Electric vehicle charging in parking lots of multi-family houses

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Abstract

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This bachelor thesis examines the possibility for electric vehicle charging in parking lots of multi-family houses. A case study is performed on two different housing areas located in Uppsala, Sweden. The capacity of the electric cables supplying the housing areas with power and the installation costs for the charging points is studied. The thesis is written in collaboration with Uppsalahem, which owns and maintains the housing areas. The areas have different parking possibilities. The investigated alternatives for charging are modifying internal combustion engine pre-heating stations to charging points and building new charging points. The investigation is performed using a model made in MATLAB.

The results show that for the first housing area, Sala Hage, it is possible to supply the parking lots, 60 in total, belonging to the area with charging points with the power of 2.3 kW or 11 kW. For installing 22 kW chargers, the capacity of the cable is sufficient for only 30 parking lots. For the other housing area Kastanjen, the required capacity of the cable for installing charging points on the 60 parking lots in the garage is 106.6 kW for the charging power 2.3 kW, 266.3 kW for the power 11 kW, and 460.2 kW for the power 22 kW. A sensitivity analysis on the results of the MATLAB model is made by changing the input parameters.

The cost for upgrading the 43 parking lots in Sala Hage from the already installed internal combustion engine pre-heating stations to charging points is 292 400 SEK. To install 60 new charging points, the cost would be 4 920 000 SEK, a cost which is valid for both the housing areas.

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1. Introduction

Electric vehicles (EVs) have existed since the 19th century [1], but for the last hundred years the market has been dominated by internal combustion engine vehicles (ICEVs). However, as stated in [2], the number of EVs has increased exponentially over the last years. In 2012 for example, there were about 1200 EVs in Sweden, but in 2017 there were almost 50 000.

According to [3], the Swedish government has set a goal to have a fossil independent fleet of vehicles by 2030 in order to reduce the negative impacts the transport sector has on the environment. To reach this goal the development of EVs is of great importance [3]. The battery in battery electric vehicles (BEVs) can be charged from the power grid. Therefore, they have no local emissions and they can contribute to lowering the levels of emissions, if the charging electricity comes from a sustainable energy mix. As a result, the government has taken actions to encourage this development [4]. One of these actions is Klimatklivet which is a state-financed program that enables financial support for investments that can reduce the emissions and the fossil fuel usage in the transportation sector [5]. Klimatklivet can for example provide financial support to municipalities, housing companies and organizations for building charging stations and thereby expanding the charging infrastructure.

The authors in [6] state that the development of EVs has had and is still encountering challenges. Compared with the ICEVs, Jannesson [7] describes that EVs have more limited driving range and are in general more expensive. Therefore, to reach a further expansion of EVs, the charging infrastructure needs to be well developed [8]. However, as stated by the International Energy Agency [9], there is a lot to take into consideration regarding the electrical grid when building new charging stations. This is especially important in garages or parking areas with several charging points. The electric grid has capacity limitations on how much power that can be transported. If too much power is being drawn from the grid, overloading of power lines and transformers can occur. The problem especially concerns low-voltage distribution grids in residential or commercial areas. Nonetheless, according to the statement from Lewald at the Swedish Energy Agency, charging at home is a condition for a further expansion of EVs [10]. Some housing companies, including Uppsalahem have therefore started to investigate the possibility for installing charging points on the parking lots belonging to their facilities. The investigations need to include several aspects, such as the capacity of the cables and the installation costs. Two of the housing areas belonging to Uppsalahem, which are of interest for these investigations are Sala Hage and Kastanjen.

1.1 Aims

The aim of the project is to investigate the potential for EV charging points on existing parking lots belonging to Uppsalahem. More specifically, the project aims to examine
the possibilities of modifying internal combustion engines (ICE) pre-heating stations to charging points and building new charging points. This will be accomplished by performing a case study on two different housing areas where the capacity of the electric cables supplying the housing areas with power will be studied. The installation costs for the constructions will also be investigated.

1.2 Research questions

- Can the current capacity of the cable to the housing area Sala Hage supply all of the parking lots belonging to the area with EV charging points, when considering a varying power consumption from the housing area and different charging powers? If the capacity is not sufficient, how many charging points can the cable supply?
- Which capacity of the cable to the housing area Kastanjen is required to supply the parking lots in the garage belonging to the area with charging points for EVs, when considering a varying power consumption from the housing area? How will this vary between different charging powers?
- How much would the different installations cost, when considering two of the alternatives of charging points, either modified ICE pre-heating stations or installing new charging points?

1.3 Limitations

The thesis will focus on two housing areas with multi-family buildings belonging to Uppsalahem, currently without charging points. As the power consumptions from the housing areas, used in the thesis, are specific for these areas the results are also case-specific. Therefore, other outcomes may appear when studying other cases. The data regarding the driving patterns is valid for Swedish conditions; hence the results are only applicable in Sweden. Another limitation is the assumption that EVs only charge at home and that they start to charge directly when they arrive at home. A further limitation is that EVs are connected to the power grid until they are fully charged and an EV only charge once a day.

