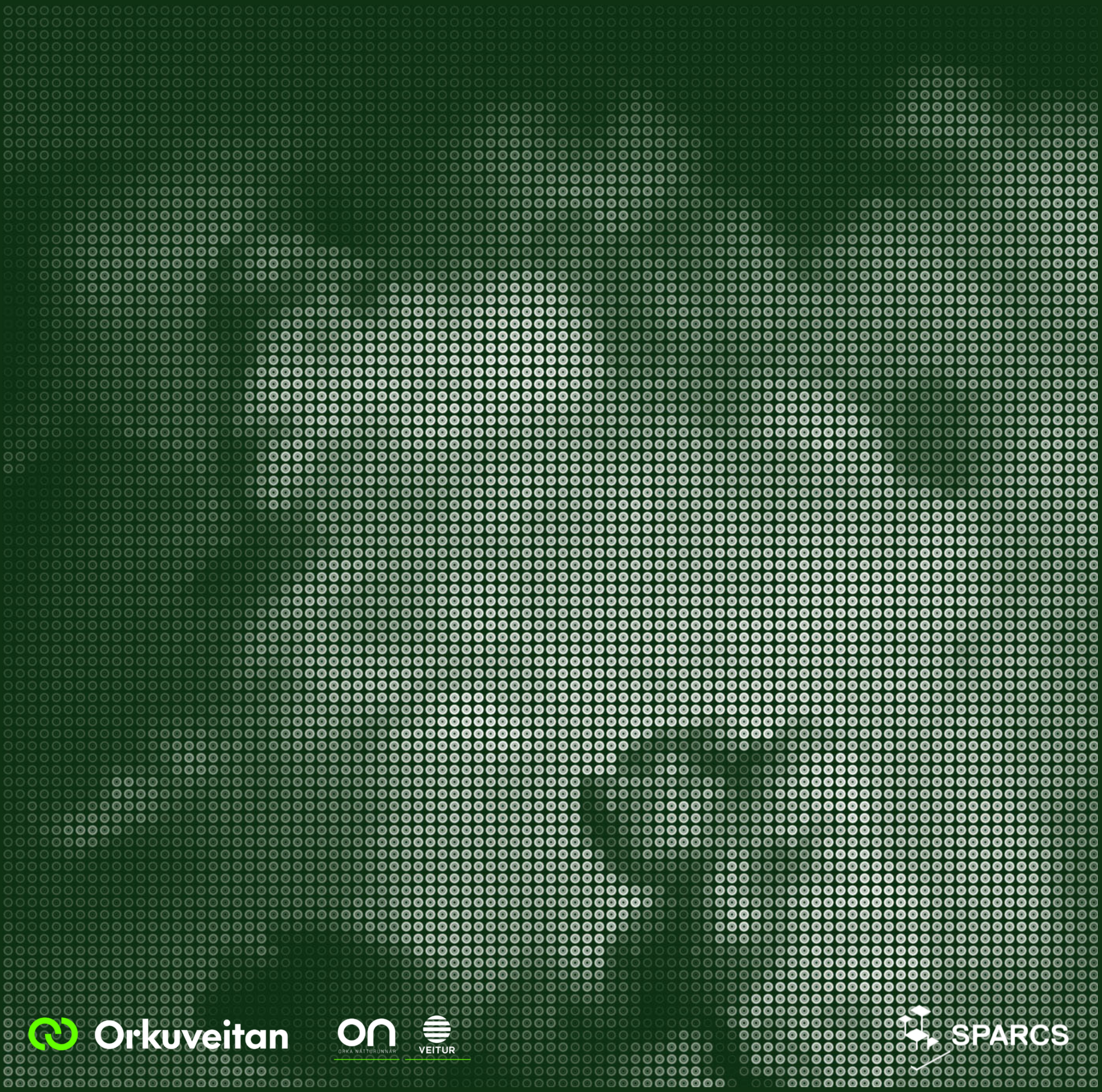
Charge Better

An Icelandic pilot project on demand response with EVs



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Disclaimer

Executive summary

With the increasing number of electric vehicles (EV), added load from vehicle charging can have a significant impact on the low-voltage distribution grid. In countries like Iceland, where the majority of newly registered passenger vehicles are electric, either fully or plug-in hybrids, it is important to explore ways to deal with this added demand.

Demand response (DR) is a method where the demand side is affected either by price signals or more direct methods, with the aim to move load to more favourable times for the distribution grid and reduce peaks. Research has shown that EV charging is suitable for DR, especially for home charging, where relatively short charging times are needed but the vehicle is connected for a long time. Some research has been conducted on this topic in Iceland but the focus has been on estimating the impact of EV load on the distribution grid and the possible benefits of DR, which can be substantial. In the pilot project Charge Better, three different DR programs were explored with 145 real EV owners in the capital region of Iceland over a 16 month period.

The participants in the pilot project had smart meters and smart charging stations installed, which offered detailed consumption data for home consumption and EV charging. Additionally, a customer portal was developed specifically for the project to give the participants better insight into their charging behaviour and to communicate the specifics of the DR programs. Many different variations of the three DR programs were researched, based on different timings, price reductions and structure. Each variation was kept for at least a month while some were kept longer with small alterations. After each month, a survey was sent out to the participants asking about the setup of the DR program in its current variation. Additionally, a final survey was sent out after the research phase ended. The results of these surveys were an important part of the research, to be able to determine which DR program would be most effective in real circumstances based on the likeliness of EV owners to participate in them.

In the project, two price based programs were explored; time-of-use (TOU) and load based pricing (LBP) as well as one incentive based program; direct load control (DLC), which was done with the smart charging stations. For every month, i.e. a variation of the three DR programs, the peak reduction compared to baseline charging behaviour was calculated as well as the load reduction for an average day of the month. These two metrics were used to analyse how much the load impact could be reduced, the first for the overall system peak and the latter for less time under high load and thus increased efficiency of the distribution grid infrastructure. These analyses coupled with the results of the participant surveys gave good indicators for the DR program effectiveness.

The results firstly showed that uncoordinated charging load, i.e. without any DR or tariff incentives, peaks at very similar times as the household consumption, creating a peaking effect. Based on the circumstances in this project, with very high EV ownership, EV charging more than doubled the total peak compared to the peak of only the household consumption. With the use of the DR programs, most variations had considerable reduction effects, but certain variations of the DLC DR program increased the peaks when the control method was too simple. The likeliness of participation based on the surveys was very high for TOU, relatively low for DLC but still sufficient, as it needs less participation to be effective since it has more control over the load. Overall, the findings indicate that DR can be effectively used in Iceland to reduce the peaks which are created by EV charging, increase infrastructure utilisation and lower the impact on the distribution grid.

The different DR programs can benefit the DSO greatly in reducing load on the distribution grid. The two price based programs are well suited for the DSO to carry out or an electricity retail supplier. However, the DLC is better suited for the retailer or an aggregator, as it requires control over the charging of the charging station or through direct communication with the EVs and those kind of services are typically not the role of the DSO. Future research should focus on finding the optimal structure for DR programs in Iceland, as they are very sensitive to both EV ownership and customer participation. This was not in the scope of this project. From the data of this pilot project, which is available to the public, this could be analysed in-depth.

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List of Abbreviations

BEV	Battery Electric Vehicle
TOU	Time of use
DLC	Direct load control
LBP	Load based pricing
DR	Demand response
DSO	Distribution system operator
EV	Electric Vehicle
IBP	Incentive-based programs
PBP	Price-based programs
PHEV	Plug-in Hybrid Electric Vehicle

1
Introduction

With the increased uptake of EVs, added load on the energy system from vehicle charging is anticipated. This additional load especially affects the low-voltage distribution part of the grid, which historically was not designed with EV charging in mind. In fast-growing EV markets, such as Iceland, ways to manage this added demand need to be considered.

