POLITECNICO DI TORINO

Master of Science in Engineering and Management

Master of Science Thesis on:

Dominant design in charging infrastructure:

Identification of technological paradigm.

Supervisor: Candidate:

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Abstract

The movement for transition to electrically powered vehicles is already here, however we are at the beginning of the road. As we face many technological challenges along the way, numerous improvements are needed in key sectors to boost the process. In the long term, lowering the cost of electric cars, increasing their efficiency-range and expanding the availability of charging infrastructure are all considered critical components of increasing customer acceptance. This paper will concentrate on the later concept.

The advancement of charging infrastructure is critical in finalizing this shift since it continues to be one of the primary disadvantages of EV technology compared to petrol stations. To close the gap common interoperability standards and protocols should come to existence internationally. First part of the report will analyze current trends and developments in electric vehicle market and its effect on charging infrastructure. In the second part common methodology to early identification of dominant design in charging stations will be developed.

Acknowledgement

I would like to thank all my teachers, mentors and colleagues who helped me in my academic life so far. I appreciate all the time and patience they showed me. For all these years of inspiration and adventure, thank you.

Furthermore, I would like to thank Professor Marco Cantamessa for inspiring me to see "innovation" from whole new point of view, for helping me with identifying my thesis work scope and supported me in writing it.

Finally, I would like to thank my parents, my family and all my dear friends for always supporting me.

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1. Electric Vehicle market trends and developments

1.1 **Trends and developments in different segments of electric vehicles**

After ten years of gradual increase, in 2020 on the roads globally was more than ten million electric cars, 42% growth compared to the year before and that represented record 4.5% of total car sales in 2020. Major trend in electric cars segment was Battery electric vehicles shortly abbreviated as BEVs, which represented approximately 66 percent of new vehicles registered and same amount of total share of stock in 2020. While China has 4.5 million electric vehicles, Europe had the biggest growth in a year, reaching 3.3 million.

The worldwide market for all sorts of automobiles has been greatly impacted by the economic consequences of COVID-19 outbreak. In the first half of 2020, new automobile registrations fell by roughly a third compared to the previous year. This was largely offset by increased engagement in the second period, culminating in a per year decline of 17% overall. Additionally, while conventional and new automobile registrations decline, the worldwide electric vehicle market share increased 70% to a record 4.7 percent in 2020. In 2020, around 3 million new electric vehicles will be registered. Europe took the lead being first, with 1.3 million new registrations. China came in second with 1.1 million registrations, followed by the United States with 294,000 new electric vehicle registrations. Numerous reasons led to the rising sales of electric vehicles in 2020. Importantly, electric vehicles are becoming more affordable in several nations in terms of total cost of ownership. Numerous governments offered or prolonged fiscal incentives that insulated electric vehicle sales from the auto industry's collapse.

In 2020, Europe's automobile market declined by 22%. Nonetheless, new electric vehicle registrations increased to 1.3 million, representing a 10% market share. Germany recorded 394, 000 new electric vehicles in the major market, whereas France registered 184, 000. Registrations in the UK more than doubled to 177, 000. In Norway, electric vehicles had a historic high sales share of 76%, up nearly one-third from 2019. Electric vehicle sales in Iceland surpassed 51%, 30% in Sweden, and 24% in the Netherlands. Despite the economic downturn, Europe has seen a boom in electric vehicle registrations. This is due to two governmental initiatives. To begin, 2020 was the anticipated year for the European Union's carbon dioxide emissions guidelines, which set a limit on a new car's average carbon dioxide emissions per km driven. Secondly, several European governments raised subsidies for EVs as part of their stimulus packages in response to the pandemic's consequences. In 2020, BEV sales represented 53% of all electric vehicle registrations in Europe, continuing to outpace PHEV registrations. Nevertheless, the number of BEV registrations increased from year before, when the number of PHEV sales tripled. The Netherlands (83 percent of all electric vehicle registrations), Norway (72%), the United Kingdom (63%), and France (62 percent) all had a high proportion of BEVs.

China's entire automobile market has been less affected by the pandemic than some other countries. Overall, new vehicle registrations fell by around 8%. In the first half of 2020, new electric vehicle registrations were lower than the entire automotive market. This tendency was altered in the second part of the year when China exerted more control over the outbreak. As a result, the company's sales share increased to 5.6 percent, up from 4.7 percent in 2019.Around 79% of new electric vehicles registered were BEVs. Significant legislative initiatives in China have reduced the market's incentives for electric vehicles. Acquisition subsidies were originally scheduled to expire at the end of 2020, however after indications that they might be phased out more gradually before and during the outbreak, they were instead decreased by 10% and prolonged until 2022. In response to fears about the economic impact of the pandemic, many municipalities eased their restrictions on how many cars could be registered. This allowed more internal combustion engine cars to be registered to help local automakers.

The United States automobile market dropped by 22% in 2020, however electric vehicle sales declined at a slower rate than the entire market. In 2020, 294 000 new electric vehicles were registered, with approximately 77% of them being BEVs, down from 327 000 in 2019.Their sales percentage increased to 2.5%. Federal stimulus reduced in 2020 because expiration of federal tax credits for Tesla and General Motors, which account for the overwhelming of electric vehicle registrations.

Other nations electric vehicle markets remained stable in 2020. For instance, in Canada, the new automobile market decreased 20%, whereas new electric vehicle sales remained largely steady at 50,000. New Zealand is an exception in this regard. Despite its robust pandemic strategy, it experienced a 21% fall in new electric vehicle registrations in 2020, in line with the overall auto market decline of 20%. The reduction looks to be mainly due to abnormally small electric vehicle sales in April of 2020, when New Zealand introduced lockdown measures. Japan being another case, where the entire new vehicle market decreased 10 percent compared to previous year to 2020, while electric vehicle registrations fell 24%. Since 2017, when it reached 53,000 registrations and a 1% market share, the electric vehicle market in Japan has declined in absolute and relative terms every year. In 2020, there were 28 000 registrations and a market share of 0.5 percent.

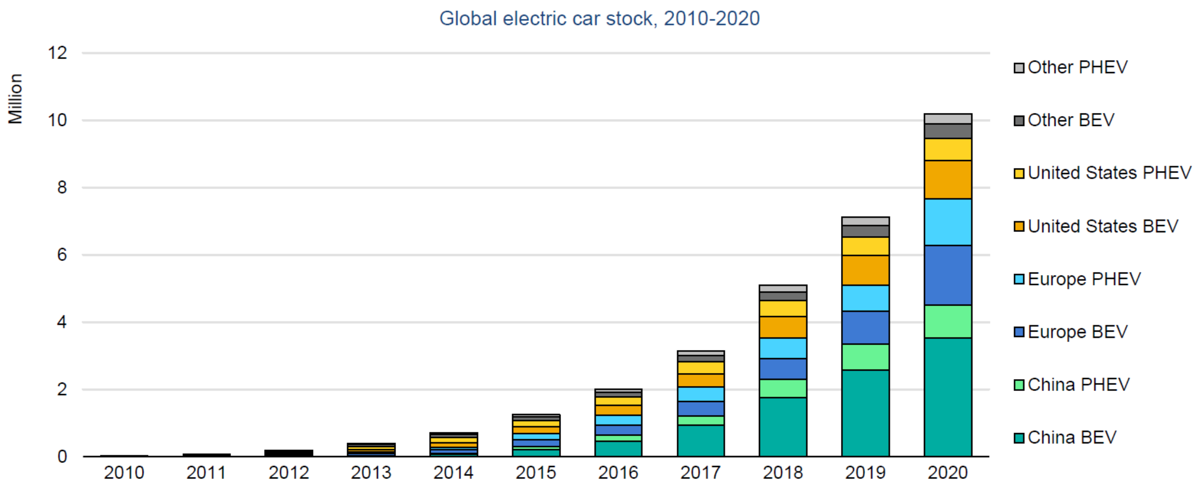


Figure 1.1 Global EV stock

In 2020, reported consumer spending was USD 119 billion on EVs acquisitions, a 49% rise over 2019, which generates a 40% rise in sales, 5% increase in overall costs. The growth in overall prices illustrate that Europe, with higher average prices than Asia, responsible for a greater share of new electric vehicle registrations. By 2020, the worldwide average price of a BEV would be approximately USD 39,000, while the price of a PHEV would be around USD 49,000.

In 2020, national authorities spent USD 13.5 billion on incentives for direct purchases and tax breaks for EVs, a 24% increase year over year. However, governmental incentives in overall expenditure on EVs has been declining steadily since 2015, falling from around 19% in 2015 to 10 percent in 2020.

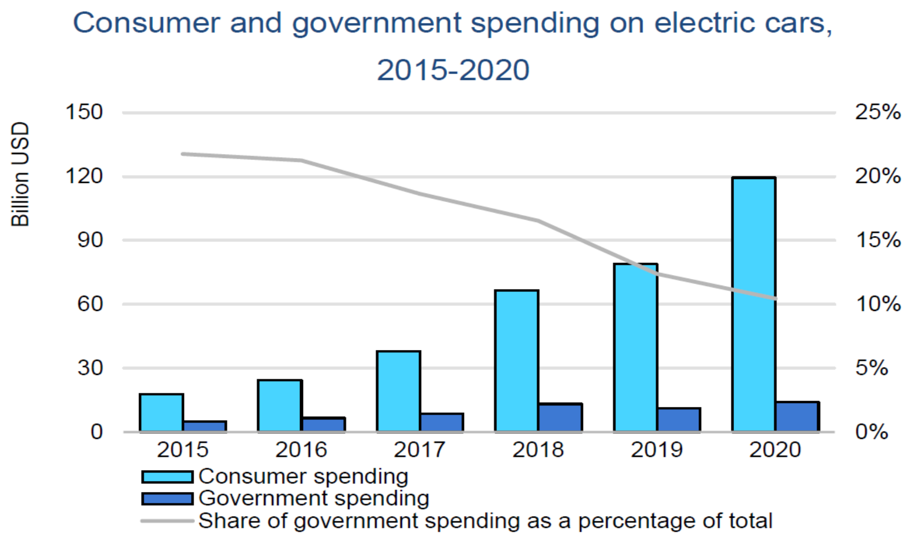


Figure 1.2 Consumer and Government spending on EVs

The average range of new battery electric vehicles has been continuously rising. While in 2020, the average weighted range of a new battery electric vehicle was around 345 kilometers, compared to 195 kilometers in 2015. The weighted average range of electric automobiles in the United States is often greater than in China, owing to China's larger proportion of compact urban electric cars. Over the last several years, the average electric range of PHEVs has stayed pretty steady at about 50 kilometers. The SUV class had the most models and saw the greatest growth in 2020. Over 54% of new vehicles revealed globally are SUVs and pickup trucks.

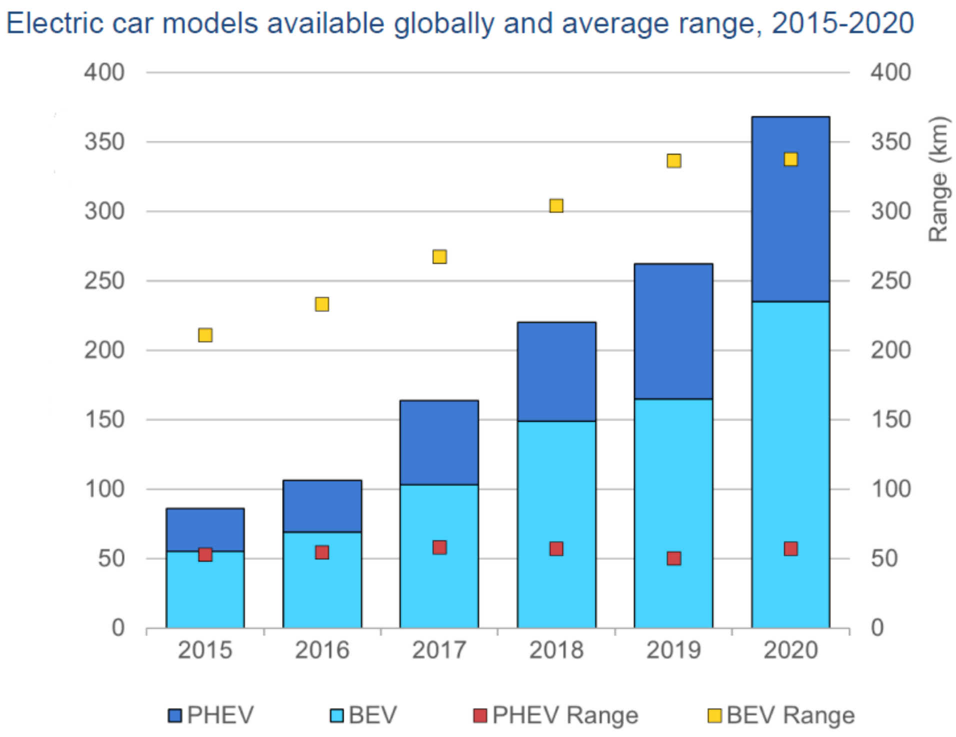


Figure 1.3 Models and range of EVs

Global market share of PEV was represented by various car manufacturing companies in the first half of 2021. Tesla was named the world's best-selling electric car maker in the first half of 2021, selling about 420,000 vehicles. Tesla's sales volume corresponds to 14.5% of the market share, Volkswagen Group coming in the second with 12.5%, making them 2 clear leaders of the market. General Motors with 8.5% came third places , respectively.

