D5.1 NATIONAL PROOF-OF-CONCEPT FOR THE SWEDISH CELL

VERSION 1.0

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About ERA-Net Smart Energy Systems

ERA-Net Smart Energy Systems (ERA-Net SES) is a transnational joint programming platform of 30 national and regional funding partners for initiating co-creation and promoting energy system innovation. The network of owners and managers of national and regional public funding programs along the innovation chain provides a sustainable and service oriented joint programming platform to finance projects in thematic areas like Smart Power Grids, Regional and Local Energy Systems, Heating and Cooling Networks, Digital Energy and Smart Services, etc.

Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

Beyond that, ERA-Net SES provides a Knowledge Community, involving key demo projects and experts from all over Europe, to facilitate learning between projects and programs from the local level up to the European level.

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1 INTRODUCTION

This report contains description of demonstration sites, national use cases, business models, simulation models, proof-of-concept setup and validation results for the Swedish Cell, comprised in Work package 5.

1.1 Purpose

In accordance with the Paris Accord (COP21), the EU has committed to the binding targets of at least 55% cuts in greenhouse gas emissions compared to 1990 levels and 27 % share of renewable energy of EU energy consumption by 2030. On the longer timeframe set by the corresponding roadmaps, the EU aims at 80 % CO2 reduction by 2050, and the share of renewable energy resources in gross final energy consumption by 75 %. These EU decarbonization targets leads to electricity increasingly coming from fluctuating renewable energy sources (RES) that are mostly exploited in rural areas. At the same time, the Europe-wide trend towards urbanization brings about increases in consumption in cities and their local energy systems where the potential for renewable generation is limited. The more energy supply fluctuates and decentralizes and energy demand is centralized, the more congestion problems in the power distribution grid lead to the need to cap renewable feed-in which entails significant RES asset downtimes and corresponding inabilities to fulfil highly ambitions decarbonization targets.

The distribution system infrastructure is not expandable proportionate to these challenges mainly for socio-economic reasons, the process of digitalization to fully steer the grid along volatile load situations has just started and the cost-benefit ratio of storage technologies is still lower than expected. At the same time, integrated local energy systems in cities and communities bear a significant potential to provide flexibility to the surrounding power distribution grid that is not sufficiently understood and vastly underutilized.

CLUE develops tailor-made solutions to measure and utilize the flexibility potential in locally integrated energy systems and at the same time to improve the cost-benefit ratio of storage options. By stabilizing the energy system and reducing asset downtimes, these solutions will increase the resilience of the system and enable large shares of renewables in local energy systems. Finally, CLUE develops tools for optimized planning, managing and monitoring of integrated regional energy systems in order to fully exploit their flexibility options.

1.2 Method

CLUE follows mainly two scientific approaches. Firstly, based on a detailed analysis of the needs and gaps of the stakeholders and the expertise of the scientific and industry partner in modelling and tool development, a tool kit will be developed and tested with the practice partner. Secondly, demonstration sites will be developed, operated, monitored, analysed and optimized. In each of the five demo sites in the four countries, different innovative concepts and technologies are implemented and tested as a proof of concept. Recommendations for further improvements will derive from the local stakeholders in a living-lab approach. By doing so, the CLUE scientific approach is also structured according to the ERA-Net three-layer research model:

Stream 1 Technology: For LEC tool kit development, progressing static and dynamic grid date, real-time data from the field, user preferences, forecasts, etc. are collected, developed and processed. New algorithms for a smart and efficient management of the integrated energy systems will be developed (e.g., based on artificial intelligence). By performance data analysis within and between the demo sites, the flexibility potential of different components will be analysed.

Stream 2 Goods and Services: The analysis of design and operation of the LEC systems will focus on the services delivered to the people living in the LEC, this means, the share of energy provided to the consumer generated by renewable energy sources locally, the share of import dependency, energy security, related costs, the freedom for consumer to generate and trade energy within the LEC, etc. The role of flexibility options to fulfil the consumer requirements will especially be analysed and recommendations developed. In addition to the design and operation strategies of the energy system, innovative business models will be developed and evaluated to provide the most cost-effective solution to the LECs as basis for replication of the LECs.

Stream 3 Stakeholders: The most relevant types of LEC stakeholders like cooperatives, project developer, DSOs, investors and owners, operators, utilities, supplier, and LEC inhabitants will participate either as partner or as participants in workshops in CLUE. Co-creation workshops and similar ideation methods as an element of the living-labs will provide the best insights in the requirements for optimization and challenges to implement and replicate the LECs.

CLUE combines research, demonstration and innovation actions in all three layers in all five demo sites in the four participating countries. Firstly, innovative technologies are under development and demonstrated like modelling tools, LowEx district heating grids or integrated wind and hydrogen energy systems. Secondly, new and innovative energy services are developed and offered to the customers and decentral energy producers, e.g., energy trading between prosumers in the LECs. Thirdly, the key LEC stakeholders will play an active role in CLUE as partners, like investors, technology providers, and local utilities. Furthermore, within a living-lab concept the planners and especially the consumers in the LECs will be approached in workshops in the demo sites to evaluate their needs in detail, test technologies and services, and work together with the researchers based on the practical experiences on improvements of the solutions.

Sweden: Not only are the relevant stakeholders in the form of regional energy providers, grid operator and technology providers part of the project. The demos are also formulated as a collaboration together with owners and users in order to lay an early foundation for adoption and implementation via a collaboration methodology. Another crucial stakeholder, both from a regional and local perspective, is the City of Malmö.

2 BACKGROUND

2.1 An energy system in need of rapid transition

South-western Skåne has a large annual transmission need from other electricity price areas, which amounts to approx. 80% of the electricity use. In addition, electricity use is expected to increase above all in transport through the increase of electric vehicles, but also in service as a result of increased growth and the establishment of data centers. In order to meet the increasing regional demand, increase security of supply and keep electricity prices down, it is important to increase energy efficiency while increasing transmission capacity and new production in the region, where the greatest potential appears to be in offshore wind power.

At the same time, southwestern Scania is heavily dependent on imports during the peak load hour, the hour when electricity demand is expected to be highest. The use in the residential and service categories and the upcoming increase in transport make up the majority of the load at this time. By identifying and quantifying the potential for demand flexibility in south-west Scania and taking knowledge-raising measures for possible flexibility suppliers, the conditions for coping with the load during the peak load hour can increase.

Malmö's local electricity production in 2019 was approx. 10% of the total electricity demand, which meant that 90% of all electricity used in Malmö needed to be transferred to the city, mainly from electricity price area SE3. There is currently only one electricity production facility run by the municipality, Sysav's cogeneration plant, and both the local and regional electricity grid is owned by E.ON. Electricity demand in Malmö is expected to increase, mainly due to electrification in the transport sector, which will likely lead to a continued energy deficit. Investments in energy efficiency can be used as a mitigating measure. In order to maintain or increase the degree of self-sufficiency, an increasing need for electricity needs to be met by new production units, where there is potential for cogeneration, wind and solar power in the municipality.

Malmö's large energy deficit also means that Malmö usually has a power deficit and imports more electricity than is currently produced. During the year's most electricity-intensive hour, the production including the network capacity reserve has the possibility of being up to approx. 25% of the current electricity demand and is therefore highly dependent on transmission capacity to the city. In order to increase security of supply, avoid capacity shortages and possibly high electricity prices, it should be of interest to facilitate the establishment of new production in the area.

Usage of flexibility becomes increasingly important as the energy system comes to rely more on renewable and intermittent energy production and when big and stable base load production is removed from the system, as in the case for Malmö where a gas-fired CHP with a 400 MW power capacity was taken out of operation in 2016. Flexibility is also a mean of increasing energy efficiency There are many different flexibility resources in the electricity system, such as flexible production, storage e.g., via batteries or hydrogen and demand flexibility and all of these will be important to safeguard for a secure electricity supply. There is a very large potential for demand flexibility in most user sectors, but there is currently a lack of knowledge and incentive among electricity end users to contribute to this potential. Unlocking flexibility potential installed in the city is an important step towards finding alternative solutions to solve the capacity issue.

2.2 Previous work

The City of Malmö and EON has a long history of working together in publicly funded projects concerning the local climate and energy transition. In the CLUE project, the basis of knowledge is based on the following project (among many others):

- Smarta Nät i Hyllie, 2011-2016
  (Swedish Energy Agency)
- Malmöeffekten, 2018
  (Swedish Energy Agency)
- Smart Cities Accelerator, 2016-2022
  (Interreg ÖKS)
- ACCESS, Advancing Communities towards low-Carbon Energy
  Smart Systems, 2022
  (Interreg RSR)

2.3 The Swedish cell within CLUE

The Swedish work package aims to verify this theoretical potential for flexibility in practice. In Sweden, the demo aims to verify the flexibility potential from power-to-heat, batteries, and e-mobility that are obtainable in a large-scale LEC consisting of multi-family houses and other building types to enable to cope with a capacity limitation on transmission side. The technologies employed in the Swedish work package are not state of the art, instead, the state-of-the-art aspect of the Swedish cell is the employment of technology. By employing new methods for steering and using technology, already installed and spread in Swedish cities today, this flexibility potential could be unlocked.

The demonstration in Sweden is also focused on raising knowledge-levels about flexibility resources. Much of the technology spread throughout the cities in the world today, such as PV solar panels, heat pumps and ventilation are commercialized and well-used for their specific purpose. Little research has been done investigating how these technologies could be employed as resources for flexibility, and what flexibility potential they would hold, should they be employed as such. The demonstration aims to innovate, not the technology, but the employment of technology for new purposes. To better understand what drives potential, new structures for tariffs will be brought on to the demonstration cases to investigate its effects on flexibility potential in an innovative co-creation methodology between the DSO, the solutions provider and the end user.

2.3.1 Task 5.1 How to include different kinds of stakeholders in the Local Energy Community

Identification of flexibility resources and respective stakeholders. Conduct interviews and workshops to gain information about appropriate methods for inclusion and adoption.

2.3.2 Task 5.2 Elaboration of selected business models (Development of flexibility business models)

Initially, the Swedish Cell also comprised a task concerning development and elaboration of selected flexibility business models. The partners were to test alternative tariff structures in selected customer pools, investigate large scale co-optimization potential with district heating assets as well as estimation of value creation for relevant stakeholders.

However, due to budget constrains from the Swedish funding agency Energimyndigheten, the partners of the Swedish Cell in dialogue with Energimyndigheten decided to cut out Task 5.2 from the Work Package and from the budget. The task is therefore not included in this report, that covers the national proof-of-concept for the Swedish Cell.

2.3.3 Task 5.3 Validation of user flexibility through demonstrations

This task comprised the following four live tests of user flexibility:

- Demo 1: Test of flexibility using smart charging in public parking garage
- Demo 2: Test of flexibility using heat pumps
- Demo 3: Test of flexibility using large scale battery
- Demo 4: Test of user flexibility on active city buildout site

Each demonstration is described more profound in chapter 4.

2.3.4 Task 5.4 Analysis of city-wide optimization potential and its regional impact

This task comprised analysis and extrapolation of results from the 4 demonstrations in task 5.3. Further, it put the results in a regional context, analysing further impact of the LEC and the flexibility potential in other regions with a similar stakeholder set-up. It also includes suggestions for alternative regulatory set-up and socioeconomic estimations.

3 STAKEHOLDER ADOPTION (T5.1)

How to include different kinds of stakeholders in the Local Energy Community

Electricity has become a central part of all social and everyday activities and the development of electricity networks is crucial for all actors in society. Traditionally, it has been a few actors, in practice energy companies, politicians, public authorities and municipalities, who have driven the development of electricity networks. However, the future smart grids require increased participation from many actors and also knowledge sharing between actors. New forms of collaboration are required to counter the lock-in effects of previous technical and organisational systems. In the CLUE project, we have focused on various new actors that have become active in issues related to electricity networks.

One such new actor is energy communities, which are introduced in the EU's Clean Energy for all Europeans Package of 2019. The purpose of energy communities under the Clean Energy Package is to generate environmental, economic or societal benefits for their members. From a societal perspective, energy communities are advocated for a number of reasons. Communities are often seen as part of a decentralised energy system that can increase capacity locally while enhancing security of supply. A community can also help to reduce power peaks on the grid. By joining an energy community, customers also strengthen their position in the electricity market. In addition, they are expected to contribute to increasing the share of renewable energy in society.

