attract private investors. The main challenge is convincing investors that the investment will be profitable as there are not yet enough EVs on the road.

Some EV front-runner country strategies for rolling out charging facilities are summarised below.

3.1.1. China

The world leader in number of EVs sold, China started in 2009 with the ‘10 cities, 10,000 vehicles’ business model to promote EV development, but established targets only in June 2012: 500,000 vehicles by 2015 and 5 million by 2020.

The programme’s first step was top-down selection of experimental sites where the central government could either test policy or try out innovative practices. The second step – evaluation and absorption – combined bottom-up and top-down approaches. Central government agents evaluated the performance of pilot projects whilst local participants reported their progress to the central authorities, documenting the most advanced practices for wider diffusion. The third step – diffusion by the central government – popularised successful practices through the media and endorsement by leading politicians. The final step was the learning and feedback loop between the evaluation and absorption process and diffusion (Marquis et al., 2013).

Five models were created in the pilot cities: state leadership in Beijing, based on public sector support; platform-led business in Shanghai, replicating international models; cooperative commercialisation in Shenzhen, based on a leasing model through strategic partnership; flexible rental in Hangzhou; and fast-charging models in Chongqing, which is close to the Three Gorge Power Grid.

The city-based pilot programmes, however, focused on local goals and firms rather than a long-term national agenda. Competition for central government support eroded cities' willingness to cooperate with each other on setting national or international standards and goals; manufacturers or players were barred from entering other cities.

3.1.2. United States

EVs are becoming more popular in the US. California leads with 2% PEV share of total road vehicles, followed by Hawaii (1.2%), Colorado (0.56%), Texas (0.23%), and Ohio (0.15%). Measures in urban areas promoted PEV charging facilities (Fitzgerald, 2017):

- development of make-ready locations by utilities that would support a variety of third-party charging stations (California, Colorado);
- implementation of TOU rates that encourage users to charge during off-peak periods (California, Ohio, Hawaii);
- provision of significant rebates of charging development for privates (Colorado, Texas); low-interest loans for businesses, non-profits, public schools, and local governments for installing charging stations (Ohio); and grants to build stations (Texas);
- legal framework that favours private ownership of charging stations by allowing private companies to resell electricity supplied by a public utility to charge EVs (Colorado);
- partnership between public utilities and private companies in developing and operating charging stations (Texas); and
- explicit right to site charging on premise for multifamily dwellings and townhouses (Hawaii).

3.1.3. Europe

Measures taken by two PEV front-runner European countries – the Netherlands and Germany – are summarised below:

- **The Netherlands**. Between 2010 and 2014, seven grid operators (state owned and regional) invested in developing charging infrastructure (Living Lab Smart Charging, 2017), which was later included in the Green Deal Electric Transport Programme (2016–2020) backed by a consortium of central and regional governments, grid operators, the automotive sector, and universities. The programme provides funding for public charging poles equally from government, municipalities, and market players, and for installation of the Netherlands Knowledge Platform on Public Charging Infrastructure (Hamelink, 2016). The programme not only develops charging facilities but also the roaming system and implements international protocol standards.

- **Germany**. The country has several financial support programmes at different government levels. The Federal Ministry of Transport's programme for EV charging infrastructure and the regional model of electromobility finance and/or subsidise development of charging infrastructure that require local or private investment.

In other European countries – front runners or followers – state-owned agencies, with or without big private partners such as grid operators, first financed or organised deployment of charging infrastructure. Agencies or consortia then offered financing programmes to the private sector or local government to develop charging infrastructure.

3.2. Charging Scheme Strategy

The expansion of PEVs and their demand for charging facilities have become increasingly important. The associated electricity demand will affect energy markets and the grid infrastructure. Studies on Portugal (Nunes, 2015) and the EU (Kasten and Purwanto, 2016) show the impact of EVs once they make up 5%–10% of total road vehicles.

The amount of electricity needed to meet additional demand and the greenhouse gas emissions produced to generate electric power are calculated based on the average of total power plant mix. PEVs' environmental performance would be better than conventional vehicles' if additional demand were met by a low-carbon intensive energy mix. Even if there were 300 million electric cars, if power generation were not decarbonised, CO_2 emissions would be insignificantly reduced by less than 1% (Sauer, 2019). Electric vehicles may reduce local pollution but not global emissions.

China, the EV front runner in Asia, is struggling to curb the share of coal-fired-based electric energy from 75% to 50% and to increase that of renewable sources from 25% to 50% in 2030, bringing down power generation carbon intensity by one-third and ensuring that EVs will be less carbon intensive than they are now. China uses more electricity from coal-fired generating plants during fast-charging peak demand periods and after working hours in the evening. Slow charging during off-peak hours, when energy from renewables such as wind turbines is available, would reduce CO_2 (Chen et al., 2018).

