Energimyndighetens titel på projektet – svenska Smart och Robust Elinfrastruktur för Framtiden	
Energimyndighetens titel på projektet – engelska Smart and Robust Electricity Infrastructure for the Future	
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Nyckelord: 5-7 st Kapacitetsbrist, Elbilar, Värmepumpar, Elektrifiering	

Förord

Projektet Smart och Robust Elinfrastruktur för Framtiden syftar till att identifiera och bemöta framtida kapacitetsbehov i Stockholmsregionen som uppstår med ökad elektrifiering. Projektet började i December 2016. Energimyndigheten har finansierat projektet och Fortum, Svenska Kraftnät och Elbil2020 har samtfinansierat genom deras input, data och tid. Ellevio AB har också bidragit till ett lyckat projekt genom att ger deras data av eldistributionsnätet.

Contents

Sammanfattning

Det svenska elsystemet står inför ett antal utmaningar i framtiden. Elförsörjningen kommer att vara 100 % förnybar till 2040, vilket innebär en kraftig ökning av oplanenbart produktion från sol och vind. Förbrukningen kommer att förändras avsevärt när elfordon ska integreras i systemet och uppvärmning kan ske i form av elektriska värmepumpar. Dessa förändringar påverkar både det totala elbehovet över tid men i större utsträckning behovet av effektkapacitet i överföringsnät och distributionsnät. Vi ser redan akuta svårigheter i regionala och lokala elnät för att täcka ett ökat kraftbehov. Som konstaterats av Svenska Krafnät kan denna identifierade brist på kraftkapacitet inte åtgärdas före 2030. Det aktuella projektet har tagit upp dessa utmaningar i kraftinfrastrukturen i Stockholm med lokal nivå och integrerat perspetive genom att göra: a) Lokal belastningsanalys baserad på framtida scenarier för kort och långvarig elanvändning som tar hänsyn till utveckling av elbilar och lokal integration av värmepumpar. b) Kraftflödesanalys i distributionsnät för att identifiera kapacitetsbrister och dimension för de nya belastningsscenarierna. c) Produktions- och lastkontrollanalys om hur de korta och långsiktiga lokala och regionala kraftkapacitetsbehoven kan balanseras. Projektresultaten inkluderar lokal flaskhalsidentifiering samt maximala nivåer av elfordon och värmepump. Dessutom konstaterades att strategier för belastningshantering och sektorns koppling kan sänka nätverksinvesteringar fram till 2030.

Summary

The Swedish electricity system faces a number of challenges in the future. The electricity supply will be 100 % renewable by 2040, which implies sharp increase of fluctuating production from solar and wind. Consumption will change significantly when electric vehicles are to be integrated into the system and heating can take place in the form of electric heat pumps. These changes affect both the total electricity demand over time but to a greater extent power capacity needs in transmission networks and distribution networks. We are already seeing acute difficulties in regional and local electricity networks to cover an increased need for power. As stated by Svenska Krafnät, these identified shortage of power capacity cannot be remedied before 2030. The present project has addressed these challenges in the power infrastructure at Stockholm using a local level and integrated perspetive by doing: a) Local load analysis based on future scenarios for short and long term electricity use that takes into account electric vehicle loads development and local integration of heat pumps. b) Power flow analysis in distribution networks to identify capacity deficiencies and dimension for the new load scenarios, c) Production and load control analysis on how the short-term and long-term local and regional power capacity needs can be balanced. The project results include local bottlenecks identification as well as maximum levels of electric vehicle and heat pump. Additionally, it was found that load management strategies and sector coupling strategies can post-pone network investments until 2030.

1 Motivation/Background

The Swedish government and parliamentary parties in the summer of 2016 agreed on the pillars of energy policy in the future to realize climate goals through a goal of zero net greenhouse gas emissions 2045 and fossil-free power generation 2040. In order to achieve these goals, not only do electricity generation and use change, but also transport needs to be climate neutral. This translates into a significantly increased share of electric vehicles in the transport fleet with 2TWh 2030 and 7TWh 2050. The use of heat pumps for heating is also increasing in households with increasing conversion efficiency and low electricity prices. However, deciding on a future robust electrical system based on production and distribution capacity is not only about that total energy consumption, but also about coverage of power demand. The need for power in the future is largely due to the proportion of electric cars and electric heating that will be present in the system and when these will be used.

There are shortcomings in the electricity infrastructure already in the Stockholm region, where grid restrictions lead to restrictions on the expansion of electricity intensive infrastructure within the Stockholm ring. However, it is not only power constraints in the grid which constitute potential barriers to increased electricity use in the Stockholm region, but also limitations in low and inter-voltage networks that distribute the electricity from the grid to the customers. Current distribution stations and cables have not been dimensioned for a significant power increase as electric car charging and heat pumps can mean.

In a study on the impact of increased penetration of electric cars and heat pumps in residential areas in Gothenburg region [1], it was concluded that the maximum power output can increase more than 80% electricity use should follow a price-optimal usage strategy. Loss optimization strategies for power outlets car and heat occur during low load periods, on the other hand, only increase power consumption around 10% in the surveyed areas. Uncontrolled charging would still increase the maximum power output by over 30% as many distribution stations and cables are not designed for today. This study stated that low voltage networks need to be investigated as well and dimensioned for future load and that the electrical heat connection needs further highlighted. The reliability of the results of the study above is of course directly dependent on the scenarios for future use of electric vehicles and electricity for heating. The longer the time horizon, the more difficult it is to predict the future cargo image. Today, we lack load scenarios at regional and district level in the Stockholm region that directly address the use of electric vehicles and electricity heat and that can be used as input for dimensioning analyzes in the distribution networks.