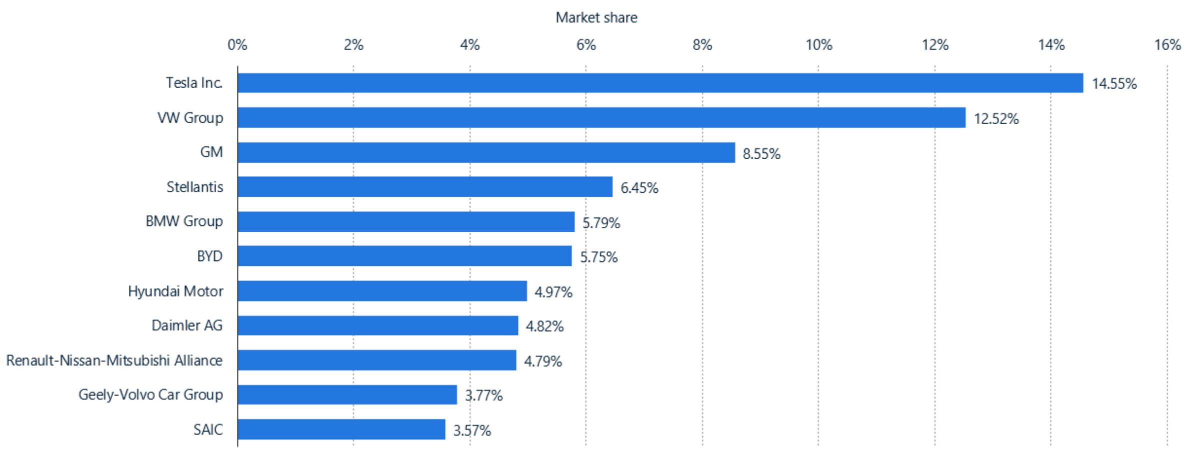
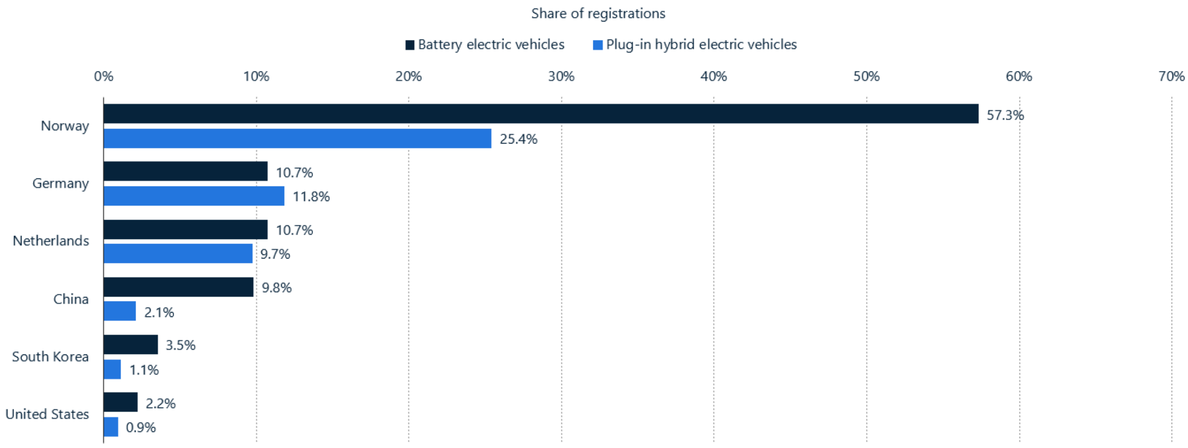


Figure 1.4 Market shake at first half of 2021 by companies

If we look at the Plug-in electric vehicles as a share of new vehicle sales in particular countries in first half of 2021, Norway is a clear leader and front runner in all electric transformation movement with approximately 80% of new vehicle sales being either Battery electric vehicle or Plug-in hybrid electric vehicle. Most popular car being Audi e-tron and tesla in second place selling over 7800 units of “model 3” alone. In 2020 more than 350,000 electric vehicles and 18,000 publicly accessible electric charges was registered in Norway

Germany, Netherlands and China come in next 3 places close to each other with approximately 12 to 20% of all vehicle sales being PHEV.



1.2 **Commitment of private sector**

Despite a difficult year, large corporations worldwide are speeding up the process of shifting to electric mobility by converting fleets to electric cars and constructing charging stations. The Climate Group's EV100 Initiative unites over 100 organizations in 80 markets dedicated to make electric vehicles the new normal by 2030. This means that by 2030, 4.9 million cars will be switched to electric vehicles and 6,400 places will have chargers.

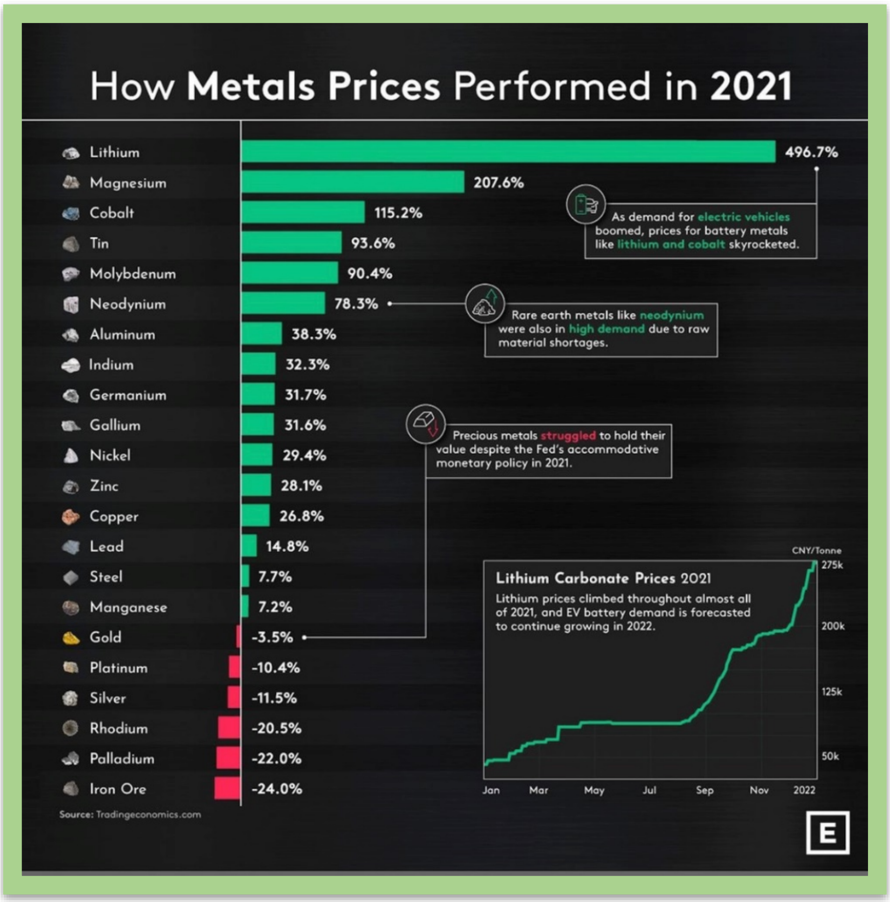
By 2020, members of EV hundred have already deployed 168 000 zero-emission cars, more than double the previous year's deployment. Even though firms regard business vans and heavy trucks as the most difficult to find EVs, the quantity of commercial EVs increased by 22% in 2020, with electric trucks tripling in size. Members of the EV100 are also boosting access to charging infrastructure for workers and consumers, with over 16,800 charging stations established at over 2,100 sites globally. More than half of EV100 representatives operate their charging operations entirely with renewable energy.

Private sector declarations related to electric commercial vehicles

Company	Operating area	Announced	Target / actions
Amazon	Global	2020	Orders 100 000 BEV light-commercial vehicles from start-up company Rivian. Amazon aims to be net-zero emissions by 2040.
Anheuser-Busch	United States	2019	Orders up to 800 hydrogen fuel cell Nikola heavy-duty trucks.
DHL Group	Global	2019	Delivery of mail and parcels by EVs in the medium term and net-zero emissions logistics by 2050.
FedEx	Global	2018	Transition to an all zero-emission vehicle fleet and carbon neutral operations by 2040.
H_2 Mobility Association	Switzerland	2019	19 of Switzerland's largest retailers invest in Hyundai hydrogen trucking services that will deploy up to 1 600 heavy-duty zero-emission trucks.
Ingka Group (IKEA)	Global	2018	Zero-emission deliveries in leading cities by 2020 and in all cities by 2025.
Japan Post	Japan	2019	Electrify 1 200 mail and parcel delivery vans by 2021 and net-zero emissions logistics by 2050.
JD	China	2017	Replace entire vehicle fleet (> 10 000) with New Energy Vehicles by 2022.
SF Express	China	2018	Launch nearly 10 000 BEV logistics vehicles.
Suning	China	2018	Independent retailer's Qingcheng Plan will deploy 5 000 new energy logistics vehicles.
UPS	North America	2019	Order 10 000 BEV light-commercial vehicles with potential for a second order.
Various companies	Multinational	2018	Walmart, Pepsi, Anheuser-Busch, FedEx, Sysco and other large multinational corporations pre-order 2 000 Tesla Semi models within six months of truck's debut.
Walmart	United States	2020	Electrify the whole vehicle fleet by 2040.

There are still sufficient obstacles to EV adoption. Members of the EV100 identified a shortage of charging stations as the primary issue (especially in the US and UK). The firms also identified a recurrent barrier as a lack of adequate vehicle types. The price of electric vehicles remains a major barrier, despite the fact that many employers recognize the huge cost benefits associated with decreased fuel and maintenance expenses throughout the vehicle's lifespan. To help overcome these challenges, 70% of EV100 members support more favorable tax incentives for electric vehicle purchases and 71% support more supportive policies at the state, regional, and local government levels. 60% of member firms support the government's goal of eliminating gasoline and diesel vehicles by 2025.

In 2021, as demand for electric vehicles climbed historic high, prices of metals that constitute electric battery materials like Lithium, Magnesium and Cobalt skyrocketed in yearly increase of 496.7%, 207.6% and 115.2% accordingly. As these metals happens to be scarce, difficult in mining and located in few specific location, as demand for these materials continues to rise prices will go up accordingly.



