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# ENERGY AND COST EFFICIENT ELECTRIC VEHICLE CHARGING SOLUTIONS FOR RESIDENTIAL AND COMMERCIAL BUILDINGS

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# ABSTRACT

Anna Saarenhovi: Energy and cost efficient electric vehicle charging solutions for residential and commercial buildings
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The demand for charging electric vehicles in residential and commercial buildings grows as the number of electric vehicles increases. In October 2020, the Parliament of Finland agreed on a new law requiring every condominium and non-residential property to invest in electric vehicle charging by 2025 if the site undergoes extensive renovation work or a completely new site is built. This new law is expected to add tens of thousands of new electric vehicle charging points to Finland. There are several of energy- and cost-effective charging solutions for consumers, housing associations, and businesses available in the market. The challenge is to understand what to choose, where, and why.

The objective of this thesis is to clarify which features make an electric vehicle charging system energy and cost-efficient. This work focuses on residential and commercial properties as multi-device systems will primarily be the ones to challenge local electrical systems and the carrying capacity of a low-voltage network. As a preliminary review for the empirical part, the theoretical part focused on the existing charging technology, requirements, and the Finnish market conditions. The work also sought to clarify how much different energy and cost-efficient charging systems cost and what creates the largest cost-share in the investment.

The results of the study show that factors affecting energy and cost efficiency include the age of the building, the heating system and the state of the electrical system, the available charging capacity, the system size, load management, smart charging, and the choice of charging device. It is challenging to assess the effectiveness of the factors in relation to each other, as all the identified elements affect the solution's energy and cost-efficiency in one way or another. However, differences in factors affecting energy and cost efficiency could be observed between residential and commercial properties. Another significant finding of the work is that the larger the system, the lower the investment costs per installed kilowatt usually are.

There is no detailed description of an ideal charging system. The solution's content should always be customized to suit the needs of the property and the user. Significant improvements in energy and cost efficiency optimization could likely have been achieved by selecting pilot sites and with a building-specific approach. Also, the work focused on finding solutions from a very theoretical point of view, so practical calculations of efficiency improvements could have added value, especially from a business point of view.

To conclude, this thesis provides a valuable preview on energy and cost-efficient charging systems for consumers, housing associations, and businesses interested in investing in a new charging system. In order to achieve a more comprehensive overview of the efficiency and cost of charging systems, further studies could not only look into investment costs but also system maintenance costs.

Keywords: Electric vehicle charging, charging system, energy-efficiency, cost-efficiency

# TIIVISTELMÄ

Anna Saarenhovi: Asuinrakennusten ja kaupallisten kohteiden energia- ja kustannustehokkaat latausratkaisut
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Sähköautojen latauksen tarve taloyhtiöissä ja kaupallisissa kohteissa kasvaa sähköautojen määrän kasvaessa. Eduskunta hyväksyi lokakuussa 2020 uuden lain, jonka mukaan jokaisen uuden asuinrakennuksen ja yrityksen on investoitava sähköauton latausvalmiuteen tai sähköauton latauspisteisiin vuoteen 2025 mennessä, mikäli kohteessa tehdään kattavat peruskorjaus työt tai mikäli kyseessä on täysin uusi kohde. Tämän uuden lain odotetaan lisäävän kymmeniä tuhansia uusia sähköautonlatauspisteitä Suomeen. Markkinat tarjoavat useita energia- ja kustannustehokkaita latausratkaisuja kuluttajille, taloyhtiöille ja yrityksille. Haasteena onkin ymmärtää, mitä valita, minne ja miksi.

Tämän tutkimuksen tavoitteena on selvittää, mitkä ominaisuudet tekevät sähköauton latausjärjestelmästä energia- ja kustannustehokkaan. Työ keskittyy taloyhtiöihin ja kaupallisiin kohteisiin, sillä ensisijaisesti usean latauslaitteen järjestelmät tulevat haastamaan paikalliset sähköjärjestelmät ja pienjänniteverkon kantokyvyn. Esiselvityksenä tutkimukselle teoriaosuudessa keskityttiin olemassa olevaan latausteknologiaan, vaatimuksiin ja Suomen markkinatilanteeseen. Lisäksi työ pyrki selkeyttämään, kuinka paljon erilaiset energia- ja kustannustehokkaat latausjärjestelmät kustantavat ja mikä investoinnissa on usein kalleinta.

Tutkimuksen tulokseksi saatiin, että energia- ja kustannustehokkuuteen vaikuttaviin tekijöihin lukeutuvat rakennuksen ikä, lämmitysjärjestelmä sekä sähköjärjestelmän tila, saatavilla oleva latauskapasiteetti, järjestelmän koko, kuormanhallinta, älykäs lataus ja latauslaitteen valinta. Tekijöiden voimakkuutta suhteessa toisiinsa on haastavaa arvioida, sillä kaikki tunnistetut elementit vaikuttavat tavalla tai toisella ratkaisun energia- ja kustannustehokkuuteen. Eroja energia- ja kustannustehokkuuteen vaikuttavissa tekijöissä voitiin kuitenkin havaita asuinrakennusten ja kaupallisten kohteiden välillä. Toinen työn merkittävä löytö oli, että investointikustannusten havaittiin laskevan asennettua kilowattia kohden, mitä suuremmasta järjestelmästä on kyse.

Ideaalille latausjärjestelmälle ei ole yksiselitteistä kuvausta ja latausratkaisun sisältö tulee aina kustomoida kohteen ja käyttäjän tarpeiden mukaiseksi. On todennäköistä, että merkittäviä parannuksia energia- ja kustannustehokkuuden optimoimiseen oltaisiin voitu saavuttaa valitsemalla pilottikohteet, joille oltaisiin rakennuskohtaisesti lähdetty etsimään optimaalista latausratkaisua. Lisäksi työ keskittyi hakemaan ratkaisuja hyvin teoreettiselta kannalta, joten käytännön laskelmat tehokkuuden parantamisesta olisivat voineet tuoda lisäarvoa erityisesti asiantuntijanäkökulmasta katsottuna.

Lopuksi voidaan todeta, että tämä opinnäytetyö tarjoaa arvokkaan esikatsauksen energia- ja kustannustehokkaisiin latausjärjestelmiin kuluttajille, taloyhtiöille ja yrityksille, jotka ovat kiinnostuneita investoimaan uuteen latausjärjestelmään. Jotta saavutettaisiin kokonaisvaltaisempi katsaus latausjärjestelmien tehokkuuteen ja kustannuksiin, voisi jatkotutkimuksissa tarkastella investointikustannusten lisäksi myös järjestelmän ylläpitokustannuksia tai vertailla latausjärjestelmän infrastruktuurin vaatimuksia ja kustannuksia uudiskohteiden ja vanhojen rakennusten kesken.

Avainsanat: Sähköauton lataus, latausjärjestelmä, energiatehokkuus, kustannustehokkuus

# PREFACE

This Master's Thesis was done for the Consumer Solutions Procurement department in Fortum Power and Heat Oy. I want to sincerely thank my team and all colleagues who supported me and shared their expertise during the process. Special thanks to Pasi Kaukojärvi for offering me the opportunity to write my Master's Thesis in the team and providing me with this interesting topic, Pekka Akin for being my Fortum-side supervisor and Jaakko Eklund for helping me with cost information data collection.

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Helsingissä 12th February 2021

Anna Saarenhovi

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# SYMBOLS AND ABBREVIATION

| | |
|---|---|
| AC | Alternating Current |
| BEV | Battery Electric Vehicle |
| CCS | Combined Charging System |
| CHAdeMO | CHArge de MOve |
| CPO | Charge Point Operator |
| DC | Direct Current |
| DLM | Dynamic Load Management |
| DSO | Distribution System Operator |
| EMSP | E-Mobility Service Provider |
| ESI | Energy Service Interface |
| EU | European Union |
| EV | Electric Vehicle |
| HEV | Hybrid Electric Vehicle |
| OCHP | Open Clearing House Protocol |
| OCPI | Open Charge Point Interface |
| OCPP | Open Charge Point Protocol |
| OICP | Open Intercharge Protocol |
| OpenADR | Open Automated Demand Respond |
| OSCP | Open Smart Charging Protocol |
| PHEV | Plug-in Hybrid Vehicle |
| RCD | Residual Current Device |
| RFID | Radio Frequency Identification |
| V2G | Vehicle-to-grid |

# 1. INTRODUCTION

The disadvantages of burning fossil fuels like coal have been known for centuries. Despite this fact, people have begun to understand that fossil fuels in transportation have to be replaced by climate-friendly fuels like renewable biofuels and electricity. It is impossible to reduce greenhouse gasses resulting from road transportation if fossil fuels like gasoline are still used actively. Reducing the use of fossil fuels in transportation and improving vehicles' fuel-efficiency have been seen as a short-term solution to making progress. In the long-term, the aim is to speed up the transition to plug-in hybrid electric vehicles and battery electric vehicles that are seen less pollutant and more fuel-efficient options. [1, 2] The change towards an emission-free nation has begun in Finland, and it is the government's obligation to maintain and speed up the diffusion rates of emission-free mobility. [3]

In Finland, over 90 % of national transport emissions originate from road transportation. [3, 4] According to the Government Program, Finland will be carbon neutral by 2035, and transport emission reduction targets must meet this goal. [5] The national goal is to halve emissions from domestic transport by 2030 compared to the level of the year 2005 [6]. As the greenhouse gas emissions from domestic transport in 2005 were about 12.7 million tonnes, the total emissions in 2030 should be only about 6.35 million tonnes. [3, 6] Transport emissions must therefore be significantly reduced in order to reach the target.

The use of electricity as a driving force for transport is snowballing both in Finland and worldwide. [7, 8] This is one of the most crucial transportation system changing megatrends. Because Finland is a sparsely populated country and a car is an essential means of transportation for many people, the transition towards emission-free vehicle options must be comfortable as well as accessible and happen efficiently for Finland to meet its' targets in time. The most significant emission reduction potential for electricity relates to battery electric vehicles that can replace longer trips with conventional internal combustion engines. [3]

One of the influencing factors in the transition to e-mobility is how developed the charging infrastructure that supports electric vehicle motoring is. [9] So far, the charging network's growth has lagged, and it has been considered whether electric vehicle motorists will end up queueing at charging stations [10]. Today, more than 90% of electric car charging is done at home and work [3]. Therefore, condominiums and commercial buildings could become a bottleneck in the transition to e-mobility [10]. It would be necessary for each electric vehicle to have its own charging point at home or work, emphasizing the critical role of housing associations in the electrification of transport. Large-scale home charging during quiet consumption would facilitate system functionality from the point of view of electricity generation.

Combating climate change and transitioning towards electric mobility is also an opportunity in many ways. Measures to combat climate change in the transportation sector can be planned and implemented so that the entire transportation system becomes not only fossil-free and more energy-efficient but also healthier, more cost-effective, and affordable for the users [3].

In October 2020 Finnish Parliament approved a law that will significantly increase the number of residential and commercial charging points. It is estimated that the new law will create approximately 73,000 – 97,000 charging points and charging readiness for 560,000-620,000 parking spaces by 2030. [11] The underlying question is how scaling up charging in residential and commercial locations should be implemented to meet the needs of growing demand and be both energy and cost-efficient for all parties involved.

The purpose of this Master’s Thesis is to elucidate what makes a charging solution energy and cost-efficient in residential and commercial locations. The study aims to seek factors that affect the efficiency and answer how strong influence these factors have. To understand what a charging system consists of first, one must know what kind of technical solutions there are on a global level. As the context of this research is Finland, national regulations, policies, incentives, and market conditions must be taken into account and investigated. Together, these two entities create a base for this study's primary purpose. To understand how costs are incurred and divided in a vehicle charging project, the study is concluded with a cost analysis that examines costs of now previously delivered electric vehicle charging solutions.

With the purpose of understanding how energy and cost efficient charging solution is constructed, this text aims to answer following questions:

Q1: What different electric vehicle charging technology and solutions exist globally?

Q2: What is the state of Finnish electric vehicle market and charger and what kind of policies and incentives have been implemented in the Finnish electric vehicle market?

Q3: Which elements make electric vehicle charging solution cost and energy efficient in examined locations in Finland and how?

Q4: How much are the system costs for an efficient electric vehicle charging solution for residential and commercial buildings?

The research strategy uses a literature review, interview research and cost analysis. The literature review creates a theoretical base for the research, which is used in the empirical part. The interview survey is conducted as individual expert interviews. The conduct of the interview survey is discusses in more detail in the section 4.3 and the cost analysis in 4.5. In the literary review Tampere University's information retrieval portal Andor was used to support research. Searching for sources was performed by specifying search queries to help find a wide variety of information under each topic. Perceived sources were also used to search suitable publications in their source list. The purpose of the literary review was to increase researcher's understanding and knowledge on the research topic before conducting empirical research.

Among other countries, also in Finland electric vehicle charging is typically divided into private, semi-public and public charging. Fortum, the collaborative partner of this Master's Thesis, divested its public charging points and charging operations in April 2020. Today, Fortum focuses on electric vehicle charging projects delivered specifically to private and semi-public locations. As the focus of the company business is on residential and commercial properties, this study concentrates on these types of locations. The choice of target locations was also influenced by number of charging devices. This study focuses on properties where demand for charging devices is usually more than one and therefore charging solutions for detached houses are not included in the work. The outline was made as it was seen that adding a single charging device to a buildings electrical system often does not require special modifications or pose challenges system-wise. Residential and multi-dwelling buildings in particular can become a bottleneck for development of e-mobility and for that reason it is important to build a system that can withstand a larger number of electric vehicles charging simultaneously.

Chapters 2 and 3 focus on theory. The first theorical part, chapter 2, explores charging solutions from a technology perspective. This chapter examines the different charging modes, power levels, plug options, standards and communication protocols. Moreover, second chapter also takes a closer look at smart charging and the features it enables in electric vehicle charging. Chapter 3, the second theoretical part of the thesis, delves into the Finnish electric vehicle and charger market, guidelines, regulations, policies and incentives. Chapter 4 describes in more detail the implementation of the research and collection as well as analysis of used data. Chapter 5 summarizes the results of the interviews, presents a cost estimate for an electric vehicle charging solution for residential and commercial site and covers discussion. Chapter 6 presents conclusions of the study. The question frame for the interviews and Excel files used in making the cost estimates are collected in the appendices. In general, the study is divided into a literature review (chapters 2-3), an empirical research and results (chapters 4-5) and conclusion of the study (chapter 6).

# 2. ELECTRIC VEHICLE CHARGING TECHNOLOGY

In this chapter, global markets, electric vehicle charging technology, charging power levels, modes, and charging standards are reviewed. This chapter aims to provide an overall understanding of development trends and requirements of electric vehicle charging on a global level.

## 2.1 Global market

According to the International Energy Agency, the number of electric cars increased to 7.2 million in 2019. Around 2.6 % of global car sales accounted for electric vehicle sales in 2019, and by the end of the year, 1 % of global car stock consisted of vehicles that run on electricity. Today, at least 20 countries have reached a market share above 1 % in vehicle markets. [7]

As electric vehicle markets are growing in multiple countries, also the infrastructure for electric vehicle charging is expanding. There were 7.3 million chargers worldwide in 2019, 6.5 million being in private use and 0.8 million for public use. Like most electric vehicles, most public chargers are located in China, especially in locations with a high population density. Around 600,000 public chargers are categorized as slow chargers and 200,000 as fast chargers. China is the front runner in fast charging as the vast majority of fast chargers are located in the country because of the high demand in dense urban areas where private charging is not possible. [7] In figures 1 and 2, distribution between countries for private and public slow chargers are illustrated.

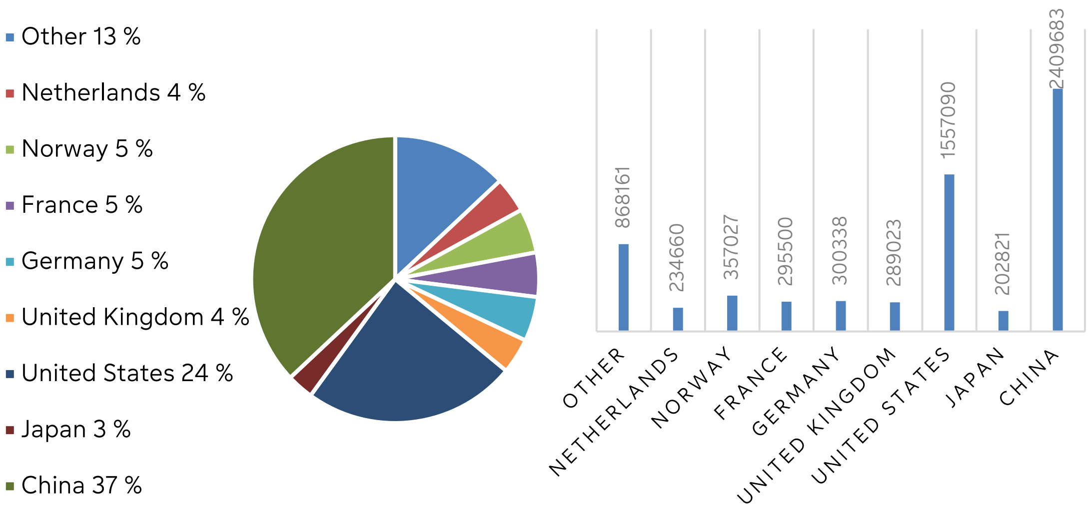


**Figure 1.** Distribution of global private slow chargers [7]

As shown in Figure 1 and the doughnut chart, China holds the most considerable amount of global private slow chargers by having over 2.4 million devices used today. The United States is ranked second by possessing almost a quarter of all private chargers with over 1.5 million devices. In Europe, leaders are Norway, France, and Germany that all have a 5 % share of all private charging devices. [7]

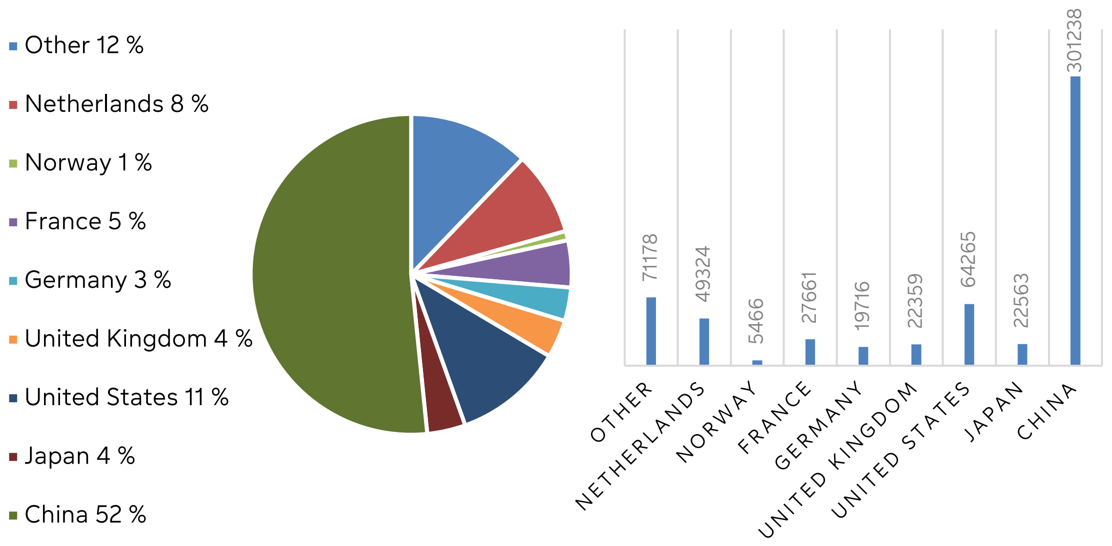


***Figure 2.*** *Distribution of global public slow chargers* [7]

Figure 2 presents how also in public slow chargers, China leads the way by possessing over half of the global 301 238 public slow chargers. The United States comes second also in this category by having an 11 % share of ownerships with 64 000 slow charging devices.

Even though car sales collapsed in Europe due to the global pandemic, electric vehicles' sales grew significantly, and so the charging infrastructure too. In 2020 there are nearly 200,000 public charging points in Europe, of which 20,000 are fast chargers with higher power output than 22 kW. There is a clear preference for slow alternating current chargers, but the rapid charging infrastructure is continuously growing. Most fast charge points are located in the Netherlands, Germany, and Switzerland. Currently, there are seven electric vehicles per one public charging point in Europe, and as the charging infrastructure is continuously developing and the charging network is already dense enough, it is not a problem for Europeans to own an electric vehicle anymore. [12] According to Transport & Environment, 3 million new public charging points will be needed by 2030 for the estimated growing number of electric vehicles. In other words, it means that the infrastructure will need to grow 15 times larger than it is today in Europe [13]. For now, remarkable market leaders in e-mobility are Norway, Sweden and The Netherlands [14].

Many parties in e-mobility affect the flexibility and market adoption of electric vehicle charging. Current roles including charger and vehicle manufacturers, charge point operators (CPO), roaming operators, electric mobility service providers (EMSP) and end-users as well as energy market players like distribution system operators (DSO), electricity retailers, aggregators, and energy companies will all have to adapt to electric vehicle charging market situations as new guidelines and requirements for charging are introduced continuously to different stakeholders. [15] In addition to charger manufacturers, CPOs and EMSPs are actors that are influencing the e-mobility field, and that is why it is essential to clarify the roles, duties, and responsibilities of these players. According to Virta, a Charge Point Operator is an organization that operates a pool of charging points and stations [16]. CPO delivers value by connecting intelligent charging stations to Electric Mobility Service Providers. A CPO is in charge of, In turn, Electric Mobility Service Providers are organizations that offer electric vehicle services to electric vehicle drivers. An EMSP delivers value to the user by enabling access to many charging points and enables drivers to find charging points, start charging sessions and invoice them automatically with various methods. Ownership of equipment therefore, usually belongs to an EMSP. [16]

Trends that are seen to change the industry permanently are direct current (DC) fast charging, green electric vehicle charging, vehicle-to-grid technology, reward programs, and predicting charge time accurately. [17, 18] Even though fast chargers create only a quarter of public electric vehicle chargers, it has been seen that the numbers are growing, and DC chargers and several electric vehicle charging network operators are already focusing on mode four charging (introduced in paragraph 2.3). [7, 19] Technological development of electric vehicle charging hardware and software will have an impact on electric vehicle users' charging preferences and how they use charging applications. Today charging stations can determine exact charging times for electrified vehicles even before plugging the car into the charging station. Time prediction is crucial, especially when planning trips and building charging schedules. [17, 20] It even plays a role in green charging features as scheduling charging enables users to charge when renewable energy is available.

Green charging is applicable both in residential and public charging spaces. It is closely connected to smart charging technology and scheduling of charging to the times when general power consumption is lower or when there is climate-friendly energy available. [21] While green electric vehicle charging focuses on charging from the emission-free energy sources, V2G technology aims to solve problems regarding power demand peaks, frequency regulation, and increasing renewable energy storage capacity. According to the Finnish Ministry of Transport and Communications, an average passenger vehicle is parked around 95 % of the time [22]. V2G technology exploits that. Whenever a vehicle is parked or not charging, the electric vehicle driver can leave their car plugged in to let the charger draw power from the vehicle and feed it back to the grid. With V2G technology, electric vehicles can be included in the energy reserves for the times when power demand is high. [23] However, to have consumers act as desired, firm guidance and reward programs are needed. [9] Reward programs can be approached from several perspectives. For example, electric vehicle owners can receive rewards for charging when electricity demand is low or get rewards using the same operator’s charging station and network repeatedly like in a traditional petrol station refueling model. Nevertheless, the trends mentioned above go hand in hand by allowing each other to develop and exist.

Today many companies provide e-mobility goods, either or both services and products. As there are many companies in the industry, there are few market leaders and key players in the field too. It is difficult to determine the critical performance indexes when measuring the performance of a business in such a broad field as the electric vehicle charging business is. Nevertheless, few companies have earned their ‘place on a pedestal’ in the market. Those who have a strong customer base are better market position than others who are just joining the e-mobility business.

Significant market player ABB has made large investments in power generation gear over the last years. Currently, ABB is offering hardware solutions for private and public charging. Another market leader is BP, a British charge point operator who is slowly becoming one of the largest charging point providers in the United Kingdom. [19] Also, Dutch-British oil leader Shell has adapted to the changing vehicle and transportation industry. Shell has more than 30,000 charging points across Europe as it acquired an electric vehicle charging specialist New Motion in 2017. Shell also launched the first 150 kW rapid charger in the UK, and it has announced its goals to grow electric vehicle fast-charging infrastructure in Germany. The United States-based ChargePoint claims to provide the largest electric vehicle charging station network globally. Today it has around 113,500 charging points available for users in the US, Mexico, Australia, and Canada. ChargePoint’s goal and commitment are to deploy 2.5 M charging points by 2025. [19] Other noteworthy leading companies in the electric vehicle charging field are Schneider Electric, Eaton, Tesla Motors, and Webasto. [19, 24]

## 2.2 Charging levels

Charger power level is one of the main parameters that affect charging time, cost, and equipment needs. [25] The dividing of charging infrastructure and charging equipment into different levels is commonly used in North America. However, identifying different categories of power output is used worldwide even though the description and content of the categories and levels change depending on the area, country, and party acting as the definitor. There are three major categories for chargers' power output: normal, medium, and high power chargers [25]. These are also referred to levels 1, 2 and 3 of charging [25, 26]. The following definitions and power output levels follow European regulations regarding electric systems and current supply.