For members of an energy community, research shows that there are many different drivers. These drivers can be grouped into several different areas such as political, economic, environmental, technological and social benefits to society. As part of the research in the CLUE project we have followed a neighbourhood project in Malmö, Sege Park, and its ongoing planning process, which included both creating the conditions for the formation of an energy community in the area, among other things with the aim of jointly owning solar cells together with a local microgrid. We have conducted two rounds of interviews with the actors in Sege Park and can conclude that there is great interest and willingness to start an energy community and produce and share electricity together with neighbours. At the same time, there are currently many obstacles that the actors need to overcome. For example, it has not been legal to build a jointly owned microgrid in an area. However, in January 2022, the regulations were eased, and it is now possible to apply to the Energy Market Inspectorate to establish a jointly owned electricity network in an area. However, it will take persistence and a lot of time for the stakeholders to bring the idea of an energy community to fruition and we will continue to follow the process in Sege Park to see how the energy systems will be designed when the area is completed in 2025.

Within the project we have also studied how to engage actors and make them committed to energy efficiency at construction sites. Improved energy efficiency is important for the building sector, but energy efficiency at construction sites has so far been under-researched and these actors are overlooked as contributor to a flexible smart grid. In the project we have investigated the barriers to and drivers of energy efficiency at construction sites. There were barriers related to finance, such as lack of money and that the combination of short projects and long investment pay-off times resulting in split incentives, where the actors paying for energy efficiency were not the same that benefit from the reduced electricity bill. A potential financial driver identified was a support scheme to push the market. Lack of regulations were seen as a barrier, while regulations forcing actors to implement energy efficiency was mentioned as a potential driver. Another driver was environmental and building certifications such as BREEAM. Lack of knowledge and information about energy efficiency were seen as a major barrier. A driver was on the other hand to be part of an industry network where knowledge on energy efficiency was shared. When the top or site management was working with energy efficiency this became a driver, but when their support was lacking it was a barrier for improved energy efficiency. Another driver encouraging energy-efficient behaviour and routines were competitions between construction sites which engaged the staff in a positive way which made them motivated to take part of the transition. When a company had a back-office supporting with information and advice on energy efficiency measures, this was also seen as a crucial driver. Another essential driver was client demand of energy efficiency.

In the project we have also discussed data centres as an actor who can suppress local actors and even force less powerful actor to re-localise their business because there will be a lack of capacity in the electricity grid due to the establishment of an energy intensive industry like a data centre. We introduce the concept of energy gentrification to highlight this potential conflict which can be a result if several data centres establish in Sweden. (Libertson F. , 2022)

The project has also focused on the role of households as end-users and their potentials of providing flexibility. Flexibility as a trait is gaining importance within the energy sector, in order to maintain stable energy systems. Historically, flexibility has been a function of the production side and the balance has been maintained by adjusting production according to consumption. However, with the introduction of renewable energies, along with the modernization of the energy grid, the function of flexibility is moving from the production side to the consumption side. This means that end-users are increasingly expected to be flexible in their electricity uses.

Flexible electricity use entails adjusting one’s electricity use in time, space or intensity to accommodate someone else’s need for power. For example, by using less electricity at a certain time of the day, or by relocating the electricity use to another time of the day, end-users provide flexibility to the energy system. This may help to reduce peak loads and flatten the curve if done on a large scale.

The project also focused on how the changing of activities impact the daily lives of the electric vehicle driver, and therefore their decision in relation to charging. By looking specifically at how end-users perceive smart charging technology, the project identified how the electric vehicle driver experience a trade-off between on the one hand convenience and on the other hand grid stability. In general, respondents were positive towards smart technology and towards contributing to grid stability by being more flexible in charging their vehicles. However, they were also concerned about whether this new way of charging was compatible with their daily lives. The respondents identified that the capacity to be flexible was to some extent beyond their control, as being flexible is not only a matter of choice. Other factors, such as work patterns, household composition, technological assets and dependencies, health status and knowledge also influence the capacity to be flexible, and these are factors that the user cannot affect directly, at least not in a short-term perspective.

For Parkering Malmö, the conclusion is that there is great potential for flexibility in electric car charging, especially considering that the number of charging points will increase dramatically in the coming years. Another conclusion is that their customers do not notice if the charging speed is lowered for shorter periods.

From an academic perspective the project concludes that more research is needed on the flexibility capacity of end-user, in order to better understand the factors influencing flexibility. The project deems that this understanding is of significance, as it will better define the role of end-users in the energy system and ultimately allow for a better integration of smart technology. (Libertson F. V., 2021)

4 VALIDATION OF USER FLEXIBILITY THROUGH DEMONSTRATIONS (T5.3)

4.1 Demonstration 1 – Test of flexibility using smart charging

4.1.1 Background

The aim of this demonstration was to investigate flexibility potential in public parking with smart charging. There are hundreds of charging spaces owned by P Malmö and utilizing smart charging there could make a significant contribution in providing needed electric power flexibility to the local electric grid.

4.1.2 Description of demonstration site

In the first part of the demonstration, three different use-cases with reduction of charging speed were tested to identify the optimal ratio between delivered flexibility and consideration of customer comfort. The tests were carried out with 28 public EV charging points in two different multi-storey car parks, in which one of them the parking customers were informed about the ongoing tests. The target was to determine the optimal relation between delivered flexibility and customer comfort. Three use cases with different sets of conditions for which chargers were eligible for load reduction were tested:

1. Use Case 1, Site based: All active charging sessions within time period eligible for reduction.

2. Use Case 2, Session based: Reduction allowed if charging session has been active for at least 1 hour and has transferred at least 2 kWh to customer.

3. Use Case 3, Customer based: Condition for reduction based on previous data for individual customers. Reduction is allowed if a customer has been parked for 75% of their average charging time, or if they have managed to charge 75% of the average charging energy.

The signals controlling the system is sent by the Virtual Power-Plant software (VPP) developed by E.ON, in which the user may tweak different parameters such as active time period or the conditional variable in the use cases. An overview of the smart charging scope and relations between actors and component is shown in figure 1.

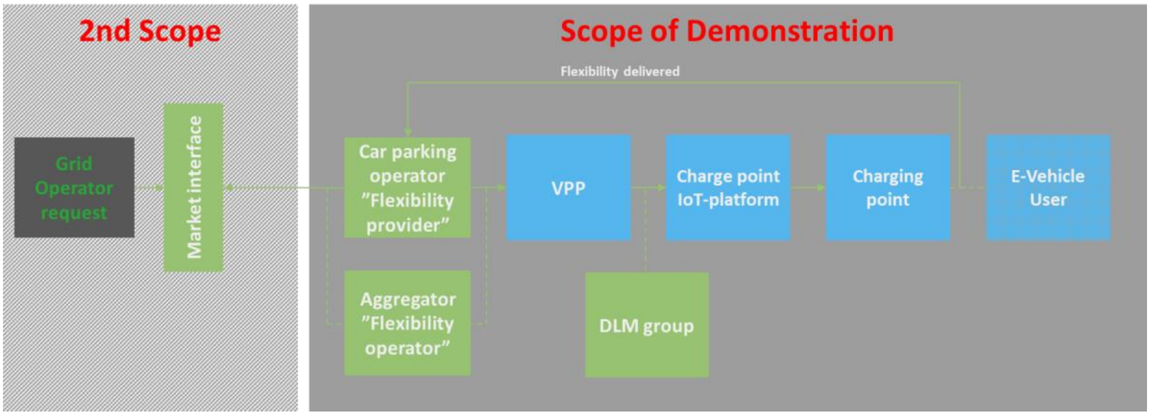

Figure 1 Overview of the smart charging scope and relation between actors and components

The second part of the demonstration was focused on delivering flexibility to the local flexibility market platform SWITCH with a 78 charging points.

In addition to the technical test, surveys and interviews with owners to electric vehicles were made to shed light on their will to contribute with flexibility.

4.1.3 Business model

The estimated flexibility that could be delivered a certain time period by lowering of the charging power were offered to the capacity market platform Switch as a bid.

4.1.4 Validation results

During the first tests there was a sizable reduction in energy used during the test time slot compared with a reference period the previous year as shown in figure. The energy used was reduced between 15 and 30 kWh/h by decreasing the charge effect by half on 16 chargers. Based on initial analysis of the first testing period Use Case 3 was deemed to have to low reduction potential so for the second part of testing Use Case 1 and 2 were used.

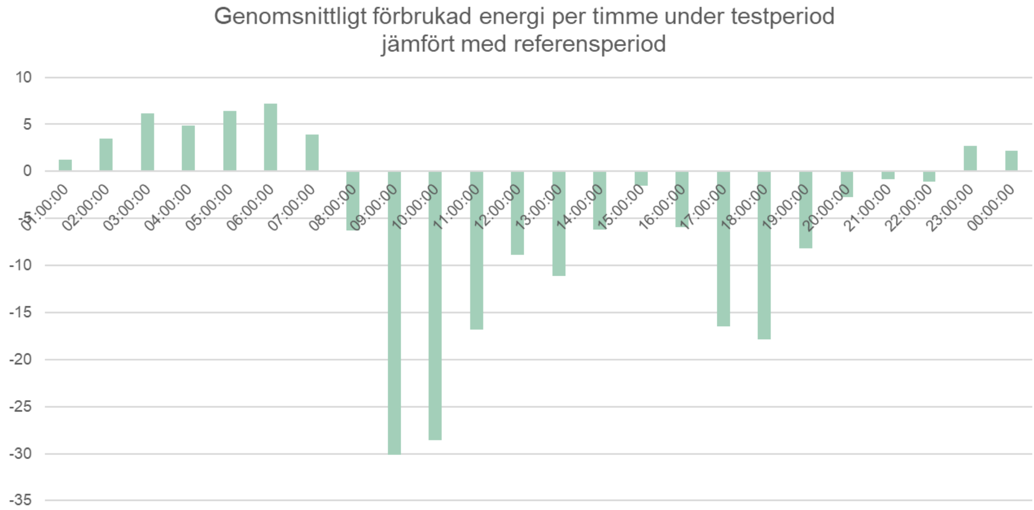

Figure 2 Energy used per hour during the test period in comparison with a reference period the previous year. Unit on the y-axis is kWh.

In *table 1, from the* Master thesis by Philip Johansson (2022), key parameters for the second part of the tests are shown. The ongoing power is the charging power when the active testing period started, the reduced power shows the reduction when the active testing period started, and the added power is the charging power that was increased due to charging sessions that started within the time slot. The key number is thus the Reduced Power, that is the flexibility that was delivered. Reduction initial analysis is an analysis made during the initial evaluation of the data.

Table 1 Evaluation of the second part of the testing. The total charging power of the time slot before the test started, reduced power, reduced relative power and added power (from charging sessions with start time within the test time slot) is shown together with an analysis of how much the charging power was reduced.

Date	Time	Ongoing Power	Reduction factor z	Reduced Power	Reduced Power (%)	Added Power	Reduction Initial analysis
22 March	9-11	79 kW	50 %	18.5 kW	23.4 %	16.5 kW	N/A
22 March	17-19	N/A	50 %	27 kW	N/A	27.5 kW	2 kW
23 March	9-11	92 kW	50 %	37 kW	40.2 %	6.4 kW	14 kW
23 March	17-19	29 kW	50 %	4 kW	13.8 %	21.3 kW	-1 kW
24 March	9-11	N/A	50 %	29 kW	N/A	12.5 kW	17 kW
24 March	18-19	29 kW	50 %	6 kW	20.7 %	17.2 kW	2 kW
25 March	9-11	87 kW	35 %	36 kW	41.4 %	13.2 kW	12 kW
25 March	17-19	40 kW	50 %	16 kW	40.0 %	13.8 kW	14 kW
26 March	9-11	65 kW	54 %	37.5 kW	57.7 %	16.4 kW	21 kW
26 March	17-19	32 kW	60 %	26.2 kW	81.9 %	8.7 kW	8 kW
29 March	17-19	14 kW	70 %	2 kW	14.3 %	32.4 kW	N/A
30 March	9-11	78 kW	39 %	34 kW	43.5 %	25.8 kW	N/A
30 March	17-19	N/A	N/A	8 kW	N/A	19.4 kW	N/A

Analysing the data from the tests was not without difficulties and the following paragraph goes into that. *Figure 3* show three examples of charger behaviour. The blue curve shows a typical and expected behaviour. By the time the reduction period is active, the charging effect is reduced and by the time the active period is ended the charging power resumes the high value. The yellow curve displays similar behaviour. However, this charging session commences much closer to the start of the reduction period. At the start of the reduction period, it displays the same reduction as the blue charger, but it should not, according to User Case 2 conditions. The charging had not been active for a least one hour. This type of early activation was common throughout the tests. Another example of charging behaviour that is not expected is the red curve, where reduction clearly should have taken place, yet no such reduction seems to have executed.