1.4 Disposition

After the introduction, Section 1 this bachelor thesis continues with Section 2, where background information is presented. The background section is followed by a methodology section, Section 3, where the methods used in this thesis are described. In this section, the model and the data that have been used are introduced. Thereafter, the results are presented in Section 4, followed by a sensitivity analysis. The results are analyzed and discussed in Section 5. The report ends with conclusions, Section 6, where the thesis questions are answered.
2. Background

In this section, a background is presented. The section starts with general information about EVs and then continues with a section about the power grid in Sweden. Further, information about charging of EVs followed by the future of EVs in Sweden are presented. The last part of the background describes Uppsalahem and the specific housing areas that has been chosen for this project.

2.1 Electric vehicles

According to [11], the first EV was introduced more than 100 years ago and by the year of 1900, EVs constituted one third of the total vehicle fleet. As further stated in [11], the EVs were silent and did not emit any smell from fuel. Despite these advantages, the EVs almost disappeared from the market by the year of 1935. However, on account of the increasing price of fossil fuel in the 1970s, the potential for EVs were once again under investigation. Nonetheless, it was not until the end of the 1990s that the development of the EVs rapidly proceeded. In 2006 the startup company Tesla Motors announced that they were going to launch an EV with a driving range of 200 km. This was one of several motives that inspired other vehicle manufacturing companies, already established, to start their development of EVs.

As stated in [12], there were about 50 600 EVs in Sweden as of March 2018, of which 28% were BEVs and the remaining percent were hybrid vehicles, both plug-in hybrid vehicles (PHEVs) and hybrid electric vehicles (HEVs). This number has increased with 60% over the past year. The three most common hybrid vehicles models in Sweden are Passat GTE, Mitsubishi Outlander and Volvo V60 Twin Engine, and the three most common EVs are Tesla Model S, Nissan Leaf and Renault Zoe [2].

Further on, in this thesis when referring to EVs, both BEVs and PHEVs will be taken in consideration since those types can be charged by connecting to the power grid, following reference [13]. The charging procedures are also the same for those types of vehicles.

2.2 The Swedish power grid

The Swedish power grid consists of three different types of networks, see Figure 1. The transmission network transports a large amount of electricity over long distances and has a very high voltage, up to 400 kV [14]. Further, the transmission network is divided into regional distribution networks after transformation of the voltage [14]. The voltage in the regional distribution networks is between 20-130 kV [14]. The regional distribution networks are followed by the local distribution networks, when in steps the voltage is transformed to line voltage of 400 V [14].
2.3 Charging of electric vehicles

Currently, there exist approximately 5000 public charging points in Sweden [12]. This represent a value of 0.1 charging point per EV. Due to the growing number of EVs, the charging infrastructure needs to expand at the same pace [8].

According to the Swedish Energy Agency [8], private owned EVs are parked 23 hours a day on average. Moreover, the most common charging, about 80-90%, occur in a non-public place, which is either at work or at home. Therefore, it is important that the charging possibilities for EVs at home improves [8], especially if the number of EVs should be able to continue to increase.

In Sweden, there are mainly three different charging levels for EVs [15]. The slowest charging alternative, also called normal charging, is by using regular sockets with the power of 2.3 kW or 3.7 kW. According to [16], the power 2.3 kW is used when charging with a modified ICE pre-heating station, with the current 10 A and the voltage 230 V. The second charging possibility is the semi-fast charging which has charging points with 11 kW or 22 kW and the voltage 400 V from a 3-phase [15], which are commonly used in households [17]. The third charging possibility is fast charging [15]. This type of charging has a power level over 22 kW and are often located at, for example, gas stations. For fast charging at public stations the charging time and the efficiency are improving [17]. However, the charging time depends on for example EV models, battery size, supplied power and temperature [17].
2.3.1 Charging challenges

During the hours 18.00-19.00 in the evening the consumption of electricity reaches its maximum [17], which can be explained by the fact that these hours represent the time that most people are at home combined with dinner time. This results in power peaks in the power grid [17]. Figure 2 shows the electricity consumption for one of the housing areas used in the case study, for one randomly chosen day, the 15th of February in 2017. As also mentioned in [17], the peaks are expected to increase due to charging EVs. The power grid has a limitation on how much power it can supply [18]. Therefore, there might be a limit on how many EVs that can charge simultaneously. Improving the grid infrastructure might be necessary to fulfill the future demands. As argued in [18], it is possible that the energy production will be enough to satisfy the electrical demands, but at some hours during the day the power peaks can induce a problem.

![Electricity consumption graph](image)

*Figure 2. Electricity consumption in one of the housing areas, 15th of February 2017 [19].*

There are several motives for trying to reduce the power peaks in the grid, both economic and technical [20]. For example, a flatter load in the power grid gives a possibility to connect more users to the power grid and increase the amount of electricity that comes from renewable energy sources [20]. The economic aspect of reducing the power peaks can also be beneficial for the consumers of the electricity [20]. According to [21], the electricity is cheaper when the demand is lower, for example during the night.
2.4 The future of electric vehicles in Sweden

Pursuant to the Swedish Energy Agency in [22], the attitude towards EVs is overall positive and research shows that more than 50% of the people, that are planning on buying a vehicle in the next five years, are considering buying an EV. However, the lack of general knowledge about EVs and its usage, for instance regarding the charging infrastructure, is one of the reasons why people choose not to buy an EV. Therefore, the general knowledge about EVs needs to increase to get more people to invest in EVs in the future.