**Normal charging**, also called slow charging, is rated with power that is 3.7 kW or less and is mostly used in residential locations and when parking vehicles for more extended periods. The connection is through the one-phase alternating current with 10-16 amps. [25] Normal charging in domestic applications is also referred to **as level 1** charging in North America. In the United States, level 1 charging is limited to 120 V, limiting the charging power output to 1.4 kW. [26] The residential charging has two modes, mode 1 and 2, that are discussed more in section 2.3.1.

**Medium power** from 3.7-22 kW, also known as quick or semi-fast charging, is used both in private and public electric vehicle charging locations. It is either with one- or tri-phased electric power, and the maximum current is between 16-32 amps. [25] Medium power charging and chargers are referred to as AC **level 2** charging in Northern America. [26] Level 2 charging infrastructure can be found in workplaces and shopping malls [27]. The equipment in level to is compatible with all electric vehicles and plug-in hybrid vehicles.

**High power** charging, fast or rapid charging, has higher rated power than 22 kW, mainly used in public locations. In fast charging, the energy transfer happens through direct current, and it can provide 80 % charge in less than an hour. However, it has been noticed that arctic weather conditions can lengthen the required charge time. [16] High power charging is also called **level 3** of charging. [26] The level 3 charging infrastructure can be found from petrol stations and next to highways where ultra-fast charging is needed most often. There is one mode for level 3 charging, that is Mode 4, and it is covered in section 2.3.4. There are specific needs in charging plugs to support the high voltage and current when charging at level 3.

## 2.3 Charging modes

Electric vehicle charging systems can be divided into “off-board and on-board types with unidirectional or bidirectional power flow” [25]. In bidirectional charging, the system supports energy flow back to the grid from the vehicle’s battery, whereas in unidirectional, the charging limits requirements for equipment and simplifies interconnections issues. [25]

A charging system located inside the vehicle converts the alternating current from the grid to direct current that is then supplied to the battery [28]. The system enables charging anywhere an adequate power source is available. On-board chargers often have limited power capacity because of the weight, the space they need, and the costs of these kinds of systems in their entirety. However, the availability and continuously developing fast-charging infrastructure has reduced the need for on-board chargers and their energy storage requirements as in off-board charging, the converting takes place in the charging station itself. [25, 28] Because the converting technology is still bulky, fast and rapid charging stations are often heavy and large. By locating the charger off-board into a charging station, the vehicle becomes smaller, lighter, and more affordable. [28]

Charging equipment for electric vehicles plays an essential part in grid integration and electric vehicles' everyday use. The charging system typically includes a charging cord, a stand, a plug, power outlet, vehicle connector, and protection system. The system's configuration varies depending on the country, frequency, voltage, electrical grid connection, and standards. Charging time and even the lifetime of an electric vehicle are both linked to the features of the battery and the charger. In other words, the used charger must guarantee a safe charging of the battery. Suitable, safe, and good charger ought to be energy and cost-efficient, reliable, and has high power density, low volume, and weight. [25]

European standards are necessary to ensure convenient charging solutions EU-widely. A multiplicity of adaptors needs to be avoided and usually leads to retrofit costs. European Commission issued a standardization mandate to European standardization bodies CEN, CENELEC, and ETSI regarding electric vehicle charging in 2000. The mandate emphasizes the need for interoperable charging equipment to promote and develop the internal market for electric vehicles and to remove market barriers. However, the mandate was only promoting interoperability, not adopting a single connector or choice of a charger. Following the new regulations, two types of connectors were assessed as suitable for the European market. The choice between these two was left to the market and depend on the different national regulations.[25]

Today, one standard that deals with charging systems as a whole is multi-parted IEC 61851. When designing an electric power network for charging electric vehicles, including chargeable plug-in hybrid electric vehicles and light electric vehicles, the system must comply with the basic requirements of low voltage installation standards according to the IEC 6000 standard -series. In the IEC 6000-7-722, standard are special requirements for installations considering electric vehicle charging described more closely. The IEC 62196 is a series of international standards that define requirements and features for specifically plugs, socket-outlets, vehicle connectors, and vehicle inlets for conductive charging of electric vehicles. Electric vehicles can also be charged wirelessly by transferring energy inductively to a vehicle [29, 25]. As inductive charging has not yet been implemented in electric vehicles by industry, it has been excluded from the review and this Master's Thesis.

Standards IEC 61851 and IEC 62196 categorize electric vehicle charging into four different modes and specify different characteristics from both the charging point's and electric vehicles' points of view. By classifying charging into four modes, it is easier to recognize what kind of electrical characteristics are required and the charging period and charging activity for different types of charging [30]. These standards are used as de facto rules in the industry and help different parties and operators understand and use the technical application accordingly [25].

### Mode 1

Mode 1 is an AC charging method for light vehicle charging, mopeds, and electric scooters with low current. Mode 1 is seen to be irrelevant when it comes to passenger vehicle charging, and for safety reasons using Mode 1 is also prohibited in several countries, including the United States and United Kingdom [29, 31]. In Mode 1, an electric vehicle is connected to the grid and charged from a regular household socket-outlet, like Schuko in Europe, that has to comply with the safety regulations, have a circuit breaker to protect against overload and an earthing system [26]. According to IEC 61851-1, the rated values for current and voltage in Mode 1 should not exceed single-phase 16 A and 250 V or three-phase 16 A and 480 V. In Finland, the nominal voltage provided by the supply network is 230 V and with three-phase electric power 400 V.  Mode 1 charging is illustrated in Figure 3 [26].


***Figure 3**. EV charging mode 1* [26]

There are few limitations regarding available power to avoid risks in Mode 1. The first risk is overheating of the charging system, socket and cables, resulting from continuous and intensive use. Other existing hazard in Mode 1 concerns the fire and electric risks if the system is outdated or if some necessary protective devices are missing. Other limitation concerns the power management of a system. In a regular residence a charging socket shares a feeder with other sockets. If the consumption limit exceeds the protection limit the charging will stop as the circuit breaker trips. [26] In Europe, including Finland, the charger is supplied with AC power from a standard earthed 230 V household socket that is in good condition, protected by a 30 mA residual current device (RCD) included in the fixed installation [29].

These factors mentioned above do determine power limits in Mode 1. It seems that the value of 10 A seems to be suitable, but the limit is still to be defined [26]. Electrical vehicle service equipment must have ground fault protection and provide an earth connection to the electric vehicle.

## Mode 2

Mode 2 was developed as result of Mode 1 not having a proper earthing system in all domestic installations. In Mode 2 the vehicle is charged via standard socket-outlet of an AC supply network from the main power grid [31]. Mode 2 is used when charging method Mode 3 of an electric vehicle is not available and it can be used as a temporary or transitional solution before developed methods become more common. [29] It is a slow AC charging method where the charging equipment is located in the cable. In Mode 2, the vehicle is connected to the system with a complaint charging cable with a control and protection device unit. The charger protection unit must be supported so that the socket is not subjected to torsional or tensile stress. [29, 26, 31] Mode 2 charging is illustrated in Figure 4.

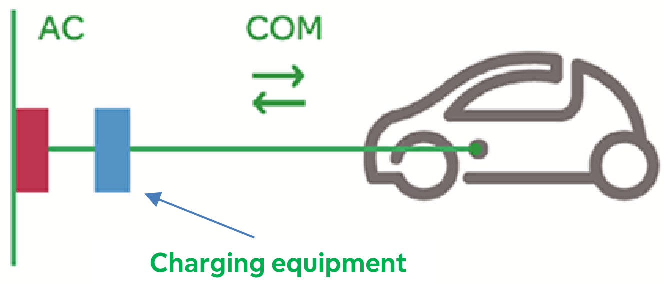


***Figure 4**. EV charging mode 2* [26]

The electric vehicle is supplied with alternating current (AC) from a household socket or an industrial socket near the vehicle, such as the car's heating socket box. According to IEC 61851-1, the rated values for current and voltage in Mode 2 should not exceed single-phased 32 A and 250 V or three-phased 32 A and 480 V [31]. The same nominal voltages 230 V and 400 V apply in Mode 2 in Finland. Like in Mode 1, there are restrictions on using a household outlet in Mode 2. Household sockets are often protected by a 10 A fuse or circuit breaker, and experience has proven that a household socket does not withstand a continuous rated current of 16 A in the long run. An electric vehicle and a rechargeable hybrid can be both charged from a regular household outlet providing that the long-term charging current taken by the vehicle is limited to 8 amps. The industrial socket can be loaded from with its rated current for longer periods. [29]

## Mode 3

Mode 3 is the most used and recommended charging method of electric vehicles for day-to-day use [29]. In this mode, the charger in the EV is connected directly to the electrical network and supplied with an alternating current via special cable and plug according to standard IEC 62196 [29, 26]. ]. Installation, which can be on the wall or in a pole, includes a permanent control and protection function. Also, in some cases, the plug and the cable can be embedded into the charging station. In Mode 3 in Europe, the de facto connector is Type 2 plug, determined by an EU directive [32]. Plugs are discussed more in detail in chapter 2.4. Mode 3 charging is illustrated in Figure 5. [26]

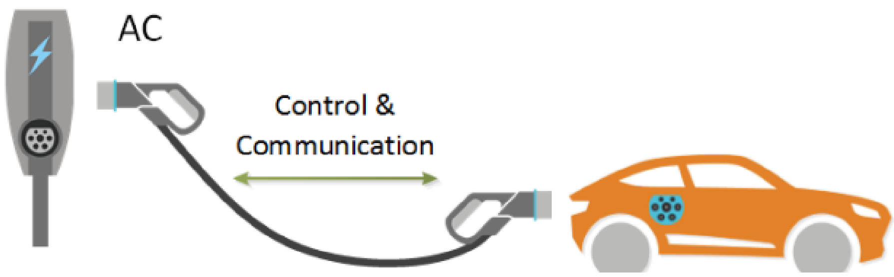


***Figure 5**. EV charging mode 3* [26]

In Mode 3, either with rated single-phase 250 V or three-phase 480 V, the charging current can be up to 63 A and reach its maximum 43 kW charging power [26]. In Finland, nominal supply voltages are 230 V and 400 V, determining the charging power. Mode 3 charging is an active connection between the electric vehicle and fixed electric vehicle charging equipment [26]. When charging, the plug(s) connects and locks mechanically to the mating piece. The charging system includes a communication lane that ensures that the vehicle is correctly connected to the charging station. [29]

It is recommended to use an intelligent charging system in Mode 3. [29] Smart communication between the car electronics, charging station, and the charge point operator enables the use of smart charging features like reserving, invoicing, ITC-connection, scheduled charging, and V2G-technology. With an ICT connection between the vehicle and charging equipment, it is possible to control the charging power during a charging event [33].

## Mode 4

Mode 4 is a DC charging method that enables high-speed charging of an electric vehicle. [25, 31] In Mode 4, a battery of an electric vehicle is supplied with direct current with an external DC charger. DC charging is also called fast, or in some cases, rapid charging. In Mode 4, the charging cable is part of the charging station, and a plug of the charging cable must comply with structure FF or AA from the IEC 62196-3. Structure FF is also commonly known as CCS-connector and structure AA as CHAdeMO. [29] These connectors are suitable for fast and rapid charging of electric vehicles. Current EV charging solutions can supply the vehicles with a direct current of hundreds of amps and have charging power up to 150 kW [20]. Mode 4 charging is illustrated in Figure 6 [26].

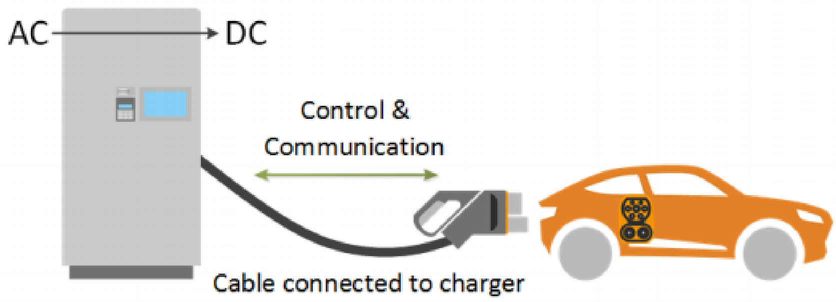


***Figure 6****. EV charging mode 4* [26]

According to EU-wide and Finnish national legislation, public charging stations must have either Type 2 plug that complies with the IEC 62196-2 or a structure FF plug, CCS, that complies with IEC 62196-3. It is advised to use smart charging solutions in all public charging stations if possible. [29] Smart charging solutions are discussed in more detail in chapter 2.5.

## 2.4 Plugs and charger connectors

To charge an electric vehicle, one must know what kind of connector to be used with the car. As with phone charging cables, the car charging cables also have two connectors. One that plugs into the vehicle socket, and the other plugs into the charge point. The type of a connector depends on a vehicle's inlet port, charger type, and a charge point's power rating. The likelihood of having only one charging connector used on a global level is low because there are different electrical grid systems worldwide, and different connectors and plugs are also designed to support that. While Europe and China opt for a charging connector with single-phase 230 V and three-phase 400 V access, Japan and North America choose to use a single-phase connector on a 100-120/240 V grid. [26] There are four main types of plugs that are used widely. For slow and semi-fast charging, known as AC charging, connector types Type 1 and Type 2 are typically used. For fast and rapid charging, connectors CHAdeMO and CCS (Combined Charging System) are mostly used.

Connector **Type 1**, also known as SAE J1772, is 5-pinned and a single-phase plug used in Asia and North America. With Type 1 plug, it is possible to have a charging power of up to 7,4 kW depending on the charger, the vehicle, and grid capacity. Asian car manufacturers like Nissan and Mitsubishi prefer Type 1 inlets in their vehicles [34].

**Type 2** connector is also often called the ‘Mennekes’ connector after its German inverter and manufacturer. Type 2 connector complies with standard IEC 62196-2 [35], and like discussed in section 2.3.3., connector Type 2 is the norm in Europe for chargeable electric vehicles and plug-in hybrid electric vehicles on a standard AC electricity supply. As a result of directive 2014/35 [32] determined by the European Union in 2014, Type 2 socket can be found and used in most public charging stations.

For vehicles, European electric vehicle models from, for example, Audi, BMW, and Volvo are usually equipped with Type 2 inlets for AC charging [34]. Type 2 plugs are 7-pinned and can be used with three-phased power as they have three wires letting the current run through. In private locations, like residential buildings, charging power can reach up to 22 kW, while in public locations, AC charging power can be up to 43 kW with 400 V and 63 A. However, in countries like the United Kingdom, where Type 2 charging points are used with single-phase electricity supply at private locations, the power limit can only reach up to 7.36 kW with 230 V and 32 A. With Type 2 connector, it is possible to have a charging speed of approximately 20-240 km/h depending on charger type, a vehicle that is charged, and grid capacity. Type 2 plug is illustrated in Figure 7. [26, 36]

**CCS**, Combined Charging System, in an enhanced version of Mennekes or Type 2 plug, and in practice, the CCS is combined with Type 2 or 1 socket. The CCS is designed especially for charging away from home purposes. It has two additional power contacts for fast charging, and it supports both AC and DC charging levels up to 170 kW. In Europe, **CCS Combo 2**, that has a Type 2 AC connector at the top and a CCS DC connector at the bottom, illustrated in Figure 7, is most common and widely used. In practice, it means that when going for a quick charge, the bottom connector permits the fast charge, whereas the Type 2 connector located above is not involved in the charging session. When wanting to charge on AC, one plugs a standard Type 2 plug into the upper half. Manufacturers that use CCS on their new vehicle models are, for example, BMW, Audi, Jaguar, Peugeot, Citroen, and nowadays Tesla too. The CCS Combo 2 connector is illustrated in Figure 7. [34, 36]

***Figure 7****. Type 2 connector (left) and CCS Combo 2 connector (right)* [36]

CHAdeMO plug, named after 'CHArge de MOve', which means *'move by charge'* [26], was first developed in Japan and enables charging powers that are up to 63 kW [37]. It is a competitor of CCS when it comes to fast charging. CHAdeMO's significant technical advantage is that it supports bidirectional charging, so vehicle-to-grid (V2G) solutions can be used with the plug [37, 36]. It was proposed as a global industry standard by an association called CHAdeMO in 2010 and was included in IEC 61851-23,-24 and the IEC 62196 standard as a configuration AA [26]. Vehicles with CHAdeMO sockets also always have either a Type 1 or 2 socket for AC charging purposes. CHAdeMO is a suitable connector for fast charging, such as Nissan's and Mitsubishi's rechargeable vehicles. [36] CHAdeMO connector is illustrated in Figure 8 by itself and with a combinational socket system with two different options, CHAdeMO and Type 2 connector.

***Figure 8**. CHAdeMO connector (left) and two socket combination with CHAdeMO and Type 2 connectors (right)* [36]

There are also other connectors used in vehicle charging like **Tesla Superchargers**. The Tesla connector is a modified version of Type 2 plug. Tesla Supercharger recharges Tesla vehicles up to 80 % within 30 minutes. However, as Tesla chargers are designed to use only on Tesla vehicles and are exclusively used only by Tesla drivers, the connector used in Superchargers will not be covered closely in this study. Another used connector in electric vehicle charging is **GB/T** plug that is suitable for DC charging and is mostly used only in China [26].

## 2.5 Smart charging

Smart charging is a broad concept that has many definitions. It can imply, for example to cost-reflective and effective charging, charging technology that is considered to be smart or smart infrastructure for charging. [38, 33] With cost-reflective charging, the fluctuating energy markets and network prices can be leveraged over the course of one day by encouraging users to charge at times when it is desirable in the perspective of energy markets. On the other hand, smart technology is the critical resource to achieve the optimized flexibility that electric vehicles and smart charging devices can provide, primarily when used in conjunction with smart pricing. Smart infrastructure refers to the strategic siting of electric vehicle charging stations and infrastructure. If designed carefully, both private and public charging infrastructure can cover mobility demands and use existing grid capacity to provide balancing charging services. Combining these two smart infrastructures reducing the cost of integrating e-mobility into the power system is possible. [38]

In its most used version, smart charging means smart communication between a vehicle, a charging station, and a charge point operator. According to Virta, smart charging, also known as intelligent charging, refers to a system where an electric vehicle and a charging device share a data connection, and the charging device shares a data connection with a charging operator' [33]. It is opposite to the traditional 'plug and charge' system where the charging device is not connected to the cloud. Traditional charging systems are sometimes called dumb charging systems as there is no communication between the equipment. Communication channels, protocols, and standards are discussed more closely in section 2.6. With a smart charging system, the charging station owner can monitor, manage, invoice, optimize energy consumption and restrict the use of a device through cloud connection to the system. In smart charging operating happens remotely.

A smart electric vehicle charging system is run by an intelligent backend solution. From the cloud solution, it is possible to monitor real-time data from all connected devices and charging events. For smart charging to be possible, it requires an electric vehicle user to identify itself at the charging point. [33] Identification can happen, for example, through a radio-frequency identification (RFID) [38] Via identification, a linkage can be created between a charging point, electric vehicle user, and charging event. When an electric vehicle is plugged in, the charging station sends data via the internet to a centralized cloud-based management platform. [33]

According to Virta, intelligent charging is essential, especially when it comes to the energy market. [33] With cloud connection, it is possible to consider local electricity consumption, fluctuating energy production, and other possible peaks in grid usage when managing the use of a charging station. As the number of electric vehicles and their users is continually growing, more flexibility will be needed.

Smart charging offers multiple benefits for electric vehicle drivers as well. When chargers are connected to the internet, finding available charging points is possible. Consequently, driving routes and times can be planned in more detail. A smart device will automatically use maximum power available and compared to the regular household socket, it is notably safer charging option as a smart device always tests the connection between a vehicle and a charging device before allowing it to start the charging. It is easy to track consumption data, and in most cases, the billing also happens automatically through the system. A smart charging system enables the optimization of a charging event so that it is possible to charge one's vehicle when renewable energy is available or when electricity consumption is low, in other words, outside peak hours. It is both cheaper for the user and helps to balance power demand. [33, 38]

Businesses also benefit from the smart charging of electric vehicles. As devices are connected to the cloud, it allows 24/7 monitoring and controlling of charging events. Faults can be detected, and issues reported faster. When charging stations are connected, managing them in a stack is possible. [33] This simplifies load managing even though many charger manufacturers, like Ensto, have already designed and are building dynamic load management (DLM) system inside the equipment. Billing of charging events becomes possible, and so also gaining revenue from the business.

An intelligent charging system enables the offering of service business in addition to selling hardware, so it also benefits the company from a business point of view. For electric vehicle charging networks, this is a prerequisite. [33] As discussed earlier, electric vehicle charging needs are growing, and the need to plan and manage the power balance is becoming more and more relevant [38]. With smart charging, energy management features can be passed on to the electric vehicle driver, which creates an opportunity for the user to take an active part in demand response programs.

Demand response and side management mean transferring electricity consumption from hours of high load and price to times when power demand and electricity prices are lower. [39] From the perspective of smart charging, demand response can be contemplated from two perspectives. Smart charging technology allows a charging system to schedule the charging session to times when power demand is generally low and enables V2G-functionality in which power can be drawn to the grid from the vehicle itself. [40] For consumers to participate in this, it needs firm guidance and incentives. A network operator, usually the charging point operator or e-mobility service provider, can create device groups, pricing models, and packages for end-users. [33] This way, it is possible to design an offering to fulfill each customer's individual needs.

Smart charging creates business possibilities for aggregators as well. In e-mobility an aggregator agent is a party between system operators and electric vehicles. An aggregator can be seen as a large source of generation or load, in this context, loaded electric vehicle batteries that can provide services like regulating the reserve. As smart charging technology enables features like V2G, aggregators can play a vital role in balancing the power demand by regulating the reserve that electric vehicles could be part of. It can be considered to be a competitive business like other trading activities in the market. [41, 42]

Figure (9) below illustrates the possibilities that smart charging enables for different players in the field.

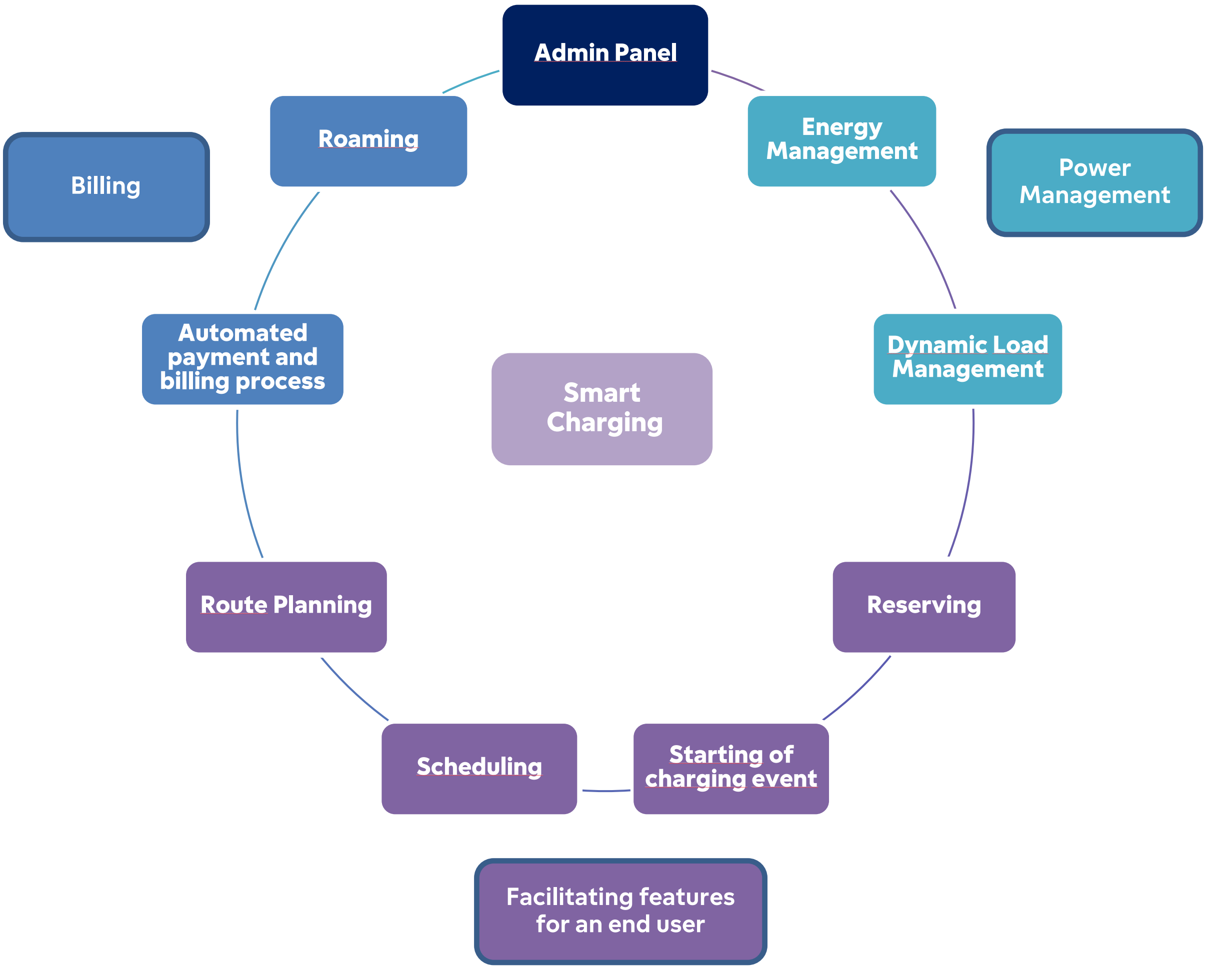


***Figure 9***. *Elements of smart charging*

In conclusion, there are few elements that a smart charging system makes possible and that are required in intelligent charging. All managing and operating happen via the admin panel. The panel can provide tools to report statistics, make changes in the features, or for example, change charging prices. A convenient feature of smart charging is the automated payment and billing process. Instead of having to do it manually, charging customers happens through the platform. In many cases, the operator provides mobile or a web app for the end-users. Charge point reserving, starting of charging event, scheduling, and route planning can occur via mobile application. Another feature of smart charging is roaming, which provides a possibility to charge at charging points with different operators. It attracts more users and helps to gain more income. Also, load management is possible to achieve through a smart charging system. Dynamic load management (DLM) is a feature that refers to the ability to distribute the available power between the building's electronic devices and the vehicles that are being charged at the same time. In addition, energy management features are included in smart charging. They are critical components in connecting an electric vehicle to the grid. Without a charging station with smart attributes, the vehicle cannot support the grid and electricity system.