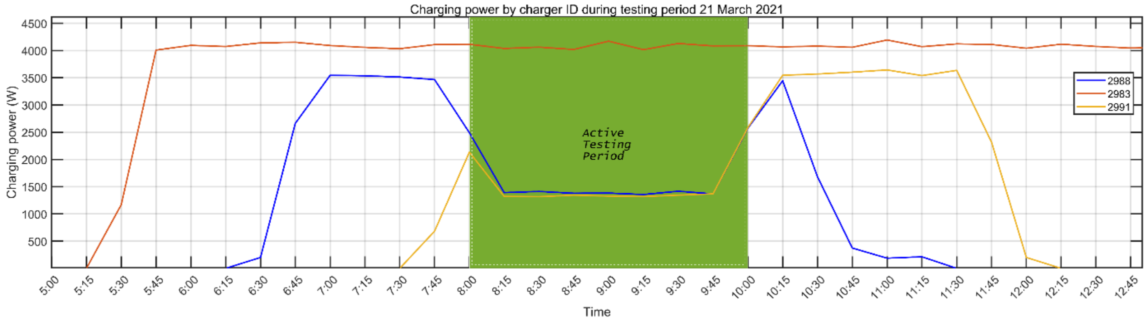

Figure 3. Examples of charging behaviour. Average power for each 15-minute time slot is shown for three individual chargers: charger 2988 in blue, charger 2983 in red and charger 2991 in yellow. The active testing period is highlighted with green.

4.1.5 Conclusions

Evaluating delivered flexibility is key to the success of capacity markets, such as Switch. The results show that the ways in which the power reduction was done in this demo have room for improvements and examples on how improvements could be made was done in the Master thesis by (Philip Johansson, 2022).

From Parkering Malmö's perspective, it is clear that flexible charging power is a potential flexibility source. During the first part of the demonstration, several customers complained that they experienced problems with charging their car. However, these complaints came only from customers in the car park where information that tests with reduced charging power was ongoing were given. It could also be determined that most of the complaints regarded times where no reduction was made. In the car park, where no information was given, there was only one customer complaint, which was also due to problems not related to the testing. The conclusion for Parkering Malmö is that customers hardly notice a temporary change in power reduction but are quite worried about the consequences of such a reduction. The second part of the demonstration included 78 charging points with 22 kW charging and gave power reduction of up to 37,5 kW. It is a small flexibility source compared to the flexibility need in southern Scania, but when scaling up charging infrastructure in Malmö the flexibility potential could be quite substantial, even if most of Parkering Malmö's charging points will have 3,7 kW charging.

The surveys and interviews were able to shed light upon customer attitudes to being part of a smart charging scheme.

In line with previous research on smart charging, the results indicate that several factors are important for user acceptance. The performance of the technology appears to be a major factor. For example, PHEV (plug-in hybrid electric vehicle) drivers appear to be more accepting towards smart charging than BEV (battery electric vehicle) drivers. Similarly, respondents who deemed fast and full charging to be important parameters of the charging session were less accepting towards smart charging. Also, respondents dependent on public charging infrastructure were less willing to accept smart charging. Personal values were another factor that appeared to influence user acceptance. Respondents who listed grid stability as their main reason for accepting smart charging had higher acceptance than respondents who listed financial incentives.

In general, the respondents were very positive towards the technology and towards participating in smart charging schemes. However, several respondents also indicated that their participation to some extent was beyond their control, as factors like work life and home conditions also influence their ability to provide user flexibility. Successful implementation and optimization of smart charging technology should therefore also consider these factors.

4.2 Demonstration 2

4.2.1 Background

The aim of this demonstration is to evaluate the potential for electric power flexibility within a building. There is also a goal to increase the understanding about which potential for flexibility can be associated with different types of heating solutions, heat pumps specifically.

4.2.2 Description of demonstration site

This demonstration takes place at the Triangeln property, shown in figure 4. The property contains different businesses: offices, restaurants, stores and living spaces. The property is supplied with heat through both heat pumps, connected to aquifers, and district heating. Initially two different tests to demonstrate flexibility were identified as relevant. One where the thermal inertia in the buildings was utilized to enable load control of the heat pumps and ventilation without impacting comfort. By influencing so that heat is controlled reactively and/or proactively power peaks can be cut and instantaneous power output from the heat pumps can be reduced. The other test would involve switching energy source between heat pumps and district heating. If the load in the electricity grid is high but power is available int the district heating system and the logic is to relieve the electricity system through this, production can be prioritized against district heating.

Figure 4 Demonstration site 2: Triangeln

A schematic view of the control steering for Triangeln is shown in Figure 5. Data interfaces is managed cloud-to-cloud. There is a modbus interface for data acquisition and control. The control priority/periods are managed by ectocloud.

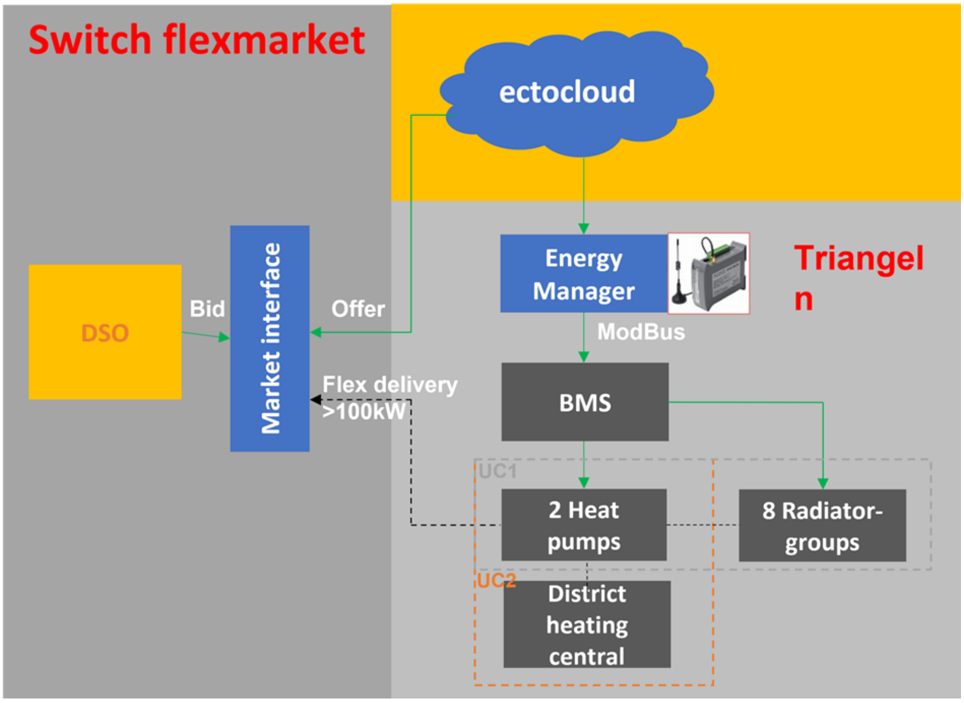

Figure 5 Schematic view of the control steering for Triangeln

4.2.3 Business model

By using the thermal inertia in the building and/or switching heat source to district heating the reduction in power to the heat pumps can be offered as a bid to the capacity market platform Switch.

4.2.4 Validation results

Initial tests were made to gather knowledge about the buildings' thermal properties. Those initial tests show a favorable thermal inertia in the property and energy system which allows for dynamic load control without affecting comfort.

The initial tests were performed according to a testing matrix, shown in table 2. The percentages correspond to calculated heating effect delivered by a power controlling service. That heating effect is translated to an offset, in degrees, of the water going to the radiators.

Table 2 Testing matrix with schedule and heating adjustments.

Day	Time	Setting	Note
1	08 - 11	-50 % 4 h	Curtain heater start 10.00
2	08 - 12	-50 % 2 h, +50 % 2 h	% based on temperature setpoint
3	00 - 03	-100 % 3h	lowering during nighttime in stores and offices (5 degrees offset)
4	08 - 11	-100 % 3h	
5	00 - 04	-50 % 4 h	
	15 - 18	-100 % 3h	
6			
7	22 - 07	+25 % 3 h, -25 % 6h	Start day 6

An example of the results is shown in figure 6. The bars in the figure displays the power used by the heat pumps each hour and the yellow line is outdoor temperature. The figure shows data from day 3 in the testing matrix, when the heating was set to be reduced 100 % from midnight to 3:00. The electricity used show a sharp decrease, of over 120 kWh/h, at the appropriate time.

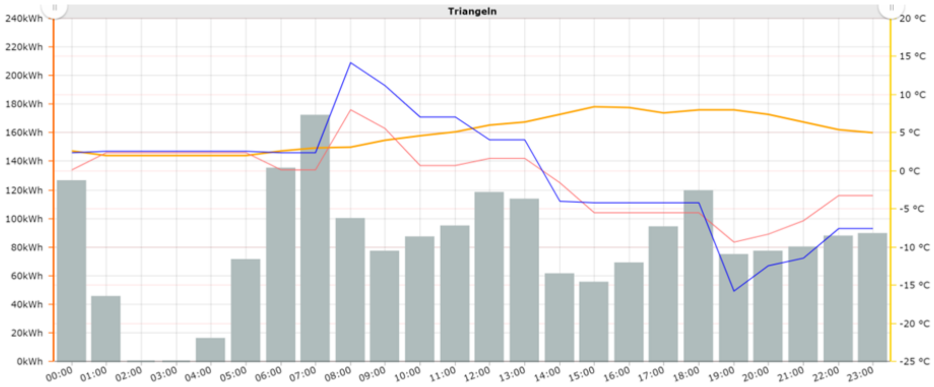

Figure 6 Data from day 3 in the testing matrix. The bars display electricity used by the heat pumps each hour and the yellow line is the outdoor temperature

4.2.5 Conclusions

The initial tests indicate that there is indeed a big potential to deliver flexibility without impacting comfort. However, during those tests the outdoor temperature were not very low so in order to further evaluate the system further tests are planned to be performed during winter. Results from the follow up tests and conclusions from those will be included in the final report.

4.3 Demonstration 3 – Stationary battery in a residential building

4.3.1 Background

The aim of this demonstration was to investigate the business potential of a large-scale battery. The goal was to understand the requirements needed to enable a commercialization in a near future.

4.3.2 Description of demonstration site

The demonstration was taken place in the student apartment building Rönnen. The set up included a hardware solution with a stationary battery (Ferroamp EnergyHub XL28 bi-directional converter and two Pylontech Li-ion battery rack) with a total capacity of 51.8 kWh and a maximal efficiency of 24 kW, and an IoT-gateway (Energy manager) in figure 7. The aim was that the Energy manager collected data from smart meters and the battery status. If the test site would have included solar power data from that would also have been collected by the power manager. The data was supposed to be processed in the cloud platform ectocloud that combined historical data with predictions of future events and conditions (figure 8). This would enable control of assets in an optimal way by even out or adjust the power consumption of the building and increase the utilization of own production.