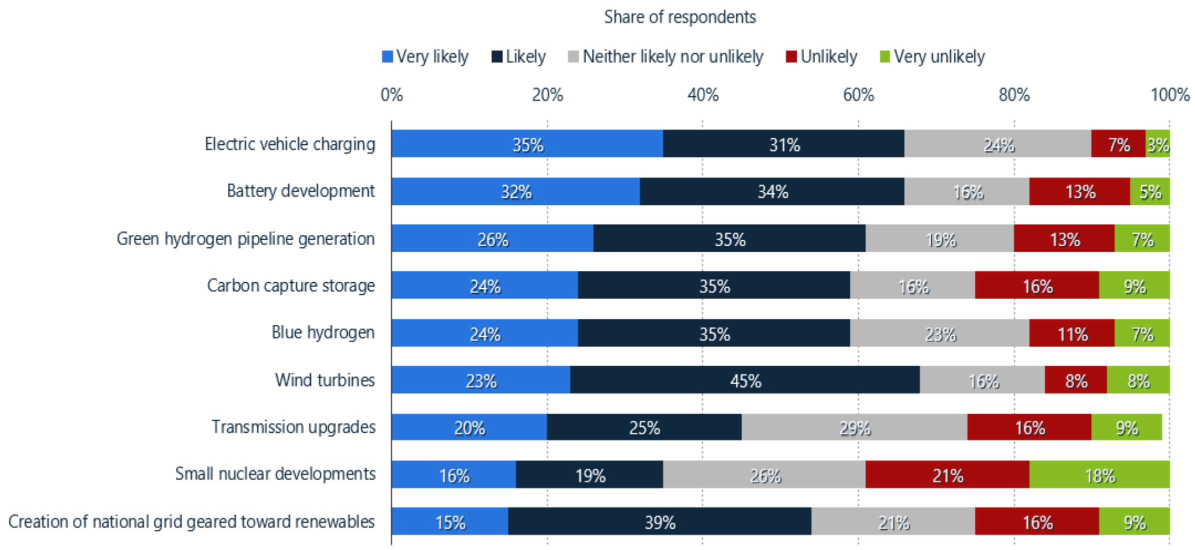
In 2020, vehicle lithium-ion (Li-Ion) battery output increased by 32% to 160 gigawatt-hours (GWh). The rise is due to a 40 percent increase in electric vehicle sales and a consistent medium capacity of battery 54 kilowatt-hours (kWh) for battery electric vehicles and 14 kilowatt-hours (kWh) for PHEVs. Battery demand for alternative forms of vehicles grow 10%. China is a leader in battery manufacturing, accounting for more than 71% of worldwide battery cell capacity.

China was responsible for the biggest chunk of battery usage in 2020, accounting for about 80 GWh, whilst Europe increased by 112 percent to reach 51 GWh. In the United States, demand was constant at 20 GWh. Nickel-manganese-cobalt remains the most widely used Li-ion battery chemistry, accounting for around 70% of sales, with nickel-cobalt-aluminum accounting for the majority of the remainder. Although lithium-iron-phosphate battery chemistry has recovered market share, it remains far below 5% in the electric vehicle industry.

According to the BNEF's annual assessment of battery pricing, the calculated cost of car batteries decreased 12% from 2019 to USD 137/kWh at the pack level in 2020. Discounts are available for large volume purchases, as shown by a teardown investigation of a VW ID3 that revealed an approximate cost of USD 100/kWh for its battery cells.

In 2021, demand for batteries in Europe will surpass local manufacturing capacity. Today, the majority of Europe's battery manufacturing plants are situated in Poland and Hungary. Capacity is now at 36 GWh per year, but projected potential might reach 400 GWh by 2025. In 2020, Europe demonstrated momentum with the announcement or building of many new battery factories. In the US, both Korean and American battery makers have indicated significant interest in a market now controlled by a joint venture between Tesla and Panasonic.

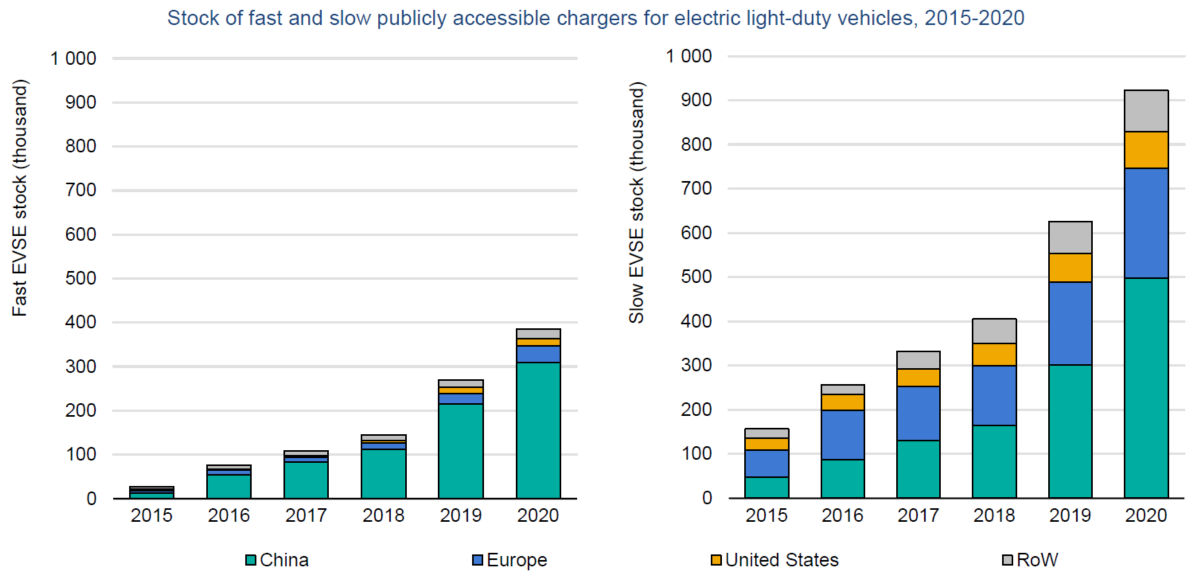
In a survey dedicated to predict likelihood of energy company's engagement or investment in public/private partnership of more than 160 respondents, which included major energy sector decision-makers including executives, legal counsel, and investors. Wind turbines, according to the poll, provide the largest opportunity for energy businesses to participate in public-private partnerships. Approximately 70% of respondents said they would invest in this clean energy technology "very likely" or "likely". At 65%, electric vehicles and battery development came next. 35% of respondents answering that it is very likely that energy companies would engage in this sort of investment.



1.3 **Deployment of electric vehicle charging infrastructure**

While the majority of electric vehicle charging happens at home and at work, expanding public charging infrastructure will be crucial as nations that have led the way in electrical vehicles reach a point when electric vehicle owners seek more simplicity and autonomy. In 2020, there will be 1.2 million publicly available chargers, 30% of which are fast chargers. Deployment of publicly available chargers increased by 43 percent, slower than the 83 percent increase in 2019, due to work interruptions in important markets caused by the pandemic. China is the global leader in terms of accessibility of both slow and fast public chargers.

In 2020, the rate of slow charger installation (charging power less than 21 kW) in China rose by 64 percent to around 450 000 publicly available slow chargers. This accounts for over the half of the world's slow charger infrastructure. Europe is in second place with over 245 000 slow chargers, with deployments expected to increase by one-third by 2020. The Netherlands is Europe's leader with almost 62 000 slow chargers. In 2020, Iceland, Finland, and Sweden doubled their supply of slow chargers. In 2020, the quantity of slow chargers installed in the US rose by 29 percent from year before to 82 000. Korea built 44% more slow chargers in 2020, reaching 55 000, placing it in second position.



In 2020, the rate of fast charger (charging power more than 23 kW) construction in China climbed by 43% to about 300 000 fast chargers, slower than the yearly growth rate of 93 percent in 2019. The relatively large number of publicly accessible fast chargers in China is intended to compensate for a scarcity of private charging choices and to aid in the accomplishment of the country's quick EV deployment targets. Fast chargers are being installed at a faster pace than slow chargers throughout Europe. There are now around 39 000 public fast chargers, growing 55% by 2020, with over 8000 in Germany, 6 000 in the UK, 4 000 in France, and 1 950 in the Netherlands. In the US, there are 18 000 fast chargers, roughly 62% of which are Tesla superchargers. Korea has a total of 10000 rapid chargers. Fast chargers located in public locations promote longer travels. They will allow longer travels and will attract late adopters who do not have access to private charging to acquire an electric car.

1.4 **Policies to put forward electric vehicle ecosystem development**

Significant economic incentives accelerated the early adoption of electric light duty vehicles and fueled the growth of the electric vehicle and battery sectors. The measures – mainly purchase subsidies and/or car purchase and registration tax refunds – were implemented to close the price gap between electric vehicles and conventional automobiles. Such measures were established in Norway as early as the 1990s (battery-electric automobiles have been free from registration tax and value added tax since 1990 and 2001, respectively). In Norway, such taxes may equal up to half or even the whole original (pre-tax) car purchase price.) in the US in 2008 and China in 2014.

The continuous tightening of fuel economy and exhaust carbon dioxide limits has emphasized the need for electric vehicles to meet these demands. Today, approximately more than 80% of automobile sales globally are governed by similar rules. The European Union's carbon dioxide emission rules had a significant impact on increasing electric vehicle sales, which more than doubled to 2 million by 2020. Certain authorities have mandated some sales goals for electric vehicles, for instance, in California for several years and since the end of 2016 in China.

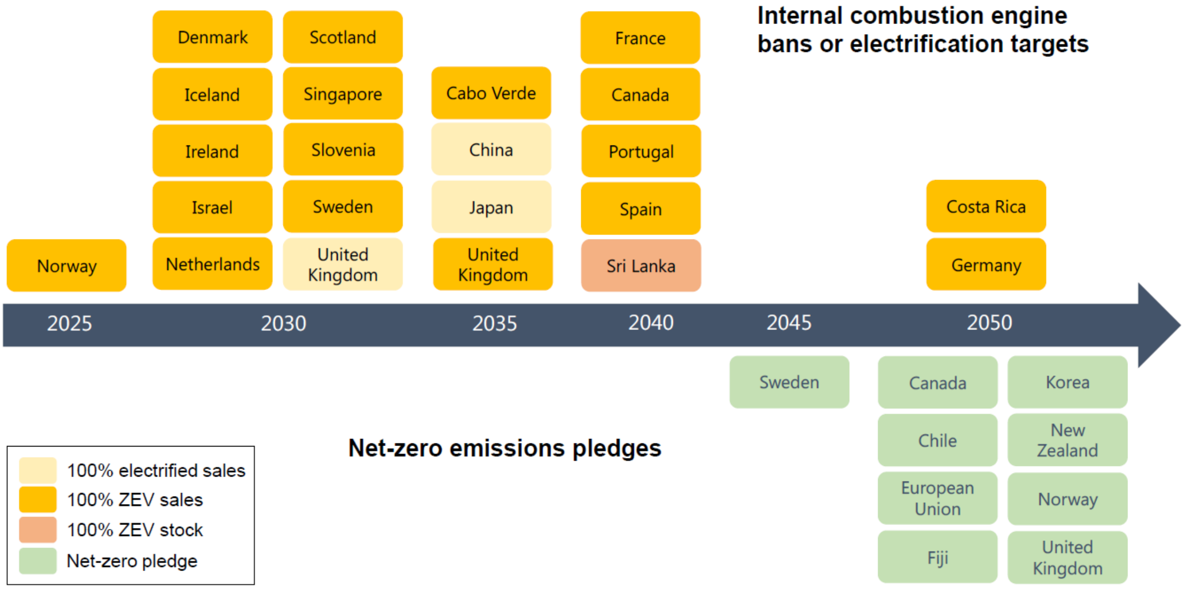
Convenient and cost-effective public charging stations will become even more critical as the use of electric vehicles increases. To tackle this, governments have subsidized electric vehicle charging infrastructure through initiatives such as direct investment in the installation of publicly accessible chargers or financial incentives for electric vehicle owners to install charging points at home. In certain areas, such as residential buildings and retail enterprises, building rules may require charging stations as part of new construction or significant remodels.

Cities efforts to increase the value of electric vehicles have boosted sales outside of metropolitan areas. Among these strategies are the strategic deployment of charging infrastructure and the establishment of favorable flow or access schemes, including low and ZEVs or varied circulation charges. Such policies had a significant influence on electric vehicle sales in Oslo and a number of Chinese cities.

To make the 2020s the decade of electric vehicles, both industry first movers and late followers must demonstrate more commitment and effort. In markets that made great progress in the 2010s, a fundamental objective for 2022 and beyond should be to continue implementing and tightening regulatory instruments while also broadening them. For example, the European Union's carbon dioxide emissions legislation for automobiles, China's requirement for New Energy Vehicles (NEVs), and California's mandate for ZEVs. Near-term efforts should concentrate on maintaining the competitiveness of EVs and progressively eliminating purchasing subsidies as sales increase. This could be done by taxing cars and fuels differently based on their impact on the environment, as well as by strengthening regulations that encourage the growth of the green car market.