## 2.6 Communication protocols for charging solutions

Now that electric vehicles are becoming a significant part of the transportation ecosystem, there is a need to shift towards chargers' standardization and the introduction of new industry protocols. Keeping up with constant technology developments and ensuring that the technology complies with the latest standards and regulations is challenging. E-mobility service providers and charging point operators see that it is especially challenging to expand the business internationally when dealing with different protocols, multi-currencies, regulations, and roaming capabilities [43]. In this section, a list of electric vehicle charging industry standards and protocols that make electric vehicle market more flexible and will be enablers for future charging infrastructure developments are listed and introduced. Standards and protocols are introduced in categories according to what interface and communication type they are specifically created for.

### Smart charging

An electric vehicle can be externally controlled when charged. Controlling the charging provides the electric vehicle an ability to integrate into the whole energy system in a grid- and user-friendly way. The following protocols and standards have been developed to support the needs mentioned above in enabling intelligent charging.

**Open Smart Charging Protocol** (OSCP) was first created by a Dutch distribution system operator (DSO) Enexis and an EMSP and CPO GreenFlux. Later on, it was developed further by Open Charge Alliance. [44] According to Open Charge Alliance, the goal for OSCP is to offer a uniform solution for the communication method between the charge point management system and the central system [45]. The protocol communicates forecasts of the electricity grid's available capacity to other systems. It is based on a budgetary system where other systems (charge point management system) can indicate one's needs to the central system (energy management system) that is guarding the grid against overuse [43, 44]. ]. If a system demands more budget, it can request more and vice versa. The Open Smart Charging Protocol does not have a direct relationship with any charge point. The protocol is designed to be generic, and it can be used for capacity allocation in general, and it can be used to communicate 24 h predictions of the available capacity [45]. High-level use cases are in capacity-based smart charging and grid management. [44]

**The Open Automated Demand Response** (OpenADR) standard was developed by the United States Department of Energy's Lawrence Berkeley National Laboratory in 2002, and it has been maintained ever since by OpenADR Alliance. It is a standard for dynamic demand response and is a standard by international standards development organization the Organization for the Advancement of Structured Information Standards Energy Interoperation Technical Committee. [44] At the end of 2018, The OpenADR 2.0 became an IEC standard [46]. The protocol is intended for automating the communication in demand response. The use cases that OpenADR supports are the following: registration handling, grid managing, and smart charging. [44] OpenADR is highly secure, open and the information exchange occurs two-way with the model. [47]

**The Open Charge Point Interface protocol** (OCPI) is a communication standard for exchanging information between CPOs and EMSPs. However, sometimes these roles are not separated in the markets, and in some areas and countries, two roles are managed by the same party. By splitting up these two roles, customers can use all different service providers' charge points despite being a customer of only one party. The OCPI protocol was initially designed and developed by the Dutch electric vehicle market in 2014, and several CPOs and EMSPs together with ElaadNL designed the **first version** of the protocol. **Version two** covered more of the roaming needs in electric vehicle charging and was published in 2016. Nowadays, The Netherlands Knowledge Platform for Charging Infrastructure (NKL) facilitates and coordinates the protocol, guaranteeing progress and development. The use cases supported by the protocol are billing, reservations, roaming, registration handling, and charging session authorizing. [44, 43]

**IEEE 2030.5 protocol** is a standard for home energy management and in house smart grid solutions. It is based on the IEC 61968 and IEC 61850 information models. The ZigBee Alliance first invented it, and the protocol is a follower of Zigbee Smart Energy Protocol V1. In 2013 the protocol became a standard within the IEEE. The protocol is a comprehensive one, including a wide selection of functionalities. The IEEE 2030.5 focuses on communication between the utility and Energy Service Interface (ESI). Following use cases can be applicable for electric vehicles: demand response and load control, exchanging metering data, tariff information sharing, messaging, billing, and reservation of energy flow. [44] Now there is a new bettered version of the protocol, IEEE 2030.5-

2018, approved as an IEEE standard in 2018 and published at the end of the same year. [48]

## Communication between a central system and a charge point

Perhaps the most used and known protocol for electric vehicle charging is **Open Charge Point Protocol** (OCPP), designed for the communication between electric vehicle charging devices and the intelligent backend system used for operating and managing charge points. It is an open-source, and vendor-independent standard available for free to all users. [43, 44] It is intended to exchange information considering charge point operating, including maintenance and transactions. The latest version of the protocol is OCPP 2.0 with a lot of improved features for device management, transaction handling, security, smart charging functionalities, and messaging [43]. The protocol for open charge points started as an initiative by ElaadNL in 2009. The maintenance and development of the protocol were transferred to Open Charge Alliance (OCA) at the beginning of 2014. The OCPP is considered *a de-facto* open standard for charging infrastructure interoperability in many countries, including Europe and some parts of the United States. [43, 44] Use cases supported by OCPP are authorizing charging sessions, billing, grid managing, charge point operating, charge point reserving, and smart charging.[44]

**IEV 61850-90-9** is a technical report and not a protocol itself. It describes an object model for e-mobility, and the primary purpose of it is to model e-mobility into IEC61850-7-420 ed. 2, for the integration with other distributed energy resources like wind and PV solar energy. Report models electric vehicles as a specific form of distributed energy resource according to the example definitions in IEC 61850. Even though IEV 61850-90-9 is not a protocol, it can be used as a one as the idea is to create a “logical node” model for electric vehicles. As it is only described as an object model, it cannot be used directly from the specifications, except for smart charging. In smart charging, it is defined as “optimized charging with scheduling from the secondary actor or at EV.” It is suitable for power reservations as the local reservation scheme is very defined. [43, 44]

Both of the above mentioned, OCPP and IEC 61850-90-8, can be used in controlling charging points. However, OCPP has become a de facto standard, and it is used in many companies. IEC 61850-90-8 is not in general use, and because of that, it is not easy to compare these two protocols.

## Communication between electric vehicles and charge points

**The IEC 61851-1** edition 2 standard was published in 2010. [44] It is counted among official IEC standards, and it considers basic charging. The standard describes four modes for the charging of electric vehicles. [31] The IEC 61851-1 standard is publicly available, and currently, the standard for electric vehicle charging in Europe, thousands of charging points, and every electric vehicle support the standard. Charging modes according to the standard were discussed in more detail in section 2.3.

**The ISO 15118** is an international standard, and it specifies the bi-directional communication between an electric vehicle and a charging station. The ISO standard currently consists of several parts that describe the protocol on different levels. The protocol for advanced communication enables electric vehicles to communicate information to a charge point without the electric vehicle user intervening in the process. The action required by the electric vehicle user is to only plug a charging cable into the car or charging station. ISO 15118 can be used in authorizing charging sessions, smart charging, electric vehicle charging, and reserving of charging points. [44]

IEC 61851-1 is used in essential communication between a charge point and an electric vehicle for charging, and the standard is only targeted at electric vehicle charging. ISO 15118 is considered as advanced communication between the two interfaces, and it is considered as a critical enabler of the Plug & Charge capability

### Overview

In Figure 10, different protocols and roles are visualized. For some of the protocols positioning to the model below (Figure 10) is easy as some of them are created for specific purposes. However, some protocols do not have such a clear purpose and are used more generically in the electric vehicle market.

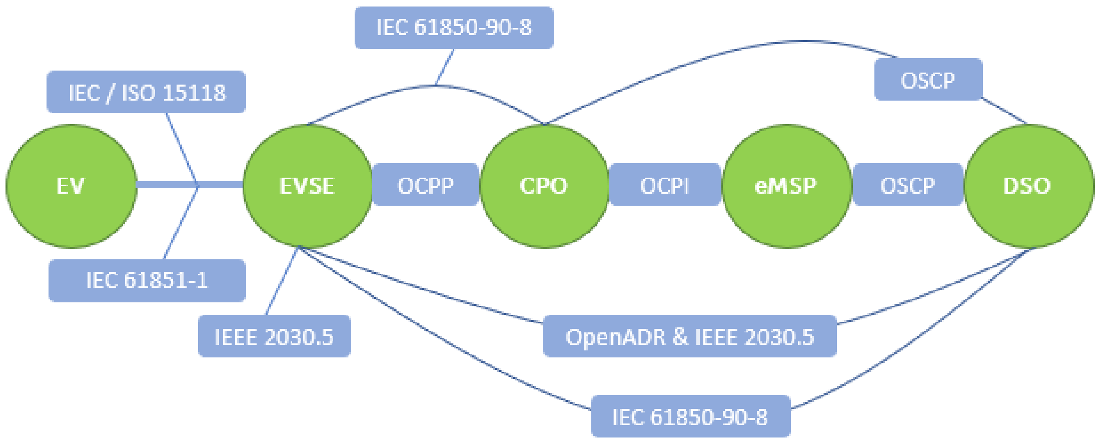


***Figure 10.*** *Overview of electric vehicle communication protocols* [44]

It is essential to understand that these actors in Figure 10 are roles, not specific companies. The same role can be filled by the same company or by many different companies. In reality, the structure is more complex and not as evident as the model suggests. It is more transparent and easier to see in the model how and where different protocols and standards overlap each other.

# 3. ELECTRIC VEHICLE AND CHARGER MARKET IN FINLAND

Electronic road transportation has increased significantly since the middle of last decade, for example, in the United States, China, and many European countries. [7] The development has been driven by the need to reduce greenhouse gas emissions and oil dependence in transportation. Also, improving energy self-sufficiency and overall energy efficiency has accelerated the change towards electrified road transportation. [1] The supply of electric vehicles has increased over the years, and many vehicle manufacturers have introduced both battery electric vehicles and plug-in hybrid electric vehicles to the market.

In Finland, opportunities and challenges in e-mobility were assessed more closely at the end of the 2010s, and new guidelines were drawn for future development. [49] There were only a few electric vehicles in use at that time, and no public charge points were available in Finland. In addition to the electric vehicles, other alternative propulsion vehicles, such as gas cars, opportunities were assessed to replace internal combustion engine vehicles in the future.

## 3.1 State of electric vehicle market

Before 2011 there was very little activity regarding e-mobility, and only around 25 electric vehicles were in use in Finland [8]. There were an apparent chicken and egg problem. Finland had no, or very little, charging infrastructure, and the use of an electric vehicle was difficult. On the other hand, as only a few people were driving with electric vehicles, no infrastructure was needed. Initially, battery technology got better and driving ranges longer, which accelerated the adaptability of e-mobility.

Sähköinen liikenne -initiative was set up in 2011 as part of Tekes's Electric Vehicle Systems (EVE) -program that funded projects that were allocated explicitly to piloting, testing, and demonstrating purposes of e-mobility in Finland. The purpose of the EVE program was to create an ecosystem for e-mobility that could provide new information and knowledge on electric vehicle technologies and e-mobility services. Sähköinen liikenne -initiative was one of the five initiatives granted the funding from EVE-program. The main goals of the Sähköinen liikenne -initiative were to launch e-mobility in Finland starting from Helsinki metropolitan area and create new businesses and business models. The aim was to focus on the opportunities and challenges of future e-mobility and closely related electric power infrastructure. [49]

Within two years, a test environment for several hundred electric vehicles was to be built in the metropolitan area, which would serve as a platform for studying the usability of electric vehicles and developing and testing services related to technological solutions in e-mobility and smart grids. The companies and organizations participating in the initiative committed to procuring the electric vehicles needed for testing purposes. Feedback was to be collected from the users to assess the opportunities and challenges. [49]

Eera Oy was the original initiator in assembling the Sähköinen liikenne -initiative consortium and acted as the project coordinator. At the start of the initiative, the consortium included 20 key organizations in the field, five cities, transport authorities such as the Finnish Transport Agency (Liikennevirasto), Department of Traffic Safety (Trafi), and three other research and educational institutions; Aalto University, Metropolia, and Center for Consumer Society Research. [49]

According to Antikainen and Eera Oy, whom both created final reports from the project, critical objectives of the Sähköinen liikenne -initiative were achieved in the view of both funders and the project consortium [50, 51]. The initiative was able to launch e-mobility in Finland and create conditions for future expansion. Moreover, it created new businesses and business activities in the e-mobility field. The project was also able to increase the general awareness on electric vehicles and electrified transportation amongst the Finns. [49]

Before starting the Sähköinen liikenne -initiative in 2011, there were only 56 registered electric vehicles and no infrastructure for e-mobility in Finland. [49] During the first few years, the electric vehicle traffic was only located in the capital area, but when the initiative came to its end in 2015, the electric motorists spread out to the whole country.

From Q2 in 2019, the number of electric vehicles on the road grew by 87 %; growth was 83% in electric vehicles and 88% in plug in hybrids. At the beginning of 2020, electric vehicle numbers on the road grew over 40,000 in Finland. At the end of Q2 of 2020, there were registered 33,883 rechargeable hybrids and 6,432 electric cars. In Q2/2020, electric vehicles' overall market share increased up to 15 % and almost tripled compared to the corresponding time in 2019. [52] At the end of Q3/2020, the electric vehicle fleet grew to 47,921 electrified vehicles and kept up with the annual increase rate of 90 %. The market share increased to 23 %. [53]

It was noticed that the government, especially the purchase subsidy, stimulated the first-registries of new electric vehicles. However, the market's strong development was overshadowed by the global pandemic as some interruptions in productions and delivery times were expected and experienced [52, 7].

Sähköinen liikenne ry is a Finnish association that promotes electric mobility, coal, and emission-free transportation and smart charging of electric vehicles to support the Finnish energy system in a long run [54]. According to *Sähköinen liikenne ry,* it seems that emission reduction goals regarding passenger vehicle traffic are feasible and realistic [52]. Nevertheless, it requires strong guidance towards the registrations of the low-emission vehicles, and broadening the availability of the purchase grant to all electric vehicles, including plug-in hybrid cars, would positively accelerate the development of the market. In Figure 11, the development of the number of electric vehicles and plug-in hybrid electric vehicles on the road are visualized [8]. Development is portrayed by using a graph below.

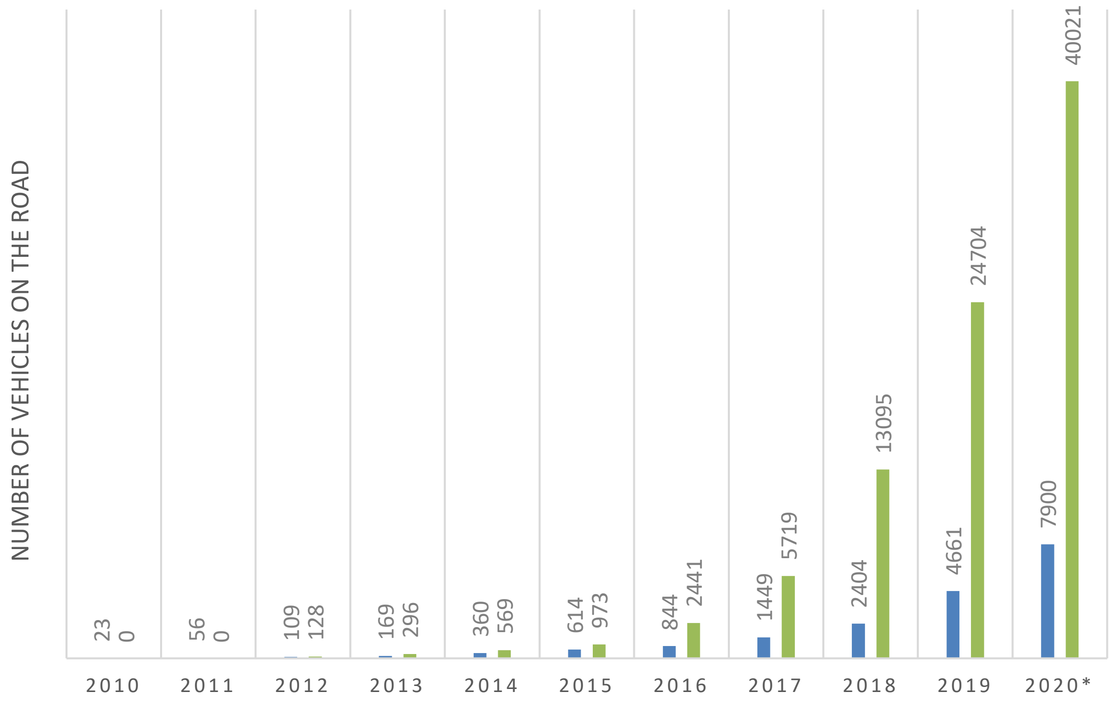


***Figure 11****. Development of electric vehicle fleet in Finland.*

** Numbers from 2020 are from Q3/2020.* [53]

Figure 11 shows how the electric vehicle fleet has grown exponentially in recent years. The growth is remarkable, especially in 2018 and 2019 when new incentives and purchase grants were introduced to the consumers (discussed in section 3.3). The plan was to have at least 20,000 electric-power vehicles on the road by 2020. As the graph shows, the number was exceeded already in 2019. The second national goal is to have at least 250,000 electric cars, plug-in hybrid electric cars, and hydrogen fuel cell vehicles on the road by 2030 [6]. In the light of the latest numbers, it seems that current national targets may be underestimated. It has therefore been debated whether the 2030 vehicle target should be raised to 700,000 electric vehicles [3]. National targets are shown in Table 1 below [55].

***Table 1.*** *Electric vehicle targets in the national distribution infrastructure program (includes both all-electric cars and rechargeable hybrids)* [55, 6]

| | 2020 | 2025 | 2030 |
|---|---|---|---|
| Passenger vehicles | 20,000 | 100,000 | 250,000 |
| Electric vans | 2,000 | 6,000 | 13,000 |

Today in 2020 the most registered battery electric vehicle models in Finland are Tesla Model 3, Seat Mii, Volkswagen Up!, Volkswagen Golf and Hyundai Kona. When it comes to plug-in hybrid vehicles most popular ones are Volvo XC60, Skoda Superb, BMW 5 Series, Mercedes Benz GLC and Volvo V60. [52]

## 3.2 State of electric vehicle charger market and infrastructure

As the number of electric vehicles is constantly growing, also need for developing charging infrastructure is more considerable. Even though most of the charging takes place at home, a growing car fleet also needs a high quality and functional public charging point network.

In the Sähköinen liikenne -initiative (2011-2015), a framework for a public charging infrastructure was designed and built, which was considered an absolute prerequisite for the broader launch of e-mobility. At the end of 2015, electric motorists were able to use about 400 public charging points in different parts of Finland, the northernmost of which was in Rovaniemi. When the government started to create a charging point network, the first aim in 2014-2016 was to cover 20 of the largest cities, railway stations, airports, harbors, and the most critical road sections and traffic hubs. The last phase's ultimate plan was to have a network that covers the whole of Finland by 2020. [49]

In Finland the expanding of the charging point network happens mainly on market terms. [56, 3] The EU Alternative Fuels Distribution Infrastructure Directive has set indicative target for infrastructure to have one charging point for every ten electric cars. [32] National goal in Finland was to have 4,000 public charging points by 2020 that would serve

40,000 electric cars. Meanwhile, the number of fast chargers ought to be 400. The directive does not include targets for private charging points. [56] Nevertheless, since electric cars' charging is explicitly based on slow residential charging, the number of private charging points also has a significant impact on the potential adoption of electric vehicles and e-mobility.

According to Sähköinen liikenne ry, at the end of Q2 of 2020, there were 3,830 public charging points, including both slow and fast chargers, in Finland. Around 3,500 were for slow and semi-fast charging, and the rest 300 for fast and rapid charging. [52] In Q3/2020, the number of public charging points increased to 4,122 pcs, indicating that the number of charging points increased by 1191 pcs in one year. From the whole public charging point fleet, 3,790 are for slow and semi-charging, and the rest 332 are for fast and rapid charging. [53] Most charging stations are located in Uusimaa, Varsinais-Suomi and Pirkanmaa [52, 53]. Current number of public charging points in Finland and relative growth one year are presented in Table 2 below.

***Table 2.*** *Public EV chargers in Finland in 2019 and 2020* [53].

| | **Q3/2019** | **Q2/2020** | **Q3/2020** | **Growth (1 yr)** |
|---|---|---|---|---|
| Slow charging points | 2,646 | 3,528 | 3,790 | + 43 % |
| Fast charging points | 220 | 302 | 332 | + 51 % |

The public and semi-public charging network has been built mainly by energy companies and private parking facilities that have made investments in the e-mobility field. Also, numerous businesses have invested in workplace charging. Charging points have been built in shopping malls, and in new property plans, charging points are included almost every time. Generally, cities have not been involved in the construction of the charging network but have taken on planning and coordinating it with the existing transport system plans. Active cities have been, for example, Turku, Tampere, and Helsinki, where e-mobility is part of the city’s broader development plan. [56]

Private charging points are built in the parking areas of both detached houses and condominiums. The actors in the construction of a private charging network are therefore both individual consumers and housing associations, in some cases also companies that provide parking services and manage parking areas. Home charging investments are mainly funded privately. [56]

Today, no statistics are available on the number of private charging points in Finland as there is no official national reporting for private charging. Motiva Oy estimated that at the end of 2018, private properties had roughly 9,000-13,000 charging points, assuming that each battery electric vehicle and around 50-80 % of the rechargeable hybrids had their own charging point in the garage.

Over the last eight years, electricity consumption has decreased by around 8 TWh. When Finland reaches the number of 250,000 electric vehicles on the road, it has been estimated that the electricity demand will increase around 1 TWh resulting from progressing charging needs. So if all vehicles in Finland ran on electricity, it would mean that the demand for charging energy would only be around 10 TWh and the electricity consumption would be roughly the same as in the peak year 2007. [57, 58] The overall electricity consumption in 2019 was 86.1 TWh and 15.6 MWh per inhabitant. About 66 TWh was produced domestically from the yearly demand, and the rest 23 TWh were imported from neighboring countries like the Nordics, Russia, and the Baltics. [59]

The adequacy of electricity energy in Finland is not going to cause restrictions on the adoption of electric vehicles. [3] The utilization of electricity as a driving force for transport should not create significant needs to increase electricity generation capacity if the charging is directed intelligently to times when power consumption is generally low on a national level. [56] Times of low consumption often coincide with early mornings between 2 and 6 am [60].

Locally problems might occur at low voltage levels when charging multiple cars simultaneously as charging can impact low voltage network stability. In a worst-case scenario, when electric vehicle penetration rates are high enough, it can collapse the local low voltage network. [61] With solutions that smart charging can provide, a battery's charging time can be regulated and thus create a significant demand response solution to both the electricity market and local electrical systems. Smart charging solutions can take other electrical loads into account: charging a car can be slowed down when other sources like electric heating inside a building are needed. [57] Intelligent charging can be implemented with automatic controls so that it has no practical effect on the vehicle's use. To fully utilize the benefits of e-mobility, smart charging should become the core of the whole charging system. [56]

## 3.3 Electric vehicle policies and market incentives

To accelerate the adoption of e-mobility and electric vehicles, different policies are needed to minimize risks related to electric vehicles, and they can play a significant part when aiming to increase the attractiveness of electric vehicles. [62, 63] Policies can be executed through different incentives, sanctions, and investments targeted at different players in the field; consumers, organizations, fuel industry, and manufacturers. Implementations can be applied on a national or local level in specific cities and areas.

According to Laukkanen & Sahari, there are six different policy instruments targeting e-mobility diffusion; fuel taxation, vehicle taxation, purchase subsidies, infrastructure investments, electric driver-based benefits, and other informative campaigns [9]. In this study, vehicle taxation alludes to a tax collected based on vehicles' emission levels and their contribution to global warming. However, vehicle taxation can also be referred to as a value-added tax. Both of these taxes are collected and paid when purchasing a vehicle. Decreasing or even removing the tax, like in Norway for battery electric vehicles, has a significant impact on an electric vehicle's purchase price.

In Finland purchase decisions considering vehicles are controlled and guided via *vehicle taxation*. [9] The vehicle tax is paid when purchasing a new vehicle. Amount of paid taxes depends on the CO2 emissions that are produced by the vehicle. The taxation system is staggered and it also acts as a form of support as it lowers the price of an electrified vehicle. In Finland, electric vehicles have the lowest vehicle taxation level. Gradual vehicle taxation method according to greenhouse gas emission is used several countries in European Union. [64]

Operating cost create a significant part of total costs in motoring. According to Laukkanen & Sahari several studies have shown how rising fuel prices have an increasing impact on the sales of electric cars. [9] Today the costs of using an electric vehicle in Finland are clearly lower than the costs of an internal combustion engine vehicles. However, cost of purchasing an electric vehicle is still higher. A *fuel taxation* is an effective way to control motoring as it both has an effect on the use of existing car fleet and steers new purchases towards fuel-efficient and low-fuel vehicles.

Number of electric cars can be increased by lowering vehicle’s purchase price through *subsidies*. The discount can be granted directly as a monetary discount, i.e. tax deduction, or conditionally on the old car’s scrapping. [62, 9] Subsidies are typically targeted at vehicles below certain emission limit. It has been studied that price reductions have significant impact on increasing demand for subsidized vehicles. The greatest impact occurs when support is visible in the purchase price of a car.