According to [23], there are approximately five million private owned vehicles in Sweden, of which 1% are EVs. An investigation of the development of the Swedish fleet of private owned vehicles, conducted by the Swedish government agency for transport policy analysis, presented a scenario for the year 2030 where the forecast predicts that the EVs will represent 19% of the private owned vehicles [24].

The increasing adoption of EVs is beneficial to the environment since it reduces the dependency of fossil fuel [8]. However, it creates a higher demand of charging opportunities and the charging infrastructure of EVs. According to [25], research about future charging possibilities is upcoming, for example conductive and inductive charging. With conductive charging, electric energy is being transmitted via fixed conductors, while driving. As further presented in [25], this type of charging demands some sort of connector on the vehicle that reaches the conductors in order to be able to charge. Inductive charging, however, is wireless but requires special charging spots and the vehicles must be equipped with an induction receiver. This technique is not revolutionary since it is used for example in electric toothbrushes, but it has not been applied in the charging infrastructure of EVs before [25]. With this method, the vehicles charge in places where they have to stand still, for example at a red light. Another advantage with this technique is that the charging equipment is hidden in the ground and there is no need of charging cables [25]. However, this charging alternative still induce some problems regarding power losses while charging and a high temperature [26].

Further, ongoing research about charging possibilities is involving the opportunity to replace the battery of the EV with a fully loaded battery instead of charging the EVs' battery [25]. Although this would entail a faster and a more comfortable charging for the driver, the technique is expensive and difficult to apply to all kinds of EV models.

In this thesis, only charging by connecting the EVs to a charging point with 2.3 kW, 11 kW and 22 kW are taken into consideration. Accordingly, neither conductive charging, inductive charging or battery replacement, as explained before, is investigated further in the model.
2.5 Uppsalahem

Uppsalahem, according to their own website [27], is a housing company owned by the municipality in Uppsala, founded in 1946. Their aims are to own, manage and develop real estates in Uppsala and to offer all kinds of residences adapted to different stages in people’s life. Today Uppsalahem is one of Uppsala's biggest real estate developers with approximately 16 000 residences and about 30 000 tenants.

As mentioned in [27], Uppsalahem focus on sustainability in everything they do. Their vision is to create a city full of life both now and in the future. They decrease their energy consumption by for example energy saving renovations such as insulation of the ceilings, walls and floors. In addition, changing the windows and replacing lighting to a more energy efficient alternative is another investment that decreases their energy consumption. They also have ethical demands towards their providers, they inspire their tenants to live more climate smart and they are building environmental certificated residences that will stand for generations to come. Because of these and several other efforts, Uppsalahem have managed to reduce their CO$_2$ by 40% since 2004 [27].

2.5.1 Electric vehicle charging at Uppsalahem

According to Tomas Nordqvist, Head of energy department and energy project manager at Uppsalahem [28], there is a possibility for the tenants at Uppsalahem to install a charging point for EVs in their parking lots. This can be accomplished through modifying ICE pre-heating stations. Such a modification costs 6800 SEK per point, including installation, according to [28]. The charging point has a capacity of 2.3 kW which comes from the one phase outlet with 230 V and 10 A. Currently, the tenant is charged 500 SEK extra per month for a parking lot with a charging point. This includes both installation and operating costs. Also stated by Nordqvist [28], this modification of the ICE pre-heating station is rarely requested, only three of Uppsalahem's tenants have requested this modification. Currently, Uppsalahem has no charging points in their garages. However, some housing areas have only parking possibilities in garages, which is why charging in a garage is an interesting aspect to investigate.

Another possibility for EV charging as a tenant at Uppsalahem, is to install a new charging point [28]. This point has a charging power of 11 kW or 22 kW. The cost is around 82 000 SEK per charging point. This includes both the installation and the equipment costs.

2.5.2 Sala Hage and Kastanj

Two of the housing areas belonging to Uppsalahem are Sala Hage and Kastanjen. These areas are chosen as case studies in this thesis.
One of the housing areas, Sala Hage, described in [29], is located around two kilometers from Uppsala city center. The area consists of one house built in 1986. There are 89 apartments in the house and the tenants are able to rent both parking locations in an unheated garage and parking lots outside, with or without ICE pre-heating stations. According to Nordqvist in [28], there exists 60 parking lots in total in the housing area, of which 43 parking lots provide ICE pre-heating stations.

The other area of study, Kastanjen, described in [30], is located close to Sala Hage. In this area, four multi-family houses are located, and they were built between 2012 and 2013. There are 118 apartments in total and there exists 60 parking lots, in a garage in the basement, available for renting.
3. Methodology

In this section of the thesis the methodology is described. Firstly, an overview of the model and its input parameters is introduced. This is followed by a section regarding the data used in this thesis. Thereafter, the calculations in the model is presented. In the final section the calculations that has been used in the thesis are described.

3.1 Model overview

The method that has been used in this thesis is modelling in MATLAB, see [31]. The model simulates the power consumption from charging a given number of EVs and adds this to the power consumption from the housing area. A whole month is being simulated. The driving distance and the arrival time are parameters in the model. These parameters are used for calculating the charging time for each EV and the power consumption from the simulated EVs for every hour in the month. Further on, the power consumption from the EVs and the house power consumption for the whole month is being summed up. In Figure 3, a flowchart of the structure of the model is shown. The total power consumption can be compared with the maximum capacity from the cable that are supplying a housing area. The model can be simulated for different numbers of EVs to be able to see if the maximum capacity of the cable has been reached.