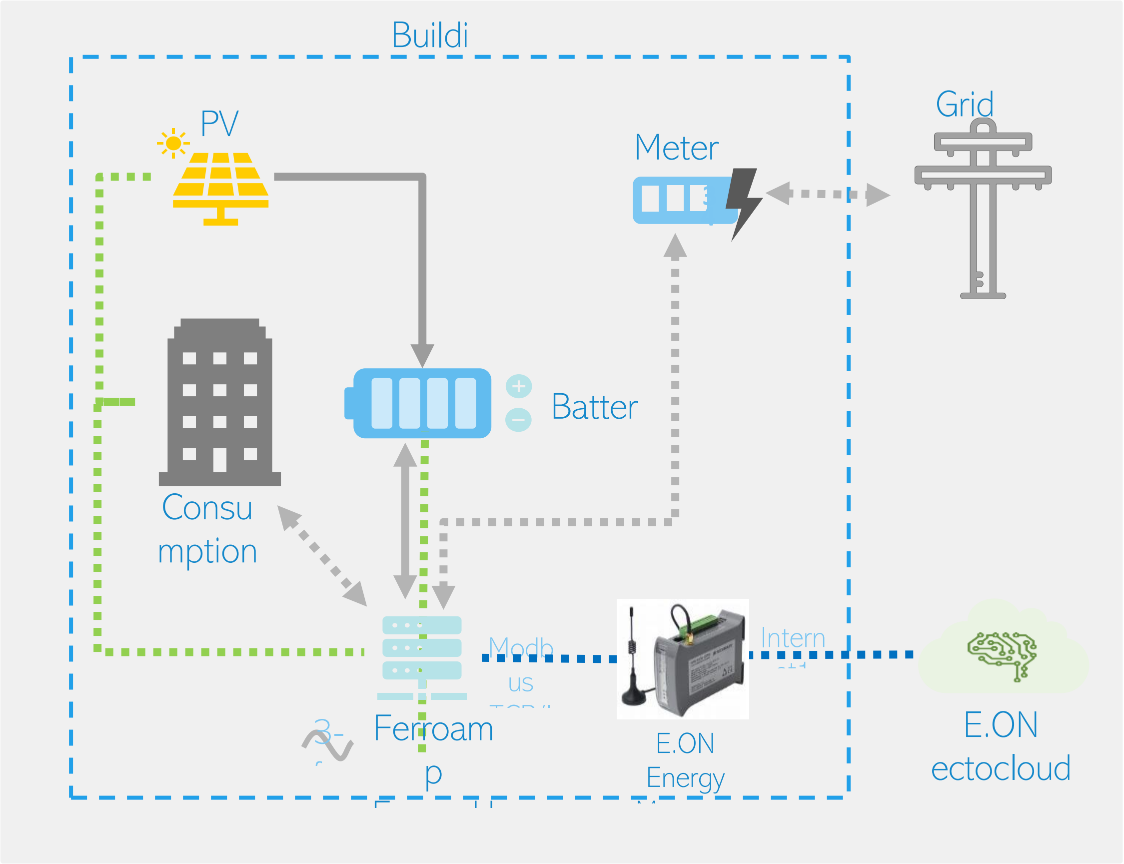

Figure 7 Demonstration set up

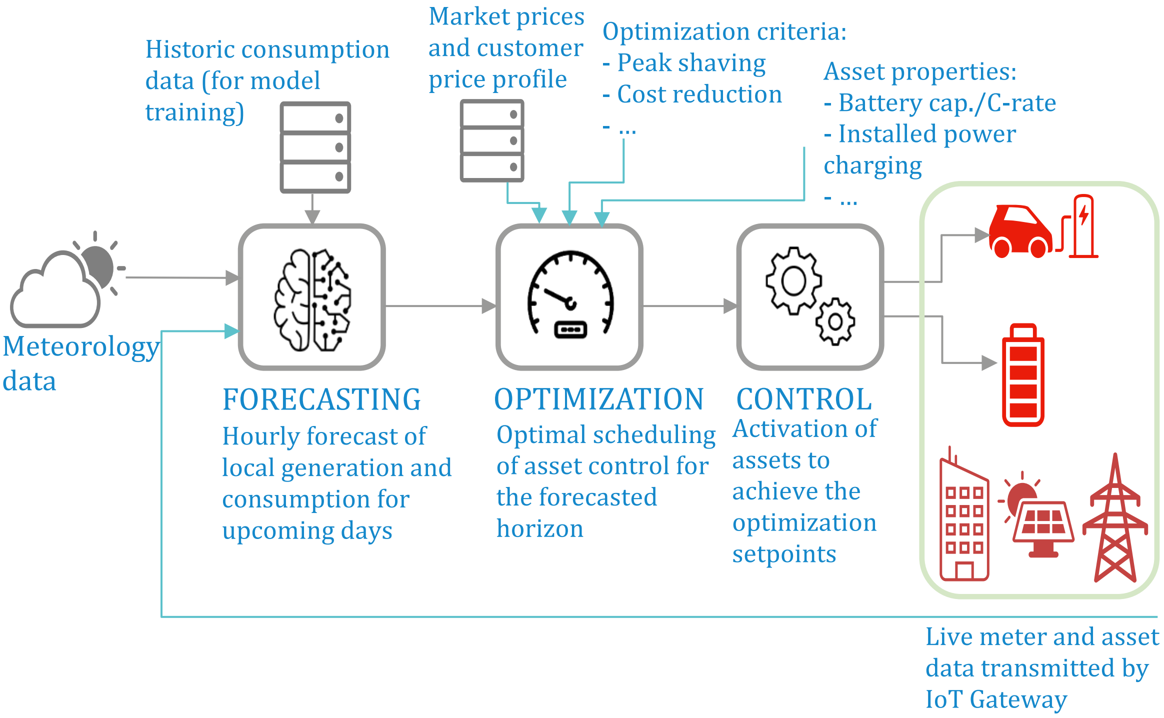

Figure 8 Principal of local balancing architecture

4.3.3 Business model

There are two types of business models that can be used for this demonstration set up. The first model is based on subscription structure (Build – Own – Operate). E.ON does the investment and owns the energy equipment. In that case, E.ON has the responsibility of delivery, operation and maintenance. The second model is based on an investment structure (Build – Sell). The customer does the investment and owns the energy equipment. E.ON always has the responsibility of operation and maintenance connected to the local balancing services independent of the chosen business model.

4.3.4 Validation results

The demonstration encountered some difficulties during the set up. Difficulties with battery delivery and lack of routines for installations delayed the configuration and commissioning. There was also constrains in the property owner's policy regarding network. Therefore, a separate network with a router was needed to be installed to be able to commission the local balancing service. At the time of writing all hardware and software is in place and data collection has started but no evaluation has been made.

However, work has been done to access supporting documents and processes to create enablers for a commercialization in the future. These include among other things:

- Contract basis
- Delivery process
- Installation manual

4.3.5 Conclusions

There have been lessons learned in the project, even though the demonstration has not been completed. These are from practicalities connected to communication needs between the different components and how that can be secured for the purpose. Also, business models, visualisation needs, and other structures have been clarified for the user. Further, evaluated results and conclusions thereof will be included in the final report of the project.

4.4 Demonstration 4

4.4.1 Background

The aim of this demonstration was to investigate electricity demand and profiles for various needs and demands on an active construction site. It was also in the aim to investigate flexibility potential for various demands, e. g. drying concrete, cranes, construction facilities, tools etc. The stakeholders for this demonstration include the construction company, equipment renter, building site managers and union. The stakeholders' interests are related both to economic aspects and when it comes to habits and routines at the workplace that can affect peak energy consumption and energy efficiency.

4.4.2 Description of demonstration site

The demonstration was taken place at the construction site of Long stay Hotel "Kosterbåten" in Västra Hamnen, Malmö. The total electricity usage at the construction site was measured. Sub metering on selected places on site were also done. This sub metering is shown in Figure 9 and was divided in three: the building crane; other onsite electricity, such as electrical heating and lighting; and the building barracks site which included charging of tools and heating and lighting for the barracks. The measured data will be compared with diaries from the building site to be able to connect high energy use to certain activities. The construction has since the start of the project been finished and all collection of data is completed.

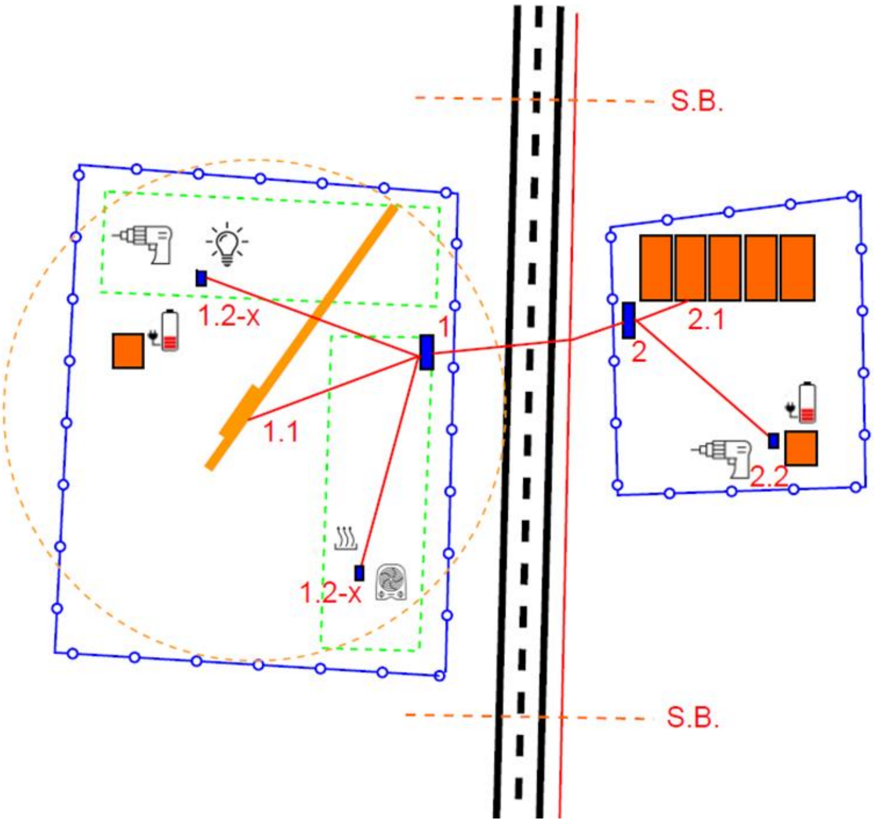

Figure 9 Electricity usage is measured on site in subsets 1, 1.1 and 2

4.4.3 Business model

The business lies in the potential to even out peaks in power consumption and separately the potential for energy efficiency measures.

4.4.4 Validation results

All data has been gathered and are in the process of being evaluated. Preliminary evaluation indicate that the building crane has a large impact on the electric power used at the building site as shown in figure 10.

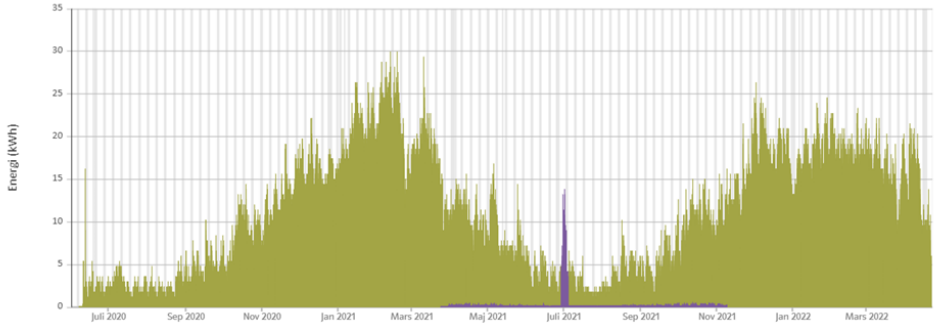

Figure 10 The total energy usage at the site in green with the building crane in purple.

There was also a study made where professionals relevant to building site were interviewed about drivers and barriers related to energy efficiency measures at building sites.

4.4.5 Conclusions

Pending evaluation of data from building site and publication of interview study.

5 ANALYSIS OF CITY-WIDE OPTIMIZATION AND ITS REGIONAL IMPACT (T5.4)

How to include different kinds of stakeholders in the Local Energy Community

This section summarizes the work in T5.4 which aims to estimate the flexibility potential in Malmö and analyse the system-level impact if the flexibility solutions are implemented and upscaled. Scenarios 2030 and 2040 are defined concerning population growth, electrification, grid capacity expansion, etc. Corresponding to demo 1-3, the flexibility potentials of following resources are estimated: space heating, hot water preparation, EV charging and PV systems with battery. The flexibility of different resources is then aggregated and compared with the grid capacity to evaluate how the flexibility solution could reduce needs of import and mitigate congestion risks between the regional grid and the transmission grid.

5.1 Background

The electricity system in southern Sweden e.g. Malmö is facing capacity problems. The electricity demand keeps growing due to the population growth and electrification of fossil-based processes including transport, heating, and industries. On the other hand, the import capacity from the transmission grid is limited.

A grid model is set up in the study based on historical load data in Malmö during 2018- 2019. The historical load is provided by E.ON in the form of normalised load curves for three sectors: industry, residential buildings, and mixed city. The normalized load curves are scaled to demand values according to the annual electricity demand statistics (SCB, 2022a). The statistical electricity demand is divided into several sectors which are mapped to the three sectors as Table 3.

Table 3 Mapping between the three sectors of the normalized load curves and the sectors of the electricity demand statistics

Sectors of the normalized load curves	**Sectors of SCB statistics about electricity demand**
Industry	- Industry and construction activities - Agriculture, forestry, and fishing
Residential buildings	- Small houses - Country homes
Mixed city	- Multi-family houses - Public businesses and services - Other services

Figure 11 shows the scaled electricity demand of Malmö in 2018. The mixed city has the largest share of the total electricity demand. An apparent seasonal variation can be observed in the residential buildings. This is mainly due to that a large share of the residential buildings are heated by electricity, either through direct electric heating or heat pump.