The attractiveness of electric vehicles is closely linked to the availability of charging points. Charging overnight might be sufficient for daily driving but for longer journeys dense public network is needed. Because average travel ranges of electric vehicles are still not as good as with internal combustion engines, importance of a functional charging point network, more specifically fast charging network, needs to be emphasized. Setting up a charging station or network is worthwhile if payback time is reasonable in relation to the amount of an investment. [9]

In Finland, the charging network for electric cars is still being built. The charging network coverage affects consumers' willingness to buy an electric vehicle, so the *investments in charging infrastructure* and standardization of charging methods can have a significant impact on the market. It has been proven that *supporting the charging infrastructure* can be a more effective way to accelerate the adoption of e-mobility than supporting vehicle purchases is. Here, Norway acts as an excellent example; for many years, Norwegians have received several financial subsidies and benefits, but the number of public charging stations has explained the most robust growth in the electric car fleet. There are empirical results from three different markets: Italy, Norway, and the United States. Investments in infrastructure do not provide financial benefits to consumers but can narrow down the conceived risks linked to e-mobility and electric vehicle purchases. [9]

Different user-based benefits are offered to stimulate demand for battery electric vehicles and plug-in electric vehicles. In Norway, there are no road rolls for electric vehicles. Electric vehicle motorists are allowed to drive on lanes for public transport, and ferries are free. [65, 66] These benefits can worth thousands of euros a year. From a driver's perspective sitting in traffic can be costly in a time-saving perspective. From the perspective of decision-makers, these actions are an appealing way to increase the number of environmentally-friendly vehicles. No new investments or subsidies are needed to be included in the budget. However, the user-based benefits can have significant non-monetary cost, too, like increased traffic jams in specific lanes [9].

Lack of consumer knowledge or uncertainty about alternative technologies may limit alternative fuel vehicles' demand. If consumers cannot compare, for example, fault statistics or resale values of the purchase in the same way as for internal combustion engines, it could affect the demand. Uncertainty and lack of information can be addressed by producing and sharing information about e-mobility in a wide variety of ways through different channels. It has been estimated that a Norwegian active electric vehicle association has made a significant contribution to the growth of the electric vehicle market share [9]. As investments in infrastructure, *information campaigns* do not provide financial benefits to consumers.

All the carrots mentioned above, trying to encourage consumers to adopt low emission vehicles by offering financial benefits or mitigating risks, are governmental policy instruments. An alternative way to increase the adoption rate of new technology is to use *sticks*, sanctions, and prohibitions that can lead to high penalties if actions do not comply with the nation's regulations.

Even though policies and incentives are usually introduced by the government, do commercial parties like vehicle manufacturers and other actors in the industry play a part in the diffusion of e-mobility. Manufacturers can offer their own subsidies when a consumer purchases an electric vehicle. [67] This practice is already used in Finland; in every purchase subsidy there is a governmental and industry share included in one discount.

Today, car emissions are limited by various regulations in many parts of the world. Regulations are not entirely consistent across continents, and therefore car manufacturers may make versions of the same cars with different emission technologies for different markets. In Europe, emissions harmful to the health of passenger cars are regulated by directives and CO2 emissions by the so-called CO2 regulations [68]. As the EU regulates emission requirements for vehicle manufacturers, it forces commercial parties to increase the supply of emission free vehicles. Directly this is a commercial measure that affects the electric vehicle diffusion rates but indirectly a governmental one too.

## Policy portfolio in Finland

Before plug-in hybrid electric vehicles and battery, electric vehicles were introduced to the market, the only measure to manage the car fleet was **vehicle taxation**. At the beginning of 2000' internal combustion vehicles that run on gasoline and diesel were the only ones available in the market [49]. As a result, vehicle taxation was fixed to those vehicle types. Vehicle tax depended on the brand, vehicle model, and also on the fuel type it used. Two tax categories were used; one for diesel and one for the other cars. This taxation law was valid until 2003 when the vehicle tax got reconstructed to consider other drivetrains, power of the vehicle, and vehicle style. [69]

In 2008, at the same time when a new law came into force, the Finnish government developed a strategy regarding reducing greenhouse gas emissions. In the new law, vehicle taxation was set based on greenhouse gas emissions. The vehicle taxation began to follow a 'bonus-malus' system that was also used in Norway. The lower the CO2-emissions of a vehicle were, the lower the taxation for the particular car was. Consequently, the pressure moved towards vehicles that produced more emissions. The latest form of vehicle taxation was put to use in 2018. The most significant change was in the measurement method of fuel consumption and emission level of a vehicle; the old NEDC measurement procedure was replaced gradually with the new WLTP method. [69] The new procedure was supposed to unify the policies and give more realistic results of vehicle consumption and emission profiles.

Moreover to the one-time vehicle tax, a Finnish passenger vehicle owner needs to pay a yearly tax. It is divided into two parts; a base tax and a motive power tax. [70] The first part is paid according to the CO2-emissions or weight of the vehicle if emissions are not reported. The second part is a tax which is paid according to the drivetrain, active use days of the vehicle and the weight of the vehicle. In comparison, a battery electric vehicle driver pays around 0.015 €/day or 5,5 € per every 100 kg while an internal combustion engine vehicle, that runs on diesel, user pays around 0.055 €/day or 20.1 € per 100 kg. For plug-in hybrid electric vehicles the amount is around 0.049 €/day. Internal combustion engine vehicles that run on gasoline do not pay motive power taxes. [70, 64]

The Finnish government uses also fuel taxation as a third tax instrument to influence driving behavior. Taxation of petrol and diesel consist of excise duty and value added tax (VAT). Taxation of transport fuels is relatively high in Finland by international standards. Fuel taxes have over doubled the price of diesel and tripled the price if gasoline. In March 2020, around 65-70% of the consumer price of gasoline consisted of taxes and about 55 % of the price of diesel consisted of various taxes. [71]

There have also been other policies implemented to induce the electric vehicle adoption rates. First iniative was founded in 2011 as a part of the Energy investment program (more about this in section 3.1) [49]. Around 10 million euros were budgeted for subsidizing chosen organizations in the field of electric car leasing and infrastructure building. The subsidy program was originally planned to last for two years but it was decided by the Ministry of Employment to extend it till 2017. In 2016 the program was extended second time and new 4.8 million euros were budgeted for developing public charging infrastructure. For 2020 there are 5.5 M€ budgeted for projects concerning investments in electric vehicle charging and gas refueling networks [72].

Because the subsidy program covered just commercial companies, the government decided to budget separately for housing associations and condominiums. *Asumisen rahoittamis- ja kehittämiskeskus* (ARA), the Housing Finance and Development Centre of Finland, budgeted 1.5 million euros for housing associations and condominiums that are planning to set up charging points for their residents. Originally the subsidy covered 35 % or 90,000 € of the total expenses. Today, ARA provides a grand to residential property owners for changes to the electrical systems required by electric vehicle charging points. The grant covers 45 % or 55 % of the actual cost, up to a maximum of 90,000

€. A prerequisite for the grant is that the community builds capacity for at least five charging points. Grants are also given for the purchase of the chargers. A total of 5.3 million euros have been budgeted for 2020. The subsidy promotes the spread of home charging possibilities for electric vehicle owners and thus the growth of the electric car fleet in accordance with the objectives of the national climate-energy strategy. [73]

In 2018 the Ministry of Transport and Communications decided on a law that the government grants a direct purchase subsidy for private battery electric vehicle buyers. Subsidies are provided in 2018-2021. [74] The plan was to double the battery electric vehicle fleet from the numbers of 2017 [75]. The requirement for receiving the grant is that the vehicle is full battery electric vehicle, it costs less than 50,000 € (including VAT and vehicle tax), it is the first registration of it and that the buyer is a private person. [74]

The government is planning on relaunch scrapping bonuses for the year 2021. Condition for receiving a scrapping bonus is that the old scrapped vehicle is replaced by a new passenger vehicle, a new electric bicycle or a public transport ticket. The scrapped vehicle must be at least 10 years old and a scrapping certificate must be obtained. The purchased passenger vehicle must run on gas or electricity or be a rechargeable hybrid vehicle that pollutes CO2 maximum of 95 g/km. This rule applies to the battery electric vehicles and gas fueled vehicles. The law is expected to come into force at the end of 2020 and remain in force until the end of 2021. The subsidy would be granted by the Finnish Transport and Communications Agency (Traficom). [76]

In March 2020 the government proposed a new law according to which a new or large-scale renovated residential building must be equipped with charging capacity for each parking space if there are more than four parking spaces. In case or a new or extensively renovated non-residential building with more than 10 parking spaces, one high powered or alternatively few normal powered charging points shall be installed in stages, depending on the number of parking spaces. The law also applies to existing non-residential buildings with more than 20 parking spaces. These should have at least one high powered or normal powered charging point installed by the end of 2024. It is estimated that approximately 73,000 – 97,000 charging points and charging readiness for 560,000-620,000 parking spaces will be created by 2030. [11] The new law was approved by the parliament on 16.10.2020 [77].

According Income Tax Law there is a new temporary exemption from taxing of the electric vehicle charging benefit provided by the employer in 2021-2025. Taxable income is not generated when the employer pays for the charging of employee's own car or the company car at the workplace or at a public charging point. [78, 79] The tax exemption for the charging benefit applies to all cars that are charged with electricity. The provision does not apply to charging at the employee's home. Therefore, the employer cannot pay the electricity billed on the basis of the employee's home electricity meter or the electricity billed by the housing association tax-free. [79]

If an employee charges a car as a free car benefit with electricity paid for by his employer, the employee does not receive a separate taxable benefit from the electricity used for charging as the value of the free car benefit also includes the car's value's propulsion costs. The same applies to charging such a car at home if a separate measuring device can reliably verify the amount of electricity used for charging. [79]

A home charger is not included in the vehicle's tax value because the charging device does not travel with it like car accessories. However, according to the Tax Administration's instructions, an employer-sponsored charger is a monetary benefit for a company car driver, and the value of it depends on who eventually owns the charger [79].

## 3.4 Charging in residential and commercial buildings

Charging systems in residential and commercial buildings have a positive effect on the property's value. Having charging points in condominiums can alleviate the sale of apartments and, in turn in commercial buildings have a positive effect on the attractiveness of the property [80]. The possibility to charge can attract visitors, new residents, customers, or even businesses to set up an office in such well-equipped locations. While investing in charging points can be costly, especially when it comes to larger systems, it can nonetheless be a profitable investment.

The electric vehicle charging infrastructure's investment costs mainly consist of the price of the electric connection, the purchase price of the charging device, and the costs of installing the charging device. The amount of the investment costs is also substantially affected by whether the charging readiness is constructed and devices installed when building a new property or added to an old system in existing buildings, in which case technical work and modifications to electrical systems are often required. [56]

The construction of the charging points requires decision making by the property owner. If there are multiple real estate owners like in condominiums, fair cost-sharing is a critical issue. This mainly applies to residential buildings and housing associations, and other co-owned properties. Housing associations have an essential role in ensuring that vehicles can be loaded in car parks managed by the association. However, standard practices are still emerging, and condominiums have not yet established a routine to handle charging devices' requests. Clarification and harmonization of decision-making and licensing practices related to the construction of charging points for housing companies are an integral part of promoting electronic transport. [80]

Decisions on properties must be based on equal treatment of shareholders when sharing construction, maintenance, and operating costs. The easiest way to get started is to build charging points initially only for the amount that does not yet cause changes to the property's electrical system [29, 80]. If there is a sufficient amount of capacity, installing charging points can be decided by having a simple majority in the Annual General Meeting, provided that the shareholders' obligation to pay does not become unreasonable. To increase the capacity can also be decided by a simple majority in the Annual General Meeting, even if it is done solely for the construction of charging points. [80]

Before deciding on investing in a charging system, both residential and commercial property owners ought to consider following factors [80, 29]:

- Who is charging and what is the demand for charging points now and in the near future? In condominiums the principle of equal treatment of shareholders requires that all shareholders are inquired about their willingness to acquire a charging point. Charging in both residential and commercial locations should take into account the scalability of the charging system when the demand grows.
- How many charging devices can be installed and added without making modifications to the electrical system of the building? What is the condition and adequacy of buildings internal network and electricity connection?
- Who pays the project and equipment costs? In residential buildings if all the parking spaces are converted to be suitable for charging and the housing association is paying for the construction work, a consent from all shareholders will be needed. Otherwise those shareholders who wish to charge or have the option will pay for the work.
- When choosing a charging device it must be suitable for the use and the environment. The charging points ought to be placed in a way so that the electric vehicle can be connected to them with a charging cable of normal length.
- In the planning of inputs, provision must be made for load controlling, energy consumption metering and remote controlling. For safety reasons, it may also be

necessary to connect the charging system to other automation or security systems, such as a fire alarm system, in which case, charging can be interrupted under the control of a fire detector.

- The possibility of supplying electricity from the vehicle to the grid must be taken into account if possible. Other sustainable energy solutions like solar energy and battery energy storage systems can be used to cut peak loads and to provide affordable electricity at all times.

Separate charging of charging electricity is recommended, and this is often particularly important for the property owner to ensure fair and equitable treatment for all. The actual metered electricity consumption is the best charging basis. A higher parking fee can also be set for car parks managed by the company to cover charging electricity costs. Especially in commercial locations like in the workplace charging, possible billing needs should be taken into account. [80] If the operation of charging points is outsourced, the billing of the user is done automatically by the third party, and so the property owner does not have to worry about maintaining the charging system.

# 4. MATERIALS AND METHODS

This chapter presents the methods for conducting the research and described data collection methods and how it was analyzed. The most crucial factor in choosing methods is selecting methods suitable for solving the problem under investigation. Using several different research methods yields broader perspectives through different responses, which in turn increases the study's reliability. In a multi-method approach, many methods, researchers, materials, or theories can be used to conduct research. [81] Multi-method approach is useful if it offers better opportunities to research the chosen topic and if it makes the results and conclusions of the study more reliable [82]. Figure 12 below illustrates the flow of using different chosen research methods, data collection and its analysis.

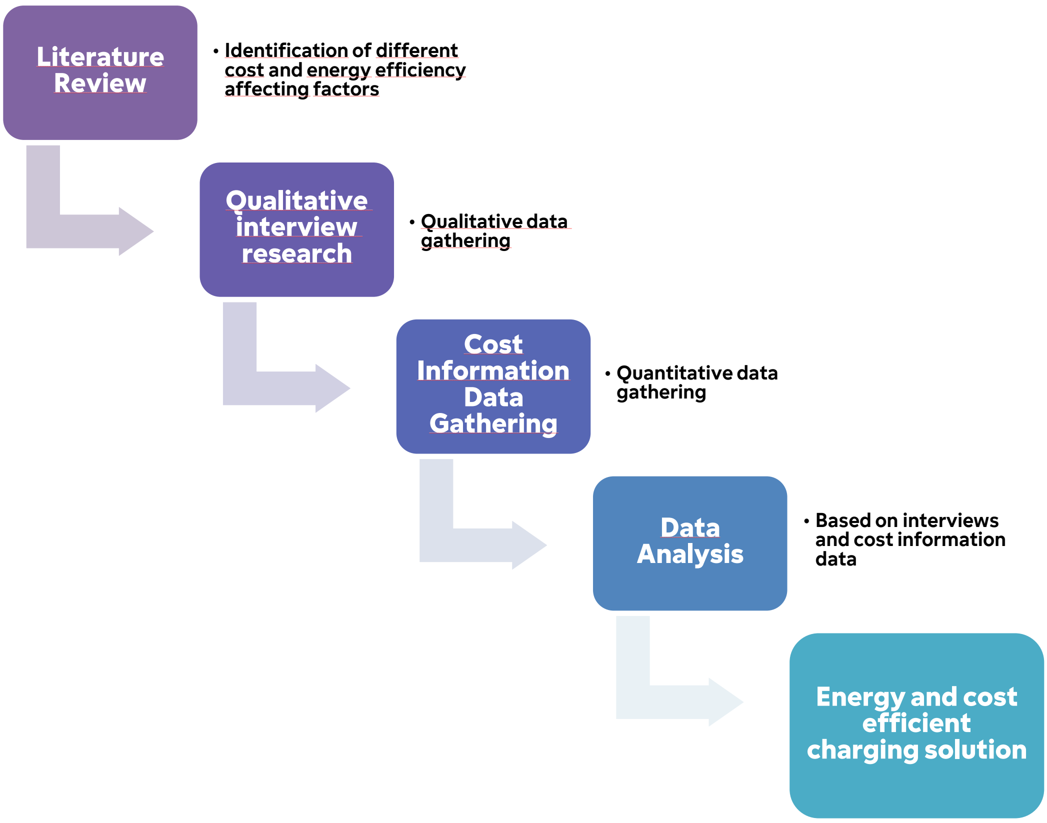


***Figure 12**: Implementation of the study and work phase flow.*

The literature review, which consisted of scientific articles, reports, and online sources, aimed to create a clear overall picture of electric vehicle charging backgrounds from a technology and market perspective. Moreover, the literature framework enabled the identification of various factors that impact the cost and energy, or rather capacity, the efficiency of different charging solutions. As affecting factors were identified and recognized in the first part of the study, the study's empirical part focused on how strong influence the different elements have.

The second part of the research utilizes expert interviews. Many factors influencing the cost and energy efficiency of electric vehicle charging were already identified in the theory part. The expert interviews focus more closely on how strong influence these factors have when designing and building an optimized charging solution in the study's target environments. The interviews aim to provide mainly high-quality qualitative data.

Quantitative data, the cost information material, for cost assessment is collected from internal databases. In the cost data analysis, the costs are broken down into categories presented later on in this chapter. Quantitative data analysis aims to provide cost estimations for efficient electric vehicle charging solutions and reflect the results of interviews. Costs are presented in percentages to protect case company’s trade secrets.

## 4.1 Studied locations; residential and commercial properties

This study concentrates on electric vehicle charging solutions for certain types of locations: residential and commercial buildings. More specifically, the study focuses on location types where, by default, more than one charging station is usually installed. However, fully public locations are excluded from the study as they are not included in the partner company's business scope, and public charging is a broad concept and would need its own study itself. Due to the nature of the business and infrastructure, the solutions in public charging have their unique requirements, and these are not taken into account in this Master's Thesis.

In the study's scope, a residential building means a building that provides most of its floor are for dwelling purposes. Half of the Finnish population, around 2.7 million people, live in multi-dwelling buildings. There are around 90,000 condominiums, and almost all of them have available parking spaces for their residents to use. [10] A commercial building is a building for commercial purposes. They include office buildings, warehouses, and retail. In this study, the scope for commercial buildings is semi-public locations, like offices that enable charging for their employees and shopping centers that offer charging for their registered customers.

The Finnish Parliament agreed on a long-prepared law on charging points for electric vehicles on 16.10.2020 (discussed in detail in section 3.3). Due to the newly approved law, it can be expected that the demand for new charging points in residential and commercial locations is going to increase considerably. Because of this and the growing electric vehicle fleet in Finland, this Master's Thesis focuses specifically on solutions for these location types.

## 4.2 Background of interviewed experts

In this study, three external experts were interviewed. Experts were chosen by their competence and suitability for the study. Based on experience and some background work, three experts were selected for the interviews from different organizations. The aim was to find people from different backgrounds who would have the most comprehensive knowledge and expertise from all aspects introduced in earlier chapters of electric vehicle charging. All interviewees use and drive battery electric vehicles on a daily basis.

The first expert (E1) currently works for a national electrotechnical standardization organization. Before his current position, he was a lecturer in a university of applied sciences, teaching vehicle electronics and electrical installation technology in buildings. Before teaching, the expert worked as a journalist for different magazines and technical university as a lecturer and researcher. The expert has a Master's degree in electrical engineering and electronics.

The second selected expert (E2) works in a management team of a company that collaborates with Fortum on the electric vehicle charging business. The company provides comprehensive solutions for the needs of e-mobility for consumers, communities, and enterprise customers. The focus is on sensible and cost-effective models that are adequately designed for customer's charging needs. Before his current position, the expert cumulated his knowledge on charging electric vehicles in a position of responsibility in another company in the same field.

The third interviewed expert (E3) is a doctoral researcher working on his dissertation in a faculty of information technology and communication sciences. He is also an entrepreneur and co-founder of a company that develops rapid and affordable electronics, delivers software projects and mechanical designs, and does consulting regarding the e-mobility field. Before his current positions, he was involved in developing a charging business in a company that is today one of the national industry leaders in the e-mobility field. His interests and know-how are focused on renewable energy systems and electric vehicles.

## 4.3 Qualitative interview research

The first part of the study is mainly qualitative. Qualitative research aims to contextualize, interpret, and understand the perspectives of the individuals involved in the research. Qualitative research can involve several research methods, and the selection of suitable methods ought to be based on the following criteria: efficiency, economy, accuracy, and reliability. [81]

The empirical part of this study uses expert interviews as a research method. Interviews are suitable for a wide range of studies due to their flexibility. In this study, interviews are performed by an individual interview, which was chosen due to the nature of the study. Individual expert interviews were seen to provide an opportunity for broader discussion, in which the expert's point of view could be expressed the best. The individual interviews in the study are thematic and semi-structured. It is common for thematic interviews that the interview proceeds with a focus on the themes and it does not have precisely formulated questions nor order for the questions. The purpose of the interviews is to bring out the interviewees' different perspectives. [81]

The interviewees were gathered using purposive sampling. Purposive sampling enables the researcher to use one’s own judgment to select experts that will best enable the researcher to answer research questions and to meet one’s objectives. This form of sampling is often used when working with small samples, for example. This method can also be used to adopt a grounded theory strategy; findings from data collected from initial samples inform the way one extends samples into subsequent cases. [83] This is implemented in this study. This method's limitation is that it cannot be considered statistically representative of the total population. The logic based on the strategy for selecting cases for a purposive sample ought to be depended on research questions and objectives [83].

In the individual thematic interviews, the interviewees were selected for the study based on their background and competence. It was important that expertise in at least the areas that were identified from the literature framework was represented: charging technology, electrical installations, smart charging, Finnish electric vehicle charging market, and charging in scope locations of the study.

The request and invitation to participate in the interview were sent via email. Due to the prevailing pandemic the interviews were held remotely via online video conferencing tools. Individual interviews were held close to each other in time and all lasted around 60-90 minutes which was informed to the interviewees beforehand. To enrich the quality of discussions the interviews were held in Finnish which is the native language of interviewed persons. After interviews, the answers were translated to English to be analyzed later on in the study.

The questions that were used in the framework of the interview were selected on the basis of observations from the theoretical part of electric vehicle charging. The questions on which the interview is based on are listed in Appendix 1.

## 4.4 Qualitative data analysis: Interview research

The data collection in this Master's Thesis consists of data gathered from the interviews and case company's data bases. The data used in the empirical part of the study was collected through interviews. Discussions between the interviewer and interviewees were recorded to re-examine the qualitative data acquired from the interviews. The interviewees' positions in their organizations, the durations, and the dates of the interviews are summarized in Table 3. Recording of interviews was used as the data collection method.

***Table 3.*** *Conducted interviews in the empirical part of the study*

| ***Number of interview*** | **Expert** | **Current Position** | **Duration** |
|---|---|---|---|
| *I1* | E1 | Group and Communications Manager | 70 min |
| *I2* | E2 | Senior Vice President | 60 min |
| *I3* | E3 | Entrepreneur and PhD Student | 90 min |

In addition to interviews, qualitative data collection had a unique role in this Master's Thesis as the researcher worked for the company during the research process. Therefore, the qualitative data was collected not only through interviews and organized meetings but also in unintentional discussions that took place during the time she worked in the team. Thus, the researcher could make observations related to the research overtime on the side of work duties. Moreover, the researcher conducted a market research on electric vehicle chargers just weeks before starting the Master's Thesis project, which had given her an overall picture of the markets beforehand.

There are three stages in analyzing qualitative data: description, classification, and aggregation. In the description of the material, the interviewees' perspectives and experiences are mapped. The classification structures the results of the interviews into an easy-to-interpret format. In combining the data, the results are put together. [84] It is typical for qualitative research that the analysis of the data collected in the research takes place partly at the same time as the collection of the data. This is done, for example, by the researcher making notes on the findings and their frequency, distribution, and emerging exceptions during the interviews [81]. The qualitative data analysis has used the approach in which the researcher transcribes the interviews and organizes and clarifies the data before starting the actual analysis. In arranging and clarifying the material, parts of the material that are irrelevant or repetitive are removed, and the material is arranged into a cleaner structure. In the actual analysis of the data, the material is summarized, classified, and interpreted. [85]

When analyzing the qualitative material, the intention is to first break down the material into parts and then create a sensible and scientific conclusion from them by synthesis [82]. The data analysis performed in this study for the qualitative data has overlapped with the data gathering, as the ideas that emerged from the interviews were recorded and written down and so they gave new perspectives to subsequent interviews.

The analysis of individual interviews was started by transcribing the interviews. In the transcribing, the most relevant parts of the discussion for the study were written down - The whole interview was not written down word for word. The data is then categorized according to the questions and compared with each other, highlighting options that are unified and divergent. As the interviews progressed, the perspectives raised in the previous interviews were used in the following interviews, and an even broader understanding of the topic was sought.

## 4.5 Quantitative data analysis: Cost assessment

In the second stage of the study a cost assessment is conducted. Almost any business research undertaken is likely to include some numerical data that could usefully be quantified and help one answer research questions [83]. The quantitative data contains the acquired data from the company's databases. In more detail, the data represents the costs of the delivered electric vehicle charging projects in different residential and commercial locations in 2020. As there was no ERP system (Enterprise Resource Planning) available where data could have been extracted from in the form of reports, the data gathering was done manually. Databases used for data gathering included case company's purchase order systems and spend management tools from which invoices could be viewed individually. In the quantitative data gathering phase, an excel template was used, in which the data from internal databases was collected into an easy-to-handle numerical format.