Figure 3. A flowchart of the model.

As the model simulates the power consumption on hourly resolution for one month, a month needs to be chosen. The simulation can then be repeated for all the months that needs to be investigated. The model also takes into account whether it is a weekday or a weekend, as the data used in the model differs between these days. However, the
structure of the model creates an error in the beginning in the month as the time interval needs to begin somewhere.

3.1.1 Input parameters

Input parameters are variables that has to be assigned a value to simulate the model in MATLAB. This makes it possible to apply the model to different cases. Two of the parameters contain information about what time interval that are going to be simulated. The parameters year and month that one aims to simulate should be provided. Another parameter is average driving consumption (kWh/km), which is the value of how many kWh an EV consumes every km. The input parameter number of EVs is a value on how many EVs the model will simulate. The last parameter is charging power (kW), which correspond to the power level that the charging point provide.

3.2 Data

3.2.1 Arrival time

The arrival time corresponds to the time of the day an EV arrives to the parking lot at home. The data that has been used is based on a study, Resevaneundersökningen (RVU) [32], of people's driving behaviors conducted in 2005-2006. The model takes into account the arrival time at home, which is arriving from work and arriving from other destinations. The data is also divided into weekdays and weekends so the model separates these two occasions.

3.2.2 Driving distance

The variable driving distance symbolizes how much each EV has driven on a day. On average a vehicle drives 12 110 km per year in Sweden according to [33], which corresponds to approximately 33 km per day. In the study [32], conducted by RVU, several different driving distances are registered, for example from home to work and from work to other places. These distances are also divided into weekdays and weekends.

3.2.3 House load

The current load of the housing areas is required to examine the maximum number of EVs that can charge without exceeding the supplied cable capacity. The load data is recorded on hourly resolution for the year 2017. This results in a limitation since the data only represent the consumption one year. It is possible that the power consumption of the year of 2017 was an outlier. This might affect the results and therefore a sensitivity analysis is made on the house power consumption, see Section 4.4.1.
3.3 Model calculations

3.3.1 Arrival time

For each day, a list is created containing home arrival times which were randomly drawn from different lists depending on if it is either a weekday or weekend. This list is as long as the number of EVs that is being simulated. Since the arrival time data is given in minutes, the values are converted into hours and then rounded to the nearest integer towards minus infinity. In the same manner, a list of arrival times of each day in the month is being created. The arrival time results in a list as long as the number of days in a month times the number of EVs that are being simulated, with random picked arriving times for each EV, every day.

3.3.2 Driving distance

The data for the driving distance, used in the model, is divided into weekdays and weekends. For the driving distance of weekdays, a list is created with the sum of the distance from home to work and the other way around. This is done as the average value of the driving distance one day then became around 33 km, the average driving distance in Sweden [33]. Accordingly, a list for the weekends is created with the sum of the distance from home to other, where other represents all places except work and home, and from other to home. The variable driving distance is then being sampled randomly from these lists. The number of random values that are being sampled each day, is the same as the number of EVs, which is an input parameter in the model. This results in a list, as long as the number of days in the month times the number of EVs that are selected. The final list contains random values of the driving distances every day.

The registered data of driving distances from the study conducted by RVU regarding the driving patterns in Sweden, only contains data from people who has driven a certain distance each day. This is why an assumption of the model is that each EV drives a distance every day. Therefore, the model does not take into consideration that an EV might stay at home during a day.

3.3.3 Maximum driving distance

An assumption in the thesis is that the average driving consumption for EVs is 0.2 kWh/km, according to [34]. Mentioned in [35], one of the EV models with the longest driving ranges is Tesla model S 100. The EV model, stated in [36], has a battery capacity of 100 kWh. Therefore, the maximum driving range used in the model is 500 km according to,

\[ d_M = \frac{C_b}{c}, \]  (1)
where $d_M$ is the maximum driving distance in km, $C_b$ represents the capacity of the battery in kWh and $c$ equals to the average driving consumption in kWh/km. This value is used in the model, since the lists with driving distances for a vehicle each day contains trips that exceed the maximum length. Therefore, these trips are rounded down to the maximum driving range of 500 km. However, this modification has a limited effect in the model because even after the modification, the average driving distance each day is about 33 km, which, as mentioned before, is the average driving distance in Sweden [33].

A limitation of the model is the assumption that all of the EVs possess the same qualities regarding capacity of the battery and consumption of electricity. These assumptions regarding the capacity of the battery and the driving consumption are being investigated further in the sensitivity analysis, see Section 4.4.

### 3.3.4 Charging time

For all the EVs, the charging time is calculated for every day, which results in a list as long as the days in the month times the number of EVs. The charging time, $t_{C,i}$ in hours, is the time during which EV $i$ must be connected to the power grid to be fully charged. This time is calculated according to,

$$
t_{C,i} = \frac{(d_i \cdot c)}{P},
$$

where $d_i$ is the driving distance for EV $i$ and the $P$ is the charging power in kW. The charging time is rounded to the nearest integer towards plus infinity in the model, since the model only takes whole hours into account. This makes a source of error since the charging time becomes longer than it should be. Because of this, the result might show too few vehicles than the capacity of the cable can supply. However, this makes the number of EVs stay on the safe side of the limit of the cable capacity.