This project builds on the studies from [1] to address current and future capacity needs in distribution infrastructure in both the between and low voltage networks in the Stockholm region with consideration to scenarios for future electricity and electricity demand. We also want to investigate how and to what extent identified capacity shortages can be met with new local production capacity. The overall objective of the project is to based on scenario analyzes for future electricity and heat demand identify capacity shortages in regional power grids and power generation infrastructure. For those identified capacity shortages should be found smart solutions that optimally combine load balancing methods, network capacity expansion and local production capacity. Methodology shall apply to model district in Stockholm region but should be generally applicable to other regions in and outside Sweden. The project was carried out at the Department of Energy Technology, KTH from 2016 to 2020.

2 Implementation

The project was subdivided in five work packages (WPs) and targetted six specific goals. The majority of the work was carried out at the KTH - Energy Technology Department with input from the other project partners. This section proceeds to describe the content and methods developed within each WP as well as their correlation to the goals (G).

WP1 Electricity consumption scenario development for short and long term visibility in selected model districts in Stockholm. The scenarios were based on national energy investigations and local trends of future electricity and heating needs in the region, with a focus on electric vehicle use and heat pump installation. The methodology carried out for this WP was a literature review and gathering of publicly available data.

G1 Development of 3 future scenarios, with 5 and 25 years visibility, of electric vehicle use and heat pump installation in 5 selected model districts.

WP2 Intermediate voltage power flow analysis in selected model districts in Stockholm. This was done to identify power capacity shortages in the regional distribution network and analyze the effect of load balancing measures. The methodology used in this WP consisted of electric power flow analysis.

G2 Analysis of load capacity in the intermediate voltage network of 5 model districts to identify power capacity shortages based on 3 different load management alternatives.

WP3 Low voltage power flow analysis of a district to identify local capacity shortages and dimension network upgrades (long and short term). The methodology used in this WP consisted of electric power flow analysis.

G3 Analysis of load capacity in the low voltage network in one critical model district for two load scenarios to identify capacity shortages in the distribution grid.

WP4 Analysis and optimization of new local local production capacity and load balancing methods as well as balancing between network infrastructure and production capacity investments. The methodology used for this WP consisted of co-simulation of heating and electricy sectors as well as linear optimization algorithms.

G4 Optimization of distribution infrastructure investments in low- and medium-voltage networks together with load control and balancing to identify solutions to the power capacity shortages,

G5 Aggregation of the overall demand picture at district and regional level for identification of energy and power needs in the region,

G6 Identification of technoeconmic optimization of possible production capacity in the region to cover the capacity shortages in the short (5 years) and long (2040) term with regards to both power and heat demand development.

WP5 Final Reporting of the project as comprised within this report.

3 Results

This chapter describes the results and conclusions generated within the framework of this project. The coming sections are named in accordance to the WP structure shown in Chapter 2.

3.1 Electricity Consumption Scenarios

The developed electricity consumption scenarios in this project were constructed based on the electric vechicle and heat pump trends described below. In addition district-level power capacity limits were also used as part of the scenarios in order to have a reference for the regional power shortages. The results presented within this section correspond to WP1 and G1.

Electric Vehicle Trends Historic data from Trafikanalys [2] was gathered up to year 2019 for Stockholm and for Sweden. Based on this, the projected rate of growth of electric vehicles was regressed towards future years. In addition, the Power Circle organization has assessed the long term market development of plug-in electric vehicles (PEV) in Sweden [3]. Their forecast was adapted to the population of personal vehicles in Stockholm. Figure 1 shows the historic electric vehicle data, its future regressions as well as the Power Circles forecast. Based on these trends, the PEV penetration levels adopted within this project are comprised within the grey area of the *Sthlm regression* and the *Power Circle Forecast*. In particular, the figure also shows the assumed PEV penetration assumed for the district of Hammarby Sjöstad as *HS Scenarios*.

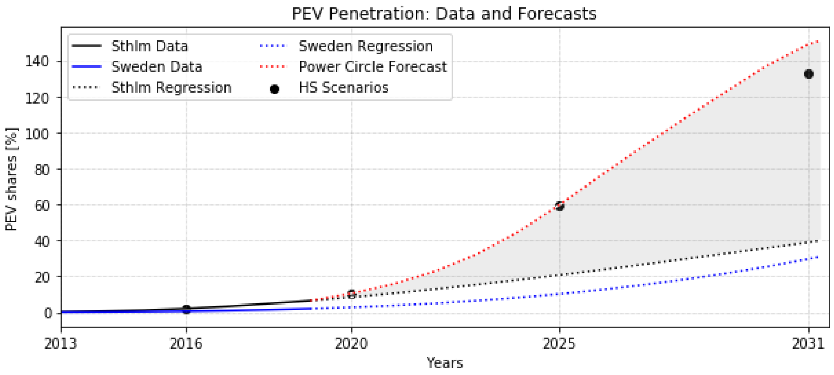


Figure 1: Historical data and future trends of electric vehicle shares in Sweden [4]

Heat Pump Trends Heat pumps contribute to the reduction of the energy demand due to an increased coefficient of performance. Due to this, the scenarios from consulted sources [5, 6, 7] all concur on an increase of these in the future energy system. According to [5], the contribution heat pumps to energy efficiency is considerable only until 2035 and even more so in the scenarios with lower electricity prices. In 2050, the contribution of heat pumps in the scenario with lower electricity prices is expected to be 24 TWh (+71% compared to 2016). In the scenario with high electrification, heat pumps are expected to contribute with 80 TWh in 2050. According to [6], heat pumps are expected to increase their market share by 2050, up to +36% compared to 2020 in the scenario with predominant individual solutions.