Generally, there are two main ways to address this added demand at the low-voltage: strengthening and reinforcing the distribution system, or affecting the demand side. With demand response programs, which is the act of affecting the demand side of electricity consumption, EV charging can be shifted to more favourable times for the distribution grid.

To understand the landscape of the research project and the current state of affairs regarding EV development in Iceland and the electricity retail market, some background information is provided in this section."

1.1. Icelandic electricity retail market

The Icelandic electricity market is fairly unique. It is completely isolated and is not connected to the mainland of Europe or its electricity markets. In many ways, it is a quite simple market, where the power market has mainly been based on long-term contracts between two parties, with no real spot market. However, two electricity power exchange companies have started recently: Elma, which plans to implement a day-a-head market and trading system in cooperation with Nord Pool in 2025(Elma, 2024) and Vonarskarð, which plans to improve the wholesale electricity trading market in Iceland(Vonarskarð, 2024).

To residential users in Iceland, the energy market has also been quite uniform with a few different electricity retail suppliers, offering one single price all year round. In the last two years, this has changed with a few retailers now offering time-of-use (TOU) tariffs, but they are only available to the customers of one DSO in Iceland, due to the still limited smart meter roll-out. Research into the effects of these newly changed tariffs on EV charging and its load impact, as well as the other DR programs explored in this project, have not been studied in real world circumstances.

Moreover, the vast majority of houses in Iceland are heated by district heating systems from geothermal power plants. Therefore, household electricity consumption is relatively low, especially for customers without EVs. The monthly cost of electricity has not been a large part of monthly expenses historically. This is also due to the price itself being low compared to other European countries. In figure 1.1, a comparison of the price of one kWh can be seen for European countries.

However, in coming years, the possibilities for dynamic tariffs increase, as the electricity market on the household consumer level will be transformed from the conventional method in Iceland, which is a a yearly reading of the electricity meter, to utilising smart meters. These future changes will further be affected by the power exchange market that is forming, as previously mentioned. In Iceland, the smart meter roll-out is currently underway with different levels of smart meter implementation by DSOs but five DSOs are active in Iceland.

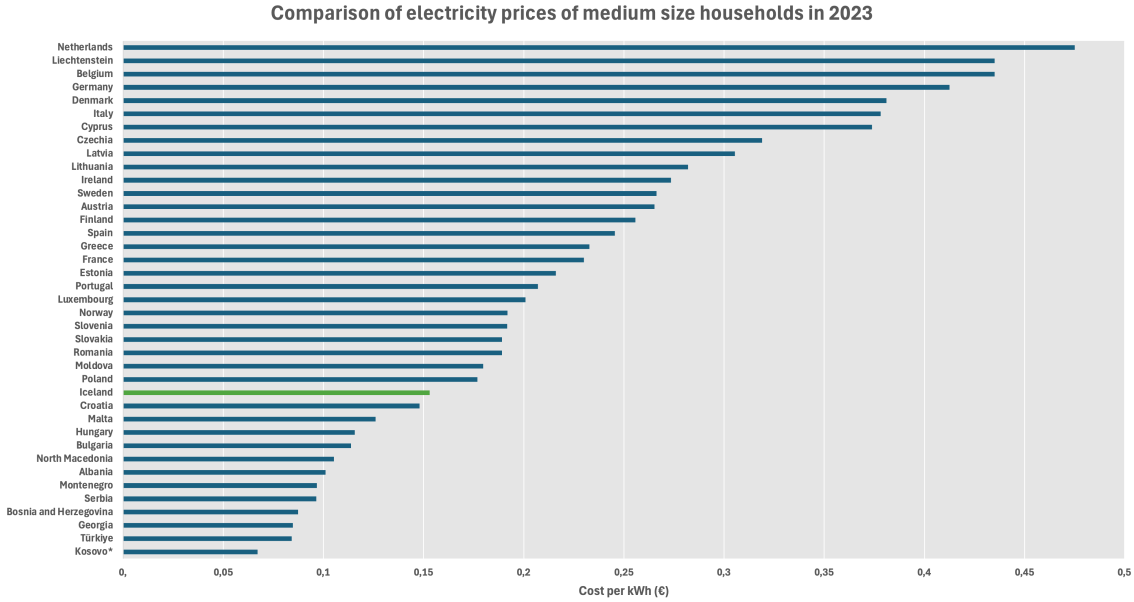

Figure 1.1: Comparison of electricity prices for European households in 2023 (Eurostat, 2024)

According to data updated in May 2024, roughly 50% of the 215.000 electricity meters serviced by the DSOs are smart meters (National Energy Authority, 2024). For Veitur Utilities, the completion of the roll-out is expected in 2025 (Veitur utilities, 2024).

1.2. Icelandic EV market

Iceland is one of the fastest growing EV markets in the world. In 2023, 61.2 % of new passenger vehicle registrations were either EVs or plug-in hybrid electri vehicles (PHEV). This is due to a number of reasons, but strong incentives in the last years as well as low electricity prices make EVs affordable in Iceland. In figure 1.2, the growth of new registrations of EVs, both BEVs and PHEVs can be seen for the last 10 years.

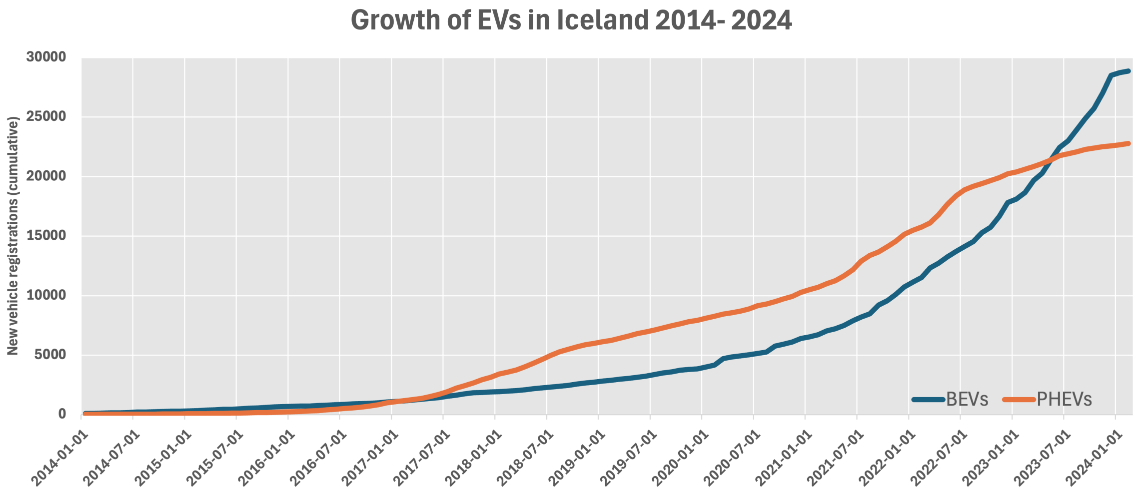

Figure 1.2: Development of EV registrations in Iceland for 2014-2024 (Icelandic Transport Authority, 2024)

In recent years, the retail price of new passenger EVs compared to passenger vehicles with internal combustion engines have been getting more competitive, which has aided in this development. The Tesla Model Y was the best selling vehicle in Iceland in both 2022 and 2023 and in the latter year, Tesla was the highest selling brand overall for passenger vehicles. This development is expected to continue, with more brands getting imported every year offering increasingly price-competitive options.