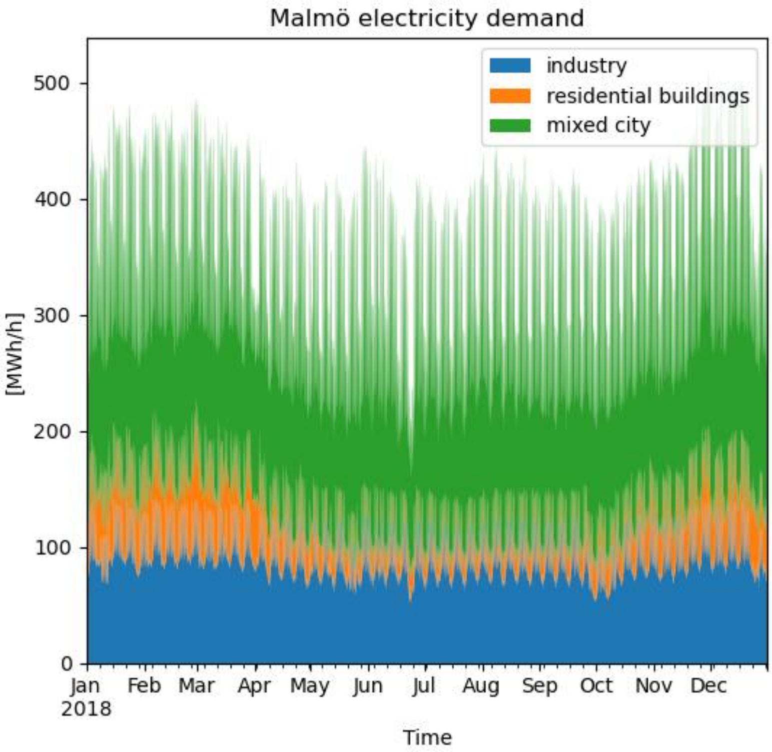

Figure 11. Electricity demand of Malmö, based on the normalized load curves from E.ON and scaled with the statistical data from SCB (SCB, 2022a)

The electricity demand is not only fluctuating over seasons but also throughout the day, as shown in Figure 12. The fluctuations of electricity demand sometimes make the grid congested. According to the information about the subscribed transmission capacity in 2018-2019 provided by EON, a load peak in the local electricity grid is when the load exceeds 400 MW. The distribution of peak hours during 2018 is shown in Figure 13.

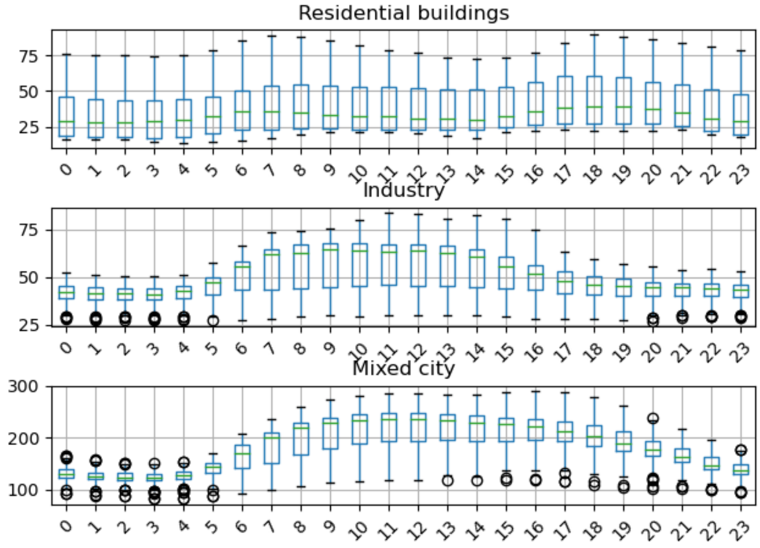

Figure 12. Distribution of electricity demand in MWh/h during a day, where the y-axis represents MWh/h and the x-axis the hour of the day

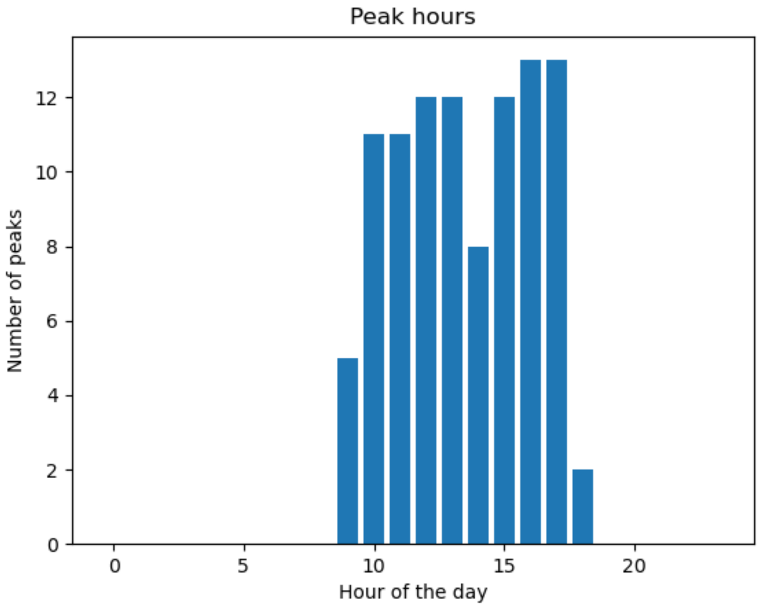

Figure 13. Peak hours in 2018, when the electricity demand exceeds 400 MW

5.2 Scenario definition

Scenarios are defined for both flexibility estimation and impact analysis. The scenario years used in this study is 2030 and 2040. The population growth in Malmö, the trend of electrification, the market and technological development of different solutions are considered. The scenarios are the basis to estimate how the electricity demand in different sectors might develop over time and how much upscaling potential of flexibility might be utilized. This subsection summarizes the main data sources and assumptions in the scenario definition.

5.2.1 Space heating and hot water preparation

Flexibility potential is analysed for space heating and hot water preparation systems in small houses. The small houses in Malmö are clustered with respect to construction year and heating solution (Figure 14).

Different thermal inertial is considered for houses built in different periods, based on the UA-values (Boverket, 2010) and the house size (SCB, 2022c). Clustering of houses constructed before 2021 is according to statistics about the number of houses built in different years (SCB, 2022b). In scenario 2030 and 2040, the number of houses built after 2021 is based on prognosis. As presented in the energy strategy of Malmö (Malmö stad, 2022), the number of inhabitants will approach 500 000 in 2045 and the number of new dwellings will reach 28 000. The ratio between small houses and apartments in the new dwellings is assumed same as in 2019. The UA-value for new houses is assumed same as the houses built in 1991-2020. Houses built before 1970 is assumed to be renovated with UA-values reduced by 10% until 2030.

Clustering of heat sources is based on national statistics for one and two dwelling buildings (Energimyndigheten, 2020). The coefficient of performance (COP) is based on the average efficiency of each heating solution (Boverket, 2009). For houses built after 2021, it is assumed that only heat pumps and district heating are used. Furthermore, the COP of new heat pumps is assumed 30% higher than the present devices.

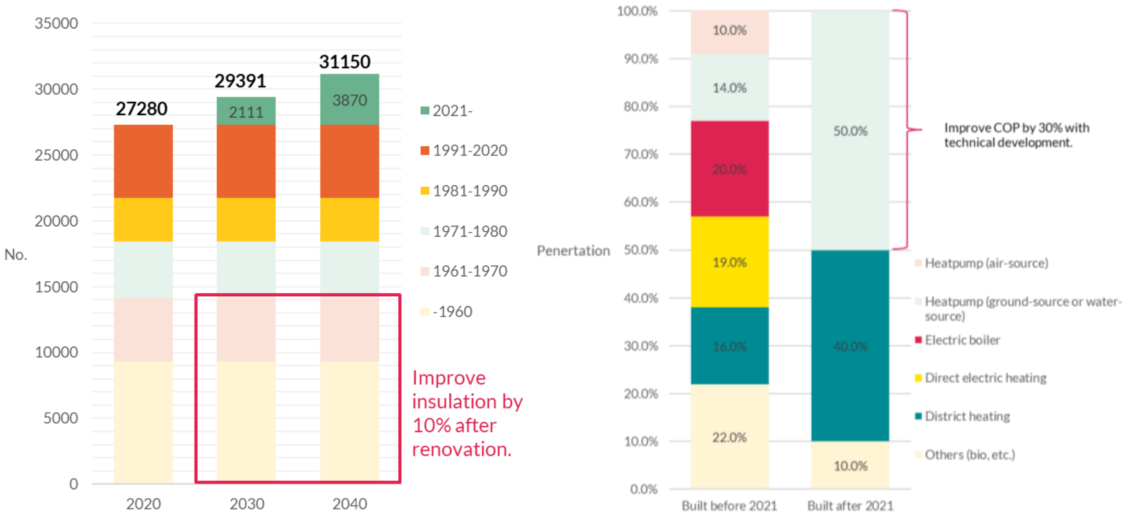

Figure 14 Clustering of small houses in Malmö. (Left: No. of houses with different construction year in each scenario. Right: Penetration of different heating solutions for houses built before and after 2021)

5.2.2 EV charging

The electrification of transport sector will add new demand to the electricity system, both in terms of energy and power. On the other hand, charging of EV can also provide flexibility to the system through smart control. Three categories of EVs are analysed in the study: cars, light trucks, and heavy trucks. The scenario development for EVs involved workshops with the Swedish partners to get their input.

CARS

Two sub-scenarios are considered for cars:

Constant number of cars: it assumes that the number of cars in Malmö in 2030 and 2040 will keep the same level as 2020, whereas with higher rate of electrification. This assumption corresponds to the climate vision of city Malmö i.e. to promote public transport and reduce the need of private cars.

Constant share of cars: it assumes that the penetration of cars among the population will be same as 2020. According to prognosis, the population in Malmö will approach 500 000 in 2045 (Malmö stad, 2022). This implies a large increase in the total number of cars.

Figure 15 shows the number of electric cars in different scenarios. The share between BEV and PHEV is based on the prediction by Power circle (Power circle, 2022). It is projected that BEV will take more than 90% market share of new sold cars around 2030 (Andersson & Kulin, 2019). The battery capacities of BEV and PHEV are based on the average capacity of 10 most sold models in 2021, i.e. 53 kWh for BEV and 10 kWh for PHEV (Power circle, 2022).

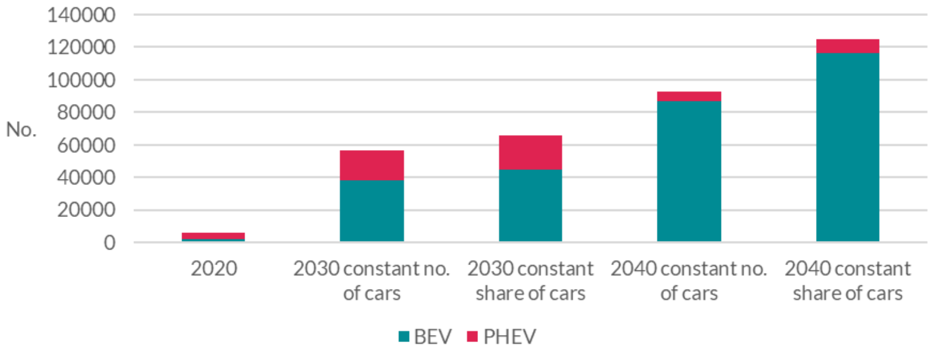

Figure 15 Scenarios of electric cars in Malmö

The study focuses on chargers with 3.7, 7.4, and 11 kW maximal charging power, which are widely used at home and public garages. It is assumed that 90% of cars only charged at home, while 10% charge both at home and at workplace. PHEVs are assumed only using 3.7 kW chargers. BEVs are assumed using all types of chargers with a certain distribution i.e. 75 % (3.7 kW):15% (7.4 kW):10% (11 kW).

LIGHT TRUCKS (WEIGHT BELOW 3.5T)

Figure 16 shows the number of electric light trucks in Malmö in different scenarios. The number in 2020 is based on statistics (Trafikanalys, 2021a). The growing of light trucks in Malmö towards 2040 is assumed following the average yearly growth in Sweden between 2011-2020 (Trafikanalys, 2021b). The electrification rate of light trucks is assumed following the same trend as the electrification of cars (Andersson & Kulin, 2019).

Charging of trucks might happen at depot, semi-public and public charging stations. According to prognosis (Fossilfritt Sverige, 2020), 80% of truck charging will happen at depot during the night. Only depot charging is considered in the flexibility estimation. The maximal charging power adopts the same assumption as electric cars i.e. 75 % (3.7 kW):15% (7.4 kW):10% (11 kW).

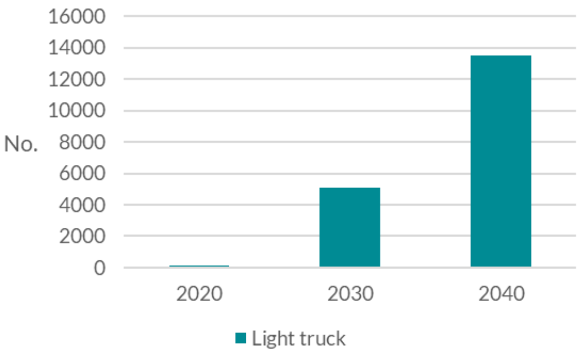

Figure 16 Scenarios of electric light trucks in Malmö

HEAVY TRUCKS (WEIGHT EXCEEDS 3.5T)

Heavy trucks are divided into three categories: local (21%), regional (63%), and long-haul transport (16%) (Power circle, 2021). The shares are assumed constant in the scenarios (Figure 17).