Regardless of how long the charging time is, an assumption is made that all EVs drive and charge every day.

### 3.3.5 EV charging load

The EV charging power, for the selected charging level, is added to the arrival hour of the EV and added for as many hours thereafter as the charging time is calculated to, see Section 3.3.4. This is done for all the EVs for every day in the month to receive the total EV charging load.

### 3.3.6 Total load

The total power consumption, $P_{tot}(t)$, in kW is the sum of the EV charging load, $P_{EVs}(t)$ and the load from the housing area, $P_{\text{house}}(t)$, according to,
\[ P_{\text{tot}}(t) = P_{\text{EVS}}(t) + P_{\text{house}}(t). \]  

This results in a list that contains the total power consumption for every hour in a month, which is the outcome of the model.

### 3.4 Calculations

#### 3.4.1 Capacity of the cable

The power capacity of the cable is needed to be able to investigate how many EVs the grid, with its current capacity, can supply. The power flowing in the cable, \( P_{\text{cable}} \), can be estimated from,

\[ P_{\text{cable}} = U \cdot I \cdot \cos \varphi, \]  

where \( U \) is the Voltage in V, the current \( I \) in A and \( \cos \varphi \) is the power factor. The power factor is assumed to be equal to 1 in this study. The housing area, Sala Hage, had nominal voltage levels on 400 V line to line and the cable had a total maximum current of 500 A. Through Equation 2, the maximum power is 345 kW for Sala Hage.
4. Results

In this section of the thesis the results for the different housing areas are presented. In Section 4.1 the results from Sala Hage is shown and Section 4.2 presents the results for Kastanjjen. Further on, Section 4.3 describes the results from the financial analysis. The result section ends with a sensitivity analysis in Section 4.4.

4.1 Sala Hage

The results for Sala Hage are based on a power consumption from the housing area of the month of December. December was chosen as that month has the highest average power consumption in the year 2017. Three simulations with different charging powers are presented. The first simulation corresponds to the case when the ICE pre-heating stations were modified into charging points in the area Sala Hage, see Figure 4. The power level is therefore 2.3 kW and the results show the simulation for 43 vehicles, as this is the number of parking lots in Sala Hage with ICE pre-heating stations. The total power consumption, see Figure 4, corresponds to the sum of the power consumption from the housing area and from the EVs. The simulation shows that the total load did not exceed the capacity of the cable, which can provide maximum 345 kW. The cable represents an oversized capacity compared to the required capacity when simulating the 2.3 kW charging level. When simulating the month of December 100 times, to account for the randomness in the model sampling, the total power consumption in 100% of the simulations did not exceed the cable capacity.

![Figure 4. House power consumption and the total power consumption during December 2017. In total, 43 EVs were simulated and charging was performed using the charging level 2.3 kW.](image)
Instead of modifying ICE pre-heating stations into charging points, new charging points could be installed. These installations could result in higher charging levels for the EVs. Semi-fast charging power levels of 11 kW and 22 kW have therefore been examined.

Figure 5 correspond to the case when the charging power is 11 kW. The simulation was performed for 60 EVs, since that is the total amount of parking lots in Sala Hage. This simulation also shows that the total power consumption did not reach the limit of the cable capacity. The cable with the capacity of 345 kW is still oversized as can be seen in Figure 5. When the simulation was repeated for 100 times the total power consumption in 100% of the simulations did not exceed the cable capacity.

![Figure 5. House power consumption and the total power consumption during December 2017. In total, 60 EVs were simulated and charging was performed using the charging level 11 kW.](image)

The results of the simulation, when using a charging power of 22 kW for 60 EVs, is shown in Figure 6. In this simulation the total power consumption has exceeded the capacity of the cable. However, this figure represents one of the preformed simulations. Since the model uses a random parameter the results can vary. The simulation was repeated 100 times each for different number of EVs, see Table 1.
Figure 6. House power consumption and the total power consumption during December 2017. In total, 60 EVs were simulated and charging was performed using the charging level 22 kW.

Table 1 presents the proportion of simulations that did not exceed the cable capacity for 30, 40, 50 and 60 EVs. This was accomplished as the simulations with 60 EVs had a low percentage of simulations that did not exceed the capacity of the cable of 345 kW. The simulation was repeated for a decreasing number of EVs in even tens, until the total load in all of the simulations was below the limitation of the cable.

Table 1. The proportion of tolerated simulation of 100 iterations for four given numbers of EVs when using the charging level 22 kW.

<table>
<thead>
<tr>
<th>Number of EVs</th>
<th>The proportion of tolerated simulations (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>40</td>
<td>96</td>
</tr>
<tr>
<td>50</td>
<td>63</td>
</tr>
<tr>
<td>60</td>
<td>14</td>
</tr>
</tbody>
</table>

4.2 Kastanjen

For the housing area Kastanjen, the results are based on the power consumption from the housing area in the month of November, since this was the month with the highest average power consumption. However, the data regarding the house consumption of
Kastanjken is missing for the months December and April. Three scenarios with the charging powers of 2.3 kW, 11 kW and 22 kW was simulated with 60 EVs as this is the number of parking lots that the garage possess, see Figures 7, 8 and 9.

**Figure 7.** House power consumption and the total power consumption during November 2017. In total, 60 EVs were simulated and charging was performed using the charging level 2.3 kW.