Maximizing the contribution of electric vehicles to vehicle emissions reduction entails integrating electric vehicles into power systems, decarbonizing electricity production, deploying charging infrastructure, and producing sustainable batteries. Countries that are currently deploying a small number of electric vehicles may use lessons gathered and advancements in automotive and battery technology to accelerate the production and adoption of electric vehicles. Charging service innovation and the skills gained in the sector would be advantageous to developing economies as well. However, they will also need to tighten fuel efficiency and emissions requirements dramatically. Developing countries that have a lot of used cars from other countries can use policy tools to take advantage of cheap electric car models, but they have to be careful about the consequences for electricity networks.

Nowadays, near to 25 nations, including growing economies including Sri Lanka, Costa Rica and others have declared the complete phase-out of internal combustion engine vehicle sales over the next decade to thirty years. Additionally, more than 125 nations (representing approximately 80 % of the world's road vehicle capacity, excluding 2 and 3 wheelers) have set economy-wide net-zero emissions commitments with the goal of reaching net zero emissions within the next few decades.



Other forms of transport, particularly commercial vehicles need more policy attention and action, since they have a rising and unequal influence on energy usage, air pollution, and Greenhouse gas emissions. Medium- and heavy-duty vehicles account for 6% of all 4-wheeled road transport yet account for about 30% of Carbon dioxide emissions. Battery advancements have resulted in the fast commercialization of an expanding number of models in larger weight classes and with rising ranges over the last several years.

California being the first state to propose a zero-emission vehicle sales mandate for heavy-duty trucks in 2020. From 2025, the Advanced Clean Truck Regulation will take effect. The Holland and a numerous of other nations are developing and deploying zero-emission commercial automobile zones. While this is a "hard-to-abate" industry with several decarbonisation options, electrifying of numerous modes of vehicles is becoming recognized as a potential avenue for reducing both local pollution and Carbon dioxide emissions. HDV electrification will need comparable regulatory backing and commercial adoption as passenger vehicles had in the 2010s. Electric buses are already making a difference in major cities worldwide, aided by national and municipal regulations aimed at combating air pollution. Electric bus policy initiatives are various; they may include competitive tendering, green public procurement programs, acquisition subsidies, and direct assistance for charging infrastructure implementation, as well as appropriate pollutant emissions requirements. Due to their vast quantity and popularity, electrifying 2/3 wheelers in developing nations is critical for near-term decarbonisation of transportation. China is setting an example by prohibiting ICE-powered two- and three-wheelers in a number of locations.

2. Electric Vehicles Charging Infrastructure overview

In general, electric vehicles can be charged in a number of ways, depending on their geographical location, connection type, and requirements. For this reason, the charging infrastructure for EVs has evolved into different types and designs for different applications in different locations. There are different standards and requirements for EV chargers, which are also called electric vehicle supply equipment. This is because each location has different features of its electric grid and the demand for EV models that saturate it.

2.1 **Specifications of EV supply equipment**

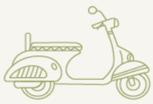
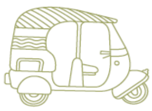
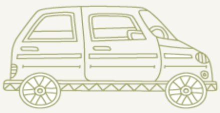
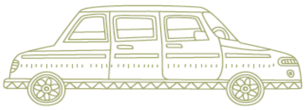
Electric vehicle supply equipment is the fundamental component of the electric vehicle charging infrastructure. The electric vehicle supply equipment receives energy from the local power grid and charges electric vehicles securely through the use of a control scheme and a cable connection. A control system for an EVSE offers a variety of operations, including user identification, charging authorization, data recording and sharing for network monitoring, and data protection. For all charging needs, it is suggested to utilize EVSEs with at least basic control and management features.

Conductive charging, sometimes known as plug-in (wired) charging, is the most widely used charging method. The conductive charging requirements for an EVSE differ according to parameters like vehicle type, battery size, charging techniques, and power ratings.

2.1.2 **Battery characteristics of different EV segments**

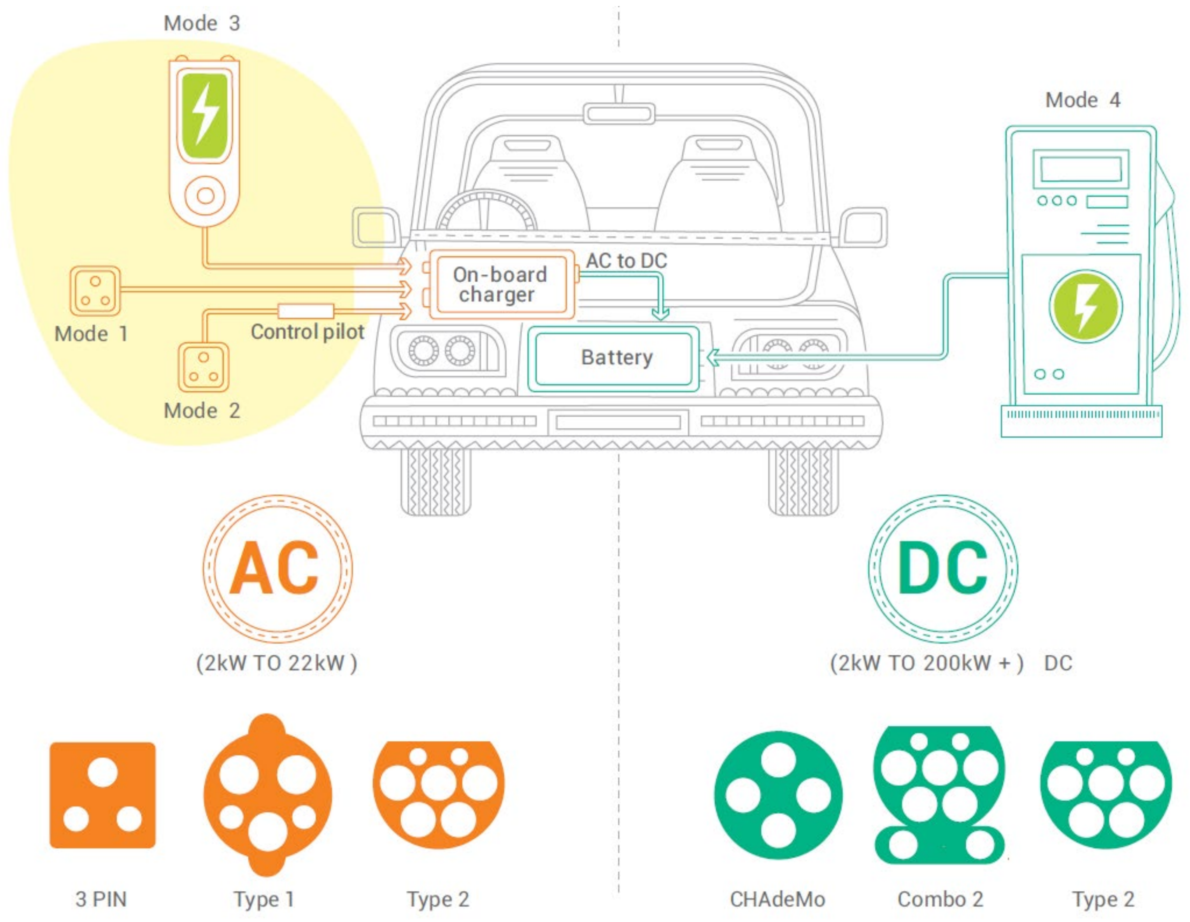
Internationally, electrification of transportation is predicted to be accelerated during the next decade by light electric vehicles (LEVs), which include 2 and 3-wheelers. The latter is mostly owing to India's and China's influence in this industry. Additionally, automobiles and light commercial vehicles (LCVs) are being electrified.

Charging criteria for electric vehicles are determined by the battery specifications, since electricity must be provided to the battery at the correct voltage and current levels to enable charging. As indicated in E-2Ws and e-3Ws, being supplied by low-voltage batteries. Low voltage batteries are also used to power the initial generation of e-cars. However, even if they continue to be used in certain applications like taxis, they are expected to fade out in the future. The second generation of electric vehicles, as shown by impending e-car models, is powered by high-voltage batteries. Low-voltage and high-voltage electric LCVs will be available, depending on their load-carrying capabilities.

VEHICLE SEGMENT	BATTERY CAPACITY	BATTERY VOLTAGE
E-2W 	1.2-3.3 kWh	48-72V
E-3W (passenger/ goods) 	3.6-8 kWh	48-60V
E-cars (1st generation) 	21 kWh	72V
E-cars (2nd generation) 	30-80 kWh	350-500V

2.1.3 **Charging methods and power ratings**

Charging an electric vehicle entails supplying direct current (DC) to the battery pack. Due to the fact that electrical distribution networks deliver alternating current (AC) power, a converter is necessary to give direct current power to the battery. Conductive charging may be either alternating current or direct current. When an AC EVSE is used, the AC power is given to the EV's on-board charger, which converts it to DC. A DC EVSE transforms external power and sends direct current to the battery through the onboard charger. AC and DC charging are further categorized into four charging modes, with AC charging being defined as Modes 1-3 and DC charging as Mode 4. Modes 1 and 2 are used to connect an electric vehicle to a conventional socket outlet through a cable and plug. Mode 1, commonly referred to as "dumb charging," disables communication between the EV and the EVSE and is not advised for usage. The portable cable used in Mode 2 is equipped with built-in protection and control and is commonly used for in-home charging. Modes 3 and 4, which require a separate charger device to power the EV, feature more sophisticated management systems and are intended for commercial or public charging.



	Power level	Current type	Compatible EV segments
Normal power charging	P ≤ 7kW	AC & DC	E-2Ws, e-3Ws, e-cars, other LCVs (up to 1 ton)
	7kW < P ≤ 22kW	AC & DC	
High power charging	22kW < P ≤ 50kW	DC	E-cars, LCVs and MCVs (1-6 tons)
	50kW < P < 200kW	DC	

EVSEs have varying power ratings or levels dependent on charging conditions, which in turn dictates the required input power for charging infrastructure. In Table 2, electric vehicle charging is classified by power level, with regular power charging reaching 22kW and high-power charging reaching 200kW. While EVSEs with a maximum power rating of 500kW are available internationally, for now they are mostly appropriate for larger vehicles such as buses and trucks. Charging using standard AC power is sufficient for e-2Ws, e-3Ws, and e-cars. Single-phase alternating current chargers with a maximum output of 7kW are sufficient for LEVs and automobiles equipped with single phase on-board chargers. Three-phase AC chargers with a maximum output of 22kW are necessary for electric vehicles equipped with bigger on-board chargers. The input power source for typical power charging may be obtained from the public energy grid. A 50kW high-power direct current charger is utilized for high-voltage e-cars with battery capacity ranging from 30 to 80 kWh. The market offers DC chargers with a power output ranging from 25kW to 65kW. However, higher-power DC chargers are on the horizon. While fast charging with high-power DC takes less time for e-cars, it needs a larger external source of power and extra infrastructure. Thus, most charging needs, even slow or overnight charging of e-cars, can be met by standard power charging outlets.

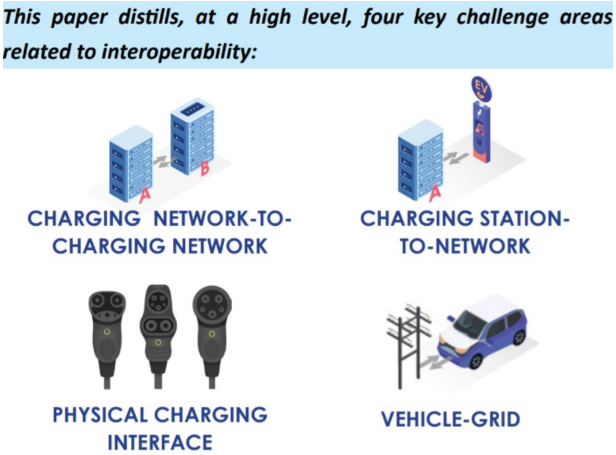
2.1.4 **Battery swapping**

Battery swapping is a technique of alternate battery charging that is gaining worldwide interest. It involves removing a discharged EV battery from the vehicle and replacing it with a fully charged one. The technology is being evaluated for usage in a variety of electric vehicle categories, including e-2Ws, e-3Ws, e-cars, and potentially e-buses.

Manual: The battery swapping machine is a self-usable unit in which batteries are physically inserted and withdrawn from the individual slots, often by hand. Manual changing stations are modular and take up little space. These are utilized for applications requiring 2W or 3W batteries, since the battery packs are lighter and the weight can be carried by one or two people.