3.2 Intermediate Voltage Network Analyses

The intermediate voltage networks of the neigborhood of Hammarby Sjöstad and the island Lidingö were analyzed in this work. These two locations were identified by Ellevio as being relevant test cases due to their predisposition for being early adopters of distributed energy resources, specially electric vehicles. The results presented within this section correspond to WP2 and G2.

Selected District Intermediate Voltage Networks: Figure 2 shows the one line diagram of the power system analyzed for Hammarby Sjöstad. The network is composed of 20 substations of 12kV/400V that are fed from 2 external feeders. About 77% of the customers in the area are residential customers and the remaining 23% are commercial activities.

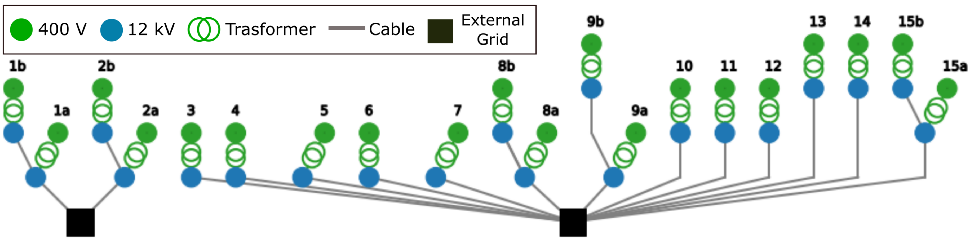


Figure 2: Intermediate voltage network in Hammarby Sjöstad

Figure 3 shows the one line diagram of the power system analyzed for Lidingö. The network is structured with 7 main stations and it includes four voltage levels (70kV, 20kV, 12kV and 0.4kV). The number of substations in the network amounts to 218. The whole island is fed externally at one location and about 95 % of the connected customers are residential. Based on the size and scale of these two network systems it is considered they cover the targeted amount of 5 districts to be analyzed within this project.

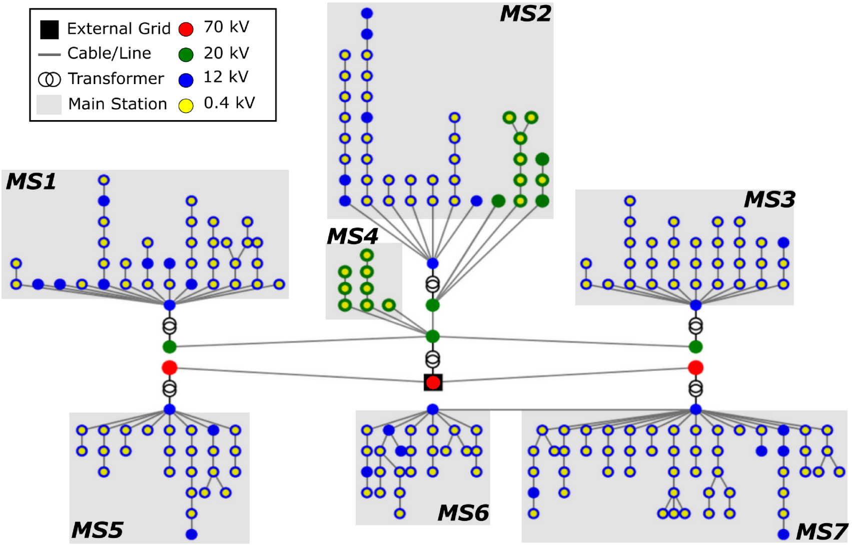


Figure 3: Intermediate voltage network in Lidingö

Power Flow Analysis and Capacity Shortages: Power flow analysis of the networks was carried out using the tool *pandapower* [8]. This was done considering different scenarios of electric vehicle penetration in the networks. Figure 4a shows the allowed PEV penetration for each substation in Hammarby Sjöstad on each scenario year for the case in which the PEV loads are uncontrolled. It can be seen that for years 2016 and 2020 there are no local or global contraints in reaching the EV Scenario (EVSCE) level. However, in years 2015 and 2031 there are limitations in the network. Figure 4b shows in more detail how the bottlenecks in 2025 are related to the external power budget (red-line) while in 2031 the bottlenecks are related to the local components as the power budget is not a problem.

For the case of Lidingö, the power flow analysis consisted of find the maximum allowed level of electric vehicle penetration among the different main stations. The scope of the study was carried out for eight typical days considering the different seasons and two types of day: weekdays (wd) and weekends (wd).