**Figure 8.** House power consumption and the total power consumption during November 2017. In total, 60 EVs were simulated and charging was performed using the charging level 11 kW.
Figure 9. House power consumption and the total power consumption during November 2017. In total, 60 EVs were simulated and charging was performed using the charging level 22 kW.

The data regarding the capacity of the cable supplying the housing area Kastanjen has not been received, therefore the total power consumption from the housing area and the simulated EVs has been calculated. This was accomplished to receive a result regarding which capacity of the cable that is needed to supply all of the 60 parking lots with charging points. The simulations were repeated 100 times for the three charging powers. From these 100 simulations the maximum total power consumption of each charging level was determined, see Figure 10. For the charging level 2.3 kW the maximum total load was 106.6 kW. If 60 charging points with the power 2.3 kW would be installed in the garage, a cable with the capacity of 106.6 kW should therefore be enough. In the same manner, charging levels of 11 kW and 22 kW would require a capacity of the cable of 266.3 kW and 460.2 kW respectively.
Figure 10. The maximum total power consumption of 100 simulations with the charging levels 2.3 kW, 11 kW and 22 kW. In total, 60 EVs were simulated.

4.3 Financial analysis

The cost to modify an ICE pre-heating station into a charging point, according to Uppsalahem, is 6800 SEK. Therefore, if installing charging points in the parking lots belonging to Sala Hage, that acquires ICE preheating stations, the total cost would be 292 400 SEK for 43 charging points. If a higher charging power would be installed, 11 kW or 22 kW, either for Sala Hage or Kastanjen, the cost for each charging point would be approximately 82 000 SEK, since ICE pre-heating stations cannot be updated. If 60 charging points would be installed with 11 kW or 22 kW, this would correspond to a total cost for the charging points of about 4 920 000 SEK.

In Sala Hage, the results show that in 86% of the simulations the total power consumption is exceeding the capacity of the cable, with 60 EVs and charging power of 22 kW. The cost for different number of charging points with 11 kW or 22 kW, is therefore presented in Table 2.
Table 2. The costs for installing different number of charging point with the charging level 11 kW or 22 kW.

<table>
<thead>
<tr>
<th>Number of charging points</th>
<th>Costs (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>2 460 000</td>
</tr>
<tr>
<td>40</td>
<td>3 280 000</td>
</tr>
<tr>
<td>50</td>
<td>4 100 000</td>
</tr>
<tr>
<td>60</td>
<td>4 920 000</td>
</tr>
</tbody>
</table>

4.4 Sensitivity analysis

In the sensitivity analysis all of the values in the model are the same as in the result section, apart from the parameter which is being analyzed.

4.4.1 House power consumption

The results in this thesis are based on data from the year 2017. The year of 2017 could have either higher or lower power consumptions from the housing areas than other years. Therefore, it is relevant to execute the simulation for different power consumptions from the housing areas to receive a more reliable result.

With an increasing house power consumption, the maximum number of charging EVs could decrease. Therefore, simulations with increased house power consumptions, +25% and +50%, have been examined. The result for the charging level 2.3 kW in Sala Hage is shown in Figure 11. The same proportional increase is visible for the charging powers of 11 kW and 22 kW in Sala Hage, see Appendix A, Figures 18 and 19. For the charging powers of 2.3 kW and 11 kW the capacity of the cable will still be enough for 43 and 60 charging points respectively, with an accuracy of 100% of 100 simulations.
Figure 11. The total power consumption with varied house power consumption. In total, 43 EVs were simulated for Sala Hage and charging was performed using the charging level 2.3 kW.

For the charging level 22 kW in the housing area Sala Hage, the proportion of tolerated simulations will be affected when increasing the house power consumption, see Table 3. For 30 EVs, the capacity of the cable will still be enough even if the current load will increase by 50%. For the other number of EVs the tolerated simulations decrease when increasing the consumption from the housing area.

Table 3. The proportion from tolerated simulation from 100 iterations for four given numbers of EVs, with varied housing power consumption.

<table>
<thead>
<tr>
<th>Number of EVs</th>
<th>Current capacity (Nov. 2017)</th>
<th>125% of the current capacity</th>
<th>150% of the current capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>40</td>
<td>96</td>
<td>89</td>
<td>87</td>
</tr>
<tr>
<td>50</td>
<td>63</td>
<td>61</td>
<td>48</td>
</tr>
<tr>
<td>60</td>
<td>14</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

For the housing area Kastanjen, the results were acquired through simulating 100 times, with different charging powers and a varying house power consumption. The maximum required power from these simulations is shown in Figure 12. See Appendix A Figures 20, 21 and 22 for individual plots of the effect on the total load when changing the house power consumption. As seen in Figure 12, an increasing power consumption
from the housing area results in a requirement of higher capacity of the cable providing the housing area. Although, when increasing the house power consumption with 50%, for the case of 22 kW, the increase of the total load was about 7% compared to the original total power consumption. This can be explained by the fact that the charging power consumption from the EVs constituted a bigger share of the total power consumption.

Figure 12. The maximum total power consumption of 100 simulations with the charging levels 2.3 kW, 11 kW and 22 kW. In total, 60 EVs were simulated with varied house power consumption.