The number of heavy trucks registered in Malmö in 2020 is around 1 900. A yearly increase of 1.65% is adopted in the scenarios according to the prognosis of increased road transport work until 2040 (Trafikverket, 2020). According to statistics (Trafikanalys, 2021a), there was no electric heavy trucks in Malmö in 2020. The electrification rate of heavy trucks is supposed to be 18% in 2030 and 65% in 2040, according to the HögEl scenario defined in the government's official investigations (Utfasningsutredningen, 2021).

Similar as light trucks, the flexibility estimation for heavy trucks focuses on depot charging. The maximal power for depot charging is assumed between 22 – 150 kW. The share of different types of chargers is assumed varying among the local, regional, and long-haul trucks, as shown in Figure 18.

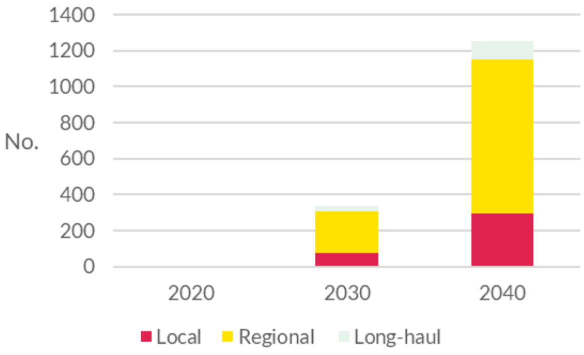

Figure 17 Scenario of electric heavy trucks in Malmö

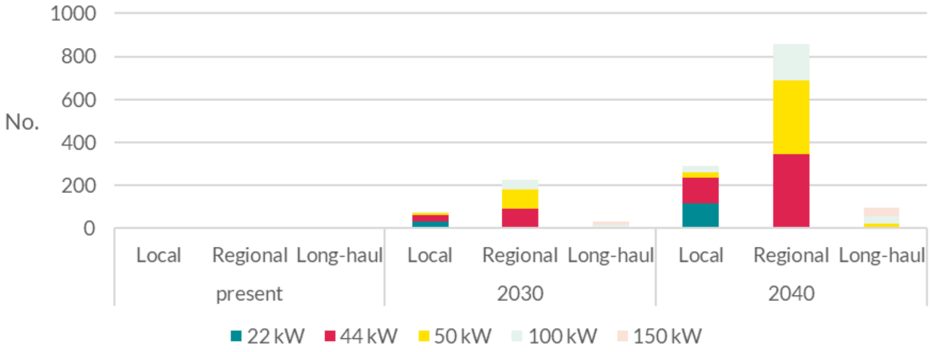

Figure 18 Share of different chargers for local, regional and long-haul trucks

5.2.3 PV and battery

The analysis focuses on the PV-battery system in residential buildings and mixed city. Figure 19 shows the installed capacity of PV and battery in different scenarios. It is based on the statistics about PV installation in Malmö (Energimyndigheten,

2022) and the grid connected stationary battery installed by PV installation companies (Lindahl, Oller Westerberg, & Vanky, 2021).

It is difficult to predict the future development of PV and battery systems in Sweden due to uncertainties in e.g. price, resource availability and regulations. For simplification, it is assumed that the PV installation follows a linear development and there is a constant ratio between the battery capacity and PV production.

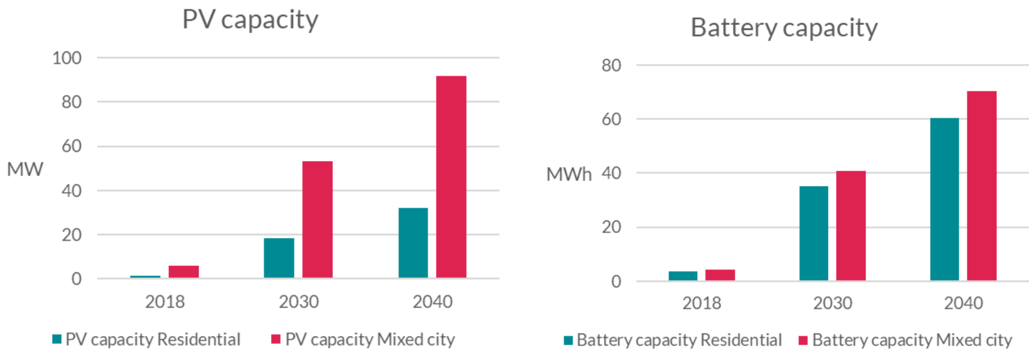

Figure 19 Installed capacity of PV and battery systems for residential sector and mixed city sector

5.2.4 Grid load

As described in 5.1 the aggregate grid load in Malmö is estimated based on the normalized electricity load curves from E.ON and statistics about the electricity consumption (SCB, 2022a). Three sectors are considered: industry, residential buildings, and mixed city. Scenarios for the three sectors are based on a report by Region Skåne (Region Skåne, 2020) which estimates how the electricity demand of each sector will develop until 2040 for all municipalities in Skåne, including Malmö. The electrification of heating and transport as well as the increasing local production from PV are also considered, based on the scenarios defined in 5.2.1-5.2.3.

According to EON, the import subscription from transmission grid is supposed to increase by 1.5-2% per year. As described in 5.1, peak load in Malmö is considered as the load exceeding 400 MW in 2018. Table 4 shows the threshold of peak load in scenario 2030 and 2040, assuming a yearly increase as 1.5%.

Table 4 Threshold of peak load in Malmö

	2018	**2030**	**2040**
Threshold of peak load [MW]	400	478	664

5.3 Flexibility estimation

There are various ways to define flexibility. The project investigates the potential of utilizing the demand-side flexibility to reduce the congestion risk in the regional grid. Therefore, the analysis focuses on the potential of reducing the load in peak hours and shifting load towards off-peak hours. For each flexibility solution, the potential is estimated by comparing a DR (demand response) case with a reference case.

- Reference case: the devices are “operated as normal” to satisfy the energy demand.

- DR case: the devices respond to a price signal to minimize the grid cost while the energy demand is still satisfied. The price signal (Figure 20) reflects the peak and off-peak hours in the regional grid, according to the load analysis in 5.1.

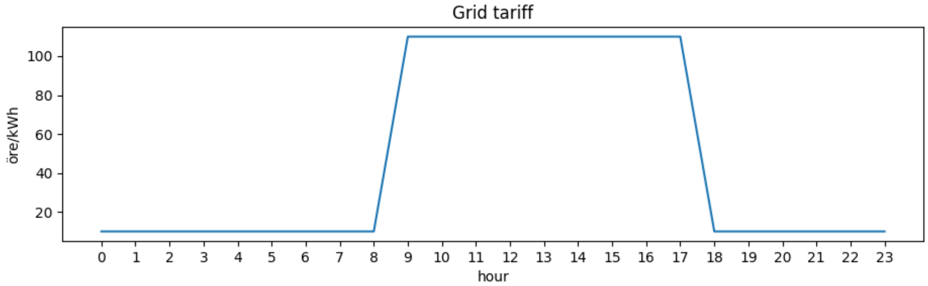

Figure 20 The Time-of-Use (TOU) grid tariff adopted in DR case

The flexibility potential is presented in two forms:

- Average reduction of hourly load: MWh/h. For all the hours when the DR load is lower than the reference load, calculate the average hourly reduction.

- Average reduction percentage: %. For all the hours when the DR load is lower than the reference load, calculate the average reduction percentage from the reference level.

5.3.1 Space heating and hot water preparation

5.3.1.1 Method

Models are developed to simulate the heating load in small houses. Figure 21- 22 illustrate the input and output of the space heating model and hot water preparation model, respectively. Both reference case and DR case are defined as optimization problems. The objective and constraints are summarized in the figures. Reference case minimizes the temperature deviation from the desired temperature. DR case minimizes the energy cost, meanwhile maintains the comfort level.

The aggregate flexibility in each scenario is estimated according to following procedure:

1) Clustering: The small houses in Malmö are clustered with respect to construction year and installed heating solution (see Figure 14).

2) Simulation: Concerning the stochastic initial temperatures, 200 house samples are randomly simulated for each cluster. For each house sample, the simulation is carried out for a year to capture the seasonal variation in outdoor temperature and solar radiation, as well as the daily variation of the hot water demand. When all the samples of a cluster are simulated, the

average heating load profiles in reference and DR cases are generated for the cluster.

3) Aggregation: The aggregate heating load in Malmö is calculated according to the average load profiles of all the clusters and the number of houses in each cluster. The potential flexibility is estimated by comparing the load profiles between reference and DR cases.

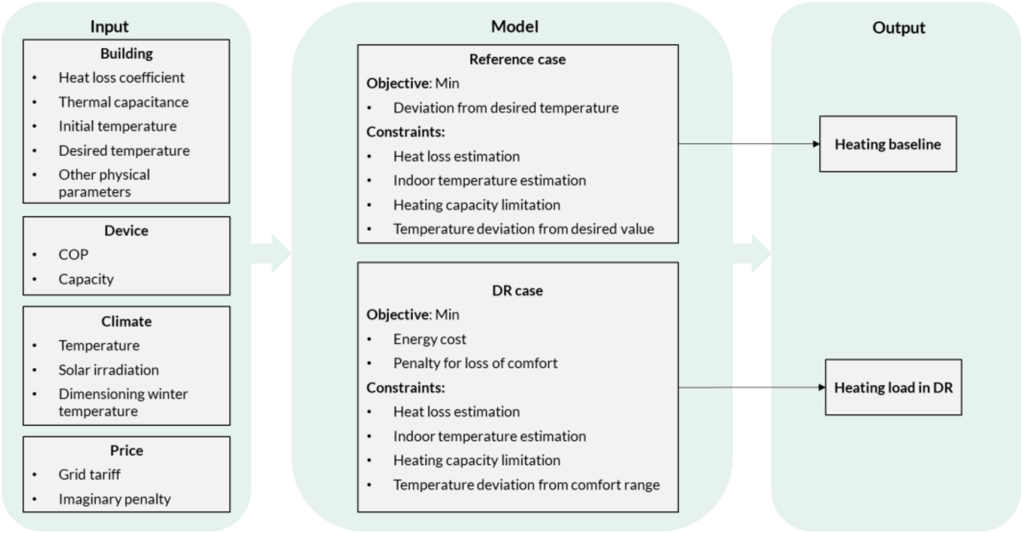

Figure 21 Simulation model for space heating system in small houses

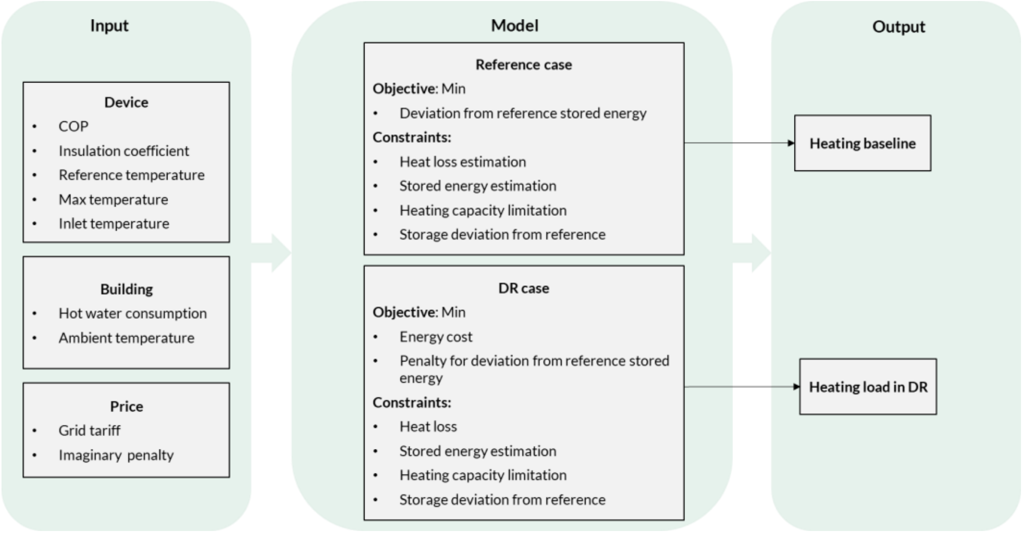

Figure 22 Simulation model for hot water preparation system in small houses

5.3.1.2 Results

Figure 23 shows the simulation result for the first week in January 2020. It assumes that the indoor temperature is maintained at 21.5±0.5°C while the hot water tank temperature is maintained at 80±5°C. In DR case, the systems respond to the TOU tariff so that the aggregate heating load is reduced in peak hours compared to the reference case.