Quantitative data in its raw form before it is processed and analyzed has very little meaning to most people. In this Master's Thesis, the quantitative data consists mostly of cost information data from different delivered projects, including costs of materials and service. This data needs to be made useful and turned into valuable information. Quantitative analysis techniques like graphs, charts, and statistics enable us to do this by describing and examining relationships or trends within the data. It aims to interpret the data collected for the phenomenon through numeric variables and statistics. The data handled in this study is numerical, which means that the values are measured or counted numerically as quantities.[83]

A project budget determines estimated costs of individual activities. A project can only come together with all the necessary materials and labor, and these both cost money. Cost estimation is a process of forecasting financial and other resources needed to complete a project within a defined scope. It accounts for every element required for the project, including materials and labor, and determines a total amount for a project budget. An initial cost estimate can determine whether a project is taken on, pared-down, or even declined. This cost assessment addresses costs from an investment perspective.

There are usually two fundamental types of costs addressed in the cost assessment: direct and indirect costs. Direct costs are connected to a single area like a project itself. Fixed labor work, materials, and equipment belong to direct costs. Indirect costs include costs incurred by the organization at large, like utilities and quality control. Due to time constraints, only direct costs are reviewed on a project level in this Master's Thesis.

After gathering the quantitative material, the data was reviewed, and unnecessary material was removed. After preparing the data, cost data were allocated to different projects according to the project numbers and other information that was possible to obtain from the invoices and orders. This was done in order for the researcher to be able to identify which costs belong to which projects as the cost analysis was to be done to each project separately. After allocating the costs to the correct projects, the costs were divided into three categories: materials, services, and others.

The study examines the costs of 24 different charging systems. Examined systems and the number of charging devices and installed kilowatts per system are presented in Table 3 (p. 49). The case company of this Master's Thesis has delivered charging systems with two different solutions. In the analysis, the systems are divided into two categories accordingly to the solution type that they are executed with. Therefore the system costs are also divided into different diagrams. Dividing systems into two categories is done because the solutions' contents differ significantly from each other. Different solutions and contents affect the system prices, and therefore separating systems according to the solution makes the costs comparable between systems with the same solutions and systems with different contents. Solution types, A and B, are described below. All systems are delivered with a turnkey principle.

**Solution A** is customized to the customer's needs and can include, among other things, different models of chargers. In the solution, it is possible to have a higher charging power, which is why Solution A is more popular, especially in commercial locations. The systems implemented in accordance with Solution A utilize the partner company's own intelligent backend system, and because of that, all the systems supplied with Solution A are in principle intelligent and contain intelligent devices.

**Solution B** is an outsourced one and has more narrow content as the systems supplied with Solution B can only have one charger model. In this Solution, the chargers' power is limited to 3.6 kW, but the devices also include the possibility of heating the car, as they also have a Schuko plug. Solution B is particularly suitable for residential buildings, but it is also used in commercial applications. A characteristic feature of the Solution is that the chargers are installed in place of heating plugs, and therefore separate contracting and modification work does not have to be done at the site. Since separate contracting is not required at Solution B sites, it is often the most affordable Solution. Solution B contains intelligent features but is not as intelligently advanced as Solution A.

First in the cost assessment, histograms present the cost distribution within the systems. For both solution types, there are two histograms. The first one illustrates the overall relative distribution of material and service costs in each system of a solution in percentages (%). The second one also illustrates the overall distribution of costs and shows a relative comparison of systems costs between the different systems. All systems executed with the same solution are presented in the same histogram so that the comparing of relative system costs and distribution of costs is more straightforward.

The cost assessment section will also include a cost curve. The cost curve is formed according to the relationship between the size of the delivered charging system in kilowatts and the cost of one installed watt. The systems are divided into two different curves according to the solutions. Also, because cost of contracting was not available for all systems, in cost curves, only cost of materials and installation has been taken into account to make the costs comparable. The cost curve for different AC charger options is also presented in the same section. This cost curve is formed according to the relationship between the charging device’s charging power and the cost per watt that indicates the power of the charger.

In addition to histograms, cost curves, and collective review of these 24 systems, 3 of the systems are reviewed in more detail. In these reviews, the relative costs of each three system in percentages (%) are presented in a doughnut chart and reflected in the contents of the system. A closer look into these three systems is made to understand better how different system contents and decisions affect the distribution of costs in a project. Individually examined systems are presented in Table 4.

***Table 4**. All 24 examined charging systems*

| ***System*** | **Solution** | **Number of charging devices** | **Installed kilowatts** |
|---|---|---|---|
| *System 1* | A | 4 | 14,8 |
| *System 2* | A | 10 | 37 |
| *System 3* | A | 3 | 66 |
| *System 4* | A | 3 | 66 |
| *System 5* | A | 2 | 44 |
| *System 6* | A | 2 | 44 |
| *System 7* | A | 4 | 88 |
| *System 8* | A | 2 | 44 |
| *System 9* | A | 30 | 660 |
| *System 10* | A | 48 | 1150 |
| *System 11* | B | 1 | 3,6 |
| *System 12* | B | 5 | 18 |
| *System 13* | B | 6 | 21,6 |
| *System 14* | B | 2 | 7,2 |
| *System 15* | B | 2 | 7,2 |
| *System 16* | B | 1 | 3,6 |
| *System 17* | B | 1 | 3,6 |
| *System 18* | B | 1 | 3,6 |
| *System 19* | B | 3 | 10,8 |
| *System 20* | B | 2 | 7,2 |
| *System 21* | B | 2 | 7,2 |
| *System 22* | B | 2 | 7,2 |
| *System 23* | B | 1 | 3,6 |
| *System 24* | B | 1 | 3,6 |

In Table 3, the sorting of systems for the assessment is shown. Systems inside the blue box are systems executed with Solution A. A separate histogram and a cost curve of system costs are formed for these. Systems inside the red box are systems executed with Solution B. Separate diagrams are created for these systems costs as well. Systems whose costs are reviewed with a closer look are marked with yellow boxes in Table 4. These include the following features and equipment presented in table (5) below.

***Table 5.*** *Absolute costs of three different delivered electric vehicle charging systems*

| | |
|---|---|
| **System 2**<br>(Solution A) | System is in a residential building. A total of 10 chargers were installed at the site and separate cabling was laid for the chargers, which is why, in addition to material and installation costs, the construction costs are also included in project costs. The installed chargers are smart Mode 3 devices and have 3.7 kW charging power. The devices are connected to case company's own backend system through which load balancing and monitoring of energy consumption also take place. Internet connection to the devices was obtained with ethernet cabling and a modem intended only for charging devices. The devices communicate according to the OCPP. |
| **System 10**<br>(Solution A) | System is located in a commercial building (office) and it has been built for work place charging. It has 46 AC chargers with 22 kW charging power and 2 pcs 55 kW DC chargers. Devices have intelligent features, built in dynamic load balancing capability and they are suitable for Mode 3 charging. Chargers are connected to case company's own backend system where monitoring of energy consumption takes place and billing of charging events. Internet connection was achieved via data cabling and ethernet connection with few separate modems. Devices communicate according to the OCPP. Costs include construction work, installation, materials and other costs like license fees. |
| **System 12**<br>(Solution B) | The third system is located in the parking area of a residential building. System includes five 3.6 kW chargers installed directly in place of the heating poles. As a result, no major alterations to the site have been required. The devices in the system are suitable for Mode 3 charging and connected to a different, outsourced backend system. This backend system does not require OCPP connectivity and the chargers do not communicate according to the OCPP although they have smart features. However, the intelligence of the devices is not as advanced as in the chargers of the two previous systems. |

# 5. RESULTS AND DISCUSSION

So far, this Master's Thesis has presented a literature framework of electric vehicle charging and market conditions in Finland. This chapter presents the empirical results of the research and cost estimate for electric vehicle charging systems.

## 5.1 Factors that affect energy and cost efficiency of a charging solution

An energy and cost-efficient charging system is a broad concept that encompasses several varying features, and there is no detailed description for it. In some cases, energy efficiency can be considered part of the cost-effectiveness of a solution as these two factors go hand in hand in most energy related cases. Energy efficiency in itself is also a large concept, and when specified, in the context of this Master's Thesis, energy efficiency alludes to capacity efficiency that can be considered to be included in the energy effectiveness of a system.

When beginning to design and construct a charging solution for almost any location, it can be assumed that the solution aims to be both. Who would want to pay extra for a solution or the charging energy anyway? What is an energy and cost-efficient electric vehicle charging solution and what features does it cover? Based on the literature review and interviews, the following conclusions could be drawn about factors that affect a charging solution's energy and cost-efficiency in residential and commercial buildings. In figures 13 and 14, these factors are presented both for residential and commercial buildings. An affecting element's effectiveness is described using plus signs on a scale of 1-3. Experts' comments and answers are presented in Appendix 2 in more detail.


***Figure 13.*** *Factors that affect charging system's cost and energy efficiency in residential buildings*

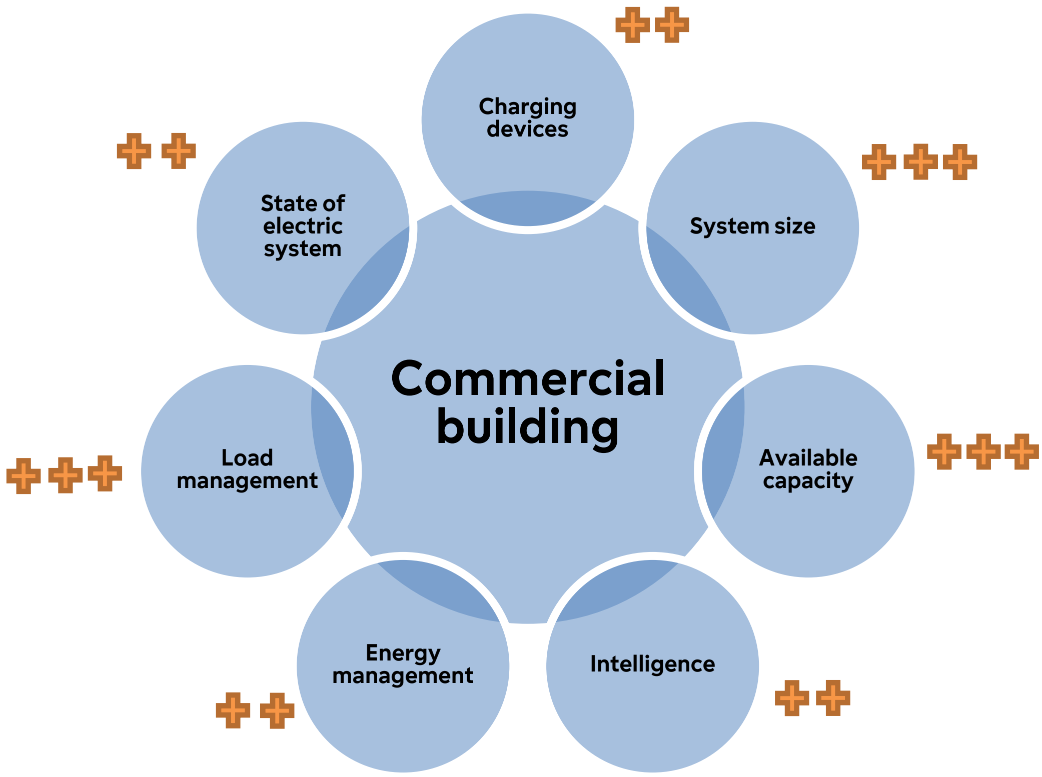


***Figure 14.*** *Factors that affect charging system's cost and energy efficiency in commercial buildings*

These elements shown in figures 13 and 14 are discussed in more detail in the following chapters. Lastly, an optimized solution content and features for energy and cost-efficient charging system are presented both for residential and commercial buildings.

## Property’s electrical system

One separate entity could be identified from the interviews' results: the property's electrical system. Building's age, heating system, power distribution center, and available power capacity all affect the energy and cost-efficiency of a solution, and these are discussed in more detail in this section.

According to all the experts, every residential and commercial building needs a site-specific customized solution. Nevertheless, this does not prevent the searching and offering of indicative solutions. All three interviewed experts stated that the energy and cost-efficiency should always be considered to be customized according to the customer's need. There is no one right way to design and construct a system.

In terms of minimizing costs, renovations and alterations made to the electrical system and main distribution board ought to be delayed as long as possible. If electricity can be drawn from the old main switchboard, the costs are also lower. However, according to Expert 2, it makes the most sense to build a separate fuse board in the main distribution center, which determines how large capacity is reserved for the charging overall. This is worthwhile, especially if more than one charging device is installed, which is usually the case in commercial and some larger residential properties. A separate fuse board installations are one of the most common implementations as the solution enables first-level load management and makes adding new chargers to the system easier.

Properties with district heating systems can have overcapacity in power. In these kinds of locations, the instantaneous consumption peaks of electricity occur when many electrical devices are on at the same time, such as during public holidays. Consumption peaks are only momentary and often do not limit available capacity. According to Expert 2, this is not always the case if several electric vehicles need to be charged simultaneously.

Both experts, 1 and 2, agreed that properties with electric heating systems differ from the others even though the trend has long been to move towards less consuming and more energy-efficient devices and systems. Nonetheless, the adequacy of power capacity and the features of the property's electrical system should always be determined during a first site visit and a pre-mapping phase.

The electrical systems, specifically in older residential buildings, can create other possible bottlenecks. In older buildings, the capacity reserved for charging is often lower, which can lead to the need to enlarge the electric power lanes. This means that also the project costs will most likely increase. If the property is built in the 21st century, the available capacity often does not impose significant charging restrictions unless it is a multi-device system.

The overall costs will always increase significantly if ground or asphalt needs to be excavated open to add power cables. Thus, it is not advisable to increase the available power capacity or dig additional electric power lanes if there is no need. Some local electricity distribution companies, such as Caruna Oy in Finland, offer new electricity connections to properties located in the sphere of activity. However, the excavation and cabling work will be paid for by the customer.

The easiest and most affordable solution is to replace the car heating poles with charging stations. Though this can only be a temporary solution as the cabling, originally meant for only heating, cannot provide higher charging powers or a charging system that stands the test of time. If the need for charging capacity is high or more charging devices enter the system, it is useful to take that into account on a central distribution center level and build a separate fuse board for charging devices.

### Load management

Load balancing is a feature that is essential to incorporate into an electric vehicle charging system, especially as the number of electric vehicles and chargers in the system is increasing. [61] Limiting the charging load protects the local electrical network and prevents the electric power lane to overload even if all the charging stations are used simultaneously. Balancing and managing the charging load prevents the need to grow capacity and reduces the costs of a charging system.

All properties will not withstand momentary consumption peaks caused by electric vehicles' charging. There will be no unlimited amount of additional power at any location, especially in the future when the expansion of e-mobility is expected to occur. According to Expert 2, load management has had to be considered in all systems in which he has been involved in delivering the system. The system must stand the test of time for the system to be cost-efficient, and load management enables this.

The dynamism of load management was seen to provide a clear advantage as it ensures energy-efficient charging. In dynamic load management, the chargers communicate with each other either via a shared network connection or an intelligent backend system and share the available power in proportion to how many vehicles are being charged at the same time. If there is 100 kW reserved for 15 devices, all get around 6.7 kW if used simultaneously. However, with a dynamic system, if only five charging devices are used simultaneously, all stations get a significantly higher charging power of 20 kW. According to Expert 1, dynamism in a load management solution is a feature that cannot be compromised unless it is a property with and redundant power capacity that heats by district heating. Dynamism can only be achieved with Mode 3 and 4 chargers with smart features.

As stated in the previous section, load management should be independent of a separate backend solution because if the operation service had to be given up for one reason or another, the system would soon become inoperable. On the other hand, the backend system enables an intelligent and dynamically operating system. A separate backend system in load management is emphasized, especially when the context is the entire property and its electrical system. Experts saw that intelligent load management that could manage the property's electrical load throughout would serve as a future solution when prices drop, and technology evolves.

The downside of dynamic load management is the uncertainty it creates about the power level at which charging can be obtained. Expert three, therefore, sees load balancing as a so-called mandatory evil. For example, if the need was to charge with 22 kW power for 4 hours, but only 7 kW is available during that time, the battery will be charged significantly less. It creates difficulties in planning the charging schedule and using the vehicle efficiently. Since increasing the available charging capacity is costly, the dilemma regarding dynamic load management could be solved, for example, by clearly communicating the power level at which the battery can at least be charged. In such a case, the promise is fulfilled, and the expectations for available charging power will not be unfeasible.

## Demand response and smart home solutions

Demand response is especially needed when inelastic and renewable energy production increases. [39] Demand response can also happen site-specifically, and it is possible through smart home solutions. In terms of cost for the consumer, scheduling charging for times the price of electricity is at its lowers is the most cost-effective way to charge. This can also support the sustainability of the electrical grid and the adequacy of energy in the long run.

According to Expert 2, monitoring the entire property's consumption and distributing power to devices that need it in the first place improves the energy and cost-efficiency of a solution. Expert 3 also believes that there is an existing demand for a self-limiting system that could improve buildings' overall energy efficiency. A similar solution where all electrical devices of an intelligent system communicate with each other may also become a necessity in a large parking area. If a residential building has only a few charging stations, investing in a smart home solution is not reasonable as a so-called dumb system works well enough in those locations and is more affordable.

All three interviewees agreed that smart home and site-specific demand response solutions are for the future in the electric vehicle charging context. Because charger volumes in properties are still relatively low and smart home solutions expensive, they are not yet cost-efficient enough. For the solution to be justifiable to install, enough large and flexible electrical loads would need to be found from the system to keep the project costs reasonable. Such loads can be found in commercial locations but not in smaller residential buildings.

In the bigger picture, yet the Finnish market does not offer a solution where the system could react to electricity price. The power for electric vehicle charging still comes from the building's electric power lanes, and if smartness does not exist on a property level, neither the property nor the charging device can react flexibly to the price of electricity. If the system could take the electricity price into account while charging, it would be very cost-effective for the user and system-wise.

## Charging devices and technology

Chargers are highly standardized products both in Europe and around the world. Standards were discussed in the theory section (p.10-17). Therefore there are rarely remarkable differences in charging devices. However, the details and different functionalities can affect the user experience and functionality of a device.

From a power point of view, medium power AC charging that guarantees a charging power of around 3-22 kW is often enough in residential and commercial locations. With Mode 1-3 charging, it is possible to achieve charging power from this range. In particular, Mode 1, 2, and 3 are popular charging methods in condominiums and Mode 3 and 4 in commercial locations, which was also stated by Falvo et al [25]. It is not recommended to charge in Mode 1 for long periods due to fire safety reasons, but if the charging current has been limited enough and the system is grounded, it is an easy way to charge one’s car [29].

High power DC chargers create value mainly in the public charging infrastructure. In addition to the public charging, the potential need for high-power charging occurs only in workplaces or large office buildings, and there should be a larger parking area for a fast charger to be useful. A fast charger can increase the overall level of a charging service and have a positive influence on a brand of a company that chooses to offer fast charging. When the whole charging system is assessed as a whole, it may be cost-efficient to invest in a Mode 4 charging after all.

According to Expert 3, it is the most profitable to choose the most reliable option from all possible devices, even if it means that the costs are higher. If a charger does not work correctly, it will ruin the service both for the consumer and the service provider. It has an impact on the maintenance costs as costs increase when the device has to be repaired frequently. The guaranteed long-term performance of a device impacts cost-effectiveness as often it takes time both at the back office level and in the field to locate and repair a single, seemingly insignificant, fault.

Although chargers' manufacturing is standardized, it is Expert 2 that sees these guidelines can still be interpreted differently. For example, integration into a possible backend system is more challenging for some devices. Thus, apparent differences can be observed, especially in convenience. In addition to installation, the device may need tampering if its components have failed. Chargers have wearing parts that sometimes ought to be replaced. Therefore serviceability must be taken into account when choosing a charging station.

As noted earlier, the load management feature is an essential part of charging devices and systems to avoid the collapse of a local low voltage network. [61] The ability to control the load externally and inform the device how much power and electricity is allowed to take for charging is a valuable feature. It also enables the charging system to stand the test of time and have a longer life span. Expert 1 would choose to install a Mode 3 charger with a Type 2 connector, which is the typical solution, especially in Europe [13], only if the device is designed with an intelligent load management capability. Nevertheless, both experts 1 and 2 thought that Mode 3 chargers enable useful features for charging and the system. Expert 3 favors safely implemented Mode 1 charging with three-phase power and Schuko-plugs for charging, especially in residential buildings, as he aims to avoid the hassle around charging devices.

In general, experts did not see the design and external features of a charger affecting the selection of the device. Particularly in environments where the charger is used only by specific predefined individuals, a fixed cable was seen to benefit the user experience.

From the point of view of the electric vehicle driver, functionality is the thing that matters, not the design. Since a battery electric vehicle must be charged almost every day, ease and functionality should be the priority in charging. For the user experience, indicative lights that communicate charging status to the user are more valuable than complex touch screens that often act up.

Currently, authentication and thus payment for the charging takes place mainly through applications or RFID-tags provided by the service providers. Expert 3 stated that identification by registration number is not a new invention and could ease the charging process. This feature would increase the overall efficiency of a charging process, especially in locations where identification is needed, like in commercial locations. The harmonization of authentication methods would simplify the charging for both consumers and service providers.

### Smart charging

In the context of cost and energy efficiency, only a few features, mentioned by Virta and in the theory section, provided by smart charging have a primary effect on the efficiency of a solution: dynamic load management and smart energy management [33]. Of course, other features can indirectly have a positive effect on efficiency too. For example, route planning and automated billing process can save time and, therefore, indirectly impact cost efficiency by decreasing the costs of operating a system.

A charging solution should be able to function at least at some level, even if the backend system and the so-called intelligence fall out of the system. Full dependence on a backend system should be avoided, and load management should be arranged so that its functionality is not dependent on external systems. In the interview, it was debated if a charging solution should perhaps be as dumb as possible, but still only as dumb it will not limit necessary functions.

The possibilities of smart charging were also considered from the perspective of demand response and electricity prices. Utilizing stock electricity prices in charging is cost-efficient but would require batteries to support the system so that affordable electricity would always be available. Indeed, if the electric load is managed by the backend system and the demand response solution, it could have a reducing effect on electric power lane sizes, which in turn would reduce costs.

According to Expert 2, smart backend systems will be utterly building-specific in the future. In this case, chargers would be connected to the property's backend system, and all the electrical devices in the property would communicate intelligently with each other. Smart home and energy management solutions were discussed in more detail in the previous section.

If intelligent charging is the way to go, the charging stations must somehow be connected to the internet. Establishing a network connection with SIM cards and subscriptions is a reasonable alternative, especially for locations with only a few charging devices, as it is the easiest solution. Before making the decision, it must be considered that SIM cards and subscriptions only work on the ground as there is rarely reception in parking garages that are located underground. The downside of SIM cards and subscriptions is that they always need to be managed, which increases operating costs.

Routing a separate data cable is often more expensive but more cost-efficient if many chargers are added to the system. Adding new chargers to the same system is very simple this way, and the cost of an internet connection will not rise like they would in acquiring additional SIM cards and subscriptions. Unlike SIM cards, the data cable is the best choice for underground locations. A system that connects to the internet using data cables also includes a modem. In all experts' opinion, the most sensible solution would be to have a separate SIM card and subscription for the modem as properties' network connections are often weak. Connecting the system to one of these kinds of weak networks can cause interruptions in charging, which can cause fault conditions. Resolving fault cases is expensive, so to achieve cost-effectiveness, it is worthwhile to arrange the internet connection in the most reliable way possible, whether it is a large or small system.

## Costs and financial aids

High costs are often the primary reason for not taking on a project. Experts agreed that whether project costs were high or not, clients often favored lump sums over monthly fees.

Like Chapter 3.3 presented, ARA provides support to housing companies to implement electric vehicle charging projects [73]. The support provides considerable financial relief to condominiums and encourages condominiums to invest in residents' charging capability. However, the interviews discussed whether it was sensible for a housing association or any other property to invest more than the amount corresponding to the demand for charging points. At least five or more charging readiness spots or points must be constructed and installed to the location to receive financial aid. Only in few condominiums, especially those outside the Helsinki metropolitan area, there is a need for more than five charging points as electric cars still represent a minority in the car fleet. As a result, housing cooperatives are not particularly interested in investing large sums in comprehensive alternation work.

Experts agreed that in the future, changes will inevitably have to be made to the solutions, regardless of whether they are now made modern and high-tech or not. Even though it can take five or even ten years to add chargers, it is good to have an action and financial plan to grow the charging system in the future.

## Energy and cost efficient charging solution for residential and commercial buildings

Based on the interviews, the content of an energy and cost efficient charging system for both a residential and commercial locations is summarized below. Figure 15 illustrates optimized contents of these two systems.