Furthermore, the Icelandic government has from 2018, when they announced their Climate Action plan for 2018-2030, had very ambitious goals for decarbonisation in the transport sector. Most notably is a proposed ban on new vehicle registrations of internal combustion engine passenger vehicles, currently proposed from 2028. Moreover, the government aims towards net zero emissions in 2040 (Ministry for the Environment and Natural Resources, 2019). In their newly updated Climate Action plan in 2024, over 150 actions items are outlisted that aid in decarbonisation and sustainability. Among those are incentives for construction of public charging stations, public transportation and continued measures for making EVs more feasible. Those for example include tax reductions for companies making them more affordable to operate, grants for the public for purchasing EVs under approximately 65.000 € and a demand for a certain share of EVs for car rental companies (Ministry of the Environment & Climate, 2024).

1.3. Demand response with EVs

As mentioned earlier, one of the ways to deal with the added load demand of EV charging is demand response (DR). There are many different types of DR, specific to the type of demand and the energy market it is intended for. In recent years, DR with EV charging has been getting more popular with the introduction of peak and off-peak time-of-use (TOU) tariffs as well as real-time pricing (RTP) widely in Europe. Research has shown that by utilising DR programs for handling EV charging load, its load impact can be minimised (Lund & Kempton, 2008; Ravi & Jain, 2017). Moreover, research has shown that if charging is left uncoordinated, i.e. without any incentives for EV owners to charge during non-peak times, distribution grid problems can occur (Clement-Nyns, Haesen, & Driesen, 2011; Blasius, 2017).

Generally, two types of demand response programs are considered; incentive based programs (IBP) and price based programs (PBP) which were identified by (Albadi & El-Saadany, 2008). In figure 1.3, the different programs can be seen in a diagram, which originally comes from the same prestigious article.

Figure 1.3: Overview of DR programs, originally from (Albadi & El-Saadany, 2008)

The main distinction between the two types of programs are that PBPs utilise price signals to influence the consumer or user to alter their electricity consumption to more favourable times for the distribution grid. The differences between the five programs within PBPs is that some are designed to tackle emergent and rare peaks by pricing electricity very high during those scarce times, while others are intended for regular and frequent peaks. To ensure participation in these programs, the tariffs are usually designed in such a way that it is very economical to move your consumption to the off-peak hours with lower tariffs but in turn it can be very expensive to consume electricity in the peak hours.

Within IBPs there are two subcategories, Classical and Market Based. The first category includes two programs where generally it is the DSO that has varying level of control over the electricity loads of certain customers. Direct Control means essentially that the intensity of the load, the power can be reduced or moved in time. Interruptibe or curtailable programs often mean that the load is reduced down to zero and thus interrupted. The implementation of these programs does also vary, base on the type of customers and the type of load. The incentive for the consumers participating in these programs are also in monetary terms as is the case with the PBPs, but the tariffs are often structured in such a way that the customers are paid a premium (or get a discount) for registering in the program, so the DSO knows which customers it can affect.

For the Market Based programs, the same incentives are used but in this case the market is used to control the loads. This can be done in many ways and some of the programs are intended for different market segments. The ancillary services market program addresses the balancing market for the electricity market and distribution grid. The Emergency DR program is aimed towards infrequent loads and is used to help balance the grid. The other two programs within Market Based IPBs also serve the purpose of reducing or shifting demand towards more favourable times for the grid as is the objective of all the DR programs. The common denominator for these IBPs are that they are on a contract or agreement basis and customers get compensated for shifting their demand based on orders or signals from the DSO or TSO or in some cases, these parties directly control the loads.

1.4. The pilot project

With growing numbers of EVs in Europe as well as other parts of the world, research into DR with EVs has been increasing in the last years. Furthermore, there have been conducted a number of case studies and pilot projects exploring tariff changes and their effect on charging. In Iceland, some studies on EV charging have been made, notably a charging behaviour study orchestrated by Samorka, the Icelandic federation of energy and utility companies in Iceland. In the study, 195 EV owners were monitored for 12 months to see how their charging habits were. The study was carried out from October 2018 to December 2019, concluding with a report in 2020. The outcomes of the study showed that the charging peak happens between 18:00 and 19:00 and then again around 21:00 to 22:00 (Fleetcarma, 2020). These peak hours happen to largely coincide with the peaks of the base load in the capital region.

Some research has also been conducted in Iceland, covering topics such as cost effectiveness of EVs, the effects of EV charging on the distribution grid and the general growth of EVs in Iceland, but research into DR with EVs in Iceland has been lacking, especially with real EV owners. A research project simulating the effects of different DR programs was conducted in 2020, estimating the load reduction impact with DR in Iceland's capital region, Reykjavik. The thesis report found that relatively small EV numbers can cause problems in the low voltage grid in the capital region. Moreover, the report concluded that DR programs can significantly lower load peaks and increase the distribution grid utilisation. Various DR programs were simulated in the project, as well as varying participation of consumers. Finally, the report recommended that pilot projects with real EV owners would be needed to effectively choose the most feasible DR strategy in Iceland (Andri Páll Alfreðsson, 2020). The identified knowledge gap this pilot project tackles builds on these results. There is missing knowledge on how likely Icelandic EV owners are to participate in DR programs, the tariff discounts and structures needed to achieve participation and thus the real-world effectiveness of DR programs. Furthermore, there is also missing information on the relationship between household consumption and EV charging in current circumstances and the peak increase from current EV charging behaviour in Iceland.

This pilot project aims to fill this research gap and aid in the future development of applicable DR programs for EV charging in Iceland. The project assumes that DR of some kind will be needed with increasing numbers of EVs in Iceland and the objective is to find effective DR programs based on customer participation and satisfaction, as well as load reduction capabilities. In order to do so, a number of research questions have been formulated. The main research question, which in turn consists of three sub-research questions is:

How can demand response programs be used to reduce the load impact of EV charging in the low-voltage distribution grid?

To properly answer this main research question, three sub-questions have been identified, breaking it down even further.

1. *Do price-based DR programs suffice to reduce EV load impact?*
2. *Can direct load control be used while maintaining customer satisfaction?*
3. *What is the tariff reduction needed to ensure participation in DR programs?*

2
Methodology

This chapter describes the methodology of the pilot project. The Charge better project is a pilot study, where a subset of real EV owners in Iceland were exposed to various demand response programs with the aim of lowering load peaks and spreading the added demand from EV charging over time. To answer the proposed research questions, different scenarios of the three DR programs were formulated by altering tariff structure and pricing and communicating that to the participants. This was done on a monthly basis and following each month, a survey was carried out to measure participants' preferences for each scenario.

The chapter starts by going over the design of the research project, then goes into the pilot study itself and its structure. Lastly, it goes over the technologies that were used and developed for the project.

2.1. Research design

As mentioned previously, one of the main reasons for the missing knowledge gap of DR strategy feasibility in Iceland is the lack of studies done with real consumers in Iceland. Therefore, a research project in the form of a pilot project was chosen. Some similar trials and pilot projects have been done in other countries which include a subset of customers of a DSO or electricity retailer. In the Netherlands, one pilot study with 138 households, found that a dynamic charge management system could reduce peak lead by up to 40% (ElaadNL, 2020). In the United Kingdom, Electric Nation conducted a similar trial which at the time was the largest smart charging pilot study worldwide, with nearly 700 EV owners participating. The pilot found that with well structured electricity tariffs, customer satisfaction could be kept high as well as offer low charging costs for EV owners. Furthermore it showed that DR programs could move demand away from peak hours (Electric Nation, 2018).

Although these studies show great promise for load reduction with DR programs, the goal of this pilot project, Charge Better, was to find out if these same results are applicable in Icelandic circumstances. In the countries of these pilot projects, some of the DR programs like TOU, have been used for years. Those EV owners are therefore much better adapted towards DR in many ways than Icelandic EV owners. Therefore, the results of those studies do not necessarily translate to the area of interest of this pilot project, the capital region of Iceland. As mentioned before in 1.1, Iceland is a unique case study in many was. Some of the DR methods that were used in the previously mentioned pilot studies as well as other studies, are not feasible in Iceland. The Charge Better project aims to explore the DR programs that are applicable and likely to succeed in Iceland.