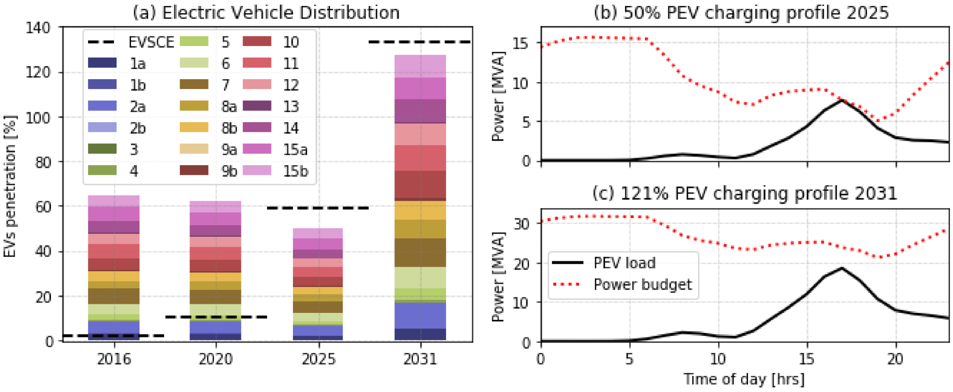


Figure 4: Maximum Electric Vehicle Penetration: uncontrolled case

Table 1: Comparison of peak power and component loading between the base case (BC) and the electric vehicle penetration case (EVC) for eight typical days in the island of Lidingö

	Peak Power [MVA]		**# Trafo $>$ 90%**		**# Cable $>$ 80%**	
Season-Day	BC	EVC	BC	EVC	BC	EVC
winter-wd	100.5	112.0	33	51	4	5
winter-we	96.3	107.1	32	49	4	4
spring-wd	85.2	88.4	13	24	2	2
spring-we	73.2	77.5	8	14	1	1
autumn-wd	88.1	101.5	19	38	4	5
autumn-we	88.3	100.3	20	35	4	5
summer-wd	52.6	61.2	4	6	0	0
summer-we	51.6	60.3	3	6	0	0

Table 1 shows the resulting power demand on the external grid of the network as well as the number of cables and transformers that exceed a certain loading level. The maximum EV penetration found for the whole island was found to be 47%. However, this share is distributed differently among the main stations of the network. Figure 5 shows the EV load profile and corresponding share distributions.

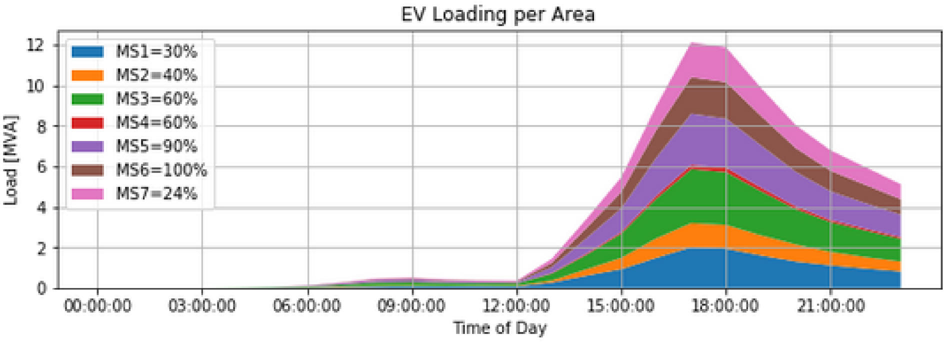


Figure 5: Maximum Electric Vehicle Penetration: uncontrolled case in Lidingö

Load Balancing Measures In Hammarby Sjöstad, years 2025 and 2031 were identified as being problematic in the uncontrolled case. The effect of load management strategies were analyzed for these two years. Figures 6 show the uncontrolled and optimized PEV charging profiles for 2025 and 2031, respectively. The loss optimization strategy distributes the PEV charging as evenly as possible thoughout the day, with a large concentration of power demand on the early morning hours due to the high amount of residential vehicles. The cost optimal load strategy actually generates new peaks in the late evening and early morning, when the network costs are low and the power budget is more allowing.

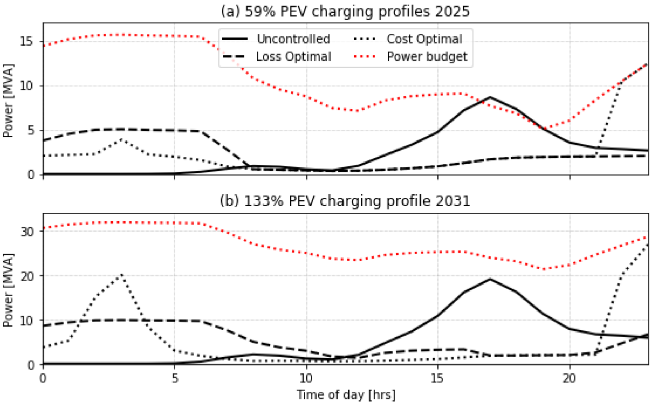


Figure 6: Load management strategies for Electric Vehicle Penetration: uncontrolled and optimized cases

3.3 Low Voltage Network Analyses

The low voltage network analyses focused on Hammarby Sjöstad. A section of the low voltage grid of the neighborhood was analyzed regarding heat pump installation and electric vehicle penetration. The results presented within this section correspond to WP3 and G3. Figure 7 shows a zoomed-in view of the selected area which includes 4 different transformer stations. The voltage level of the distribution network is 400 V.