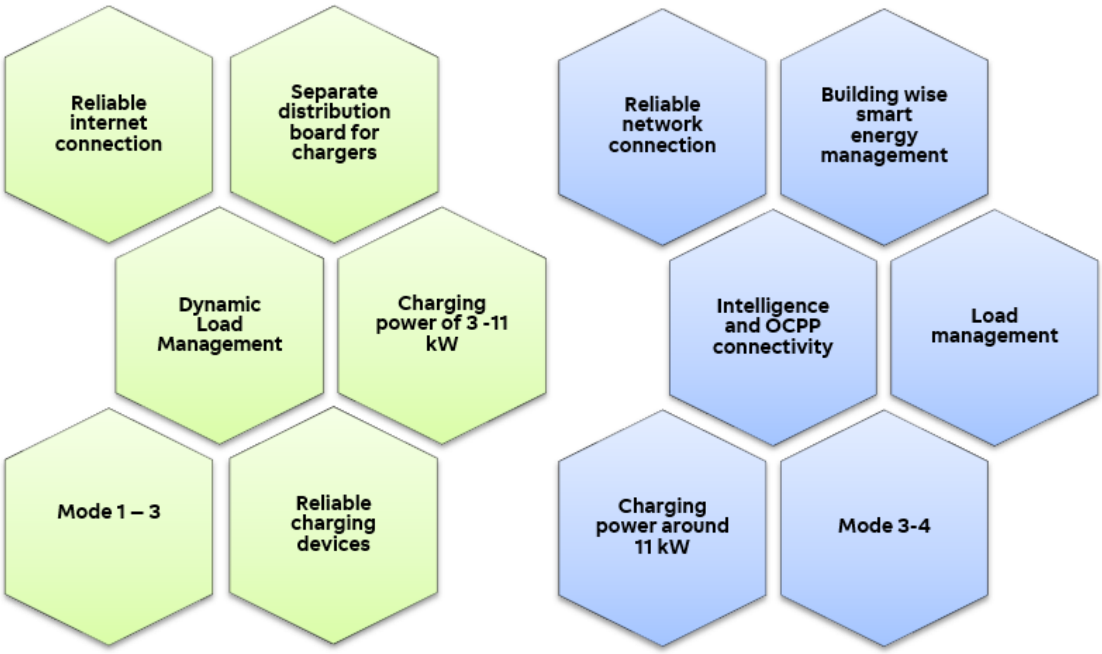


***Figure 15.*** *Features of energy and cost efficient charging systems in residential (left) and commercial (right) buildings*

Figure 15 shows that the content of energy and cost-efficient charging solutions in residential and commercial buildings are somewhat similar. Both locations need some load management system and reliable internet connection if intelligent features like dynamism in load balancing are needed. Experts agreed that shared devices do work in commercial buildings but in residential buildings all users should have their own charger in order for the charging experience to be efficient and convenient.

Undeniably reliability of devices is vital in residential and commercial locations, especially when it comes to home charging. Charging at home is the most effortless way to charge as the vehicle is naturally parked overnight in residential locations. Because most of the charging usually happens at home, it is a principle that the devices function well in residential locations. Higher quality chargers cost more but have a decreasing impact on maintenance costs over system's life span.

According to the interviews, commercial buildings and public locations benefit more from high power charging. This was also noted in the theory section p.9. As in residential buildings, users tend to stay longer, charging for long periods of time, and therefore having lower charging power is also possible there. Suitable charging power for residential locations is around 3-11 kW, depending on what kind of a vehicle is being charged and how empty the battery is. For commercial buildings like offices and shopping areas, a higher charging power around 11 kW or above was seen to be suitable as there users tend to stay for shorter periods and need faster charging for the battery. Charging mode is usually chosen according to the charging needs and the location type [26, 29]. However, the mode that fills the requirements of an efficient charging solution is Mode 3 in both target locations.

When it comes to intelligence, it benefits both residential and commercial charging systems. The OCPP seems to be a protocol that defines a lot in the charging market today and therefore choosing devices and systems that support the protocol is wise in a long run [44]. There are not many solutions in the Finnish market that utilize smart charging features like demand response, smart energy management, and electricity spot price that could be useful in residential charging systems. Whereas market players like CPOs and EMSPs have made use of features like automated billing, starting a charging event, and reserving of charging points [33]. These are all characteristics that are needed in semi-public and public charging. Therefore smart charging to its fullest extent is not necessarily needed in residential buildings even though choosing devices that still support OCPP is convenient for the future.

Smart energy management is usually a bonus and sometimes a prerequisite for having a multi-device charging system in any building. Today smart energy management considers only dynamic load management that manages either only chargers or larger entities. As mentioned in the interviews, demand response solutions that would take other large loads in the building than charging into consideration and distributing the energy according to demand are still rare. Nevertheless, in larger charging systems, like ones in large office buildings and shopping malls, smartness in energy management is considered a plus because it can allow the system to have more devices or higher charging power. Having a separate fuse for chargers is often enough on the energy management level in residential buildings. If possible and cost efficient, adding additional intelligence to manage the overall power distribution in a building is cost and energy efficient if enough high power loads can be found.

## 5.2 Cost of electric vehicle charging solution

This section presents how material, service and other costs are distributed on average within a system's investment costs. First, the system costs of two different offered solutions are reviewed and second, three delivered systems are examined in more detail and in those reviews the costs are reflected to the system's content.

### Costs of systems with Solution A

Almost all the reviewed costs of the systems with Solution A included only the costs of materials and installation work as information on what the civil works had cost and how comprehensively they had been carried out was not available. Figure 16 shows the mutual distribution of the delivered systems' costs within the projects. Figure 17 presents the relative system cost differences between Solution A systems.

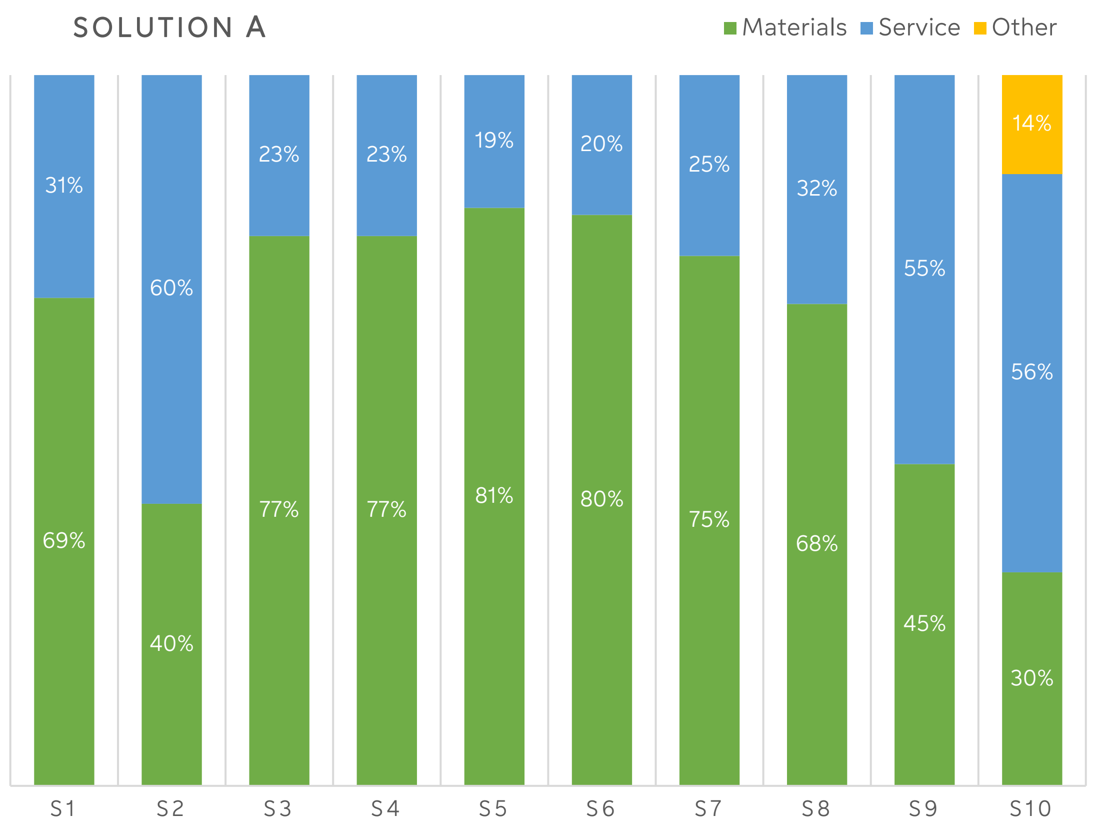


***Figure 16.*** *Distribution of project costs of systems executed with Solution A*

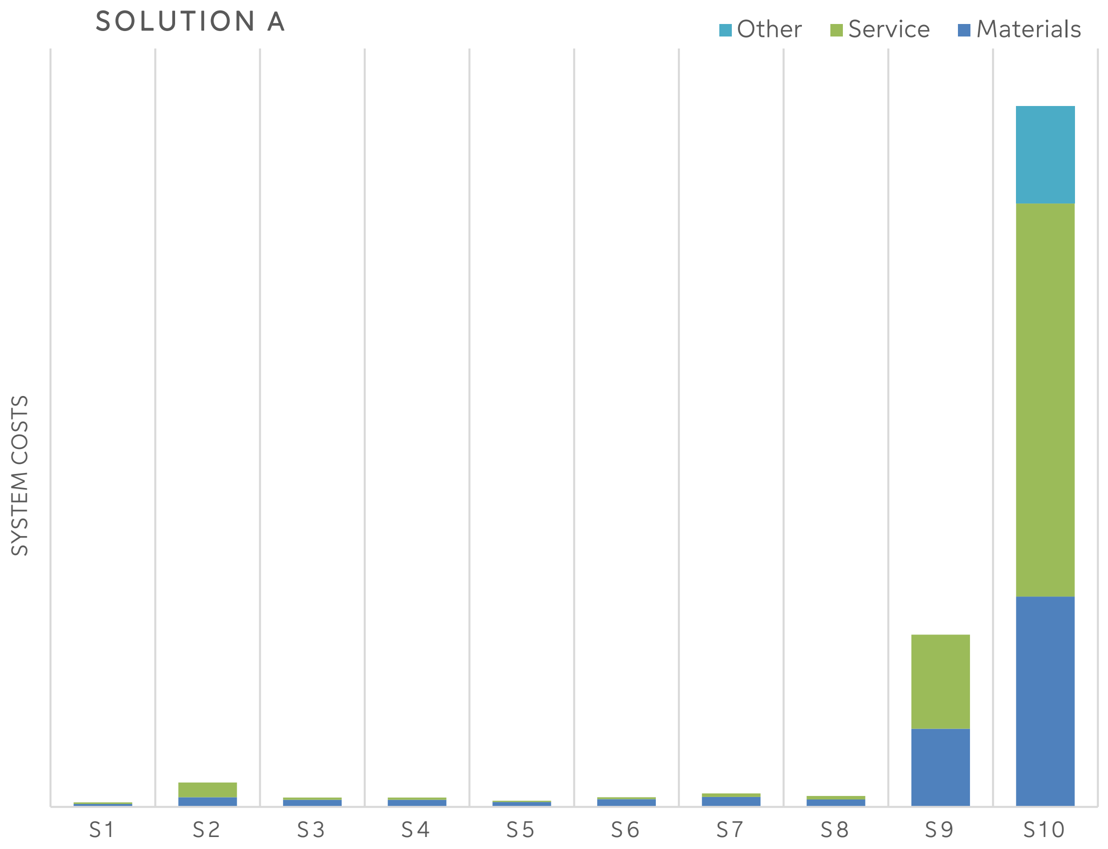


***Figure 17.*** *Solution A system sizes and costs compared*

Figure 17 shows the relative system cost differences between Solution A systems. Judging from system costs, System 10 is the largest, as presented in Table 3. Figure 16 shows how more than half of the project costs consist of material costs when the civil work is already done at the site. According to the interviews, Mode 3 chargers are still relatively expensive, and this can also be seen from the results of the cost assessment. The materials costs include charging devices, foundations, modem, and other installation accessories. The cost-share of the materials varied between 70-80 %, and the share of installation work accounted for 20-30 % of the project costs.

Systems 2, 9, and 10 differ from the pattern as the relative share of service costs are considerably higher in these three projects. The project costs of these systems also consider the costs of civil works. As stated in the interviews, civil works and growing charging capacity on site is often the most costly part of the project. In these projects, civil works consisted of an enlargement of the electricity connection, excavation of asphalt, cabling, and in System 10, the establishment of a new substation. From Figure 16, it can be inferred that building a new substation is expensive and a high capital expense in a charging project.

In most of the systems implemented with Solution A, no other costs were available to be identified except for System 10. It can be concluded that other costs in the projects have been merged with the service costs as building a charging system almost always requires a plan and a pre-mapping visit. In System 10, the other costs created around 13 % of project costs. As System 10 is also examined individually later on in this cost assessment, the closer review for this project's other costs can be found on page 69.

## Costs of systems with Solution B

In systems that were executed with Solution B, the site's modification works were included in the project costs. In this solution, modifications are part of the cost of the service and have thus been integrated into the service work integrity. The previous chapter clarified how the systems implemented with Solution B do not require significant modifications to the site if Mode 3 chargers are installed to the places conventional heating poles. In this case, the cabling and charging readiness is already done, and no extensive civil work is needed. Figure 18 illustrates the distribution of the costs in the systems executed with Solution B. Figure 19 presents the relative system cost differences between Solution B systems.

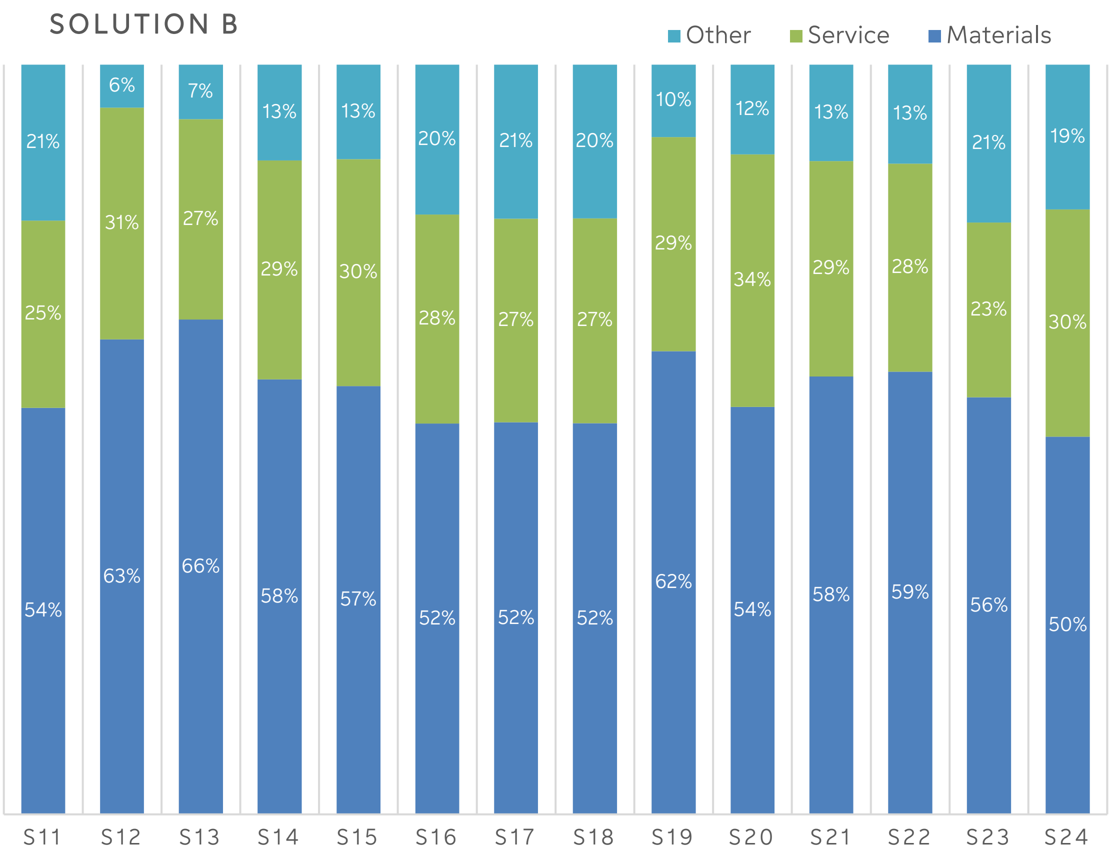


***Figure 18.*** *Distribution of project costs of systems delivered with Solution B*

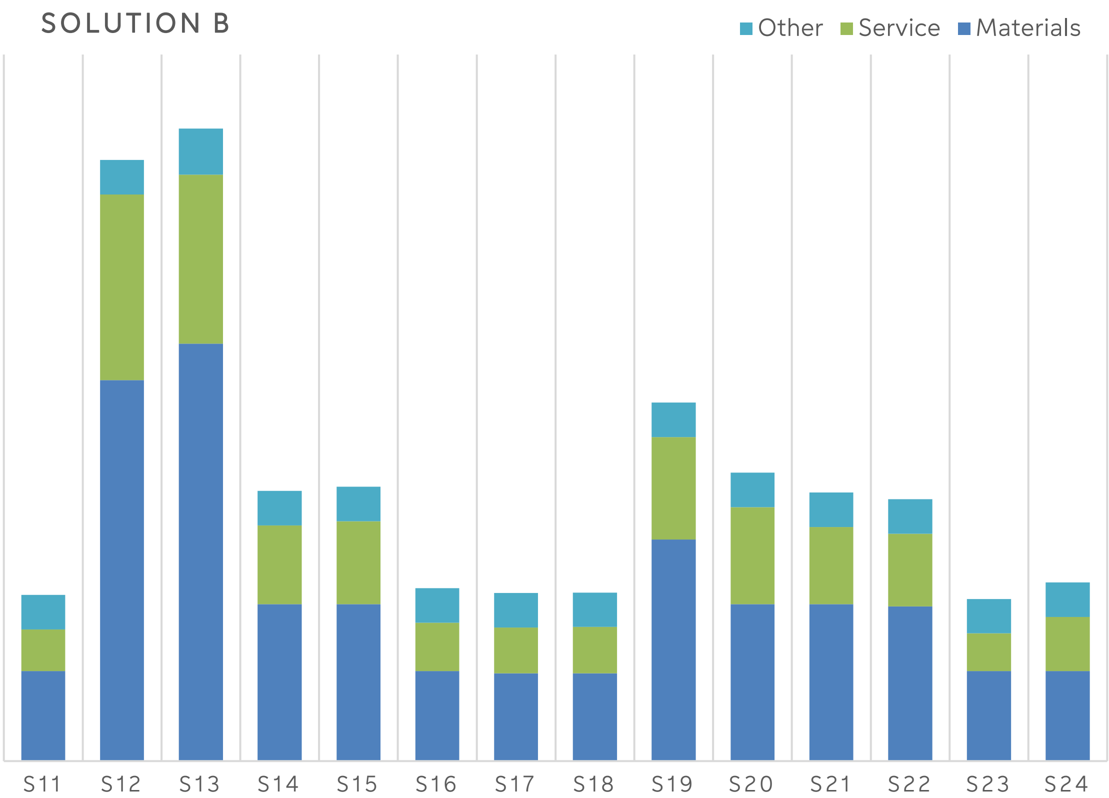


***Figure 19**. Solution B system sizes and costs compared*

In systems 2 and 14, minor changes have been made to the electrical system at the sites, but the changes have only concerned increasing the fuse size or replacing the transformer. This cannot be directly observed from the histogram because the modification costs have been relatively low. No asphalt has had to been excavated or the cabling to be redone. Although the costs of the modification works have been included in this review, the service work costs cover only around 23-34 % of the system costs due to the easily implemented content of the solution.

In Solution B, the materials include chargers, installation accessories, and a modem at each site. As it could be seen from the systems implemented with Solution A, also in systems that were executed with Solution B, the costs of materials covered the largest proportion in project costs. It can be noted from the histogram (Figure 18) that, on average, 50-66 % of the project costs consist of material costs. Without exception, the materials cover more than half of the total direct costs in all the projects.

The third observable part of project costs consists of other costs. Other costs include costs of planning and pre-mapping visits. The share of other costs varies relatively more than the costs of materials and service. A range of 6 to 21% can be observed from the histogram for other costs. The size of the system can explain the relatively wide range. When the system is larger and contains more chargers, the share of other costs also decreases in relation to material and service costs. The costs of planning and pre-mapping visit are non-recurring and do not depend on the system's size. Thus, the amount of other costs remains constant even if the system is made large or new equipment is added to the system. According to this theory, from the histogram, it can be seen that systems 2, 3, and 9 are by far the largest charging systems and contain the most devices. In these, the cost of materials is also relatively the highest.

Overall it can be observed that the relative cost of materials and service are similar in each project. As these systems have a different amount of devices in them, it can be concluded that the relative cost of materials and service stay the same in Solution B systems regardless of how large the system is.

## Cost curves

A graph was formed based on the collected system costs. The graph (Figure 18) shows the relation between investment cost (€/W) and system power (kW). Only the costs of materials and installation were taken into account in the review as cost data for civil works was not available for all systems. In this way, the systems and their costs were made comparable. The systems implemented with solutions A and B were divided into different graphs due to differences in their contents.

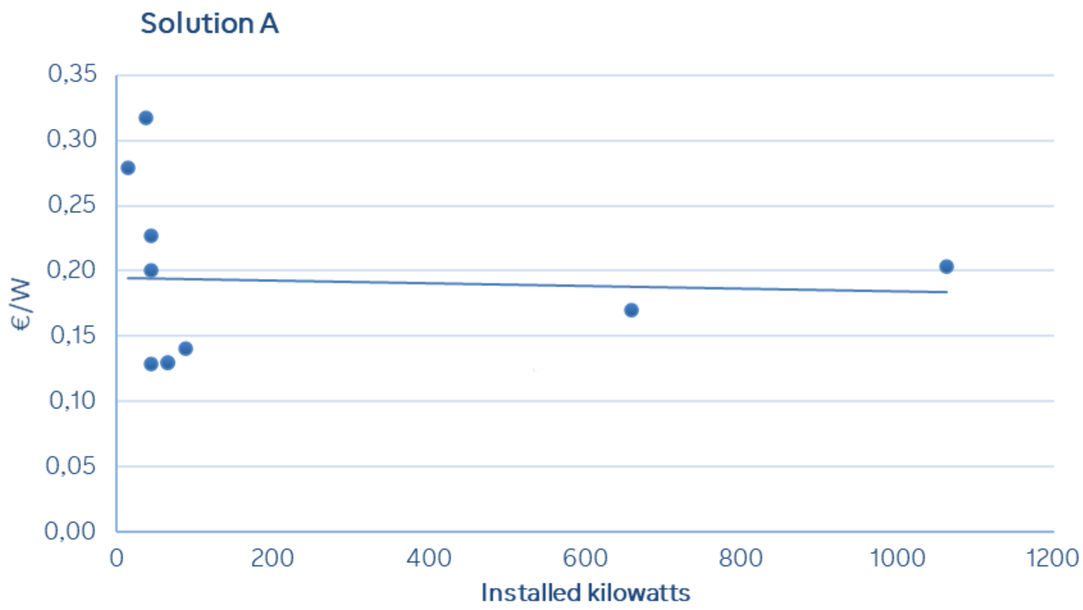


***Figure 20****. Cost curve for charging systems executed with Solution A*

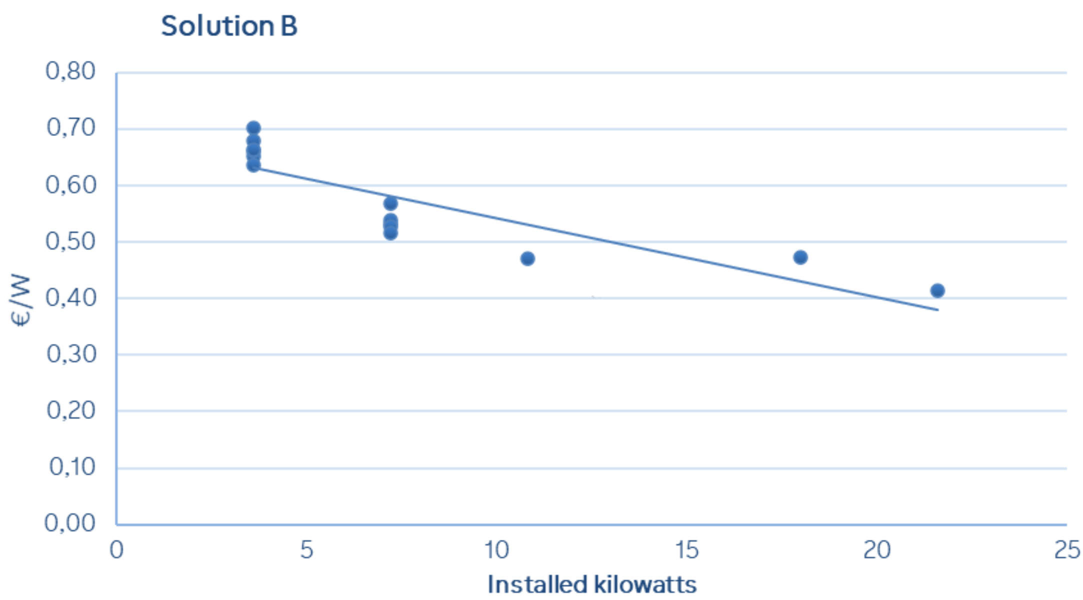


***Figure 21.*** *Cost curve for charging systems executed with Solution b*

The reviewed systems are charging systems of about 3 to 1100 kW. It can be seen from figures 20 and 21 that the systems executed with Solution A are, on average, more extensive than the systems implemented with Solution B. From both graphs, it can be concluded that the investment cost per watt installed decreases as the size and power of the system increases. Because the systems are made larger with Solution A, the average investment costs per watt installed are also lower in those systems.

For Solution A, it seems that investment costs are lower per installed kilowatt. In a way, this is true because Solution A systems are larger, and system costs per kilowatt decrease when system size increases. However, because civil works are not taken into account in the graphs (figures 20 and 21), the actual cost of an installed kilowatt is remarkably higher for Solution A than what the graph shows. As shown in figures 23 and 24, civil works can create up to 50 % of system costs, and therefore cost per installed kilowatt can be doubled for Solution A.