2.1.1. Stakeholders

The Charge better project is a joint project between Reykjavik Energy and two of its subsidiaries, ON Power and Veitur Utilities and is a part of a larger research project called SPARCS (Sustainable energy, Positive & zero cARbon CommunitieS) which is consists of seven European cities. In the project, these cities aim to develop and research projects and initiatives that aim towards sustainable solutions in transport and mobility. The project is partially funded by the European Union by the Horizon 2020 grant scheme (SPARCS, 2024).

The research team consisted of experts from each of the participating companies, Hrafn Leó Guðjónsson, Kári

Hreinsson and Guðjón Hugberg Björnsson from Reykjavik Energy, Veitur Utilities and ON Power respectively, as well as Andri Alfredsson from Skyggnir Analytics, which Reykjavik Energy contracted directly.

2.2. Pilot study

The Charge Better research project consists of three distinct phases. The preparation and scoping process, the pilot study itself and finally the analysis. As previously mentioned, Charge Better is a part of the SPARCS project and therefore somewhat follows its timeline. The pilot study phase consists of sub-phases, based on the different DR programs that were explored in the project.

2.2.1. DR scenarios

When considering the DR programs for this pilot project, some constraints were identified. First of all, as mentioned before, the retail electricity market in Iceland is quite uniform, especially at the household consumer level. Therefore, Market Based DR programs, seen at the bottom left on the diagram in figure 1.3, were excluded. Those types of programs are better suited to market regions where there are dynamic spot markets and more stakeholders are involved in the market making. For the two classical IBPs, both of those programs were considered for the project and a DR strategy that was a combination of both was explored in this project. For PBPs, TOU was an obvious candidate due to its simplicity and widespread use in other parts of Europe. A form of Critical Peak Pricing (CPP) was also explored in the pilot project.

Three different programs were thus explored in the project but multiple scenarios within those programs were formulated. Here below, the general formulation of these three DR programs in this project will be explained. The breakdown of the tariffs will be covered later in this chapter. Moreover, the exact structure of the scenarios within each program can be found in Appendix A.1.

Time-of-use (TOU) is the first of the three DR programs in the Charge better project. This type of tariff has very rarely been used in Iceland for household and individual consumers. However, during the project's research phase, a few electricity retail suppliers in Iceland started offering these kinds of tariffs. Due to the fact that this tariff is generally unknown to Icelandic EV owners, the TOU tariff in the project was kept simple. Two periods within the day were created, based mostly on peak and off-peak hours.

Direct load control (DLC) is the second DR program. It is essentially a mixed version of the classical IBPs as seen earlier in 1.3. In this program, the EV charging of the participants was influenced by either delaying the starting time, thus interrupting it or curtailing the power offered by the charging station or a combination of both measures. This was carried out with the smart charging stations that the participants had installed, which were 4G connected. The methodology behind this control will be explained later on in this chapter. The participants in the pilot project were included in the control algorithm by default but could opt-out of it and charge on their own schedule, but with those opt-out actions they received less price reduction on electricity for the month.

Load based pricing (LBP) is the last of the DR programs that was explored in the project. This is in some ways a version of peak pricing, which several of the PBPs are based on. Peak based pricing has been used in Iceland for companies and heavy industry for quite some time and the implementation drew some inspiration from that. However, most of those tariffs are based on either one or few peaks over a month's time. It was considered that this tariff structure would not incentivise EV owners in the best way, as it could make most of the month isolated from the tariff if one or a few peaks would control the price. In the pilot project, it was therefore decided that every hour should be priced differently based on the power consumption over that hour. Using multiple household appliances and charging at the same time would thus result in a more costly rate of each kilowatt hour used, compared to if this consumption would be spread out over multiple hours. The tariff structure of this DR program will be explained in further detail later in this chapter.

2.2.2. Timeline

The preparation and scoping of the project began in January 2021. In figure 2.1 below, an overview of the major events in each of the three parts of the project can be seen. Most of 2021 was spent on scoping the research project, as well as the procurement of charging stations, software development and structuring of the tariffs for the project. That involved acquiring permission from the Icelandic Energy Authority for special tariffs for the pilot project. In the later part of the year, participation recruitment was prepared and in December of 2021, Reykjavik Energy launched a marketing campaign, advertising the project and looking for participants. In January and February of 2022, the participating EV owners were chosen, based on multiple criteria, which will be explained more in-depth in the next section.

Following that, the participants had smart meters and charging stations installed over the course of a few weeks during spring and summer by contractors. Some participants had additional three phase electricity conversion done, on their own cost, while others either had that from the beginning. This meant that some participants could charge on a three phase connection but some on one phase connection. In September all these installations were finished and thus the baseline scenario of uncoordinated charging could be established. October was also used as a baseline month.

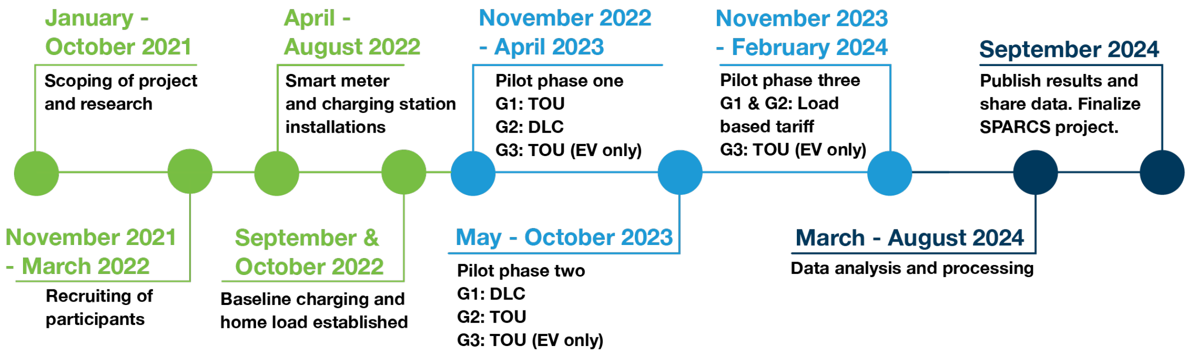

Figure 2.1: An overview of the timeline of research project.

The participants were divided into three groups. This was both done to observe the differences if any, between starting with TOU or DLC, for Group 1 and Group 2 respectively, but also to be able to explore more demand response scenarios. Furthermore, three subgroups were formulated inside each of these groups which had different structures of the active DR program.

For group three, which consisted of inhabitants of a single apartment building, the same demand response program, TOU, was carried out throughout their whole pilot phase. Due to shortage of smart meters from Covid supply chain disruptions, smart meters could not be installed for these participants before the start of the pilot project. Therefore, only charging behaviour was analysed. This group also started a month later, in December of 2022 and finished a month earlier, in January 2024. This was based on the fact that less time was needed to explore their scenarios based on the single DR program.

Following the pilot phases, the data and results were analysed and summarised in this report. In September of 2024, the results were published and non-identifiable data shared.

2.2.3. Participants

In the preparation phase of the project, it was decided that 150 participants in single-family homes would be ideal for the pilot study based on the constraints of budget and scope but still offering enough variability in charging behaviour and demographics. In December of 2021, applications to participate in the project opened up and roughly 400 Icelandic EV owners applied. In return for being a part of the study, the participants got a free installation of the smart charging station and free use of that station for the duration of the project. They also got an accelerated installation of a smart meter but the smart meter roll-out of Veitur Utilities is currently underway. Additionally, the participants got discounted tariffs during the project.