Autonomous: These sorts of swapping stations use a robotic arm, with the battery swapping procedure being semi-/fully automated. Robotic battery swapping is employed in 4W and e-bus systems because to the bigger and heavier battery packs that need mechanical help. Additionally, these exchanging stations are costlier and demands more space.

2.2 **EV charging standards for interoperability**

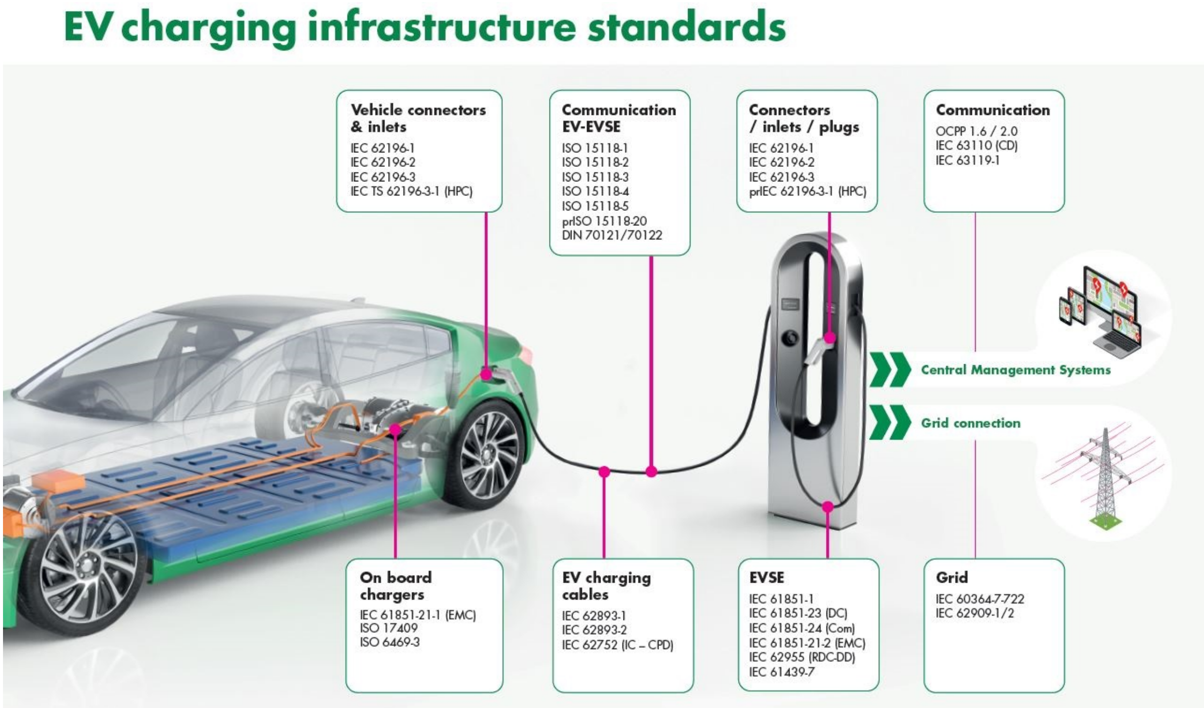


Charging network-to-charging network: Electrical vehicle service providers tend to run their separate networks as islands, without connectivity or cooperation with other networks. In the present industry jargon, interoperability most commonly refers to a concept in which electrical vehicle owners may use public charging stations from any provider through a unified platform and a single network membership or agreement, sometimes termed "e-roaming." Numerous EVSP systems have signed bilateral agreements to create international partnerships in the past year, representing critical progress towards expanded access to networked public charging.

Charging station-to-network: Networked charging stations must connect with their supporting networks. Exclusive protocols can lead to "vendor lock-in" issues, which bind consumers, usually the charging station owner, to a single, locked provider for the life of the charging equipment. An open standards-based strategy that combines both technological abilities and contractual rights enables owner-operators to move between network service providers and install additional charging stations without changing network service providers. This can assist to increase market competitiveness and preserve infrastructure investments from obsolescence. The Open Charge Point Protocol (OCPP) is a public networking standard that is popular in Europe and is gaining momentum in the United States. While current versions (OCPP 1.5, 1.6, and 2.0) have considerable feature gaps, their adoption by most network providers and ongoing development are critical to solving network interoperability.

Physical charging interface: While a single standard for common AC charging is largely recognized in the United States, with Tesla vehicles needing an adapter, 3 separate DC charge ports are now in use. The implementation of the SAE J-1772 standard, which gives manufacturers and others building charging infrastructure with an uniform system design, alleviated issues with fragmentation in the early Level 2 AC charging industry. Meanwhile, the lack of a single approved standard for DC charging for light duty EVs adds operational complexity and expense, as well as the potential for user misunderstanding as public DC fast charging spreads.

Vehicle-grid: To adopt new vehicle-grid integration technologies, cooperation among power vehicle and charging station makers, network operators, location hosts, and power companies are required. Both the power grid and the car owner profit from vehicle-to-grid charging. At the moment, electric corporations and grid operators are constrained in their efforts to enable safe, cost-effective, and dependable public charging stations on a large scale due to a lack of interoperability across networked devices and an absence of adequate publicly accessible protocols for electric company communications.



Without fully resolving interoperability challenges, global public charging infrastructure would continue to develop along fragmented and unproductive pathways, potentially resulting in greater prices, far than ideal client experience, and forsaken investments. Reliable, sustainable infrastructure development needs a common focus on interoperability, openness, and common standards to ease integration capabilities and enhance the customer experience. From the customer's standpoint, the aim should be a system that gives comfort, trust, and security.

3. Brief theory of Dominant design

According to Abernathy (1978) and Anderson and Tushman (1990), the dominant design is an unique design that develops supremacy in a product class. Its appearance is typically seen as indicating the development of a sector or a class of products. The idea of the dominant (technological) design holds a prominent place in the body of literature dealing with the development of technology and the structure of markets. It has been connected to changes in industry structures, firm and product performance, firm entrance and leave rates, time-of-entry advantages, kinds of innovation shifts, and changes in industrial and organizational development.

The efforts of Abernathy and Utterback is where the idea of the dominating design first appeared (Utterback and Abernathy, 1975; Abernathy, 1978; Abernathy and Utterback, 1978). Their study and subsequent studies on the development of technology have found that this evolution is not arbitrary but rather follows a cyclical pattern of variation, collection, and retention. Technology advances that result in a paradigm change at the beginning of technological cycles are unpredictable and discontinuous (Anderson and Tushman, 1990). Such technical discontinuities start periods of variety, when many manufacturers offer a number of and sometimes incompatible varieties of the ground-breaking technology, as the new technology is first poorly understood. The phase of modification is followed by a period of selection, during which competing designs are assessed (through use, frequently by end users), some of which may be further developed, and ultimately, some of which are preserved and some of which are eliminated. The outcome of this selection process is the development of a single dominant design that gains market dominance in the product category and is imitated by the majority of industry producers. Up until a new technical discontinuity emerges to make the previous dominant design outdated and restart the technology cycle, additional variation in the key elements of the product architecture is uncommon (and typically associated with niche markets).

Monitoring the market share of rival designs is one method for figuring out when a dominating design emerges. It may be said that a design has attained dominance when it represents more than fifty percent of new product sales or new process installations over a sizable period of time (Anderson and Tushman, 1990). Of course, the "substantial length" criterion (four years for Anderson and Tushman, 1990) and the fifty-percentage market share cutoff might be arbitrary and situation-specific. However, they have been widely employed because they are data-driven, simple to use, and typically consistent with ideas about dominance. Scholars have taken a somewhat different tack, viewing products as layered hierarchies of supporting subsystems and connecting processes (Henderson and Clark, 1990; Murmann and Frenken, 2006). Some of these subsystems and connection mechanisms are essential to the functioning of the final product (such as the engine in a vehicle), since they may need changes to other parts of the product's design as well. While modifications to core components may imply changes to other, less crucial components, the latter are not affected by changes to the former. Instead, they may be dictated by them. When goods converge on their essential features, one might say that a dominating design for the finished product has formed. After that, peripheral component advancements continue without affecting or undermining the central design.

But what are the actual driving forces underlying this convergent selection of a single dominating design? Two theories have been proposed: scale economies and network externalities (Klepper, 1997). In fact, the contemporaneous existence of several designs hinders manufacturers' ability to profit from economies of scale and confuses customers. In contrast, the establishment of a dominant design enables manufacturers to streamline operations, increase productivity, and maintain more stable relationships with vendors, vendors, and consumers (Anderson and Tushman, 1990). Scale in manufacturing decreases uncertainty and possible issues with design incompatibility, which benefits consumers by lowering pricing and product expenses.

The ecosystem that develops around an industry benefits greatly from convergence on one dominating design. However, this knowledge alone does not explain the precise processes that lead to the favoring of one design over another. Even minor random shocks that give one design an early advantage might determine which design finally takes the lead if scale economies and network externalities are the only factors influencing the selection process. However, some academics have concentrated more on the part that agency and social elements play in this process.

The deliberate actions of strong actors, such as a dominant producer (such as IBM's successful efforts to impose its chosen standard in PCs as the industry standard to be followed by the majority of other manufacturers as well), an important consumer (such as the government), or industry standard-setting bodies, can result in the emergence of a dominant design. Similar to how corporations might use alliance-building and strategic maneuvering to create the dominant design (Cusumano et al., 1992), Suarez and Utterback (1995) emphasize the significance of such sociopolitical and institutional issues by pointing out that scale economies are a byproduct rather than the cause of the establishment of a dominant design.

Overall, it seems that early market share and technological leadership are not the most important selection criteria on their own. Betamax is usually regarded as having been more technologically advanced than VHS in the home videocassette recorder market, although the latter swiftly replaced it (Cusumano et al., 1992). Even though achieving dominance undoubtedly requires good performance for the task at hand, social, political, and organizational dynamics appear to play an even more significant role in guiding the process of design selection. In fact, it is generally acknowledged that the design that achieves dominance is rarely the most technologically advanced one. The issue arises at such early stages of a technological cycle because the functional consequences of various designs are not yet fully recognized or understood, and the performance indicators have not yet been well established (Clark, 1985). Users are unsure of what the new product should achieve and what performance trade-offs may be necessary or appropriate (Yoxen, 1987; Tushman and Rosenkopf, 1992). As an example, in the early computed tomography scanners, doctors were unsure of the relative importance of scan time, resolution, safety, and cost.

As a result, it might be challenging to compare several designs at first since it necessitates agreement on the pertinent metrics to be used. Producers and other stakeholders, such as users and critics, must negotiate.

Depending on their history and competitive advantages, various producers may highlight various features of the new technology. End users also develop their own understandings of new technology at the same time, which may or may not coincide with manufacturers' understandings (Clark, 1985).

Users may devise novel and unexpected uses for the product (von Hippel, 1994) or they might insist that the course of future technical development be changed.

Additionally, negotiations are needed between manufacturers and among various scientific specialties. Engineers from various scientific backgrounds collaborate to create the majority of new technical designs. For instance, in order to produce jet engines, aerodynamic, metallurgical, combustion, and mechanical experts must collaborate and decide on the primary specifications of the new product (Tushman and Rosenkopf, 1992). Distinct disciplines frequently adhere to different standards and give priority to various new technological features or performance indicators. Any new design instead equates to a compromise that is a satisfactory answer for everyone, as opposed to totally allaying the worries of any set of stakeholders.

Scholars now understand that the choice of a dominant design among competing designs is essentially a social/political process rather than one that is driven by technical determinism as a result of the social development of norms and assessment criteria. The dominant design is typically not the most technologically advanced on any parameter since there must be mutual agreement on assessment criteria as well as trade-offs between performance, reliability, and price that determine the market penetration of any design. The design that succeeds in gaining dominance typically does not cater to the requirements of any particular subset of customers or other stakeholders (i.e., it does not maximize performance on any specific dimension), but rather offers a satisfactory solution to the majority of stakeholder groups and thereby promotes mass adoption. The design that succeeds is typically not the most expensive choice (a trait of cutting-edge solutions) for the same reason, and is trustworthy enough to be accepted even by users who are still learning the new technology. Therefore, the prevailing design frequently represents the optimal compromise between rival designs and related concerns. It isn't a completely original design; rather, it results from the synthesis of disparate technical developments that have been incorporated into designs from earlier in the technology cycle, tested, maybe updated, and assessed by users and other stakeholders (Suarez and Utterback, 1995).