When and how PEVs are charged determine which generation plants satisfy additional electricity demand and have an impact on emissions. Depending on their total system and marginal costs, different types of power plants may increase production. Including this charging scheme in the analysis might change the calculation results.

Uncontrolled or user-driven charging occurs mostly after work in the evening, when electricity demand is already high, increasing system load and costs of utilities (Brandmayr et al., 2017).

User-driven charging would raise severe concerns about generation adequacy and may jeopardise the stability of the power system (Schill and Gerbaulet, 2015). Fast-charging stations use large amounts of power for short periods of time, meaning that expensive upgrades will be needed for a relatively low use rate (Hall and Lutsey, 2017). In the US, if EVs constitute 25% of all road vehicles, uncontrolled charging would increase electricity peak demand by 19%, but spreading charging over the evening hours would increase demand by only 0%–6% (Fitzgerald, 2017).

Reducing carbon emissions and the load on the local grid will be solved only by charging management schemes, some of which are described below.

- **Off peak or network-oriented charging**. Includes policies and structures that encourage off-peak-period charging, including workplace or daytime charging and night-time home charging, to avoid network congestion and physical capacity constraints. This strategy should increase system stability and grid functioning, but producing electricity during low-demand periods using conventional energy sources might have negative environmental effects.
- **Cost-oriented charging**. This strategy aims to reduce EV charging cost by shifting the charging time to periods of low energy prices. EV owners could benefit from low energy costs, and load patterns might be smoothed as the low charging cost period coincides often with low demand. Additional conventional production during low-cost periods could have negative environmental effects. Some findings are the following (Schill and Gerbaulet, 2015). First cost-driven charging promotes renewable energy more than user-driven charging, but cost-driven charging might also increase the use of the emission-intensive lignite power generation. Germany, for example, has the lowest marginal costs for thermal technology and uses more hard coal than user-driven strategies. Second, cost-driven charging reduces unused generated power more than uncontrolled charging. The opposite happens in countries with a high share of renewables, such as Denmark, which has a low share of emission-intensive generators and high share of wind power. Using a cost-driven charging system, Germany and ASEAN countries will reduce CO_2 emissions only if they build more renewable-energy generators. Cost-driven charging will work only if emission externalities are correctly priced.
- **Smart charging**. Includes controlled charging and demand response. A simpler solution such the use of in-vehicle timers to take advantage of TOU rates could help minimise stress on the electrical grid whilst also saving money for consumers. Smart charging strategies are less practical for DC fast charging than for level-2 charging as drivers expect fast charging to be available on demand (Hall and Lutsey, 2017). As the fast charging market continues to grow, fast chargers should be placed near adequate high-capacity electrical infrastructure.
- **Combined smart and cost-oriented charging**. Decreasing real-time price increases renewable energy share, such as wind as it is available during that period. The variability of wind power drops as its share increases. In this situation, CO_2

emissions could be higher than the average of the total power plant energy mix, if coal, for example, due to its low marginal costs, dominates the lower-price part of the merit order (Dallinger et al., 2012).

- **Renewable energy-oriented charging** or **low emission-oriented charging**. Aims to increase environmental performance or avoid negative impact of greenhouse gases and air pollutant emissions. The measure shifts charging times to periods of high or surplus renewable energy generation, resulting in reduced additional production by conventional plants. However, conditions vary in different energy systems and this strategy requires sufficient renewable power generation to meet additional electricity demand.

3.3. Conclusion

PEVs are amongst the most viable means to reduce the use of fossil fuel, reduce greenhouse gases, and improve air quality. The issue is how to accelerate market penetration.

- PEV charging infrastructure is more complex than ICEV refuelling infrastructure, in terms of technology, interoperability, standardisation, and impacts on the electric power grid.
- Charging infrastructure is necessary for PEV deployment but is not the only determining factor.
- The cost of rolling out public PEV charging facilities is high. National governments need to initiate significant investment at least at the beginning of PEV penetration whilst partnering with private companies until markets mature.
- Central governments should facilitate the development of charging infrastructure by providing rebates, tax breaks, low-interest loans, and subsidies to private companies to build infrastructure; building make-ready facilities for private companies to continue; and partnering with private companies in developing and operating stations.
- Local or regional circumstances such as manufacturing maturity, business characteristics, and electricity supply profile need to be considered early on to define a proper partnership approach and discourage excessive intercity competition.
- The charging scheme strategy needs to be planned as early as possible to ensure that PEV penetration reduces greenhouse gases by using less fossil-fuel–based power whilst ensuring that additional electricity demand does not further burden the electricity grid.