4.4.2 Driving consumption

The average driving consumption in the model was assumed to be 0.2 kWh/km. The driving consumption effects both the charging time and the maximum driving distance in the model. According to [34], the driving consumption of an EV can vary between 0.15 kWh/km and 0.25 kWh/km, which is why the effect of changing the value to these two options has been investigated in this section.

The simulation of 2.3 kW with 43 parking lots in Sala Hage shows a slight difference between the total power consumptions, see Figure 13. However, with a capacity of the cable of 345 kW, the effect of the different driving consumptions will be limited. Even with this varying driving consumption there will be enough capacity of the cable to install 43 charging points with the power 2.3 kW.
In total, 43 EVs were simulated for Sala Hage and charging was performed using the charging level 2.3 kW.

When considering the charging power of 11 kW, the deviations between the total power consumptions is less visible, see Figure 14. This can partly be explained by the fact that the model rounds up the charging time to whole hours. As the charging time will not differ that much from the charging time when the driving consumption is 0.2 kWh/km, it is possible that the number of whole hours becomes the same. This is also the case when charging with 22 kW, see Figure 15. Since the charging time becomes shorter, due to the high charging power, the effect of the rounding up will be extra evident. The result of this is that the varying values of the driving consumption will have a limited effect on the total load, as seen in Figure 15.
Figure 14. The total power consumption with varied values on the driving consumption. In total, 60 EVs were simulated for Sala Hage and charging was performed using the charging level 11 kW.

Figure 15. The total power consumption with varied values on the driving consumption. In total, 60 EVs were simulated for Sala Hage and charging was performed using the charging level 22 kW.
For the other housing area, Kastanjen, the outcomes of changing the driving consumption is similar to the ones from Sala Hage. See Appendix B for these simulations.

### 4.4.3 Battery capacity

An assumption in the model is that the battery capacity is 100 kWh. However, this is valid for one of the EV models with a long driving range. Since the battery capacity affects the maximum driving range of the EVs in the model, the effect of this value has been examined. As mentioned before, one of the most common models of EVs in Sweden is Nissan Leaf [2]. This model has a battery capacity of 24 kWh [37]. Therefore, the model has been simulated for this battery capacity.

With a lower battery capacity, the maximum driving distance of the EVs becomes shorter. However, as the average driving distance in Sweden is 33 km, most of the driving distances of the EVs will not be affected by the shorter maximum value, as seen in Figure 16 for the housing area Sala Hage. With an increasing charging power, the difference between 100 kWh and 24 kWh is less visible due to the rounding of the charging time. See Appendix C for simulations with 11 kW and 22 kW. The simulations show similar results for Kastanjen, see Figure 17.

![Figure 16](image.jpg)

*Figure 16. The total power consumption with varied values on the capacity of the battery. In total, 43 EVs were simulated for Sala Hage and charging was performed using the charging level 2.3 kWh.*
Figure 17. The maximum total power consumption of 100 simulations with the charging levels 2.3 kW, 11 kW and 22 kW. In total 60 EVs were simulated for Kastanjen with varied capacity of the battery.
5. Discussion

In this section, the results and the assumptions in the model are being discussed. The financial aspect is also analyzed.

5.1 Reliability

The results from this thesis show that the capacity of the cable supplying the housing area, Sala Hage, does not constitute a comprehensive problem for the charging levels up to 22 kW. Nonetheless, there might be other components such as transformers, or other parts of the power grid that might constitute a problem when charging multiple EVs at the same time. This is also the case if choosing to install charging points in the housing area Kastanjen. For this reason, a total investigation should include an analysis of the entire grid. Another aspect that the model did not take into consideration is a safety margin for the power withdrawal. If the use of power exceeds the capacity of the cable, the repercussions could be troublesome. Therefore, when implementing charging points in housing areas, a safety margin could be an important aspect to keep in mind.

Another challenge is that the charging time for some EVs will be long, with the charging level that the modified stations acquire, 2.3 kW. Even though the average driving distance every day is shorter than the driving range of an EV, the charging process should also be feasible when a lot of the capacity of the battery has been used. Considering a Tesla vehicle for example, with the battery capacity of 100 kWh, when the battery goes from empty to fully loaded the charging will take over 40 hours using the charging level 2.3 kW, according to the calculation in Equation 2. This charging power might therefore not be suitable for tenants driving these vehicles. These charging times are also problematic for the MATLAB model since an assumption is that all the EVs drive and charge every day. With a charging time that long, the EV will not be fully charged by the following day. This could result in adding the charging load from the same EV twice that day which could affect the results. However, some of the most common EVs in Sweden today does not have a battery capacity that large. As mentioned in the background section, one of the most common EVs, Nissan Leaf for instance, has a battery capacity of 24 kWh. To fully charge this EV from an empty battery, the charging time would be just above 10 hours with the charging level 2.3 kW. This charging time is reasonable for charging overnight, and the installation of charging points with this charging level could therefore be an alternative.

Another aspect that might affect the charging potential in the future is the charging infrastructure in society. An assumption in the model was that EVs only charge at home. However, if charging is easily accessible at work places or other places where people spend a lot of time, or on the road with conductive or inductive charging, the charging needs at home will decrease. As mentioned before, the model only took into account that the EVs start to charge immediately when arriving home and then load
until the battery is fully charged. However, it is possible that the tenant might use the vehicle again in the evening, thereby acquiring several shorter charging times during the day. This is an aspect which was not included in the model, and it would affect the power consumption, possibly during the peak hours. To get a flatter load on the power grid it is also a future possibility that the tenants postpone their charging to hours with less load in the grid. This scheduling of charging hours could reduce the problem with power peaks and thereby also lowering the price for the electricity.