It also suggests that it is not feasible to predict a priori which design would ultimately take the lead since a dominant design arises through sociopolitical/institutional dynamics rather than through a selection process of technological determinism. While significant players like major manufacturers can have an impact on the selection process and occasionally even impose their preferred design as dominant (such as IBM's PC), betting on any one particular design is risky for any firm as it can easily find itself locked in a design that fails to achieve dominance and is doomed to fail.

4. Methodology

As we live in a modern and constantly evolving world, new technologies emerge every day, due to rapid rate of innovation, which furthermore enables us to radically innovate existing ones. These factors often lead to emergence of dominant design in specific markets and main objective of this thesis work, as was mentioned before, consists of proposing methodology, which will allow early identification of dominant design in electric charging infrastructure.

This is a once-in-a-lifetime chance to create a worldwide charging and refueling infrastructure for electric vehicles that will last for generations. Considering the importance of the moment and considering investments worth of hundreds of billion dollars by nations worldwide, I believe it is crucial that we get it right.

4.**1 Methodology**

The methodology follows the following steps:

1. Gathering the data regarding 4 main modes of charging and their value chain. Main modes of charging will be grouped as following:
    - Home chargers: Wall-Box
    - Public chargers: Fast charging and Ultrafast charging
    - Battery swap
    - Wireless Power Transfer

2. Quality function deployment principles will be implemented on bases of customer preferences and market attractiveness. These parameters will be weighted in comparison to each mode and competing technology. Most prominent modes of charging methods will be identified in regard to these metrics.

3. Factors affecting the dominance in the market, particularly:

- Governmental regulations and policies
- Technology comparison: Prospects of home charging compered to public charging

will be analyzed.

5. Combination of steps two and three will generate combined weight of possible future dominance by one or multiple modes of charging.

4.2 **Application**

The charging ecosystem is still in its development. Customers will have a wide range of demands as sales of EVs rise and battery ranges expand, ranging from private charging at home and work to public charging while driving and at various destinations. These requirements must be met in the same manner as those relating to the use of gasoline-powered vehicles, in order to be competitive.

4.2.1 Gathering the data regarding 4 main modes of charging and their value chain

Customers' demands en-route and at destinations differ from those at home, where consumers primarily want practical and economical charging gear as well as the ability to check and control their power use. The search for charging stations along the way must be straightforward and convenient, which means customers will require high-speed charging to reduce wait times, a wide and trustworthy network, and simple payment procedures. Users anticipate quick access and pleasant locations and products while charging in a supermarket, retail mall, or sports stadium, for example.

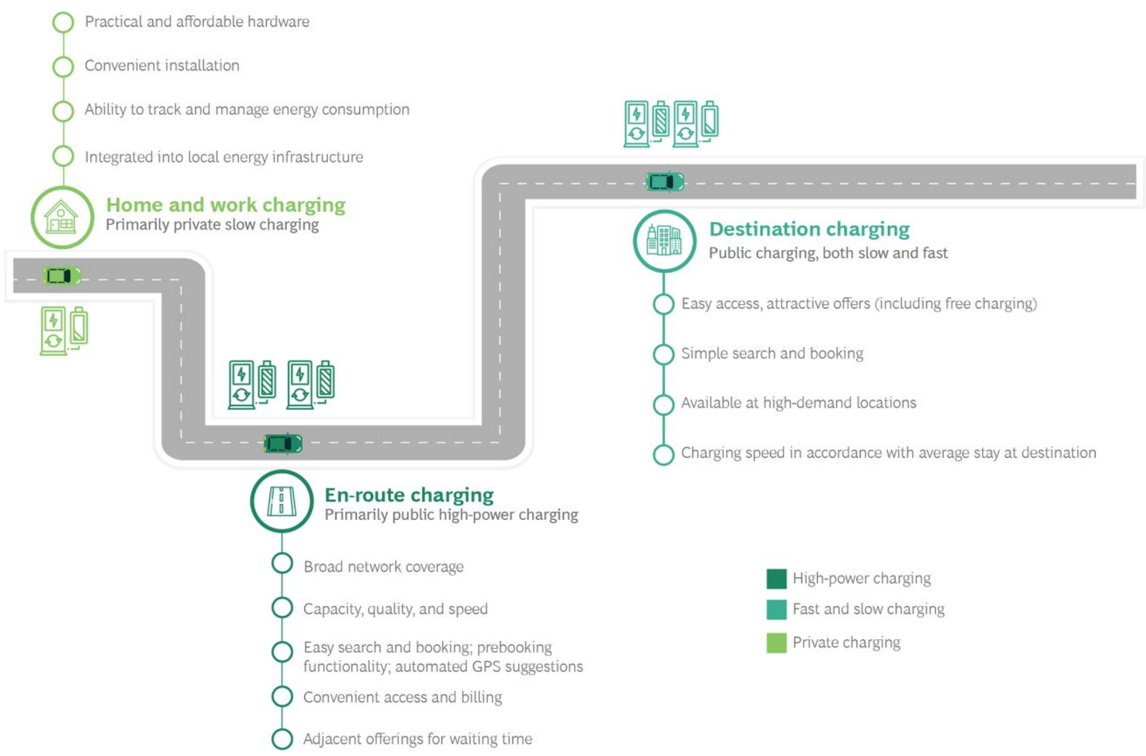


Figure 4.1 Different charging options and customer needs

In order to satisfy these needs of customers, adequate supply chain needs to be created. They will include:

- **Equipment Supply**. Starting from designing, manufacturing and selling DC/AC chargers.
- **Installation and Field Services**. Planning locations and deploying chargers, as well as frequently inspecting, repairing, and cleaning them
- **Site Ownership and Asset Ownership**. Investing in charging stations and places, obtaining power from utilities, and reselling it to end customers at a profit.
- **Charge Point Operation**. The charging points at the stations are being run. Connecting chargers to e-MSPs, tracking charger status, and arranging maintenance are all part of this process.
- **E-Mobility Services**. End-user recharging as well as other connectivity services are provided. Service maps, payment methods, and roaming services are examples of app- or charge-card-based services, where the average consumer can charge at many charging networks with a single charging device.

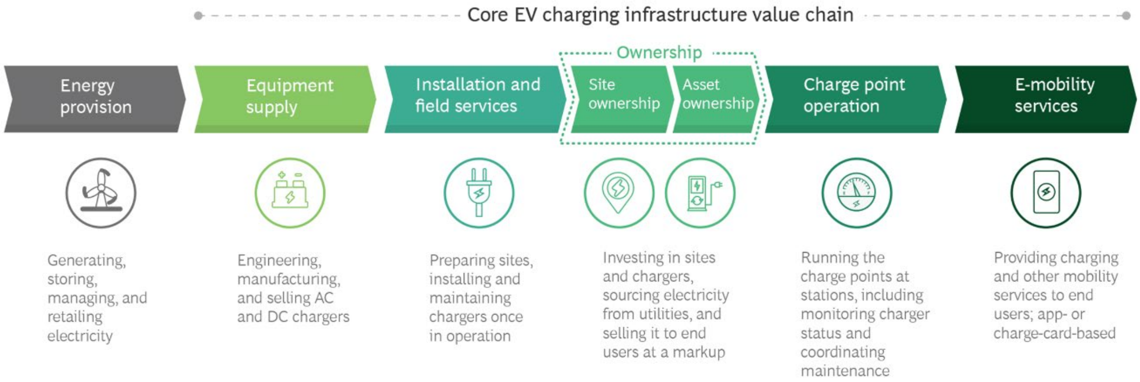


Figure 4.2 Value chain of EV charging infrastructure

Industry is not yet completely structured at this point. Companies from many regions and sectors of the EV industry are coming on board, with a variety of techniques and business models addressing various value chain components.

However, patterns are forming and we can evaluate condensed key strategic moves in the electric vehicle charging value chain from them. Some market players may specialize on a single link in the chain, while others will offer an integrated product in order to gain independence and higher profits. Most business models can be unprofitable at this early stage of market, which is due to low charger use. As a result, entrants must evaluate the advantages of obtaining first-mover advantage against the advantages of waiting for a more financially advantageous time to enter the market.

Important parties in electric charging infrastructure value chain are listed below:

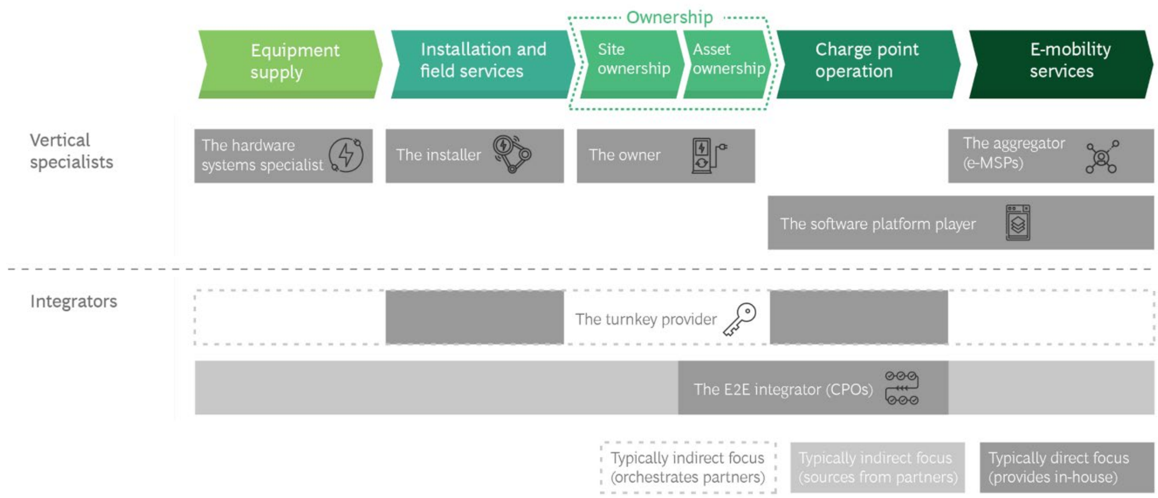


Figure 4.3 Key player in EV value chain

Once data regarding main modes of electric charging infrastructure was obtained, we will evaluate each mode separately regarding 5 parameters:

- Charging time
- Cost
- Availability
- Safety
- Geography

Across the globe when customers of electric vehicles were interviewed about what concerns them or hold back from buying electric car, 4 additional electric vehicle charging infrastructure problems was most concerning to them.

4.2.2 Quality function deployment

First, charging time would be problematic, because as a human beings we are used to petroleum gas stations. As a matter of fact, it would take up to 5 minutes maximum to fill up one's vehicle. Customers obviously would compare these two technologies of fueling the car, expecting similar or close to this time performance. Once they understand that charging electric vehicle might take from 30 minutes in case of ultra-fast charging depending on the car to 12 hours in case of Home charging using Wall-Box. I believe as time goes on and electric vehicles come into our lives and become one part of our life, we will get use to it. Important this is to build things around the public charging stations to get people busy, happy and entertaining.

Secondly, availability of charging stations in broad range of locations and their usability or ease of use would be another concern of customers. As a first-time user of electric vehicle, one inevitably would be thinking about charging options across the country and ones near city. Lack of broad range of charging locations and their lack of interoperability would be one factor stopping this mode of charging infrastructure from flourishing in the future.

Third, cost of charging and installation would be crucial factor in future dominance by one or few modes of charging. One technology that could reach cost effective method of charging and pleasant ecosystem for customers believed to take market dominance.

By the calculations of energy company Enel-x:

“charging an average-sized car at home in order to achieve a range of 100 km costs about €4.00. The cost of driving a gas-fueled car for 100 km is approximately €12.50”

As of today, we can observe petrol cost to skyrocket, due to various reasons and the difference should be even bigger. In the future, as we progress in renewable energy sector and become more efficient, cleaner in producing electricity – compelling factor of clean energy would be big factor to push majority of population to use electric vehicles.

Currently home charging is the most used form of charging for EV owners around the world. Despite constant raise in number of public chargers, electric vehicle owners choose comfort of charging at home and having fully charged car at the morning. Cost savings as mentioned before, play important role in this consideration.