Table 5 Energy demand and flexibility potential of space heating and hot water preparation in small house: Malmö, scenario 2030 and 2040. (Allowed temperature deviation: ±0.5°C for space heating, ±5°C for water tank) summarizes the energy demand and flexibility potential in scenario 2030 and 2040.

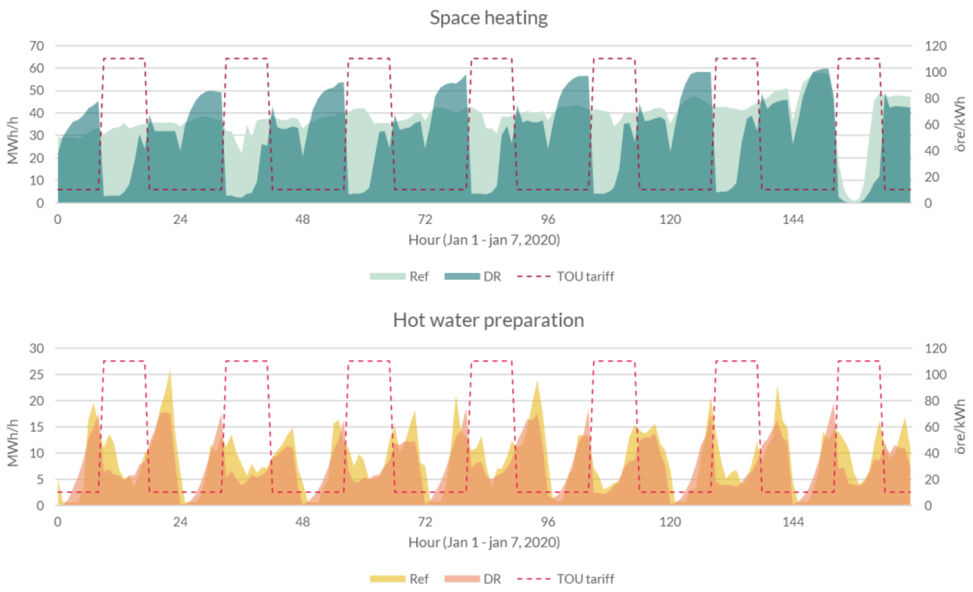

Figure 23 Aggregate load profiles in reference and DR cases: space heating and hot water preparation, small houses in Malmö, example of 1st week in 2020

Table 5 Energy demand and flexibility potential of space heating and hot water preparation in small house: Malmö, scenario 2030 and 2040. (Allowed temperature deviation: ±0.5°C for space heating, ±5°C for water tank)

End use	**Energy demand**	**Flexibility potential**
Space heating	The heating demand is estimated as 161GWh/year in 2030 and163 GWh/year in 2040, decreased by 5.2% and 4.1% from 2020 level.	The average load reduction in peak hours is estimated as about 42% (13.4 MWh/h) in 2030-2040.
Hot water preparation	The heating demand is estimated as 82.4 GWh/year in 2030 and 83.6 GWh/year in 2040, increased by 1.7 % and 3.1% from 2020 level.	The average load reduction in peak hours is estimated as about 24.2% (2 MWh/h) in 2030-2040.

5.3.2 EV Charging

5.3.2.1 Method

Models are developed to simulate the load for EV charging (Figure 24). The same models are applied for cars, light trucks and heavy trucks. Reference case refers to dumb charging i.e. charging starts when a vehicle is plugged to a charger and ends when the consumed energy is recovered. DR case refers to smart charging i.e. minimizing the energy cost and finishing charging before next departure.

For each EV category, the aggregate flexibility in each scenario is estimated with the following procedure:

1) Clustering:

    - Cars: 6 clusters for home charging and 8 clusters for public charging, concerning the type of EV (BEV/PHEV) and maximal charging power (3.7/7.4/11/22 kW).

    - Light trucks: 3 clusters concerning the maximal charging power (3.7/7.4/11kW).

    - Heavy trucks: 15 clusters concerning the type of truck (local/reginal/long-haul) and maximal charging power (22/44/50/100/150 kW).

2) Simulation: Considering the stochastic driving behaviours, 200 vehicle samples are randomly simulated for each cluster. The varied charging patterns between weekdays and weekends are also considered.

    - Cars: The departure time and start time of charging in reference case are estimated from the travel behaviour survey in Skåne (Figure 25).

    - Trucks: The start time and duration of depot charging are based on a national statistic about the daily longest stop of heavy trucks (Figure 26). The average stop duration is 8.5-15 hours for long-haul trucks and 11-17 hours for local/regional trucks (Lindgren, o.a., 2021).

3) Aggregation: The aggregate charging load in Malmö are calculated according to the average load profiles of the clusters and the number of vehicles in each cluster. The potential flexibility is estimated by comparing the aggregate load profiles in reference and DR cases.

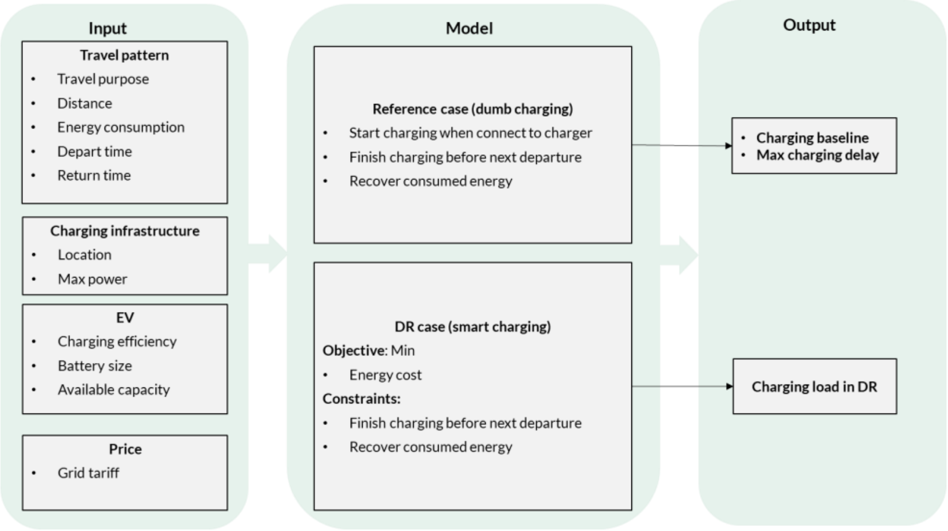

Figure 24 Simulation model for EV charging

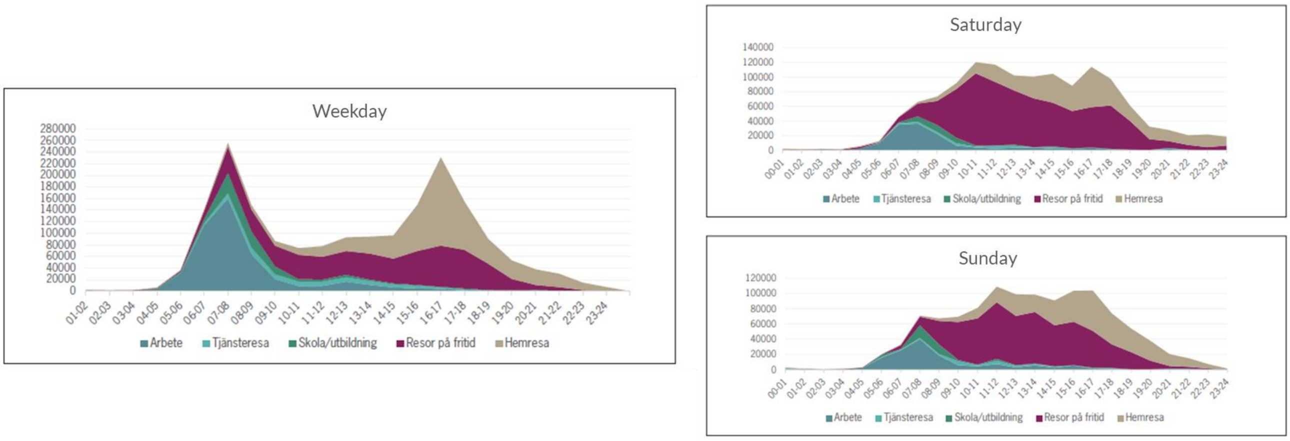

Figure 25 Distribution of the start time in different travel cases (work/business/school/leisure/return home). Y axis refers to the number of travel cases. (Region Skåne, 2019)

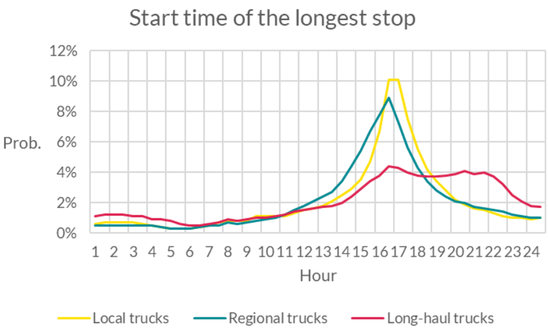

Figure 26 Distribution of the start time of the longest stop during a day for heavy trucks (Lindgren, o.a., 2021)

5.3.2.2 Results

Figure 27 and Figure 28 compares the aggregate charging load in reference case and DR cases on weekdays. In DR cases, the charging responds to the TOU tariff, leading to a peak reduction and load shift towards off-peak hours.

Table 6 summarizes the energy demand and flexibility potential of EV charging in Malmö for scenario 2030 and 2040.

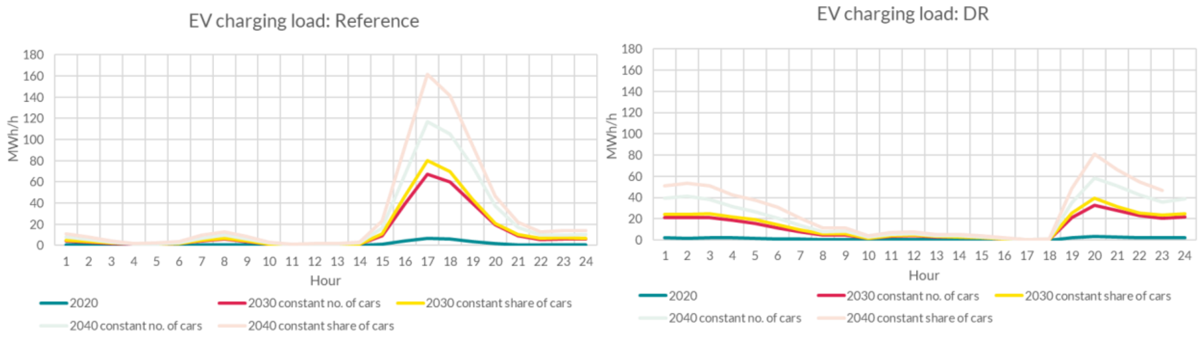

Figure 27 Aggregate charging load of electric cars in Malmö for different scenarios: weekdays

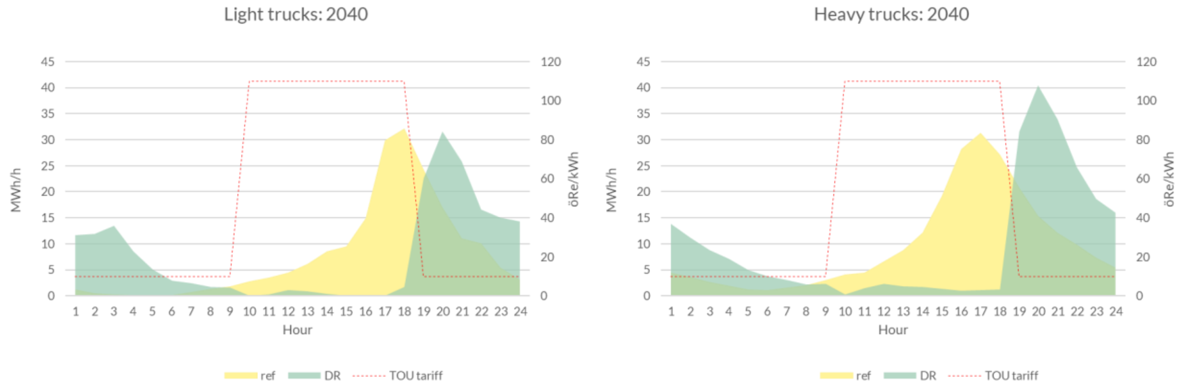

Figure 28 Aggregate charging load of electric trucks in Malmö: weekdays, scenario 2040

Table 6 Energy demand and flexibility potential of EV charging: Malmö, scenario 2030 and 2040