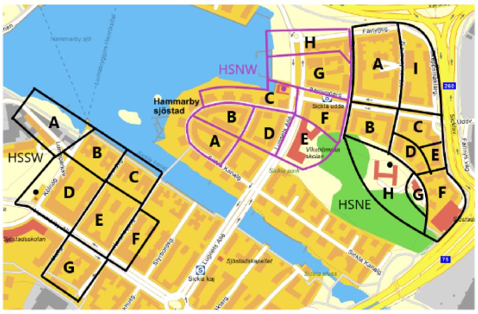


Figure 7: Area of Hammarby Sjöstad selected for low voltage grid analysis [9]

Heat pump Installation: The technical feasibility of a 100% penetration of distributed heat pumps was analyzed in one substation [10]. The focus was on assessing the impact of these distributed heat pumps on the loading of the low voltage electricity distribution grid. Whenever the heat pumps generate a peak power demand peak, causing an overloading on the electricity grid, district heating is recruited instead. Figure 8 shows a conceptual layout of this analysis. It was found that four cables (parallel ones included) should be considered critical. Figure 9 illustrates the topology of the grid and reports the level of overloading for a particular moment. This corresponds to 7:00 pm on February 2nd, when it can be shown that overloadings can reach levels of around +140% over the maximum capacity. On an annual basis, dsHPs can satisfy only 85% of the total heat load. Thus, a full independence from DH cannot be reached.

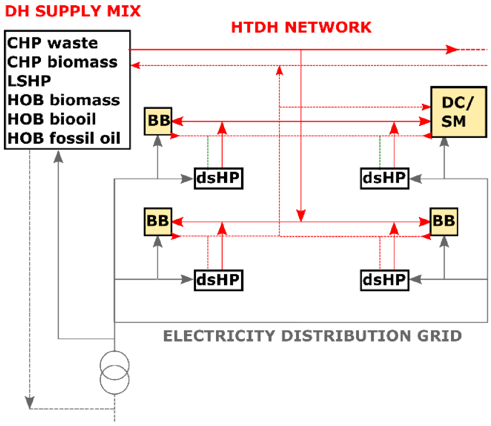


Figure 8: Conceptual layout for 100% distributed heat pumps (dsHP) and district heating (DH) as backup in the different building blocks (BB)

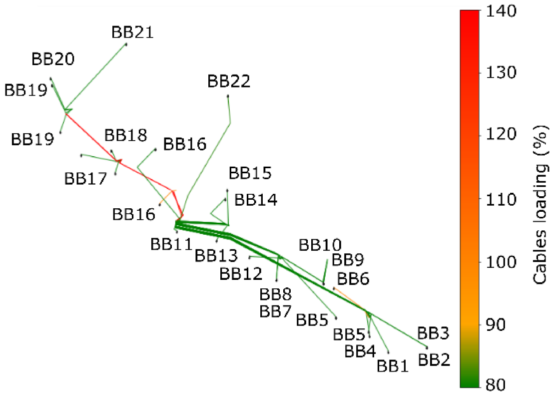


Figure 9: Critical cables for the case study shown in the topology of the grid

Electric vechicle penetration: The technical fesibility of electric vechicle penetration for years 2025 and 2040 was analyzed for three substations (HSNW, HSNE and HSSW). The penetration levels for the EVs were based on the forecasts by Power Cirles adapted to the total amount of registered vehicles in the area. For the year 2025 this value corresponds to 29.3% of the vehicles in the area charging from the grid. Scenarios for uncontrolled (UC) and controlled charging (CC) of the electric vechiles were also considered. Figure 10 shows the load profile for a critical day with regards to the transformer loading of each substation. Moreover, figure 11 shows the loading of the cables in the area for the peak of the critical day.

3.4 Network Optimization

The optimization efforts consisted of balancing between network infrastructure investments, demand side management methods and local production capacity. This also included exploiting the synergies between different distributed energy resources, such as orchestrating the operation of electric vehicles and heat pumps or electric vehicles and solar panels. The results presented in this section correrpond to WP4 and G4 and G5.

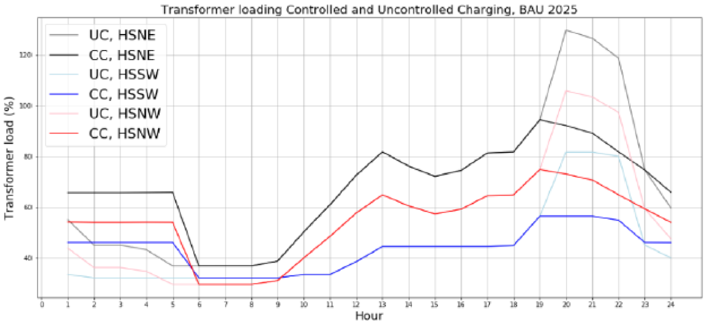


Figure 10: The transformer load (%) for all three substations using UC and the difference due to CC in 2025