In the application process a few criteria were outlisted. First of all, the participants had to own a BEV, model year 2018 or newer. This constraint was put into place due to the fast developing EV market and aimed to represent the EVs of the next years, ensuring that the results of the project were still relevant when it finished. Secondly, the participants had to live in a single family home where they were on a distinct feeder cable, i.e. the connection from the distribution electricity streetboxes into the home. This constraint was put into place to be able to get accurate measurements and to be able to have the charging station of the participants connected to the same circuit as their smart meter. This was to be able to have two distinct time series, one only from EV charging and the other for the home of the participant. It was also communicated to participants that all charging during the project had to take place through the stations, even if some participants had their own station beforehand. Additional data was acquired from the participants during the application process which included more detailed information about their electricity usage and family size but most importantly, the type of EVs they owned and the battery sizes. This was important to be able to adjust the DLC program specifically to each participant.

Another constraint was that the participants lived in the distribution area of the cooperating utility company, Veitur Utilities. This was necessary to be able to supply them with a smart meter that data could be gathered from for the project. Furthermore, constraints were also put into place regarding the voltage system. Generally, two voltage systems are in use in the utility distribution area, the older 230V system and the updated 400V system. Smart meters that worked on 230V voltage were not ready from the manufacturer before the project's start and therefore could not be installed. Furthermore, 230V as a voltage level is being phased out. Participants with 230V electricity were thus not admitted into the study. Lastly, the ease of installation of the charging station and the proposed positioning of the charging station was a big factor. A certain budget was allocated to each installation and that was based on the proposed charging location being near the electricity table of the house.

For the participants in the apartment building, several such buildings were considered as candidates for the project. EV charging in apartment buildings is very different from single family homes, where in most cases, specialised service providers operate a controlled charging system. ON Power, the cooperating electricity retail supplier of this project, services a number of apartment buildings and a few of them were contacted regarding the pilot project. The goal was to get a large apartment building to see if TOU tariffs could affect the charging profiles.

An apartment building with 29 charging stations in a large parking garage under the building was willing to join the project. The participants already had those stations as a part of ON Power's charging station subscription model and during the project the subscription fee was waived. In large parking garages like these with many charging stations, there is a sort of internal demand response in place, where the total power available to the stations is controlled by the charging station provider, in this case ON power. This works by reducing the power available to each station that is charging simultaneously so the total does not exceed the capacity of the feeder cable going into the parking garage. Based on this internal demand response, the objective was to see if a TOU tariff could still affect the charging behaviour.

2.2.4. Tariffs

Electricity tariffs in Iceland for residential users, can be quite confusing at times, as the utility sends one monthly bill and the electricity retail supplier sends another one. Moreover, the utility bill is broken down into three parts, the transmission cost, grid balancing cost and lastly the distribution cost. Additionally, there is a daily fixed cost additional to the cost of each kilowatt hour. In the retail space, there has been a lot of competition with several new electricity retail suppliers entering the market in the last few years. For some EV owners, the total price of each kilowatt hour is therefore not very clear. With regular power meters, the meter reading has been done once each year and every month is billed according to a calculation based on yearly consumption. While smart meters are being rolled out as was mentioned in the previous chapter, most electricity meters are still billed from readings rather than time series data.

In this pilot project, it was decided to combine the tariff of the utility and the tariff of the retailer, Veitur and ON Power respectively, into one electricity price that was communicated to the participants throughout the project. All of the changes to the tariffs that were done in the project and used as a control variable and incentive for the participants, were based on the standard electricity price these users would be have to pay otherwise. The price during the peak was therefore not raised, as would normally be done in real circumstances. This was done to ensure participation retention throughout the project. These prices thus followed the increments in the tariff of the utility, Veitur and the electricity prices of the retailer, ON Power. The discounts on the tariff that will be shown in this report are always based on this combined tariff. In the tables in Appendix A.1, an overview of these tariffs and discounts can be seen.

TOU
As the project is a pilot with some effort and disruption for the participants, the tariff during the peak hours was priced as the regular electricity tariff as before and the off-peak hours were at a discounted price. This tariff did not only affect the charging stations but the household consumption as well. The length of the off-peak and thus discounted period, varied from 4 to 8 hours, along with one scenario where the off-peak hours also extended over the weekend. As did the price reduction on the tariff, varying from a moderate 15% in the beginning all the way to 75% reduction. Additionally, one other TOU tariff was formulated, a special Christmas time tariff, where an increased off-peak price was offered for 84 hours leading up to the 24th of December in an attempt to alleviate the Christmas Eve peak.

DLC
For the DLC tariff structure, many different ways could have been implemented. Under most circumstances, participants in direct control DR programs subscribe or opt-in to such a program and with that give the DSO or other control entities permission to curtail or interrupt their loads. In turn, said participants get a fixed fee for a certain period or discounted tariffs during the times that control occurs.

In the Charge Better project, all of the participants are opted into to the DLC program by default. Therefore, the tariff structure was designed to reflect that. A monthly price reduction was established before the beginning of each month, which applied to all the electricity consumed that month, both from charging and household consumption. If the participants wanted to opt-out of the program and charge directly when they plugged their car in, that was possible but affected this monthly price reduction. This opt-out action would give the current session priority over the DLC, superseding it. However, after that current session, the controlled charging profile of the station would take priority again. Each opt-out decision resulted in a 20% reduction of the monthly price reduction and thus with five opt-outs the price reduction was down to 0% or the same price as before. However, excess opt-outs after those five did not affect the tariff as the "lowest" price reduction was 0%.

LBP
For the LBP DR program, the electricity consumption over each hour was the defining factor of its price. As the data used in the project was on an hourly basis, the energy used over the hour equals the mean power. If 6 kilowatt hours are used, the mean power over that hour was 6 kW. For the LBP pricing, four brackets were used based on the average power over the hour, which equals the consumption. The four brackets were:

- 0 - 2 kW
- 2 - 5 kW
- 5 - 10 kW
- 10+ kW

This DR program was included in the project with the intention of pushing the participants to spread out their loads over time. Using the dishwasher, washing machine and charging their EVs at the same time, would result in expensive hourly prices instead of sequencing these actions over time. The brackets were carefully formulated in a way that it would be viable to fit EV charging into the second or third bracket by either timing it well or reducing the charging power of the car, which can be easily done with most new EVs. The first bracket was mainly intended for base consumption, which should take up most of the hours of the year. The second could fit in a few home appliances simultaneously but also could fit EV charging if the power was reduced down to 3.6 kW. The third bracket was intended to be the most frequent charging bracket, as many EVs that use one phase charging or homes that only have a one phase charging connection, have a maximum charging power of 7.3 kW. The last bracket was the bracket that was meant to be used very rarely and thus had a surcharge, i.e. a higher tariff for those hours. The breakdown of the tariffs of this DR program can be seen in table A.3 in Appendix A.1.

2.2.5. Surveys
As mentioned in section 1.4, one of the main motivators for this pilot project is the response of real EV owners to different DR programs. To measure the effects on peak reduction and the impact on the distribution grid, data from the smart meters and charging stations were used. But that is only half of the equation. To be able to measure the feedback to these different DR programs, monthly surveys were sent out to all the participants. They were catered to the specific programs ongoing each month and formulated in a way to get as unbiased

answers as possible. Lastly, at the end of the research phase, in March 2024, a more extensive survey was sent out, summarising the project. The results of the surveys will be explained in detail in section 3.7.

2.3. Technology

In the pilot project Charge Better, various different technologies were used, many of which had not been used before in Iceland regarding EVs and electricity tariffs. In addition to the smart meters and smart charging stations that provided hourly data points, a customer portal was developed specifically for the project. The billing systems of Veitur Utilities and ON Power were not configured for DR programs or time series data collection, so many changes had to be made software-wise. Lastly, an algorithm was developed to control the charging stations in the DLC DR program.