EV category	Energy demand	Flexibility potential
Cars	**Weekdays**: The average charging demand is estimated as 292-340 MWh/day in 2030, and 517-695 MWh/day in 2040. **Weekends**: The average charging demand is estimated as 420-490 MWh/day in 2030, and 798–1074 MWh/day in 2040.	**Weekdays**: Smart charging could reduce the demand in peak hours by 72.6%-74.1% in 2030 and 73.4%-75.3% in 2040. This corresponds to an average load reduction by 32-37MWh/h in 2030 and 57-76 MWh/h in 2040. **Weekends**: Smart charging could reduce the demand in peak hours by 57.6%-57.9% in 2030, and 59.0%-59.3% in 2040. This corresponds to an average load reduction by 20-23 MWh/h

		in 2030 and 38-52MWh/h in 2040.
Light trucks	**Weekdays**: The average charging demand is estimated as 53 MWh/day in 2030 and 190 MWh/day in 2040. **Weekends**: The average charging demand is estimated as 16 MWh/day in 2030 and 57 MWh/day in 2040.	**Weekdays**: smart charging could reduce the demand in peak hours by 78.3 % in 2030 and 2040. This corresponds to an average load reduction by 3 MWh/h in 2030 and 10 MWh/h in 2040. **Weekends**: smart charging could reduce the demand in peak hours by 89.2 % in 2030 and 2040. This corresponds an average load reduction by 1 MWh/h in 2030 and 3 MWh/h in 2040 on average.
Heavy trucks	**Weekdays**: The average charging demand is estimated as 50 MWh/day in 2030 and 235 MWh/day in 2040. **Weekends**: The average charging demand is estimated as 15 MWh/day in 2030 and 71 MWh/day in 2040.	**Weekdays**: smart charging could reduce the demand in peak hours by 79.2 % in 2030 and 79.6% in 2040. This corresponds to an average load reduction by 3 MWh/h in 2030 and 13 MWh/h in 2040 on average. **Weekends**: smart charging could reduce the demand in peak hours by 83.2 % in 2030 and 83.5% in 2040. This corresponds to an average load reduction by 1 MWh/h in 2030 and 4 MWh/h in 2040 on average.

5.3.3 PV and battery

5.3.3.1 Method

Models are developed to simulate the flexibility potential of the PV-battery system in residential buildings and mixed city, in line with the sectors specified in 5.1. Figure

29 illustrates the input and output of the models. Both reference case and DR case are defined as optimization problems for cost minimization. A flat tariff is applied in the reference case, while the TOU tariff is applied in DR case.

In each scenario, the simulation is done at the aggregate level for residential buildings and mixed city, respectively. By comparing the PV capacity with the peak demand, the share of load with PV installation is estimated for each sector:

- Residential buildings: The share of load connected to PV production is assumed as 1.6% in 2018, 21.8% in 2030 and 57.3% in 2040.
- Mixed city: The share of load connected to PV production is assumed as 2.1% in 2018, 17.8% in 2030 and 29.5% in 2040.

For each sector, the simulation is carried out for a year to capture the seasonal pattern of demand and PV production.

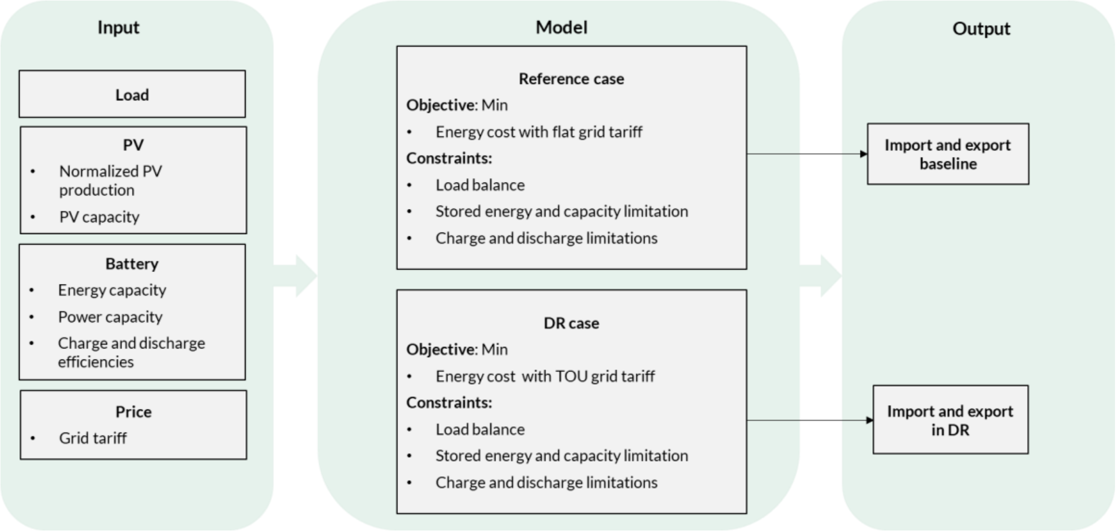

Figure 29 Simulation model for PV and battery

5.3.3.2 Results

Figure 30 shows the simulation result for a week in 2030 scenario. The load in peak hours is reduced and shifted in DR case compared to the reference case. For the residential buildings, the PV production and battery storage can cover all the demand in peak hours on the second day.

Table 7 summarizes the flexibility potential of PV-battery systems in Malmö for scenario 2030 and 2040.

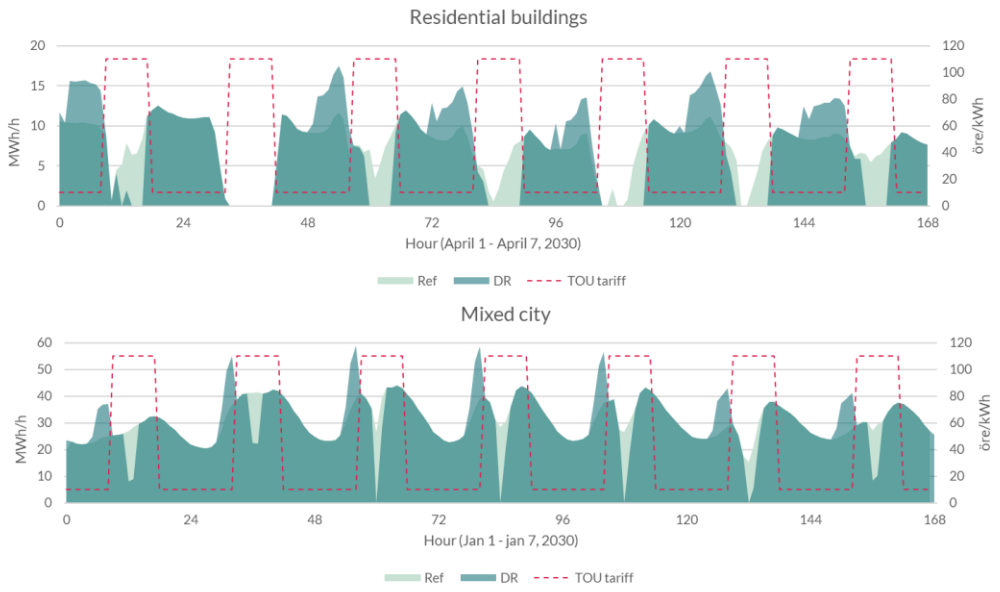

Figure 30 Aggregate import energy from grid in reference and DR cases: Malmö, residential buildings and mixed city, example of one week in scenario 2030

Table 7 Flexibility potential of PV-battery systems in residential buildings and mixed city: Malmö, scenario 2030 and 2040

Sector	**Flexibility potential**
Residential buildings	The average reduction of demand in peak hours is estimated as about 69% (4.1 MWh/h) in 2030 and 58% (8.3 MWh/h) in 2040.
Mixed city	The average reduction of demand in peak hours is estimated as about 34% in 2030 and 2040. This corresponds an average load reduction by 7 MWh/h in 2030 and 12 MWh/h in 2040.

5.4 Impact of flexibility

The regional impact of flexibility is analysed in terms of the effects on the grid load and the corresponding cost for importing electricity from the transmission grid. Based on 5.2, four scenarios are investigated when analysing the impact of flexibility:

- 2030, with constant number of cars
- 2030, with constant share of cars
- 2040, with constant number of cars
- 2040, with constant share of cars

For each scenario, the aggregate grid load in Malmö consists of baseload (inflexible parts in residential buildings, mixed city and industry) and flexible load. As described in 5.3, the flexible load includes:

- Space heating and hot water preparation in small houses
- Charging of electric cars, light trucks and heavy trucks

- PV-battery systems in residential buildings and mixed city

Figure 31 shows the load duration curve of each scenario in the reference case and DR case, respectively. The load duration curve of 2018 is also plotted as a baseline. The load increases for scenario 2030 and 2040 compared to 2018. In 2030, the different trends of electric cars i.e. “constant number” or “constant share” of cars, has almost no effect on the total load. In 2040, the total load is slightly larger for sub-scenario “constant share of cars”. For all the scenarios, the peak load in DR cases is reduced compared to the reference cases. This is due to the shift of load towards off-peak hours, as explained in 5.3. Accordingly, the load duration curves in DR cases are flatter than those in reference case.

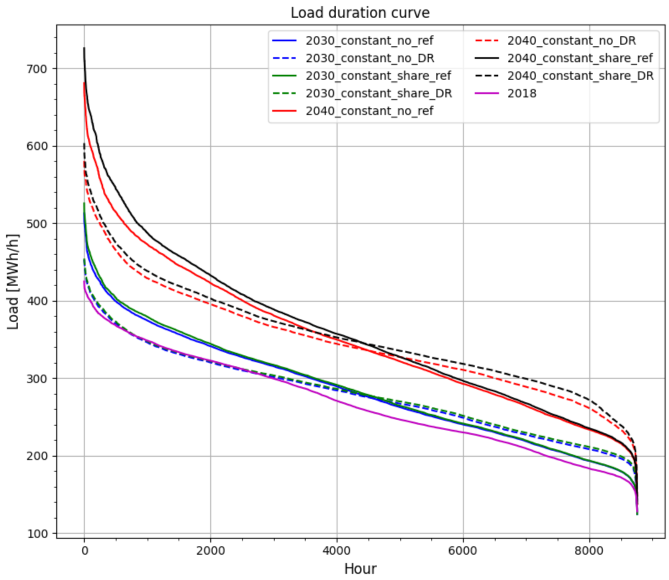

Figure 31 Load duration curve of the grid load in Malmö for different scenarios

Table 8 compares the required import capacity from the transmission grid and the corresponding power fee in different scenarios. DSOs pay a power fee to TSO based on the annual subscribed capacity. At the two transmission connection points for Malmö, Sege and Arrie, the power fee to TSO is 142-143 SEK/kW in 2022 (Svenska Kraftnät, 2022). DSOs need to pay an expensive extra fee if there is a need to temporally increase the subscription or if the load exceeds the subscription. The power fee of DSOs will be passed on to end customers. In the analysis, the highest load in a year is considered as the annual subscription to avoid the extra fee.

As shown in the table, the required import subscription for Malmö is lower in DR cases than in reference cases. The reduction is 11.7-13.6% in 2030 and 14.8-16.9% in 2040. This leads to a reduction of power fee by 8.5-10.2 MSEK/year in 2030 and 14.3-17.5 MSEK/year in 2030.

It is assumed that the threshold for peak load is 478 MW in 2030 and 664 MW in 2040 (Table 4). The number of hours when the load exceeds the threshold is calculated. In the reference case, there are 30-40 hours with peak load in 2030 and 7-46 hours in 2040. Contrarily, the load is always below the threshold in DR cases.

Table 8 Required import subscription from the transmission grid and power fee for Malmö in different scenarios

		2030 Constant number of cars	**2030 Constant share of cars**	**2040 Constant number of cars**	**2040 Constant share of cars**
Import subscription [MW]	**Reference case**	512.7	525.6	680.8	725.8
	DR case	452.9	454.4	580.3	603.3
Reduction of import subscription		11.7%	13.6%	14.8%	16.9%
Number of hours with peak load	**Reference case**	30	40	7	46
	DR case	0	0	0	0
Reduction of power fee [MSEK/year]		8.5	10.2	14.3	17.5

5.5 Conclusion

The study estimates the flexibility potential in Malmö for scenario 2030 and 2040, focusing on the flexibility solutions of heating, EV charging and stationary battery. The estimation is based on modelling and simulation, considering that the flexibility can be accessed if the demand could respond to a TOU grid tariff. The flexibility potential is presented in forms of the average reduction of hourly load and the average reduction percentage from baseline. Impacts of the aggregate flexibility is analysed. Results show that the flexibility can effectively reduce the electricity demand in peak hours while the total demand will increase in the future. This implies a lower need for importing from the transmission grid and correspondingly a lower power cost, compared to situations without utilizing the flexibility.

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