What is the Solution to go for when choosing to invest in a charging system? From a price point of view, Solution B ticks the box. When it comes to the charging system's durability, Solution A can provide more suitable systems. Systems with Solution A are customized for customer's needs, and systems have higher charging power and advanced intelligence, including dynamic load management on charger and backend level. Solution B offers a more affordable and easy to install option and is adequate for today's charging needs. Solution B systems are suitable especially for residential locations where demand for higher charging power is lower, and heating poles can be already found from the parking space.

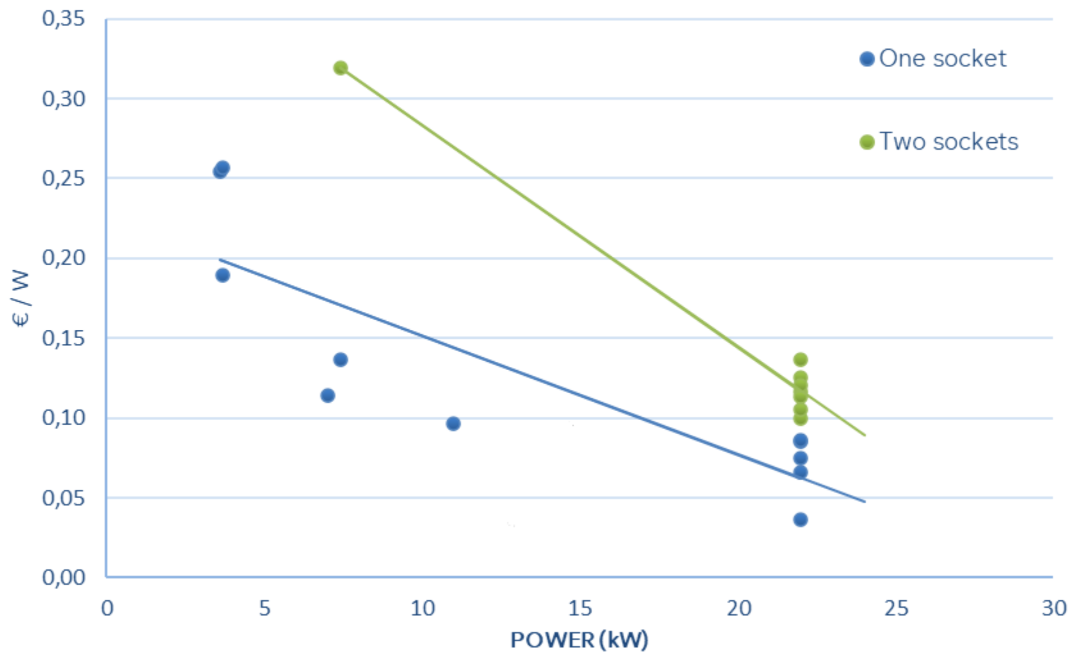


***Figure 22.*** *Cost curve for Mode 3 AC charging stations with one and two sockets*

The cost of Mode 3 AC charging stations was also assessed. As charging devices with both one and two sockets are available on the market, the devices were divided into two different curves accordingly to ensure comparability. It can be seen from Figure 19 that the investment cost (€ / W) decreases as the power of the charger increases. Although Mode 3 devices' market price is still high, it is more profitable to purchase a more efficient device as its investment costs are lower per kilowatt.

In addition to power and the number of sockets, chargers' prices are also affected by other features. Features that may affect the price can be the device's authentication method and its network connectivity (SIM cards vs. a data cable). In addition, the possibility of Vehicle-to-Grid operation raises the price of a charging device.

## Individual system reviews

### System 2

The features of System 2 (Solution A) were presented in more detail in Chapter 4, so this section focuses only on the incurred costs and reflects the system's size and its content on the investment costs. The system can be found in figures 16 and 17 (S2). The system's project costs are shown in a doughnut chart in Figure 23 below.

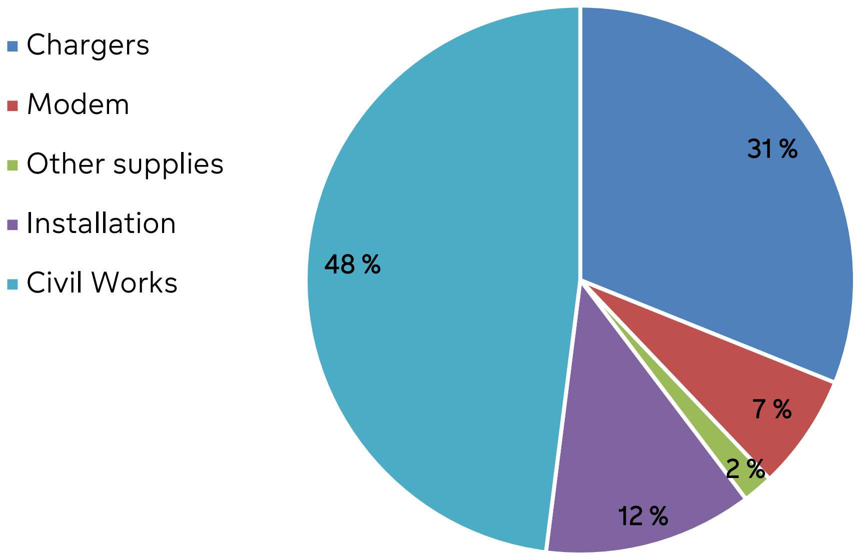


***Figure 23.*** *Doughnut chart of Project 1's investment costs*

Figure 23 shows how the civil works cover almost 50 % of the system's investment costs. This finding also supports the results of the interviews. A central capacity for 30 electric vehicle charging points was created in this residential location, and 17 parking places were cabled. The cabling was carried out so that it is possible to install a separate charger for each of these parking spots and the chosen charger model is a single-plug device.

The second-largest cost item originated from charging stations. The ten chargers installed at the site covered about 30 % of the project costs during the project. Therefore, there are still seven vacant cabled parking places for new chargers and charging readiness reserved for 20 more electric vehicles in the main distribution board.

The third-largest cost item is from the installation of 10 devices. Installation is rarely the most expensive part of a charging project if the site has undergone thorough alteration works and cabling in advance because it makes adding new chargers to a system easy, quick, and affordable.

The rest of the project costs arose from purchasing a modem and other installation supplies. When looking at the graph and project costs, it is good to note that it does not quite accurately reflect the content and distribution of system costs because the site does not have the maximum number of chargers installed and the number of parking places cabled allowed by the central capacity. In reality, materials and installation would account for a relatively larger share of the project cost. Simultaneously, the cost of the civil works would also be higher because additional cabling would still have to be done at the site so that all 30 parking spaces could be charged from at some point. The distribution of all system costs is therefore difficult to determine realistically.

### System 10

System 10 (Solution A) is the largest of the assessed systems, and it includes 46 pcs of double socket AC chargers and two pcs of DC chargers. This system can also be found in Figure 16 (System 10). The distribution of system costs is shown in the doughnut chart in Figure 24.

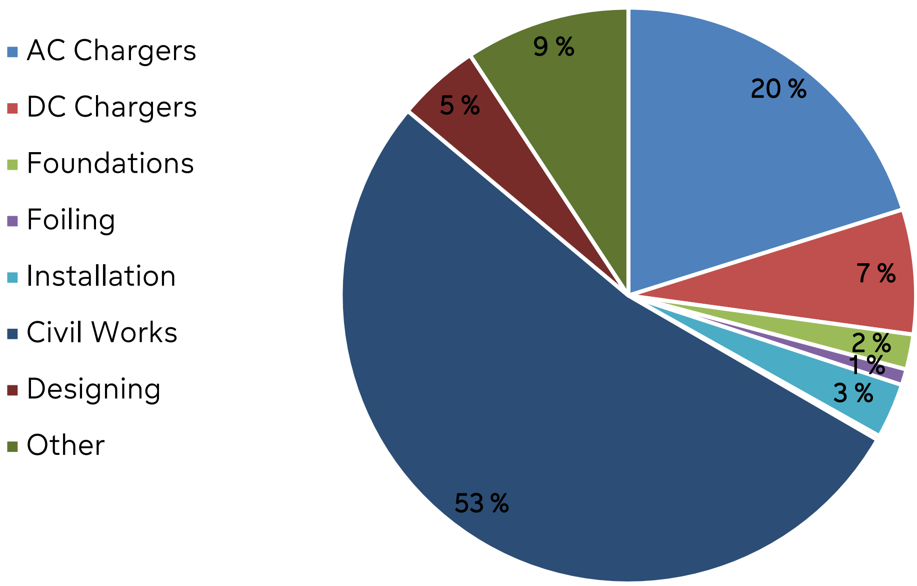


***Figure 24.*** *Doughnut chart of Project 2's investment costs*

As in System 2, in System 12, the costs of the civil works form half of the whole system's investment costs. Two new 20 kV substations with the necessary foundations were acquired for the site. A remote monitoring and operating system were built in the substations through which monitoring of the charging capacity for vehicles can be done in real-time at the group switchgear level. In addition to these, the site was cabled (for data and electricity connections), and group switchgear was installed in the places reserved for them. Also, the system was connected to the main grid. The alterations were therefore comprehensive and included extensive integrities.

The second-largest set of costs, 20 %, consists of Mode 3 AC charging stations. A total of 46 pcs of AC charging stations were acquired, but there are significantly more cabled spaces as almost every second out of hundreds of parking places is equipped with charging capability. The Mode 4 DC charging stations also contribute to charging devices' cost-share. It can be seen from the graph that the two fast chargers have been quite expensive in relation to the other costs of the project as only two Mode 4 charging stations account for about 7 % of the total investment costs. Together, the chargers account for almost a third of the project costs.

It can also be seen from the figure how the project's installation costs are considerably lower than in the system discussed previously. The reason for this can be found in the finished cabling work, which eases the installation work. Also, because civil works and charging stations had cost a lot, installation costs were not high in relation to material and civil work costs.

The third significant cost item in the projects arose from other expenses. As the project had to be rushed to keep to the schedule, it also caused additional system costs. Other costs (9 %) include permits and the costs of complying with the regulations issued by the building inspectorate afterwards.

**System 12**

System 12 differs from the two previous systems because it was implemented with a different solution (Solution B). The site includes five pcs of Mode 3 AC chargers installed in conventional heating poles in the parking lot of a residential building. This system can also be found in figures 18 and 19 (System 12). Figure 25 illustrates the distribution of project costs into different areas.

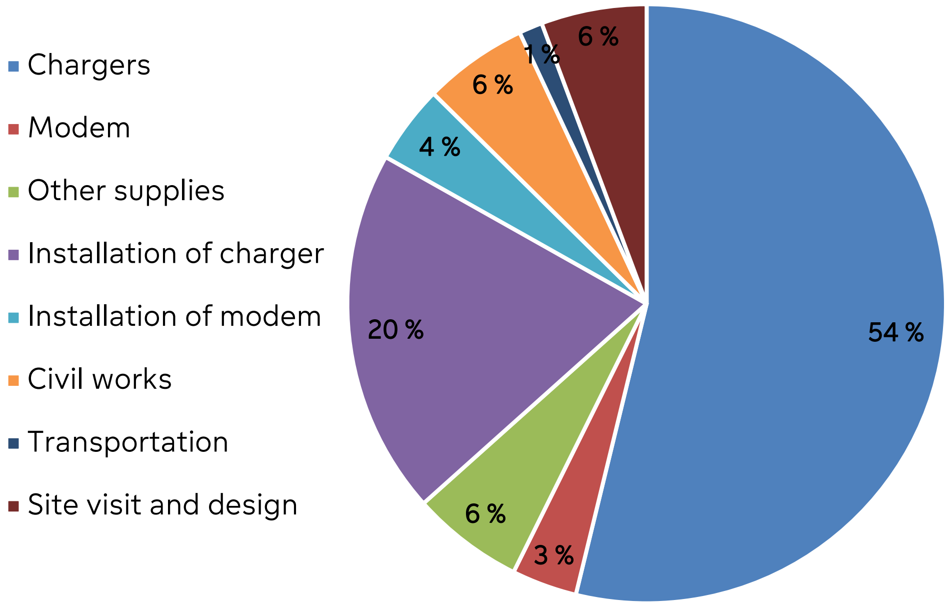


***Figure 25.*** *Doughnut chart of Project 3's investment costs*

It can be observed from the diagram that most of the project costs, about 54 %, incurred from the purchase of charging equipment. Since there are only five devices and they have only about 3 kW charging power, these devices are not likely to be the most expensive on the market according to the cost curve presented earlier (Figure 22). Therefore it can also be concluded that the other costs of the project have also been reasonable.

Minor alterations were made to the building's electric system, including increasing the fuse size and replacing the transformers. As there was no need to excavate asphalt or cabling for parking spaces at the site, the civil works' cost (6 %) is not relatively high compared to other costs. The intention with the solution is to always install the charger directly to the place of a heating pole, which makes the solution advantageous from a price point of view compared to other Mode 3 charging systems. However, the system is limited by the charging power, which reaches a maximum of only about 3.6 kW.

The installation costs cover about a quarter of the project's investment costs. One-fifth is created by installing the chargers and the remaining 4 % by the installation of the modem. From the graph (Figure 25), it can be concluded that a system that is implemented with Solution B is an inexpensive and easy-to-implement charging solution, especially in buildings where the heating poles already exist.

## 5.3 Overall discussion

In this study, charging solutions' energy and cost efficiency was evaluated based on different affecting elements in residential and commercial locations. This study showed that a charging system's efficiency is affected by many factors, and there is no unambiguous answer to what is energy and cost-effective in each building where a charging system is planned to be built. What was clear was that although the increase in the system's size had an increasing effect on the costs, the larger the system, the lower the investment costs per kilowatt installed were.

One of the significant challenges was that no precise pre-defined buildings and locations were used in the empirical part of the study when assessing the effectiveness of a charging solution. The interviews stated how the charging solution should always be site-specific and defined according to the users' needs. In the absence of an exclusive description for an efficient charging solution, the accuracy of the results could have been improved by selecting pilot locations and buildings, based on which efficient charging solutions would have been assessed on a site-by-site basis. More detailed calculations on bettering the energy and cost efficiency were left out due to the work schedule constraints.

This study focused on the charging solution's investment costs and only briefly touched the maintenance costs of charging systems. To improve the results, calculations on maintenance costs of an charging solution could have been presented. In order to achieve an accurate overview on system costs and the overall cost efficiency, it would require reviewing how much it costs to maintain an energy- and cost-efficient charging solution over its whole lifespan.

Also, since this work only considers the direct costs of the project costs, the assessment of indirect costs could provide added value, especially to companies offering charging solutions. The last limitation of the work was the poor availability of data. The cost data had to be manually searched when doing the assessment, which increases the likelihood of a human error. The most efficient way to collect similar project data would have been to utilize the company's Enterprise Resource Planning system if one had been available.

Further research on the topic could focus more on the construction side of charging infrastructure in residential and commercial buildings. This work focused more on the modifications works made for charging system in already existing buildings. The object of the examination could be to find out how charging system should be taken into account when designing and constructing totally new buildings. New sites offer a completely different opportunity to take an electric vehicle charging system into account, and from the point of view of further research it would be valuable to find out what is the optimal solution for a site where the electrical system does not initially place restrictions on the charging solution.

The requirements set by the older buildings for the charging infrastructure as well as the possibilities offered by the newer buildings could also be compared. How do modifications to an existing site differ in terms of cost and efficiency with systems built on completely new sites? The aim of further research could be to seek out the possibilities for improving the systems on the basis of evolving technology and the experience provided by the already implemented systems.

This Master's Thesis serves as a thorough preliminary study for consumers, housing associations, condominiums, and companies that are interested in investing in a sustainable and efficient electric vehicle charging system. The work provides a comprehensive insight into the current technology, the Finnish market conditions and guidelines, cost- and energy-efficient charging features, and charging systems' investment costs. Based on the empirical results a suggestion for energy- and cost-efficient charging system was made which encourages housing associations and commercial companies to invest in a system with larger amounts of chargers, higher charging capacity, intelligence and few valuable energy saving and power management features. Although technology is evolving rapidly and sooner or later, electric vehicle charging might become inductive, are relevant technologies, standards, guidelines, and procedures gathered in this study to clarify system requirements and help investors to decide on relevant charging system features. In addition to its theoretical input, this study provides valuable cost information and analysis for this Master’s Thesis’s case company and for other industry players in the field too.

# 6. CONCLUSIONS

The demand for a functioning electric vehicle charging infrastructure is continuously growing as the number of electric cars and rechargeable hybrids is increasing exponentially in our society. The goals set by the Finnish government for growing charging infrastructure are ambitious but not impossible. With incentives and financial subsidies, the regulations will encourage both individual consumers and businesses to invest in enabling electric vehicle charging.

There are various solutions and charger models available in the market. The challenge is what to choose, to where and why. At the national level, the sufficiency of electricity for charging electric cars has been proven if the charging is done when electricity consumption is at its lowest. Instead, the low-voltage network and the property's network may become overloaded when electric vehicles and charging of them becomes more common. In an extreme case, the network may crash if the system cannot withstand charging multiple cars simultaneously. This work's primary goal was to find out what is an energy and cost-efficient charging solution for sites where, in principle, more than one charger is added to the system.

The first research question sought to determine what kind of charging technology and solutions are available today and what would suit best for this study’s target locations. In Europe and worldwide, charging is regulated by standards and guidelines. Charging can be divided into categories according to power and charging method. Charging modes 1-3 that proved to be suitable charging methods for residential buildings enable charging powers from 1.5-43 kW. For the time being, higher powered charging than 11 kW is not usually needed in residential buildings and often also local electrical systems restrict the charging power. Suitable charging modes for commercial locations are modes 3 and 4. With charging modes 3-4, it is possible to include external intelligence into the system. Intelligence enables valuable features like dynamic load balancing, smart energy management, automated billing, roaming and charge point reserving and therefore it is also recommended to incorporate it to the system as well. Especially features that can positively affect efficient energy management and ease the challenges in local electrical systems and low voltage networks created by a multi-device system are valuable. In commercial buildings the need for automated billing and system features that simplify charging for both the EMSP and the user is clearer and highlighted.

The second research question was set to clarify the national electric vehicle charging market's state, guidelines that regulate the business and incentives which encourage commercial organizations, housing associations and consumers to invest in charging systems. Policies that guide consumers to use fewer pollutant vehicles in Finland are fiscal and monetary subsidies. A new law that came into force in 2021 aims to grow the number of charging points by obliging housing associations and companies to invest in charging capacity and charging devices by 2025. It is expected that the new law will increase significantly the number of charging points in Finland. This will challenge local low voltage networks even though adequacy of electricity for charging of electric vehicles has been proven on a national level.

To support housing associations in this transition period and upcoming investments, the government offers financial subsidies to condominiums to lower the costs of construction works, purchasing of chargers and installing of devices. If granted, the subsidy makes investing in a charging system more favorable. There are certain conditions in the number if installed charging points and charging power to receive the grant, but it is nevertheless advisable to invest in a system now when a subsidy is available. Especially in the southern Finland and Helsinki metropolitan area number of electric vehicles are increasing constantly and charging capacity or devices that seem now to be an unnecessary investment might turn out to be valued attributes in the near future.

The third research question was set to address this Master's Thesis's main issue. The research question aimed to determine which factors affect the cost and energy efficiency of a charging solution in residential and commercial buildings. The empirical part of the study was conducted through expert interviews. The following elements listed in Table 6 were identified as factors influencing a charging solution's energy and cost-efficiency.

***Table 6.*** *Factors that influence the energy and cost efficiency of a charging solution*

| **Affecting element** | **Effectiveness** |
|---|---|
| System size | +++++ |
| Available capacity | +++++ |
| Load balancing and smart energy management | ++++ |
| Charging technology and devices | +++ |
| Additional intelligence (apart from DLM) | + |
| Building’s heating system and state of the electric system | ++ |

The suggestion for ideal residential building's charging solution has Mode 3 charging stations, includes dynamic load management, has a reliable internet connection, and guarantees 3-11 kW charging power. Regardless the building being new or older, a separate distribution center for charging devices in the electrical switchboard should be installed, which makes it easy to add new devices to the system later on. Dynamic load management between chargers ought to be organized through a mutual local internet connection avoiding dependency on any outsourced systems.

Apart from dynamism in load management, the benefits of smart charging do not play a significant role in charging systems for residential buildings. Commercial buildings' charging solutions, in turn, should include more intelligence as automated billing of charging is only possible with smart charging. Other cost and energy-efficient elements of a commercial charging system include 11-22 kW charging power, load management, smart energy management, reliable internet connection, and charging mode 3 or 4. All in all, reliability and functionality of the system are key components to achieve an efficient charging system in both residential and commercial locations. To achieve this one should choose functional devices, reliable internet connection method depending on the building and to construct a sensible electrical arrangement that supports the amount of chargers that the system now and in the near future will have.

The fourth research question attempted to answer how much an efficient charging solution costs when the system includes more than one charger. Costs were examined from the perspective of two different solutions. The most significant difference between the solutions was that one does not necessarily need contracting at the site. The solution that requires contracting is curated and more sustainable in the long run. However, the largest cost item of a charging system without exception originated from contracting work. Therefore, the decision on whether the system needs to stand the test of time or is a more affordable and straightforward version sufficient enough, for the time being, will be left for the investor. Mode 3 chargers created the second-largest cost-share, and installation costs became the lowest identified cost item.

Perhaps the one of the most valuable discovery was that the cost of investment per kilowatt installed decreased as the size of the system increased. With the finding it can be concluded that investing in a larger and extensive charging system is more cost-effective than adding devices and growing capacity in a building bit by bit. The same trend applied to Mode 3 charging stations when it came to the charging power. As the financial support offered by the government is granted when at least 5 charging spots are constructed and the investment costs per installed kilowatt decrease by growing the system, this study recommends to construct and install at least this amount of charging capacity and devices at ones even though the charging need in a building would be less than that at the time.

This Master's Thesis provides comprehensive information for consumers, housing associations and companies that are interested in investing in a charging system. The study serves as a preliminary study for today's energy- and cost-efficient charging systems and future solutions. The empirical part mainly concentrated on already existing residential and commercial buildings' charging systems. To achieve a more comprehensive overview on the efficiency and cost of charging systems, further studies could concentrate on residential and commercial buildings' charging infrastructure more closely. One approach could be to examine only new buildings' charging infrastructure and opportunities that new locations offer for charging systems. All in all, finding an optimized charging solution that fits for all is challenging as no building or electric vehicle charging needs are quite the same in every location. Therefore the '*energy and cost efficient charging solution'* should always be site specific and serve the needs of the building and its' users whether it is a residential or a commercial one.

# REFERENCES


[1] Florent Grelier, ”CO2 EMISSIONS FROM CARS: the facts,” European Federation for Transport and Environment AISBL, 2018.

[2] B. Witkamp, R. van Gijlswijjk ja D. Kushnir, ”Impact of different drivetrain options, fuels and vehicle use on GHG emissions of cars,” International Energy Agency, 2018.

[3] A. Andersson, S. Jääskeläinen, N. Saarinen, J. Mänttäri ja E. Hokkanen, ”Fossiilittoman liikenteen tiekartta -työryhmän loppuraportti,” Liikenne- ja viestintäministeriö, 2020.

[4] Motiva, ”Liikenteen päästöt ja energiankulutus,” 26 July 2019. [Online]. Available: https://www.motiva.fi/ratkaisut/kestava_liikenne_ja_liikkuminen/perustietoa_liikenteesta/liikenteen_paastot_ja_energiankulutus. [Cited 1 January 2020].

[5] Government Programme 3.1, ”Hiilineutraali jal luonnonmonimuotoisuuden turvaava Suomi,” Valtioneuvosto, 2020. [Online]. Available: https://valtioneuvosto.fi/marinin-hallitus/hallitusohjelma/hiilineutraali-ja-luonnon-monimuotoisuuden-turvaava-suomi. [Cited 1 January 2020].

[6] F. Government, ”Valtioneuvoston selonteko kansallisesta energia- ja ilmastostrategiasta vuoteen 2030,” Työ- ja elinkeinoministeriö, 2016.

[7] International Energy Agency, ”Global EV Outlook 2020,” June 2020. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2020. [Cited 30 September 2020].

[8] Autoalan tiedotuskeskus, ”Sähköautojen määrän kehitys,” 3 August 2020. [Online]. Available: http://www.aut.fi/tilastot/autokannan_kehitys/sahkoautojen_maaran_kehitys. [Cited 15 October 2020].

[9] M. Laukkanen ja A. Sahari, ”Sähköautoilun edustämisen ohjauskeinot,” tekijä: *Ilmastopaneelin Policy Brief*, 2018.

[10] P. Lähteenmäki, *Suomen suurin sähköremontti,* Helsinki: Talouselämä, 2020.

[11] Government bill HE 23/2020, ”Hallituksen esitys eduskunnalle laeiksi sähköajoneuvojen latauspisteistä ja latauspistevalmiuksista rakennuksissa sekä rakennusten automaatio- ja ohjausjärjestelmistä ja maankäyttö- ja rakennuslain 126 §:n muuttamisesta,” 20 March 2020. [Online]. Available: https://www.eduskunta.fi/FI/vaski/HallituksenEsitys/Sivut/HE_23+2020.aspx. [Cited 20 November 2020].

[12] European Alternative Fuels Observatory, ”Electric Vehicle Charging Infrastructure,” European Commission, 2019. [Online]. Available: https://www.eafo.eu/electric-vehicle-charging-infrastructure. [Cited 30 September 2020].

[13] Transport & Environment, ”Recharge EU: How many charge point will Europe and its Member States need in the 2020s,” January 2020. [Online]. Available: https://www.transportenvironment.org/sites/te/files/publications/01%202020%20Draft%20TE%20Infrastructure%20Report%20Final.pdf. [Cited 30 September 2020].