2.3.1. Smart meters

As mentioned in section 1.1, the smart meter roll-out is ongoing. In this pilot project, smart meters from Veitur Utilities were used to collect data. The project thus got an early glimpse into what is possible with smart meter data as compared to the former electricity readings. These meters measure the electricity consumption over an hour and transfer that data over broadband networks back to the DSO. The data is transmitted each hour but are ready for storage and billing systems every 24 hours. The smart meter installations are free of charge for the participants as they are for all electricity users in Iceland. The billing and data storage systems for the smart meters of Veitur Utilities were not ready for use before the start of the pilot project, which meant that a temporary software bypass had to be created for the project. Additionally, many new tariff structures had to be implemented in the billing systems to be able to carry out the different DR programs.

2.3.2. Charging stations

In addition to the smart meters, smart charging stations from ON Power were installed for free and the participants got free use of those stations for the duration of the project. The stations used in the project, Easee Home, are smart charging stations that can communicate over 4G. They also have a dedicated back-end system that allows them to be controlled via API communication. This was vital for the use case in this project for the DLC program. The stations are AC and three phase, up to 22 kW. Similar to the smart meters, these stations output hourly consumption data. Some participants, that had more than two or more EVs, received two charging stations, to be able to sufficiently charge their cars. However, other participants with two cars decided that one charging station would suffice.

2.3.3. Participants' customer portal

For this pilot project, an intuitive customer portal was built from the ground up, developed by Aron Hrafnsson. It worked as an access controlled website, where each participant in the project got their own portal, which displayed their home and charging consumption in the same graph. It also took into account which DR program the participant was involved in at the time. It also provided an overview of charging sessions and a simple electricity bill for each month, summarising the energy used by the home and EV, electricity costs and savings based on the DR program. This is something that has not been available to regular EV users in Iceland, having the home and charging consumption separated in a graph but also a simple electricity bill that combines both the tariff of the utility as well as the price from the retailer. This was also done to give participants the ability to see straight after each month the effect of the DR program on their savings and charging behaviour, where usually there is a month delay on the bills from the electricity retail supplier and the utility. In figure 2.2, an example of the customer portal can be seen for a participant during the TOU DR program.

In this snapshot, a graph can be seen which shows both the electricity consumption of the home, provided by the smart meter, as well charging consumption from the charging stations. In this example, a participant has two charging stations which are both frequently used. In the four boxes above the graph, certain statistics can be seen that give the participant added insight into their consumption. These boxes were also designed with the intention of gamifying the process of the DR programs, which compared their statistics by the last 30 days, encouraging them to charge better.

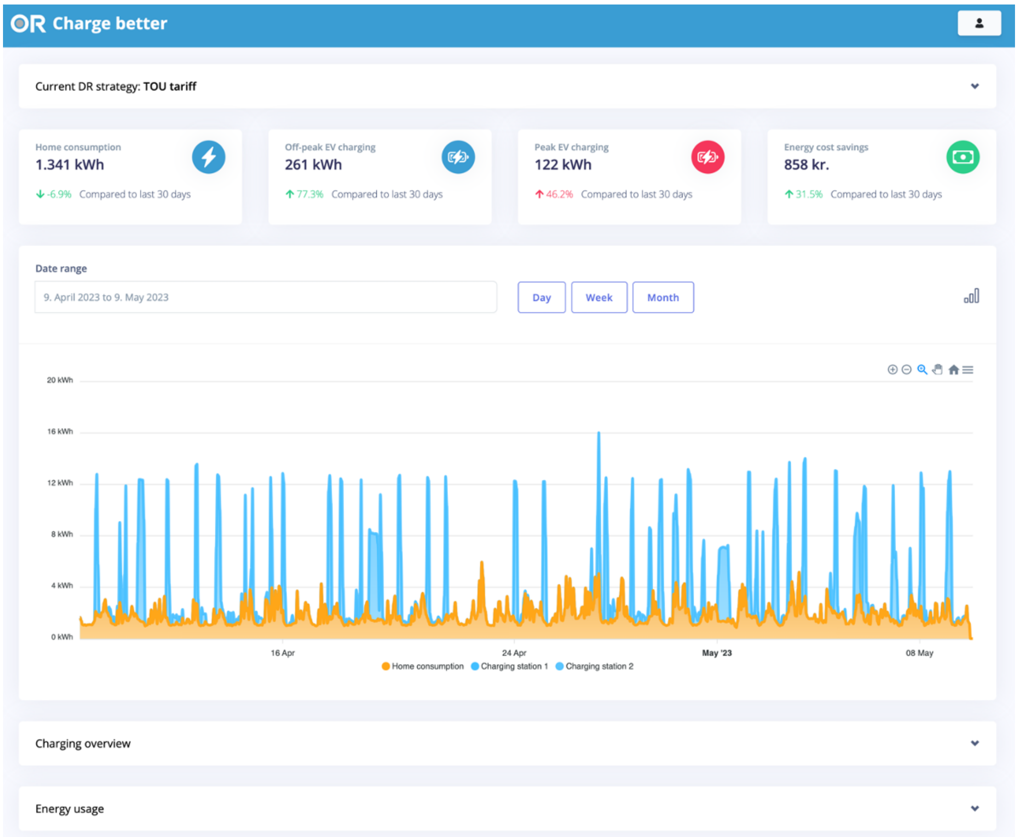

Figure 2.2: The Charge better customer portal displaying information when the TOU DR program was active.

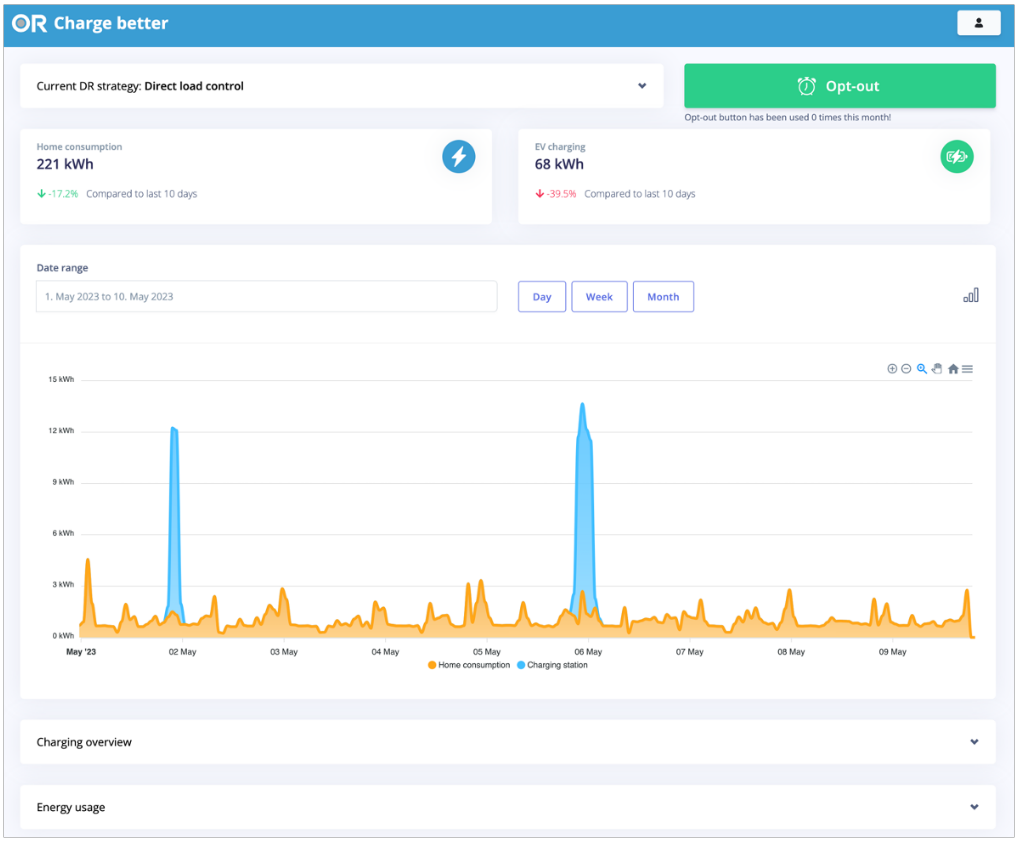

Figure 2.3: The Charge better customer portal displaying information when the DLC DR program was active.