Due to the specifications of home charging, various safety precautions must be put in place to prevent unfortunate accidents. It is critical that at-home electric vehicle supply equipment provide the highest level of protection when charging, both for the device and for anybody using it. The equipment must be protected against the risk of a possible fire, possible electric shock contact and even hand burns due to overheating by using the appropriate charging protection. Same can be said about public charging points and their maintenance.

Lastly, geography was chosen as an indicator of broad global applicability of specific technology. Main players in field of electric charging infrastructure have been selected as main focus points, including: China, EU and North America. Every aspect of considered charging technologies was analyzed according to room for improvement, possibility of scaling up and vertical markets value in particular geographical locations. Overall sum of results was given a weight from 1-5, 5 being most favorable to become dominant design.

After the analysis of every mode of charging with respect to given parameters, weights ranging from 1 to 5 was calculated to each of them. 1 being least favorable to given requirement and 5 being most favorable. At the end all the respective weights were summed up to identify most favorable technological cluster with respect to identified requirements.

VoC / Technology	Charging time	Description
Home charger: Wall-Box [22-43 kW]	3	With respect to Home charging, time to fully recharge average electric vehicle would take approximately 6 to 8 hours with the Wall-Box. Taking into consideration that owners of Evs often charge their vehicles overnight, this is sufficient enough and future improvements would bring that time even lower.
Fast charging [20-60 kW]	2	Currently most public chargers being fast charging, accounting from 20 to 60 kW of power. Charging time with respect to average electric car would require one and a half to two hours. Additional to long time of charging, they often do not provide extra activities around them to keep customers busy.
Ultrafast charging [60-350 kW]	4	Ultrafast chargers become more and more popular as sales of electric vehicles rise. Average charging time would be from 20 minutes to one hour depending on a car. They often designed around malls or some kind of playgrounds, where customers do some productive work while charging their vehicles.
Battery swap	4	Infrastructure in segment of battery swapping is popular with scooters and LDVs in China particularly. Charging time would be as fast as Ultrafast charging, taking into consideration future developments.
Wireless Power Transfer	2	Wireless power transfer currently being the least deployed infrastructure in the market, it was difficult to estimate exact time to charge an average electric car, nonetheless at our best estimates it would take as long as Home chargers - at 20 to 25 kW output power.

Table 4.1 Charging technologies weighted on their charging time

VoC / Technology	Availability	Description
Home charger: Wall-Box [22-43 kW]	4	Majority of electric charging nowadays, takes place at home. Every electric car owner that has a home to charge, has such an opportunity. However, most metropolitan cities do not provide such an opportunity due to lack of charging infrastructure at multi layered buildings.
Fast charging [20-60 kW]	3	Global count of electric fast chargers was 1.5 million at the end of year 2021. China accounting almost more than half of that amount. Nevertheless, car to public charging station remains still low.
Ultrafast charging [60-350 kW]	2	Compered to fast charging, superfast or ultrafast charging infrastructure still much behind in global account. Approximately half a million units of charging stations was deployed at the end of 2021.
Battery swap	1	Battery changing stations remains a niche market, not globally applicable because of various factors. Total number of battery swapping station accounts to be approximately between 4,000 to 6,000 units globally.
Wireless Power Transfer	1	Inductive charging or wireless power transfer technologies remains to be at its infancy regarding charging electric vehicles. It seems like market is not ready for this type of technology yet.

Table 4.2 Charging technologies weighted on their availability.

VoC / Technology	Cost	Description
Home charger: Wall-Box [22-43 kW]	5	In every part of the world, generally, charging electric vehicle at home would be much cheaper compered to public fast charging. From point of view of cost savings analysis, home charging remains the best option to charge one's car.
Fast charging [20-60 kW]	4	Fast charging other than home charging remains most cost-efficient option to charge you electric vehicle.
Ultrafast charging [60-350 kW]	3	At the moment, due to development on deployment and technology evolvement, ultrafast charging costs more expensive than home charging and fast charging. However, price per kW should come down as scaling up catches up.
Battery swap	1	Lack of battery changing stations, inability to use vertical markets and scaling up issues prevent this technology from being competitive with others ones
Wireless Power Transfer	1	Almost all the new electric cars at the market nowadays, does not have wireless power transfer capabilities. As it seems it will not be popular way of charging big batteries of electric cars in the future.

Table 4.3 Charging technologies weighted on their cost.

VoC / Technology+B3:D7	Safety	Description
Home charger: Wall-Box [22-43 kW]	4	As of today, as was mentioned before majority of electric charging takes place at home. Many regulations and certifications have been introduced to ensure safety of home charging infrastructure installment. This and many more quality suppliers of Wall-Box type charging infrastructure ensured safer environment around the home charging.
Fast charging [20-60 kW]	4	Similarly, to home charging, many regulations and certifications have been introduces to make public charging safer to everyone.
Ultrafast charging [60-350 kW]	4	Ultrafast charging remains one step below when it comes to safety of its charging environment compered to two competing technologies mentioned before. Due to much higher power outputs and relatively new infrastructure.
Battery swap	3	Even though battery swapping technology does not require the driver to physically change or even be there when battery changing process in its way, because battery of the car needs to be constantly changed, this report evaluated safety levels equal to ultrafast charging.
Wireless Power Transfer	1	Due to lack of information concerning safety of WPT method, it was difficult to calculate weight of its safety. Few studies suggest that this mean of charging would be harmful both to battery deterioration and to customers health as well. When it comes to charging big lithium-ion batteries with wireless power transfer mode, one should be aware of possible health problems this method of charging might lead to.

Table 4.4 Charging technologies weighted on their safety

VoC / Technology	Geography	Description
Home charger: Wall-Box [22-43 kW]	3	In aspect of geography, possibility of scaling up and delivering particularly more value in vertical markets was considered as an important factor in calculating the attractiveness of the technology. In places like Japan, South Korea, Germany and others, there are no broad possibilities for charging at home.
Fast charging [20-60 kW]	3	Fast charging, although has little dominance in public charging compered to ultrafast charging, its prospect to scaling up and providing particular value in vertical markets seems not much attractive.
Ultrafast charging [60-350 kW]	4	Contrary to fast charging, this mode seems to be future of public charging infrastructure. More and more new electric car allows charging at high power outputs and deployment possibilities much better than Home charging options.
Battery swap	2	Currently only slightly popular in China, with approximately 5,000 units of battery changing stations, which is not even close to compete with other modes of charging. Future prospects remain at the same level.
Wireless Power Transfer	2	Geographically wireless power transfer would be possible everywhere if technology will evolve and cost of construction roads with WPT will go down considerably. This would also imply governmental interventions and subsidies

Table 4.5 Charging technologies weighted on their geography

VoC / Technology	Charging time	Availability	Cost	Safety	Geography	Total	%
Home charger: Wall-Box [22-43 kW]	3	4	5	4	3	***19***	**27**
Fast charging [20-60 kW]	2	3	4	4	3	***16***	**22**
Ultrafast charging [60-350 kW]	4	2	3	4	4	***17***	**25**
Battery swap	4	1	1	3	2	***11***	**16**
Wireless Power Transfer	2	1	1	1	2	***7***	**10**

Table 4.6 All parameters grouped and their possible dominance % calculated

After careful determinations of weights of each particular parameter with respect to each mode, total number of weights was calculated on bases of given analysis. Further calculations were made to derive % representatives of obtained results. It seems that home charging has an slight advantage compared to public charging infrastructure.

4.2.3 Factors affecting the dominance in the market.

Once second step of our analysis is finished, we will compare home charging and public charging as a common group, most prominent modes of charging in four factors affecting the dominance in the market.

- Governmental regulations and policies to promote charging infrastructure

Demand for public charging would increase as EV markets grow. Nowadays, homes and workplaces are where most EV charging occurs. As with conventional cars, consumers will increasingly demand the same services, ease of use, and autonomy from EVs.

In 2021, there were around 1.9 million charging stations that were open to the public, with a 3rd being fast chargers. In 2021, more than 500 000 chargers were added, surpassing the total quantity of public chargers accessible in 2017. In comparison to 2020's growth rate of 44 percent and pre-pandemic building rates, the number of publicly accessible chargers increased by almost 40 percent in 2021. Between 2015 and 2019, the average yearly growth rate was close to fifty percent. Fast charging climbed by almost fifty percent in 2021 compared to 44 percent in 2020, while slow charging increased by 33 percent as opposed to 46 percent.

China continues to dominate the world in the quantity of publicly accessible chargers. It has more than 80 percent of the fast chargers and more than 50 percent of the slow chargers in the entire planet. This reflects both China's established position as a leader in the EV industry and the features of its heavily populated metropolitan areas.

Well over six times as many slow chargers were deployed in China in 2021 as there were in 2018, or around 700 000 units that were available to the general public. Although, compared to earlier years, growth has been significantly slower during the epidemic. The median yearly growth rate was nearly over 55 % between 2015 and 2020.

In 2021, EU ranked second with over 300,000 slow chargers, an increase of thirty percent annual growth. The Netherlands has the slowest chargers in Europe with over 80,000, followed by France with 50,000, Germany with 45,000, the United Kingdom with 35,000, Italy with 25,000, and Norway and Sweden with just over 12,000 each. The stock of slow chargers in the United States saw the poorest growth among major markets in 2021, rising by only 12% to 92 000 units. It climbed to almost 90 000 in Korea, a rise of about 70%.

Long trips are made easier by publicly available fast chargers. As they are used more frequently, they will make it possible to do longer trips, encourage those who don't have access to private charging to buy an EV, and address range anxiety as a barrier to EV adoption.

Fast charging installations (power rating >22 kW) climbed by over 50% to 470 000 fast chargers in 2021, which is higher than the 44 percent growth in 2020 but slower than the 93 percent high of 2019. Fast charging is being pushed out in China at a quicker rate than slow charging. Fast chargers account for nearly 40% of publicly accessible charging stations in China, far more than in any other significant EV market. Government subsidies and active infrastructure development by public utilities are the driving forces behind the fast deployment of public chargers in China.

The profitability of EV charging enterprises has increased because to legislative limits on power costs, public charging demand from city inhabitants, and an increase in the electrification of taxi, ride-sharing, and logistical fleets.

The greatest EV charging networks in the world are found in China and Europe. In terms of the worldwide EV stock in 2021, their charging networks provided the highest percentages—almost 50 percent in China and 35 percent in Europe. This should not come as a surprise because the acceptance of ZEVs depends on the deployment of charging infrastructure. In order to meet growing consumer demand, charging infrastructure in China and Europe is being improved in areas like standardization, improved charge point performance, wider locational coverage to include rural areas, customer support, and increased flexibility for installing technological advancements like high power chargers. Building intelligent and interconnected EV charging networks is a long-term strategy.

ZEV deployment commitment announcements were notable in 2021. To achieve ZEV goals, an emphasis on deploying suitable, widely accessible charging infrastructure is required. Significant investments in charging infrastructure are needed to keep up with aggressive EV implementation. A well-connected network must be built in more developed EV markets in order to provide EV charging access in developed and rural areas, residences, and important transportation corridors. This requires more advanced EV markets to do more than just increase the number of charging stations to meet rising demand. Access to power and reliable grid connections may be additional impediments in developing and emerging market economies. To maximize ZEVs' ability to reduce emissions, decarbonization of electrical infrastructure is a critical element.

Lessons learned from major ZEV markets show that the concentration of infrastructure tends to be caused by a lack of strategic infrastructure development, either by central government planning or encouraged by policy mechanisms, as well as insufficient coordination among key players, such as different government entities, utilities, building operators, and charge point providers. The availability of land and grid connections, together with supportive building codes, interoperability standards, and effective permits, have all been shown to facilitate infrastructure development in more advanced EV markets. In order to optimize EV network planning, data on mobility patterns may be used to understand charging patterns and behaviors.

China

More than 1.2 million public charging stations, a Forty percent increase from the previous year, China boasts the greatest EV infrastructure network in the world. Ten ministries and commissions provided advice for boosting EV charging infrastructure services in January 2022 as part of China's plans to electrify the country. By 2025, it is mandated that there will be enough charging infrastructure to accommodate more than Twenty million EVs, and that sixty to eighty percent of highway services would have fast charging stations. It is important to focus on developing a well-connected, widely dispersed EV charging network, especially in rural regions and along transportation routes. Currently, Guangdong Province and Shanghai are home to more than seventy percent of all public charging stations.