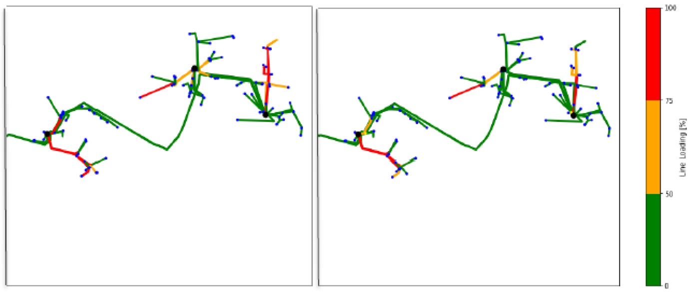


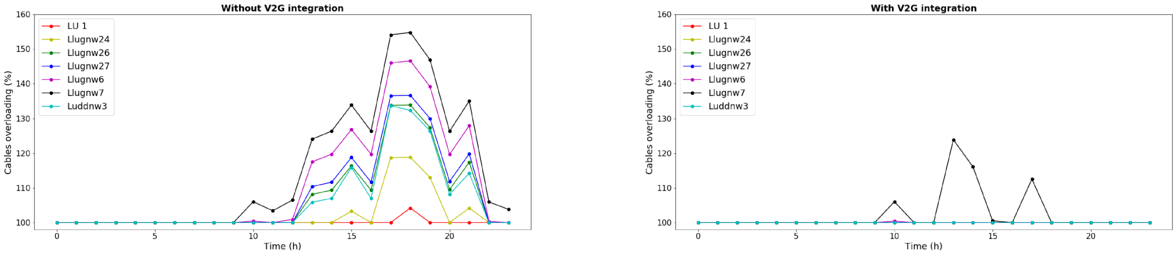
Figure 11: Cable loading (%) data plotted with actual coordinates for the year of 2025. Loading data with UC to the left, CC to the right. Green cables have a loading percentage of 0-50 %, orange 50-75 % and red cables 75-150 %.

Heat pumps and demand side management options: In order to unlock the technical feasibility of distributed heat pumps, demand side management is presented as a promising solution to the grid's overloading problem. In particular, two demand side management technologies are assessed. The first one is the control of the thermal mass (TM) in the buildings as a thermal energy storage. The second option tackles the issue from the electric power perspective, by means of vehicle to grid (V2G).

For the first case, the thermostat temperature set point, in each apartment, is allowed to vary in the range of 20 ± 0.5 ^{o}C. It is found that the use of the TM generates fewer heat pump disconnections, up to -50% depending on the buildings' TM capacity. However, the problem is considered unsolved, since, for robustness and safety, the cable overloadings should be completely eliminated. The critical cables remain the same ones pointed out in Figure 9.

V2G combines the electric vehicle battery as another option, in addition to the TM. The penetration level of the EVs is assumed to be 100%. These cars are driven to and back from work. After these trips, given a sufficient state of charge (SOC), the EVs' batteries can be further discharged to cover the cable overloadings. The charging of the EVs' batteries happens over the night, thus avoiding the generation of new power peaks. When available, the electricity stored in the EV's batteries is used to cover the overloadings caused by the heat pumps in the corresponding building. The EVs' availability is defined by two conditions: The EVs should be parked at the building's station and their SOC should be at least 80%. Figure 12 shows the impact of the V2G control strategy on the grid's loading. The critical cables left are due to the time mismatch between the overloadings occurrence and the EVs availability.

Electric vehicles and solar panels: Based on the results shown in Figure 6, the Table 2 compares theload management cases in more detail in terms of the amount of critical trafos, total losses, charging



(a) (b)

Figure 12: Cable overloadings in the heat pumps and demand side management

costs per vehicle and maximum peak. With the use of loss optimal load management strategies it is possible to reduce losses by 9.9% in 2025 and by 21.2% in 2031 with respect to the base case. Similarly, with the use of cost optimal load management strategies daily charging costs per vehicle can be reduced by 39.1% in 2015 and by 50.9% in 2031.

In addition to load management strategies, the charging of the EVs in the area was optimized with regards to local solar PV production. The first step was to map the potential for PVs in each of the substations based on the available rooftop areas. This potential is shown in Figure 13 as the yearly power per network area. The next step was to optimize PV production with the EVs charging needs. Additionaly, V2G was also considered within this analysis in order to utilize the EV batteries bilaterally (charging and discharging). Figuge 14 shows the operation of these resources based on losses (a) and costs (b) optimality for one of the network areas. The uncontrolled case of vehicle charging is also shown in the figures as ”BAU”.