A further assumption in the model was that the tenants that have an EV drive every day. An EV could also park in some other place over the night. Occurrences like these will affect the results from the model. The driving distances in the model were also based on the average driving distance in Sweden. However, it is not given that the tenants in the studied housing areas have driving behaviors similar to the measured values. With an average value, it is possible that some people drive longer, and some people drive shorter. A total investigation should therefore include a more specific analysis of the driving patterns of the tenants in the chosen housing areas.

An aspect worth take into consideration is that the model was based on data of the driving patterns valid for Swedish conditions, as mentioned before in Section 1.3. The driving patterns could also change over time, for instance due to more EVs in the transport sector. Therefore, if the model is applied to other conditions, for instance another country with different driving patterns, the outcome of the model could be affected.

One of the most important result in this thesis is that the cable capacity will constitute a problem for 60 parking lots for the charging level 22 kW in Sala Hage, see Section 4.1. If the capacity of the cable providing the housing area Kastanjen would have the same capacity as Sala Hage, similar problems would occur. However, a scenario where all the parking lots will have an EV is probably some years away according to the prognosis about 19% EVs in 2030, as mentioned in the background section.

5.2 Financial aspects

As mentioned in the background section, the cost for the two installations is 6800 SEK for a modification of an ICE pre-heating station, and 82 000 SEK for the installation with semi-fast charging, 11 kW and 22 kW. The semi-fast charging could be interesting for owners of EVs who have EVs with large battery capacities and request shorter charging times. However, these types of installations are more comprehensive and would probably require further investigations, and possibly rebuilding of the cables to the parking lots. This potential cost is not included in Table 2, which presents the total cost for installing the charging points. The demand for EV charging at Uppsalahem has been limited in the past, and there is an uncertainty about what the demand will be in the future. The results, in Section 4.3, show that the installation cost for 11 kW and 22
kW would be significantly higher than installing the level 2.3 kW, even if the number of parking lots would be fewer. However, if the tenants would request higher charging power, the economic aspect could be facilitated with financial support from the program Klimatklivet. This would decrease the initial costs and at the same time reduce the charging times.
6. Conclusion

The capacity of the cable to Sala Hage does not constitute a problem for modifying the 43 ICE pre-heating stations to charging points with the charging level 2.3 kW. The capacity is also sufficient for installing new charging stations in all the 60 parking lots belonging to the area with the charging power of 11 kW. However, the capacity of the cable becomes a problem when the charging power is 22 kW and the number of parking lots is 60. To acquire that the capacity of the cable is sufficient with a security of 100% of 100 simulations, the number of EVs could be 30.

The required capacity for the cable to the housing area Kastanjen differs between the installed charging powers. For the charging levels 2.3 kW, 11 kW and 22 kW, when installing 60 charging points, the total required capacity is 106.6 kW, 266.3 kW and 460.2 kW respectively.

For the modification of 43 ICE pre-heating stations to charging points in Sala Hage, the total cost would be 292 400 SEK. For installing 60 parking lots with the power 11 kW or 22 kW, the cost would instead be 4 920 000 SEK. This cost is also valid for the housing area Kastanjen. For an installation of 30 charging points, the number of charging points the capacity of the cable to Sala Hage can supply power to with 100% security, of 100 simulations, the total cost would be 2 460 000 SEK.
References


[19] Uppsalahem, data over the power consumption from the housing area Sala Hage for the year 2017, provided from Nordqvist, T. (2018-04-11)


Appendix A

Figure 18. The total power consumption with varied house power consumption. In total, 60 EVs were simulated for Sala Hage and charging was performed using the charging level 11 kW.

Figure 19. The total power consumption with varied house power consumption. In total, 60 EVs were simulated for Sala Hage and charging was performed using the charging level 22 kW.
Figure 20. The total power consumption with varied house power consumption. In total, 60 EVs were simulated for Kastanjen and charging was performed using the charging level 2.3 kW.

Figure 21. The total power consumption with varied house power consumption. In total, 60 EVs were simulated for Kastanjen and charging was performed using the charging level 11 kW.
Figure 22. The total power consumption with varied house power consumption. In total, 60 EVs were simulated for Kastanjen and charging was performed using the charging level 22 kW.
Appendix B

Figure 23. The total power consumption with varied values on the driving consumption. In total, 60 EVs were simulated for Kastanjen and charging was performed using the charging level 2.3 kW.

Figure 24. The total power consumption with varied values on the driving consumption. In total, 60 EVs were simulated for Kastanjen and charging was performed using the charging level 11 kW.
Figure 25. The total power consumption with varied values on the driving consumption. In total, 60 EVs were simulated for Kastanjken and charging was performed using the charging level 22 kW.
Appendix C

Figure 26. The total power consumption with varied values on the capacity of the battery. In total, 60 EVs were simulated for Sala Hage and charging was performed using the charging level 11 kW.

Figure 27. The total power consumption with varied values on the capacity of the battery. In total, 60 EVs were simulated for Sala Hage and charging was performed using the charging level 22 kW.