As mentioned before, during the months where the DLC program was active, the participants could opt-out of the controlled charging and get full charging power at that moment. In figure 2.3, the customer portal while the DLC DR program was active can be seen, in this example a participant with one charging station can be seen, looking at a 10 day period in the graph. In the top right corner, there is a green button that performs the opt-out action.

In addition to this customer portal, the participants also had access to the mobile app of ON Power. In this app, the users could observe their charging sessions while they were ongoing but also statistics from previous sessions. The participants could also remotely start their charging in the app once their cars were plugged into the charging station. However, the ON Power did not have the capability to schedule charging, i.e. delay the starting time of the charging.

2.3.4. Control algorithm

The main characteristics of the DLC strategy carried out in this project was that it was in the form of a pre-programmed charging profile as opposed to a real-time reaction to the total charging load of the participants at any given time. This was mainly due to the available methods of controlling the stations via the back-end system. The stations were, as mentioned before, called Easee Home and a feature called Charge Schedule was used to set up weekly charging constraints that either specified certain times where no charging power was available or times where the maximum charging power was reduced. The constraint of this Charge Schedule feature is that it allows only two constraints per day. This was a significant limitation for the DLC formulation in this project and its anticipated impediments are discussed in detail in section 4.2. To execute and structure this weekly charge scheduling two different control methods were created:

Alternating periods

The first one, which was in essence just a set of rules, was very straightforward and only took into account which subgroup the participant belonged to. As mentioned earlier in section 2.2.2, the participants in the single family homes were divided into two groups which were then divided into three subgroups, thus groups 1-6 were formed. This meant that during the first two pilot phases as seen in figure 2.2.2, three groups participated in DLC simultaneously. This first control method had the same charging profile for each day of the week, but different nuances for these three groups that were in active DLC at the same time. For example, in the third month of pilot phase one, January 2023, this control method was the following:

- Group 1: 50% power reduction from 17:00 - 00:00
- Group 2: No power between 17:00 and 20:00, 75% power from 20:00 - 00:00
- Group 3: No power between 18:00 - 22:00

As can be seen, these alternating set of rules were aimed towards distributing the charging power over time but more importantly, limit the load effects of the peak hours of the evening, from 17:00 - 22:00. In the first pilot phase this method was exclusively used but the timing and structure between the three groups was altered. The breakdown of those months will be discussed in more detail in the next chapter but can also be seen in tables A.1 and A.2 in Appendix A.1.

What was also important to take into account here was the maximum available charging speed of each participant. This charging speed is determined by a number of factors but the main ones are if the EV itself is one or three phase, if the home electricity system is one or three phase and the current rating of the charging cable. From charging statistics as well as data from the participants the maximum charging speed could be evaluated and this was taken into account in all of the control methods.

Custom scheduling

The second method used in the DLC was formulated after reviewing the effects of the first method, which will be explained in detail in 3.5.1 in the Results chapter. In this method, the groups were not taken into account but only the charging statistics of each participant. Data from the uncoordinated charging periods were analysed and 5% of the highest charging needs were excluded, which means that the charging that this method provided would cover 95% of charging sessions based on energy needs. The average charging length to achieve this number was then used as the goal charging time. When the participants plugged in their EVs and began to charge, it was not known how much they needed each time. Therefore this cautious way was taken, so that if a big charging session was needed it could be completed. The drawbacks of this missing charging need is discussed in section 4.2.

Based on this calculation for every charging station, a goal charging end time of 7:00 in the morning was set and backtracked from there when the charging needed to start. Then the starting point was randomly moved earlier or later by up to 2 hours in 15 minute increments. This was done to every day of the week. With this, the starting times of the charges were randomized to a degree in the aim of distributing the charging load over the evening and night. This also meant that for some that needed very long charging times for their longest charges, the charging would start during the peak hours. From 7:00 in the morning and all the way to 18:00, regular charging was allowed.

3
Results

This chapter is dedicated to the results of the pilot project. It begins with describing the data on the participants in the study, then goes into the uncoordinated charging, i.e. the baseline scenario of the study. From there it goes into the results and outputs of the different DR programs that were explored in the project. Lastly, the responses from the periodical surveys that the participants answered are then explained and analysed. For each of the DR programs, numerous scenarios were explored, both based on tariff structure and pricing. In this chapter the most important and relevant results are brought forward. Some additional results can be found in Appendix A.2.

3.1. Pilot project participants

As previously mentioned in section 2.2.3, roughly 400 EV owners applied for the project. In the end 155 participants were admitted and started in the project. In the first part of 2022, a handful of participants dropped out, mainly due to a misunderstanding of the project. Furthermore, throughout the active research phase of the project, from November 2022 until February 2024, a few participants dropped out periodically as was expected. The majority was due to moving from their homes and selling their EVs. This resulted in 115 participants that participated throughout the whole pilot phase. To simplify the data analysis and keep consistency in scaling and mean values per participant, the data and results are based on these participants that were active throughout the whole research phase. This is also due to the fact that many times it was hard to define exactly when the participants stopped participating in the study even if they dropped out later.

One of the goals regarding the participant group was to have different kinds of EV owners, not only early adopters but also people that simply bought EVs because they were more economical. This was taken into account in the application process and a diverse group of people were admitted. In figures 3.1 and 3.2 below, the age demographics and family sizes of the participants can be seen.

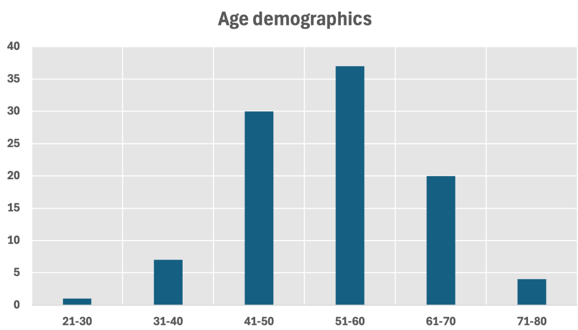

Figure 3.1: Age demographics for the participants in the pilot project. Based on 99 participants, 16 did not give this information.

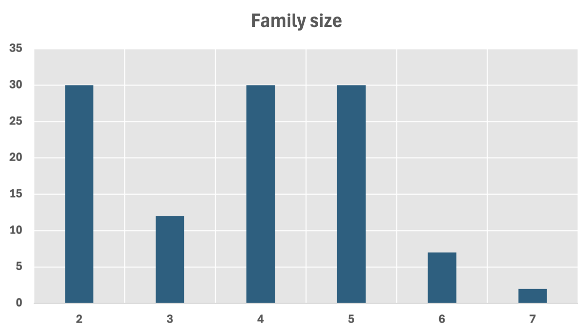

Figure 3.2: Family sizes in the project. Based on 111 participants, 4 did not give this information.