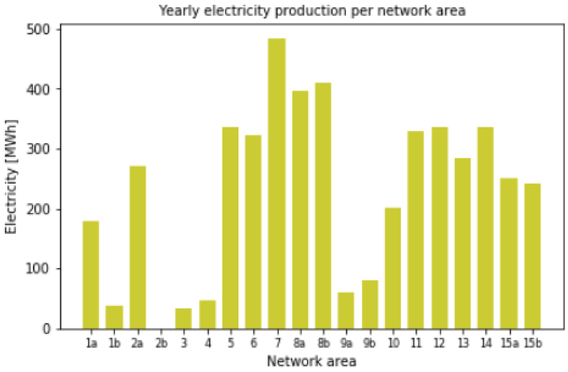
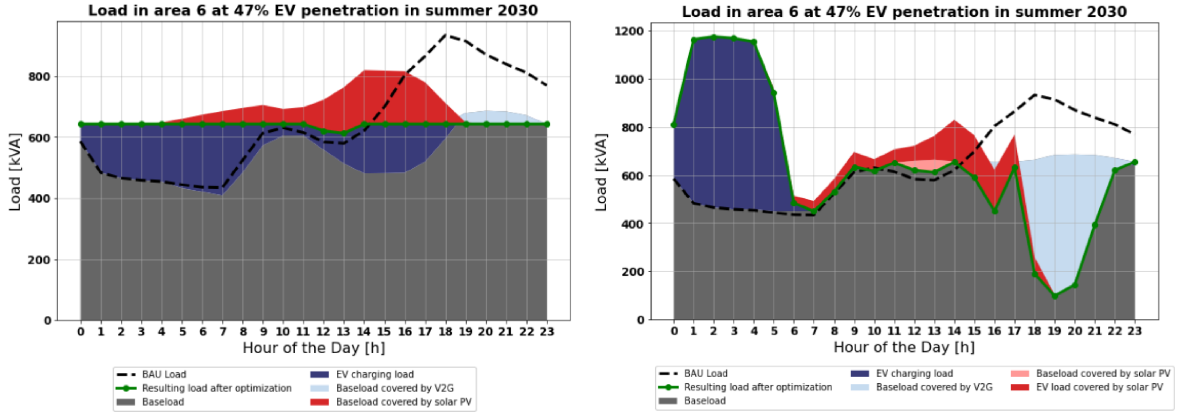


Figure 13: Yearly electricity PV power per network area

Aggregation to the whole region: The overall demand picture at the districts was gathered for three key years: 2020, 2025 and 2040. Each year has an associated base load (BL) and EV load (EVL) power demand. The BL demands were obtained from measured data on the districts and extrapolated based on population prognosis. The EVL demands were calculated using an in-house model and were based on the high scenario from Figure 1, namely: 10%, 60% and 100% for 2020, 2025 and 2040 respectively. Figure 15 shows the BL (a) and EVL (b) power demands for the districts of Hammarby and Lidingö. Figure 16(a) displays the aggregated values of BLs and EVLs for the two districts. Moreover, the EVL for the city of stockholm were calculated based on SCB data regarding vehicle statistics for the whole municipality. However, it was not possible to gather base load data at a regional level. Instead,



(a) (b)

Figure 14: PV+V2G Optimization: (a) Loss optimal (b) Cost optimal.

Table 2: Comparison between uncontrolled and optimization studies for critical years with regards to transformer status, total losses, charging costs and maximum peak

	Critical Trafos ($\geq$ 95%) [#]	Total Losses [MWh]	Charging Costs [SEK/car]	Maximum Peak [MVA]
year 2025		*59% EV penetration*		
Uncontrolled	7	14.94	9.44	23.47
Loss Optimal	**5**	**13.46**	6.43	**19.37**
Cost Optimal	13	14.66	**5.71**	22.51
year 2031		*133% EV penetration*		
Uncontrolled	15	23.20	9.35	33.83
Loss Optimal	**6**	**18.28**	6.57	**19.30**
Cost Optimal	16	22.41	**4.76**	36.87

a prognosis of these base loads was made based on keeping the same proportion between BLs and EVLs as for the aggregated pictures. This is shown in Figure 16(b), which represented the aggregated power needs in Stockholm municipality due to base loads and electric vechicle loads.

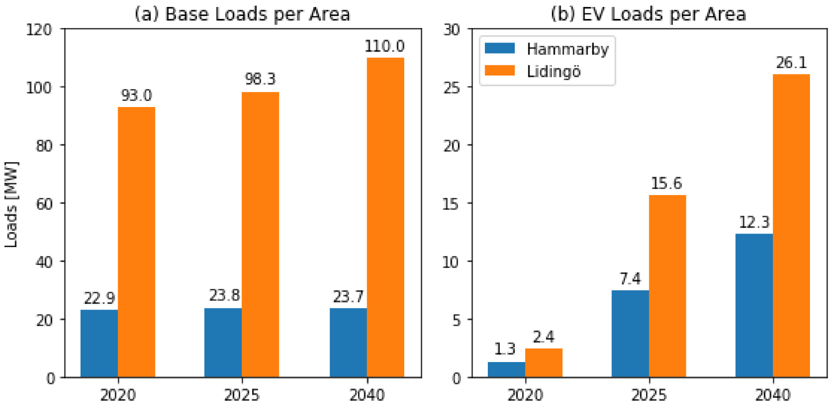


Figure 15: Power demand for each of the districts in terms of (a) base loads and (b) electric vehicle loads

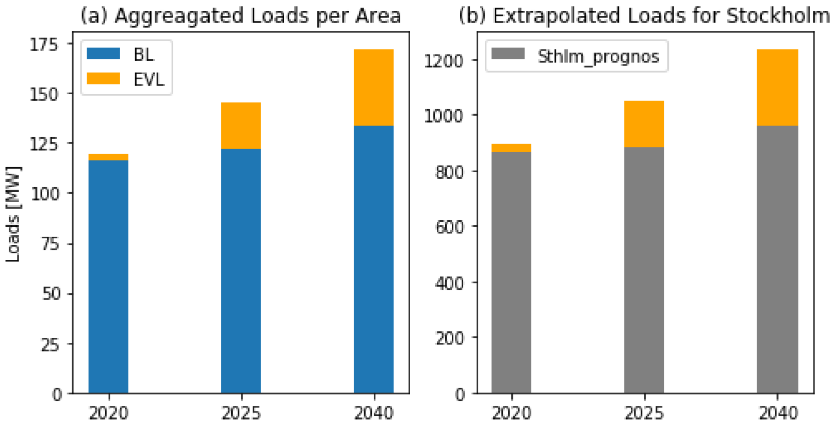


Figure 16: Aggregated power demand for (a) the districts and (b) for Stockholm City.