The government plans to build public charging networks in urban and rural areas, create community charging stations, improve facility maintenance, and increase power availability in order to realize these objectives. China's various provinces provide incentives for EV charging stations. In particular, subsidies targeted at high-quality service stations, high-power charging demonstration projects, and vehicle grid interaction are areas where the central government wants to urge local governments to improve their subsidy programs. It also aims to encourage the use of technology, support for standards, and technological innovation in order to improve battery switching.

The State Planning Commission and the Energy Development Administration, the departments in charge of providing the EV charging infrastructure, released the Viewpoint on Further Enhancing the Service Assurance Capability of EV Charging Infrastructure. This opinion aims to strengthen quality and safety supervision, set up operational subsidy guidelines connected to service quality at the local level, and increase subsidies for new technology. In order to develop more than thousand battery swap stations and create more than 100 000 battery-swappable automobiles, the Ministry of Industry and Information Technology announced pilot programs for battery switching technologies in eleven cities in October 2021.

European Union

The European Union's Smart and Sustainable Mobility Strategy seeks to increase the number of publicly accessible charging stations from the current almost 300,000 to one million by 2025 and three million by 2030. One analysis suggests that in order to fulfill the 2030 objective, expenditures in charging infrastructure of 20 billion euros will be necessary.

In July 2021, the European Commission recommended changing the AFID into the AFIR (Alternative Fuels Infrastructure Regulation) as part of the Fit-for-55 package of proposals. Adoption of the AFIR would impose a uniform and automatic obligation on all member states to achieve the goals established by legally binding legislation without requiring them to incorporate them into national laws. Due to a fragmented approach to EV charging network distribution, the rule also intends to solve concerns with a lack of central coordination of critical charging infrastructure networks and compatibility.

Each light-duty BEV registered in a member state's territory would need to have 1 kW of power output, while each light-duty PHEV would need to have 0.66 kW. Along major road corridors, such as the trans-European transportation network, minimum power and distance goals have also been proposed. The first mandatory minimum power and distance goals for HDVs have been established: every 60 km of the core TEN-T network by 2025, with a power output of at least 1500 kW and 3 600 kW by 2030. Targets for the extensive network are held steady but moved forward to 2030 and 2035 with a maximum distance of hundred km. Furthermore, the AFIF will make 1.5 billion euros available by the end of 2023 for electric rapid charging and hydrogen refueling stations on the TEN-T network as part of the EU Connecting Europe Facility transportation initiative.

The proposal to amend the RED II, which sets a goal to lower the GHG concentration of transport fuels by thirteen percent by 2030, is another significant change in the European Union. In order to encourage the use of electric vehicles, the amendment suggests a brand-new credit system that would enable renewable power providers that offer their energy through public charging stations to gain credits for the electricity that is sold to customers. The strategic plan for charging stations may be strengthened with the use of this clause. The plan also includes opportunities for private charging stations that use regular electricity to include smart charging capabilities, as well as options for mandating vehicle-to-grid functionality depending on evaluations made by individual member states.

Utilizing the 670 billion euro economic stimulus package granted by the European Union, some EU member states dedicated substantial investment to EV charging infrastructure in 2021. The key member states that have requested more funds to expand their EV charging infrastructure networks in 2021 are Belgium, Finland, France, Germany, Ireland, Italy, Spain, and Sweden. Additionally, Sweden announced financing for HDV charging infrastructure along important transportation routes in the amount of SEK 550 million in early 2022. NKL in the Netherlands has created a Roadmap for the installation of an HDV charging network. NKL will be in charge of the Living Lab project that involves evaluating solutions for heavy-duty charging.

- Technology comparison: Prospects of home charging compered to public charging

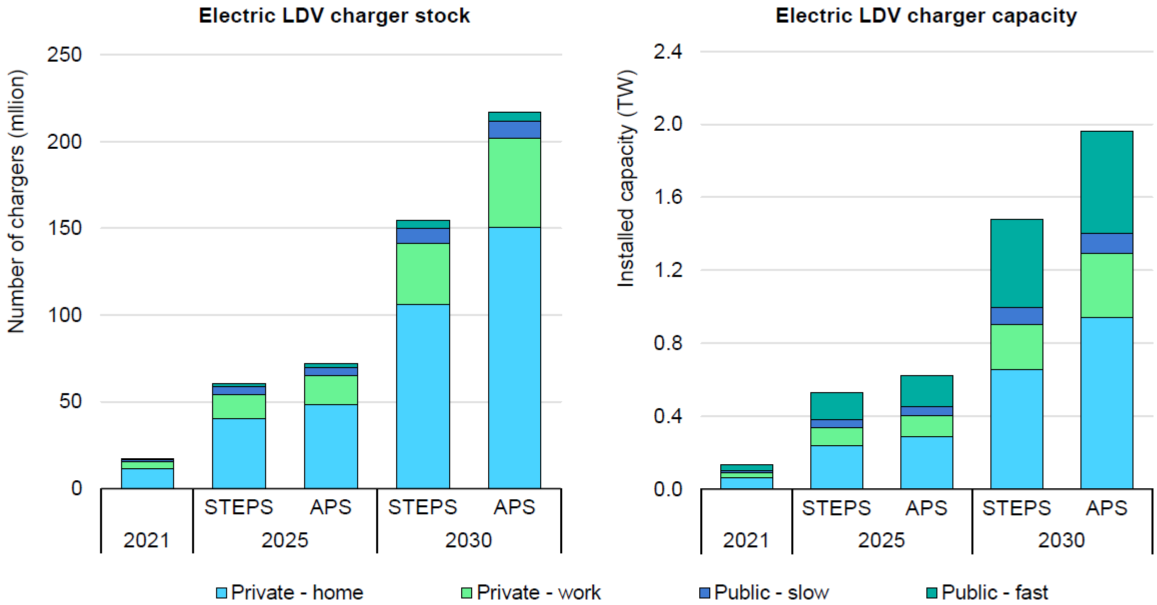


Figure 4.4 Electric LDV chargers and cumulative installed charging power capacity by scenario, 2021-2030

To accommodate the rise of EVs predicted in the Released Pledges Scenario, charging infrastructure must expand more than 12 times by 2030, adding more than 20 million charge stations annually—1.3 times more than have been implemented overall. Electric LDV owners require appropriate access to EVSE.

Private chargers: These are personal chargers that can be found in homes or places of business. They generally have power outputs between 4 kW to 23 kW. The cheapest charging solution may be available since the price of electricity through these chargers is frequently comparable to residential or business prices. With an estimated fifteen million private charging outlets globally, this is now the main method of EV charging. Two- and three-wheelers nearly always utilize personal chargers, which might be as basic as a power outlet.

Public chargers: These are public charging stations that are typically found in metropolitan settings, such as retail malls, parking lots, or other locations, or along transportation corridors. For PLDVs, their power varies from 20 kW to 350 kW. Since infrastructure and power grid expenses must be compensated, public charger power prices are often greater than those for private chargers. Prices often correspond with power rating; according to our estimation, electricity sold by ultra-fast chargers, more than 1230 kW, is priced 40 percent more than that of slow public chargers.

Public charging networks are necessary for EV users lacking access to a home charger and for long-distance trips. Around 2 million public EV charging stations are available right now.

In 2021, there are expected to be sixteen million private LDV charges (including residential and commercial). The vast majority of the infrastructure for charging continues to be made up of a growing number of private stations as EV penetration rises. In all scenarios, private chargers make up 90% of all chargers in 2030, although their installed capacity is closer to 60% due to their lower power rating than public ones. Additionally, by 2030, private chargers supply 330 TWh in the scenario with stated policies and 500 TWh in the scenario with announced pledges, or nearly 65% of the total energy consumption in both scenarios.

Private charging, whether done at home or at the office, is now the most common type of charging. The primary factor influencing private vs public charging behavior is access to home chargers. Since they can take advantage of reduced power costs and are not reliant on a modest, albeit growing, public charging infrastructure, the majority of early adopters of EVs have access to and utilize a home charger as their primary source of charging. For instance, almost 90 percent of EVs in the United States presently have access to domestic charging.

The mix of dwelling types and the age of the structures have a big impact on who has access to residential charging. Residential charger installation is more likely to be a possibility for single-family homes. The infrastructure needed to allow private charging to parking spots is more likely to be present in newer structures. Accessibility to residential charges varies significantly within and between nations as well as between different demographic segments. For instance, in the US, access to home charging is available to seventy percent of detached, one-unit residences, compared to ten to twenty percent of rental apartments. However, only around 40% of families in China have access to domestic parking, and even fewer have access to a charger. This is typical in locations where the bulk of residents live in multi-unit buildings with a dearth of parking spaces. Even EV users who have access to a home charger only satisfy fifty percent of their charging demand at home, which is a significant divergence in charging behavior from China's lower availability to residential chargers. This can be explained by China's readily available public charging infrastructure and competitive pricing.

It is predicted that between fifty percent and sixty percent of all automobiles are owned by homes with access to residential charging in Europe and the US, given the present distribution of dwelling types and vehicle ownership. The comparable figure is less than forty percent in China. According to the research, fewer than 15% of the current automobile stock will be electrified by 2030. Therefore, it is plausible that the majority of EV users will still have access to a domestic charger in 2030.

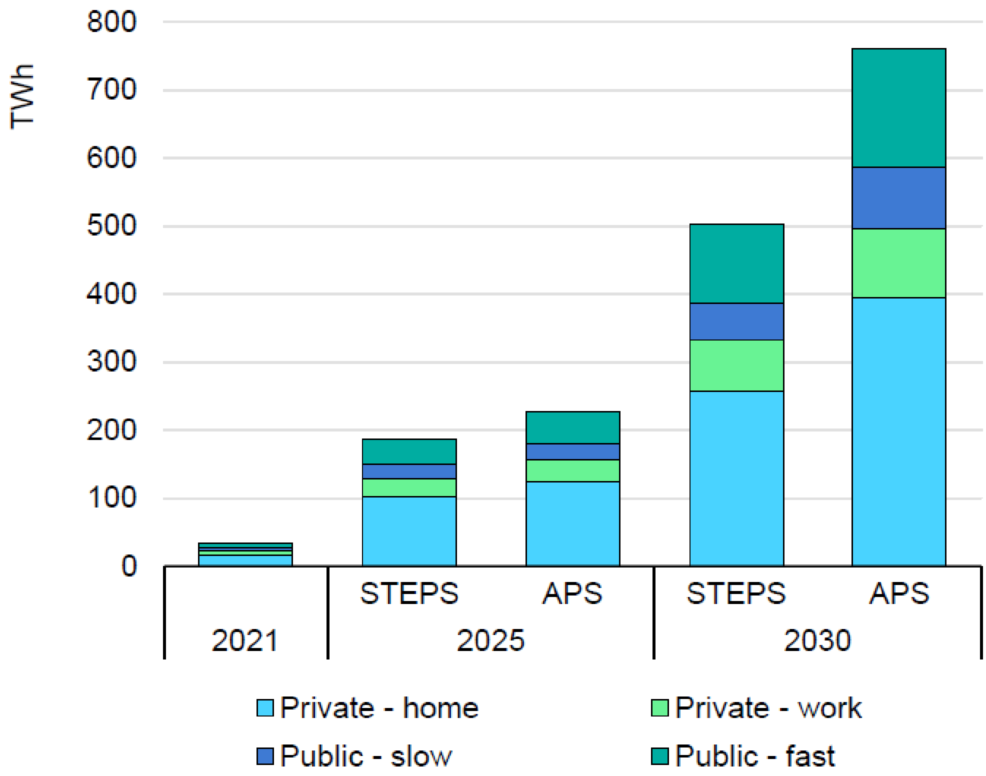


Figure 4.5 Electricity demand by charger type and scenario, 2021-2030

Conclusion

Analyzing all the data from QFD customer preferences to the factors affecting the dominance in the future 10 year in electric charging infrastructure, Wall-Box type of home charging technology seems to be dominant in term of delivering particularly more value in vertical markets and has more room to scaling up.

Moreover, public charging infrastructure is right after home charging technology remains to be semi-dominant. As geographically not every EV owner will have an option of home charging, furthermore even those who has such an option, will inevitably need public charging.

On the other hand, battery swapping stations and wireless power transfer technologies seem to have little to no future market dominance in terms of scaling up the production and delivering more value in vertical value chain.

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