[14] I. Wagner, ”Market share of newly registered passenger electric vehicles in selected European countries in 2019, by type,” Statista, 12 May 2020. [Online]. Available: https://www.statista.com/statistics/625795/eu-electric-vehicle-market-share-by-country/. [Cited 30 September 2020].

[15] R. Giesecke, ”The Electric Mobility Business Ecosystem - An Initial Agenda for Future Research Needs, Based on Organisation Theory,” tekijä: *2014 Ninth International Conference on Ecological Vehicles and Renewable Energies (EVER)* , Espoo, 2014.

[16] Virta, ”The two sides of EV charging network operators,” 21 February 2019. [Online]. Available: https://www.virta.global/blog/the-two-sides-of-ev-charging-network-operators. [Cited 5 November 2020].

[17] C. Kosche, ”5 EV charging trends to watch in 2020,” Smartcar, 31 December 2020. [Online]. Available: https://smartcar.com/blog/5-ev-charging-trends-to-watch-in-2020/. [Cited 15 October 2020].

[18] Virta, ”!5 EV charging industry trends,” 2020.

[19] Y. Cholteeva, ”Full charge: the EV infrastructure providers to watch,” Power Technology, 14 July 2020. [Online]. Available: https://www.power-technology.com/features/full-charge-the-ev-infrastructure-providers-to-watch/. [Cited 20 September 2020].

[20] J. Bi, Y. Wang, S. Sun ja W. Guan, ”Predicting Charging Time of Battery Electric Vehicles Based on Regression and Time-Series Methods: A Case Study of Beijing,” *Energies,* osa/vuosik. 11, nro 1040, 2018.

[21] Z. Salam, M. J. B. A. Aziz, A. R. Bhatti ja K. P. Yee, ”A Compreensive Overview of Electric Vehilce Charging using Renewable Energy,” *Power Electronics and Drive System,* osa/vuosik. 7, nro 1, pp. 114-123, 2016.

[22] J. Kummala, ”Liikkumisen tulevaisuudesta ja tieliikenteen automaatiosta,” 7 December 2016. [Online]. Available: http://www.varsinais-suomi.fi/images/tiedostot/Kumppanuusfoorumit/Liikenteen-ja-liikkumisen-tulevaisuus-Liikennevirasto-2016.pdf. [Cited 15 December 2020].

[23] C. Li, Y. Cao, Y. Kuang ja B. Zhou, Influences of Electric Vehicles on Power System and Key Technologies of Vehicle-to-Grid, Beijing: Science Press, 2016.

[24] Fortune Business Insight, ”Electric Vehicle Charging Stations Market Size, Share & COVID-19 Impact Analysis, By Charger Type (Fast, Slow/Moderate), By Application (Commercial, Residential) and Regional Forecasts, 2020-2027,” 2020.

[25] M. C. Falvo, D. Sbordone, S. Bayram ja M. Devetsikiotis, ”EV Charging Stations and Modes: International Standards,” *International Symposium on Power Electronics, Electrical Drivers, Automation and Motion,* pp. 1134-1139, 2014.

[26] A. Bahrami, ”EV Charging Definitions, Modes, Levels, Communication Protocols and Applied Standards,” Research Gate, 2020.

[27] F. T. Siang ja W. T. Chee, ”A review of energy sources and energy management system in electric vehicles,” *Renewable and Sustainable Energy Reviews,* nro 20, pp. 82-102, 2012.

[28] V. Linja-Aho, Ostaisinko sähköauton?, Helsinki: Into Kustannus Oy, 2016.

[29] SESKO, ”Sähköajoneuvojen lataussuositus,” Sähköteknisen alan kansallinen standardointijärjestö, 2019.

[30] D. A. Tinton ja Amin, ”Energy storage system using battery and ultracapacitor on mobile charging station for electric vehicle,” *Energy Procedia,* nro 68, pp. 429-437, 2015.

[31] Electric vehicle conductive charging system – Part 1: General requirements IEC 61851-1:2017, 2017.

[32] European Parliament and The Council of European Union of 22 October 2014 on the deployment of alternative fuels infrastructure, ”Directive 2014/94/EU,” European Union, 2014.

[33] Virta, ”Smart Charging of electric vehicles,” [Online]. Available: https://www.virta.global/smart-charging. [Cited 15 October 2020].

[34] C. Lilly, ”EV connector types,” Zap Map, 3 April 2020. [Online]. Available: https://www.zap-map.com/charge-points/connectors-speeds/. [Cited 27 September 2020].

[35] ”Plugs, socket-outlets, vehicle connectors and vehicle inlets. Conductive charging of electric vehicles. Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories (IEC 62196-2:2016),” IEEE, 2010.

[36] Electric Car Home, ”Charging Point Connector Types,” [Online]. Available: https://electriccarhome.co.uk/charging-points/charging-point-connector-types/. [Cited 29 September 2020].

[37] Wallbox, ”EV Charging Connector Types: What You Need to Know,” [Online]. Available: https://wallbox.com/en_catalog/faqs-plug-types. [Cited 29 September 2020].

[38] J. Hildermeier, C. Kolokathis, J. Rosenow, M. Hogan, C. Wiese ja A. Jahn, ”Smart EV Charging: A Global Review of Promising Practices,” *World Electric Vehicle Journal,* pp. 1-13, 2019.

[39] Fingrid Oyj, ”Demand-side management,” [Online]. Available: https://www.fingrid.fi/en/electricity-market/market-integration/the-future-of-the-electricity-markets/demand-side-management/. [Cited 20 January 2021].

[40] ”Optimal Behavior of Electric Vehicle Parking Lots as Demand Response Aggregation Agents,” *IEEE TRANSACTIONS ON SMART GRID,* osa/vuosik. 7, nro 6, pp. 2654-2665, 2016.

[41] T. Gómez San Román, I. Momber, M. Rivier Abbad ja Á. Sánchez Miralles, ”Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships,” *Energy Policy,* osa/vuosik. 39, pp. 6360-6375, 2011.

[42] R. Bessa ja M. A. Matos, ”The role of an aggregator agent for EV in the electricity market,” tekijä: *7th Mediterranean Conference and Exhibition on Power Generation, Transmission, Distribution and Energy Conversion*, Agia Napa, 2010.

[43] Driivz Ltd., ”Blog,” 22 April 2020. [Online]. Available: https://driivz.com/blog/ev-charging-standards-and-protocols/. [Cited 14 September 2020].

[44] ElaadNL, ”EV RELATED PRTOCOL STUDY - Original Study Report Version 1.1,” 2016. [Online]. Available: https://www.elaad.nl/uploads/downloads/downloads_download/EV_related_protocol_study_v1.1.pdf. [Cited 13 September 2020].

[45] Open Charge Alliance, ”Protocols,” [Online]. Available: https://www.openchargealliance.org/protocols/. [Cited 14 September 2020].

[46] S. Ramon, ”OpenADR Momentum 2020,” OpenADR Alliance, 21 January 2020. [Online]. Available: https://www.openadr.org/index.php?option=com_content&view=article&id=191:openadr-momentum-2020&catid=21:press-releases&Itemid=121. [Cited 15 September 2020].

[47] OpenADR Alliance, ”Connecting Smart Energy to the Grid,” 2020. [Online]. Available: https://www.openadr.org/. [Cited 15 September 2020].

[48] IEEE Standards Association, ”2030.5-2018 - IEEE Standard for Smart Energy Profile Application Protocol,” IEEE Standards Association, 21 December 2018. [Online]. Available: https://standards.ieee.org/standard/2030_5-2018.html. [Cited 15 September 2020].

[49] K. Hyvönen, ”Sähköisen liikenteen käynnistäminen Suomessa,” Kuluttajtutkimuskeskus, Helsingin yliopisto, Helsinki, 2017.

[50] M. Antikainen, ”EVE - Electric Vehicle Systems 2011-2015,” Tekes, Helsinki, 2016.

[51] Eera Oy, ”Sähköinen liikenne Suomessa 2011-2016,” Tekes, 2016.

[52] K. Heikki, ”Sähköisen liikenteen tilannekatsaus Q2/2020,” Sähköinen liikenne ry, 2020.

[53] K. Heikki, ”Sähköisen liikenteen tilannekatsaus Q3/2020,” Sähköinen liikenne ry, 2020.

[54] Teknologiateollisuus, ”Yhdistys,” 11 November 2020. [Online]. Available: https://emobility.teknologiateollisuus.fi/fi/yhdistys. [Cited 23 January 2021].

[55] S. Jääskeläinen, ”Liikenteen vaihtoehtoisten käyttövoimien jakeluinfra – kansallisen ohjelman seuranta 2019,” Liikenne- ja viestintäministeriö, 2020.

[56] Vaihtoehtoisten käyttövoimien jakeluverkkoa pohtinut asiantuntijaryhmä, ”Vaihtoehtoisten käyttövoimien jakeluverkko – ehdotus kansalliseksi suunnitelmaksi vuoteen 2020/2030,” Liikenne- ja viestintäministeriö, 2015.

[57] S. Haapio, ”Kestävästi sähköautoilla - Myös Suomessa on herätty sähköisen liikenteen etuihin.,” Fingrid Oyj, 22 January 2018. [Online]. Available: https://www.fingridlehti.fi/kestavasti-sahkoautolla/. [Cited 27 October 2020].

[58] J. Jäppinen, ”250 000 sähköautoa tulee – kaatuuko kantaverkko?,” Fingrid Oyj, 15 December 2016. [Online]. Available: https://www.fingridlehti.fi/250-000-sahkoautoa-tulee-kaatuuko-kantaverkko/. [Cited 23 January 2021].

[59] Tilastokeskus, ”Energian hankinta ja kulutus,” 2020. [Online]. Available: https://www.stat.fi/til/ehk/2019/04/ehk_2019_04_2020-04-17_fi.pdf. [Cited 3 November 2020].

[60] Fingrid Oyj, ”Sähkön kulutus ja tuotanto,” 2020. [Online]. Available: https://www.fingrid.fi/sahkomarkkinat/sahkomarkkinainformaatio/kulutus-ja-tuotanto/. [Cited 18 December 2020].

[61] K. Chophel, T. Lhendup, R. Chhetri ja P. Pravakar, ”Impact of Electric Vehicle Charging on Low Voltage Network Stability,” *American Journal of Electrical and Electronic Engineering,* osa/vuosik. 8, nro 4, pp. 131-137, 2020.

[62] J. H. Langbroek , J. P. Franklin ja Y. O. Susilo, ”The effect of policy incentives on electric vehicle adoption,” *Energy Policy,* nro 94, pp. 94-103, 2016.

[63] W. Sierzchula, S. Bakker ja B. Van Wee, ”The influence of financial incentives and other socio-economic factors on electric vehicle adoption,” *Energy Policy,* nro 68, pp. 183-194, 2014.

[64] T. Administration, ”Vehicle tax law 1281/2003,” 30 December 2003. [Online]. Available: https://finlex.fi/fi/laki/ajantasa/2003/20031281. [Cited 27 October 2020].

[65] P. Pfaffenbichler, N. Fearnley, E. Figenbaum ja R. Jellinek, ”E-vehicle policies and incentives - assessment and recommendations,” Institute of Transport Economics Norwegian Center for Transport Research, Oslo, 2015.

[66] N. P. R. A. Statens vegvesen, ”Traffic rules in Norway - Regulations relating to pedestrian and vehicle traffic,” July 2020. [Online]. Available: https://www.vegvesen.no/_attachment/3002307/binary/1374469?fast_title=Traffic+rules+in+Norway.pdf. [Cited 29 October 2020].

[67] M. Bosshardt, S. Ulli-Beer, F. Gassmann ja A. Wokaun, ”Developing a diffusion model of competingalternative drive-train technologies (cadt-model),” pp. 1-21, 2007.

[68] European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011, ”Regulation (EU) 2019/631,” European Union, 2019.

[69] Tax Administration, ”Ajoneuvojen veroprosentit,” 2020. [Online]. Available: https://www.vero.fi/henkiloasiakkaat/auto/autoverotus/autoveron_maara/ajoneuvojen-veroprosentit/#henkiloauto. [Cited 20 October 2020].

[70] Ministry of Finance, ”Ajoneuvovero,” 2020. [Online]. Available: https://vm.fi/ajoneuvovero. [Cited 25 October 2020].

[71] Autoalan tiedotuskeskus, ”Liikennepolttoaineiden verotus,” 2020. [Online]. Available: https://www.aut.fi/etusivu_vanha/tieliikenne/autoilun_verotus/liikennepolttoaineiden_verotus. [Cited 5 November 2020].

[72] ”Tieliikenteen infrastruktuurituki vuonna 2020,” Energiavirasto, 2020. [Online]. Available: https://energiavirasto.fi/liikenteen-infratuki. [Cited 27 October 2020].

[73] Asumisen rahoitus- ja kehittämisekeskus, ”Avustus sähköautojen latausinfran rakentamiseen,” 2020. [Online]. Available: https://www.ara.fi/latausinfra-avustus. [Cited 5 November 2020].

[74] Traficom, ”Sähköauton hankintatuki,” Liikenne- ja viestintävirasto, 2020. [Online]. Available: https://www.traficom.fi/fi/asioi-kanssamme/sahkoauton-hankintatuki. [Cited 5 November 2020].

[75] Government bill HE 156/2017, ”Hallituksen esitys eduskunnalle laiksi henkilöautojen romutuspalkkiosta ja sähkökäyttöisten henkilöautojen hankintatuesta sekä henkilöautojen kaasu- tai etanolikäyttöisiksi muuntamisen tuesta.,” 26 October 2017. [Online]. Available: https://www.eduskunta.fi/FI/vaski/HallituksenEsitys/Documents/HE_156+2017.pdf. [Cited 5 November 2020].

[76] Traficom, ”Määräaikainen laki henkilöautojen romutuspalkkiosta lausunnoille,” Valtioneuvosto, 14 October 2020. [Online]. Available: https://valtioneuvosto.fi/-/maaraaikainen-laki-henkiloautojen-romutuspalkkiosta-lausunnoille. [Cited 5 November 2020].

[77] E. Kervinen, ”Eduskunta hyväksyi pitkään valmistellun lain sähköautojen latauspisteistä – oppositio piti velvoitteita yhä liian kovina,” Helsingin Sanomat, 16 October 2020. [Online]. Available: https://www.hs.fi/politiikka/art-2000006671904.html. [Cited 20 November 2020].

[78] Finlex, ”Income Tax Law,” Finlex, 1992.

[79] Tax Administration, ”Luontoisedut verotuksessa,” 25 January 2021. [Online]. Available: https://www.vero.fi/syventavat-vero-ohjeet/ohje-hakusivu/47886/luontoisedut-verotuksessa7/. [Cited 31 January 2021].

[80] Motiva, ”Kiinteistöjen latauspisteet kuntoon,” 5 November 2018. [Online]. Available: https://www.motiva.fi/files/15446/Kiinteistojen_latauspisteet_kuntoon_paivitetty_05.11.2018.pdf. [Cited 3 January 2021].

[81] S. Hirsjärvi ja H. Hurme, Tutkimushaastattelu: Teemahaastattelun teoria ja käytäntö, Gaudeamus, 2011.

[82] J. Metsämuuronen, Laadullisen tutkimuksen käsikirja, Helsinki: International Methelp, 2006.

[83] M. N. Saunders, P. Lewis ja A. Thornhill, Research methods for business students, Pearson Education, 2009.

[84] I. Dey, Qualitative data analysis: A user-friendly guide for social scientists, London: Routledge, 1993.

[85] S. Kvale, Interviews: An Introduction to qualitative research interviewing, Thousand Oaks California: Sage, 1996.

# APPENDICES

**Appendix 1:** Interview question frame

1. What is a cost and energy efficient charging solution and what features do you think it includes?
2. What effect does building's electrical system have on the cost and energy efficiency of a charging solution?

   - Is it more efficient to use the capacity that is available without making any changes to the power center or to carry out extensive modification works, which will also cover charging capacity in the future when the demand increases?
3. Is it more efficient to install own charging devices for all users or to have shared charging points that would be used via a reservation system? Compare residential and commercial buildings.
4. How does a site-specific demand response and smart home solution have an impact on the cost and energy efficiency of a solution?
5. How do you see the choice of charger affecting the cost and energy efficiency of the charging solution?
   a. Residential building
   b. Commercial charging
6. What effect does load balancing have on the cost and energy efficiency of the charging solution?
7. What impact do you think an intelligent charging solution, i.e. charging system connected to an intelligent backend system, will have on the cost and energy efficiency of the solution?

- If you find that intelligent charging solution increases the cost and energy efficiency of the systems, the charging devices must be connected to the internet. What do you think is the optimal way to connect chargers to the internet?

8. Does something come to mind that was not asked in the interview?

**Appendix 2:** Answers from the expert interviews

*"On behalf of cost efficiency, changes to the property's electrical system should not be made unless there is a clear need for it. Intelligent load balancing between chargers has a significant impact on whether the power capacity of a property is enough or if it needs to be increased. Smart chargers should communicate with each other in such way that they are not primarily connected to a separate backend system. However, the communication could take place, for example, via a shared network connection. System's dependence on a backend system should therefore be avoided, especially when the operating service is provided by a party that has not established its position in the market. In a situation where the charging system is completely dependent on the backend system, for example for load balancing, the system can quickly become completely unusable if the charge point operation service provider goes bankrupt or the service develops in a direction that is not desirable. Charging system should be reliable and one that does need to be 'stabbed' afterwards when new chargers are added to the system. If possible worthwhile to intellectualize the entire property's electrical system, in which case the system would also take into account the electrical load caused by the chargers."* – E1

*"A cost and energy efficient charging solution consists of devices that are capable of communicating with a backed system according to Open Charge Point Protocol. In cost and energy efficient charging load management is an essential feature that can be arranged through dynamic load management between chargers. Ideally chargers can communicate with one another via a shared network connection, through which load balancing also takes place. In both residential and commercial buildings, a charging power level of 3.7-11 kW is in most cases enough as the battery rarely has to be charged from scratch. In certain cases, such as when a user has a battery electric vehicle that one drives heavily on a daily basis, one may need to consider purchasing a charger that is more efficient. However, the fast charging provided by public infrastructure can be easily utilized to fill in the gaps. Yet, consumers may often have misconceptions about the level of charging power required." – E2*

*"Energy and cost efficiency do not matter as long as the system is user friendly. The reliability of the equipment must be ensured in all aspects of charging and identification has to be made easy for users. A charging solution should be, so to speak, dumb enough to meet the primary needs of electric vehicle users. And primary need is of course to be able to charge one's vehicle as effortlessly as possible. A battery electric vehicle needs to be charged every day so way more often than traditional internal combustion engine vehicle. Yet the charging of an electric vehicle is often a complicated process especially when it comes to charging in public and semi-public locations. Of course, smart charging*

*and intelligent solutions can be utilized to meet the secondary needs but smart charging cannot ruin the charging process itself by making it too complicated. Thus, it would be most cost effective to just install a three-phase power cable as the prices of smart charging stations are still quite high, applications quite complex and prices would need to decrease significantly to make the solution reasonable." -E3*

**Electrical system of a property**

*"Each residential building requires a tailored system, there is not one suitable solution for all. It is essential to design and build an electrical system that supports charging for as many charge points as needed. " – E2*

*"In the interest of cost effectiveness, changes to main distribution board should be avoided if possible." -E3*

*"The most advantageous, of course, is that no changes need to be made and electricity can be drawn from the old main distribution board. However, when installing several chargers, it makes the most sense to design and build a separate fuse board for the electric vehicle charging stations in the main distribution board which then determines how large capacity is available for the charging overall." -E2*

*"In district heating areas, properties rather have overcapacity in available power than undercapacity. Occasional sharp consumption spikes occur rarely, for example during Christmas time when all residents are roasting their Christmas ham. An electric power lane should be therefore sufficient enough in such areas and locations." -E1*

*"Another bottleneck in capacity and electric power lanes could arise in older condominiums. If the building is built in the 21st century, amount of available capacity should be sufficient enough." -E1*

*"If asphalt has to be excavated in order to grow power capacity, the costs will increase significantly. For the most affordable and easiest solution I recommend to just replace the heating poles to charging stations." -E1*

*"The aim is always to proceed primarily with the existing power lines and available capacity. It is not advisable to acquire an electric power lane that exceeds the needs." -E2*

*"If asphalt has to be excavated in order to grow power capacity, the costs will increase significantly. For the most affordable and easiest solution I recommend to just replace the heating poles to charging stations." -E1*

*"The aim is always to proceed primarily with the existing power lines and available capacity. It is not advisable to acquire an electric power lane that exceeds the needs." -E2*

**Load Management**

*”Load management is a mandatory feature, especially in the future as charger volumes increase – properties do and will not withstand momentary consumption spikes.” - E3*

*“In almost all projects, load management has had to be added to the system as there is no unlimited amount of extra energy at any site. Load management must therefore be taken into account, at least for the future expansion of a system.” - E2*

*”There must always be dynamic load management as it makes the system durable and stand test of time. Only in case of a property with district heating and an oversized electric power lane, load management does not have to be taken into account. However, in terms of cost, in times of peaks in consumption, it would still make sense to have it.” – E1*

*”The downside of dynamic load management is the uncertainty of the power level at which charging will be obtained. If the need is to charge for 4 hours at 22 kW, but only 4 kW is available and received, the battery will be charged significantly less than originally planned.” -E3*

**Demand response and smart home solutions**

*”It would be important to be able to track total consumption of a property and distribute the power to devices that primarily need it and limit charging according to the electricity demand.” – E2*

*“In a large parking lot, it may even be necessary for devices in an intelligent solution to communicate with each other to manage the load. However, if there are only few electric vehicle charging stations in a residential or commercial property, a dumb system will be sufficient enough,” – E1*

*”The smart home solution will certainly be a benefit, but not in every location. It depends on which devices use electricity in the property and how large the electricity consumption of a building is in general. There should be enough flexible electric loads available for this kind of a smart solution to make sense and to keep project cost reasonable.” – E3*

*”Yet, there is not a solution on the market that could react based on the current price of electricity. If the system could to take into account the price of electricity while charging, it would be very cost efficient for the consumer.” – E1*

*”Solar collectors, renewable energy and batteries can increase flexibility when incorporated into a smart home solution.” – E2*

*“Artificial intelligence is theoretically and an option for the future too. In an optimized case, artificial intelligence could learn from an electricity consumption algorithm and regulate the charging of electric vehicles based on it.” – E1*

**Charging devices**

*”In large office building, there could be a need for fast charging – especially for guests to use or even for marketing purposes. However, I do not see the need for it in residential charging. Fast charging stations are expensive and residents mainly charge their vehicles at night. As the vehicles stand still for long periods of time fast charging is not needed. ” – E1*

*“There should be a bigger parking garage for fast charging to become reasonable. Nevertheless, a fast charging station could be a good investment, even if it does not individually pay itself off. Fast charging can increase the overall service level.” – E3*

*”I would choose the most reliable one, even if it is the most expensive. It a device does not work as expected, it will take away from the service from the perspective of both the user and the service provider. In addition, maintenance costs increase significantly if the device has to be repaired continuously.” – E3*

*”The charger includes wearing parts that should be replaceable. Therefore, when choosing a charger, it should be noted that if electrician has an access to these parts when they break. Serviceability is a major factor and has a significant impact on maintenance costs.” – E1*

*“Chargers are products that are highly standardized and therefore there are only little differences between devices. In the details, differences and features that affect the convenience and functionality of a charger can be noticed.” – E2*

*“The controller of a charging device plays an essential part and it must be in good condition at all times. In a dumb device these controllers are rather simple.” – E2*

*”Design of a device does not matter, the most important thing is functionality. For the user experience, indicative lights to instruct charging are useful. Touch screens are mainly useless and make the charging complicated. Easy-to-use chargers must be a priority: Internal combustion engine vehicles need to be refueled only few times a month and then there is electric vehicles that must be charged continuously on a daily basis. The easiness and functionality of the charging should therefore be self-evident.” – E3*

*”Ensto is a good charger choice for both residential and commercial locations. The equipment is more expensive as it is manufactured inside Europe, but at the same time these*

*devices are very high quality and functional. In addition, Ensto offers advanced solutions for load management. " – E1*

**Smart charging**

*"A charging solution must work at least at some level, even if the smart backend system is not with the solution used anymore. It creates a risk of charging systems life span to be unexpectedly shorter than originally planned. " – E1*

*"The system should be as dumb as possible but still as dumb as it makes sense. The solution ought to be easy to use and maintain." – E3*

*"Utilizing stock electricity prices to schedule charging would be cost-effective but would require a battery to support the system so that affordable electricity would be always available. The electric load and demand response managed by a backend system can affect the fuse sizes by reducing the need to grow capacity. This in turn can have an positive effect on costs - often high costs are reason for not taking on a project." – E2*

*"I believe that in the future, backend systems will become property-specific. The chargers are connected to smart buildings, allowing all the equipment in the building to communicate with each other and balance the load together." – E2*

*"If the project is delivered deep underground then connection needs to happen via an Ethernet cable, otherwise on the ground a SIM card and independent subscription is the most functional option." – E1*

*"If we are talking about 1-2 devices, the going for SIM cards and subscriptions is a more affordable alternative than using separate data gables." – E2*

*"If and when the system is connected to the Internet, often more problems occur too. When internet connection related problems are being sorted, it is often expensive and time consuming even if the causing is simple. Therefore, it is not advisable to connect chargers to the housing association's internet connection, as it may be weak and unstable." – E2*

*"In the long run, it would be beneficial to have a certain model or one way of forming the network connection in the sites. It makes it more cost efficient and easier to solve fault cases." – E3*