4 Discussion

The results shown in previously are discussed in terms of the measurable goals set within the project:

G1: with the gathered statistics and available prognosis from relevant sources it was possible to map the future trends for electric vehicle adoption within a fast and slow development range (see Figure 1). The speed at which this adoption occurs will depend on other factors such as policy measures, technical development and socio-economic. For the heat pumps, given the existence of district heating as an alternative, the scenarios for these are really dependant on how the market of these actors evolve. Therefore, scenarios considering heat pumps focused on how these could be better integrated into the system assuming 100% penetration.

G2: The intermediate voltage network analyses lead to the identification of bottlenecks in the substations and also to defining the maximum allowed penetration of electric vehicles within the analyzed districts. Regarding the power capacity shortages, the year 2025 was identified as critical to both districts (see Figure 4). It was also shown that loss optimal load management strategies can postpone these bottlenecks and allow for a higher integration of vehicles (see Figure 6). However, network investments using these strategies can only be post-poned until 2030 where upgrades should be made in the network components in order to allow for an increased penetration of distributed energy resources.

G3: The low voltage network analyses uncovered capacity shortages in the same area with regards to both heat pumps and electric vehicles. These shortages were observed to happen at earlier stages than the ones observed at the intermediate level. Therefore, these results serve to highlight critical cables that the DSO should invest in provided that these scenarios happen in this way (see Figures 9 and 11). On the heat pumps case, a main finding is that they can only cover 85% of the annual total heat load without incurring in electricity network overloads.

G4: Load management was identified as a solution to the power capacity shortages. However, it was found that managing the load according to the current costs structures might lead to even higher power peaks (see Figure 14). Moreover, among the solutions identified to mitigate power capacity shortages a main outcome relates to exploiting the synergies of the different distributed energy resrouces, such as: coupling heat pumps with indoor temperature control and vehicle to grid services or controlling vehicle charging schedules with respect to local PV production. One relfection in this regard is that these solutions need to be studies locally in order to assess their level of impact.

G5: The aggregation of the overall demand picture was built from extrapolating the case of the two districts studied in the project. Based on the current calculations (see Figure 16) the power needs in stockholm munipilaity will increase due to electric vehicles by 16% in 2025 and by 38% in 2040 compared to 2020. This extrapolation can be more accurate if exact data regarding the power demands of the base loads in stockholm city would have been obtained.

G6: Possible production capacity in the region to cover the power shortages in the short term (5 years) can involve sector coupling and local PV installations. Demand side management showed to have the technical potential to unlock the integration of heat pumps. The impact of solutions like the control of the thermal mass and of V2G, is reinforced when they are combined, thus linking heat and power sectors. In the long run (2040), as the power shortage situation will be alleviated at transmission level, it will be necessary to perform investments in the grid infrastructure to withstand the higher loads from electric vehicles and heat pumps.

5 Publication List

The publications made related to this project during the reported period include: three journal publications, one conference publication, four MSc. student reports and four other technical reports. These publications and reports are all referenced in the bibliography of this document. Below, the corresponding citations are made along with a short mention of how these contributed to the project implementation.

Journal Articles

[4] corresponds to **WP1-G1** with regards to the electric vehicle scenarios, to **WP2-G2** with regards to the intermediate voltage network analysis and to **WP4-G4** with regards to load balancing strategies.

[10] corresponds to **WP1-G1** with regards to heat pump scenarios, to **WP3-G3** with regards to low voltage network analysis and to **WP4-G4** with regards to heating and electricity synergies optimization.

[11] corresponds to **WP1-G1** with regards to heat pump and electric vehicle scenarios, to **WP3-G3** with regards to low voltage network analysis and to **WP4-G4** with regards to heating and electricity synergies optimization.

Conference Articles

[12] corresponds to **WP1-G1** with regards to heat pump and electric vehicle scenarios and to **WP2-G2** with regards to the intermediate voltage analysis.

Theses

[9] corresponds to **WP1-G1** with regards to electric vechile scenarios and to **WP3-G3** with regards to low voltage network analysis.

[13] corresponds to **WP1-G1** with regards to electric vechile scenarios and to **WP3-G3** with regards to low voltage network analysis.

[14] corresponds to **WP2-G2** with regards to intermediate voltage network analysis and to **WP4-G6** with regards to possible production capacity.

Other

[15] corresponds to **WP1-G1** with regards to heat pump and electric vehicle scenarios and to **WP2-G2** with regards to the intermediate voltage analysis.

[16] corresponds to **WP1-G1** with regards to electric vehicle scenarios and to **WP4-G6** with regards to optimization of possible production capacity.

[17] corresponds to **WP1-G1** with regards to electric vehicle scenarios and to **WP4-G5** with regards to aggregation at regional level.

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