Most of the participants were between 51 and 60 years old, but also younger, down to 21-30 year olds and all the way up to 71-80 were also included in the project. As with the family size, many different sizes were in the project, from two persons up to seven. This broad range of ages and family sizes helps in getting more realistic circumstances for the project, with different types of EV owners. As mentioned before, a constraint for the participants outside of the one apartment building, were that they lived in single family homes, with one meter for the feeder cable going into that house. A few types of houses fit those conditions and can be seen in figure 3.3.

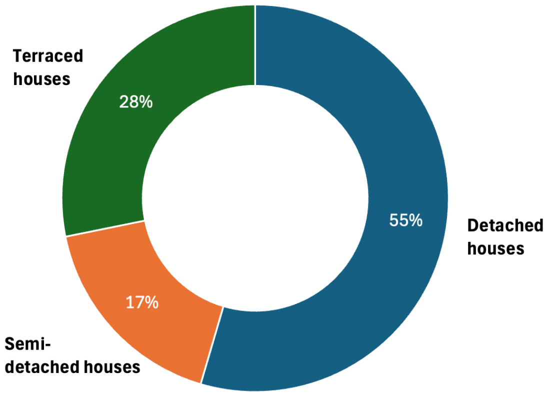

Figure 3.3: Breakdown of the house types of the participants in the project. Based on 111 participants, 4 did not give this information.

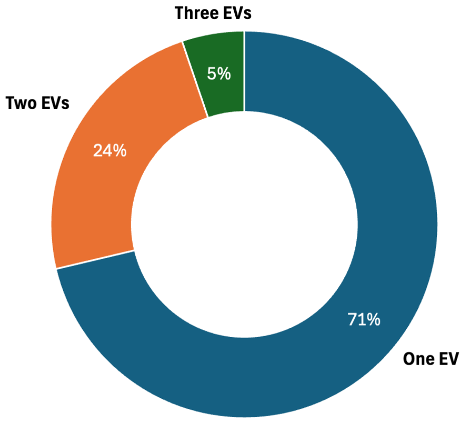

Figure 3.4: EV ownership in the project. Based on all 115 participants.

Additionally the constraint for EV ownership was that the participant owned at least one battery electric vehicle (BEV), model year 2018 or newer. However, many also owned additional BEVs or PHEVs. In figure 3.4 the breakdown of EV ownership in the project can be seen. In this figure, both PHEVs and BEVs are taken into account, but the majority is BEVs, as only 9 out of a total of 154 vehicles were PHEVs. This group of participants therefore represent the future in Iceland, where more than one EV is present in each home. However, a very important metric to note is that the average EV ownership in the project, based on data provided by the participants on how many EVs they owned as well as the total number of passenger vehicles in the homes was around 58%.

For the other group of participants in the project, outside of the ones from single family homes, one apartment building was admitted into the project as explained before. For this group of participants, 29 charging stations were active in the project and the share of BEVs compared to PHEVs was close to equal. In this result chapter, the main focus will be on the single family homes. The baseline charging as well as the charging profiles under the TOU tariff will be analysed specifically for this group later in this chapter, as well as the survey answers from this group.

3.2. Baseline scenario

To be able to measure the effects of the different DR programs, a baseline had to be set. Both for EV charging but also the household consumption. As explained before in section 2.2.2 on the timeline of the project, September and October of 2022 were treated as baseline months. A part of August met those conditions as well, but some late installations of charging stations and smart meters were finished in that month.

3.2.1. Charging consumption

For these two months, there were a total of 4401 charging sessions for 131 active charging stations. When calculating the charging statistics shown in this section, charging sessions with a duration of only 1 hour were excluded, aiming to filter out morning heating sessions of the EVs and other sessions that were anomalies.

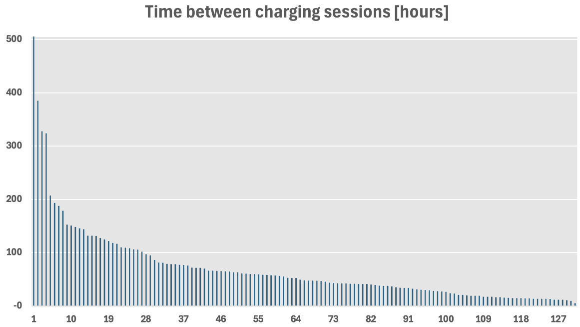

Figure 3.5: Overview of the average times between charging sessions during the uncoordinated months.

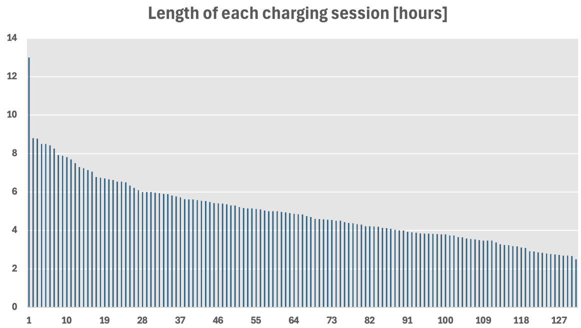

Figure 3.6: Overview of the average lengths of each charging session during the uncoordinated months.

The average charging session lasted 5 hours and on average, there were roughly 70 hours between charges or just shy of 3 days. The length between sessions was calculated starting from the end of first charging session over these two months and between every subsequent session up to the start of the last charging session. The duration until the first session started and from the last session ended until the end of October 2022 was not included. The average number of charging sessions over those two months was around 10 sessions per month per charging station.

In the two figures above, all the active charging stations over these baseline months can be seen in terms of the time between sessions and the length of each session. What is important to note here and is in itself a limitation of the data obtained by the charging station, is that this dataset does not depict the exact start and stopping time of the charges, but rather the energy used by the charging station for each hour. For both these observations, the exact number of hours is therefore uncertain to some degree.

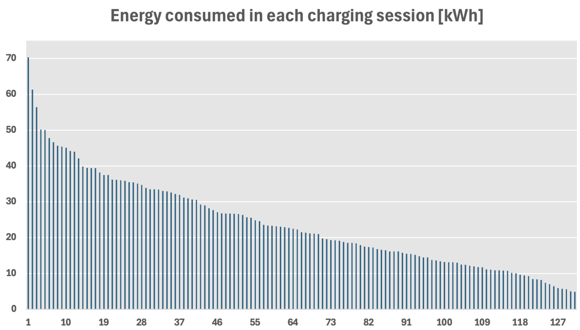

Figure 3.7: Overview of the average charging energy of each session during the uncoordinated months.

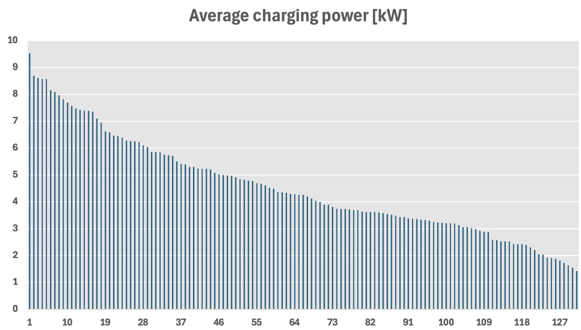

Figure 3.8: Overview of the average charging power in each session during the uncoordinated months.

The average charging power was 4,5 kW and the average consumption for each session was 23.96 kWh. The same applies here, but only for the first number as the exact counting of hours does not effect the calculation of the total consumption for each session. In figures 3.7 and 3.8 abve, a breakdown of these metrics for all the active chargers can be seen.

For the charging profiles in the baseline months, there are some differences between the weekdays and the weekend. Right away, the morning heating consumption can be seen in figure 3.9, which only happens on weekdays. In this figure, the total hourly charging power for all these stations has been combined and divided by the number of active stations. This way, an estimation of the impact of each charging station in terms of load can be observed. What can also be seen is that the average charging over those two baseline months, in the beginning of winter in Iceland, exceeds 1 kW simultaneously for these roughly 130 charging stations.

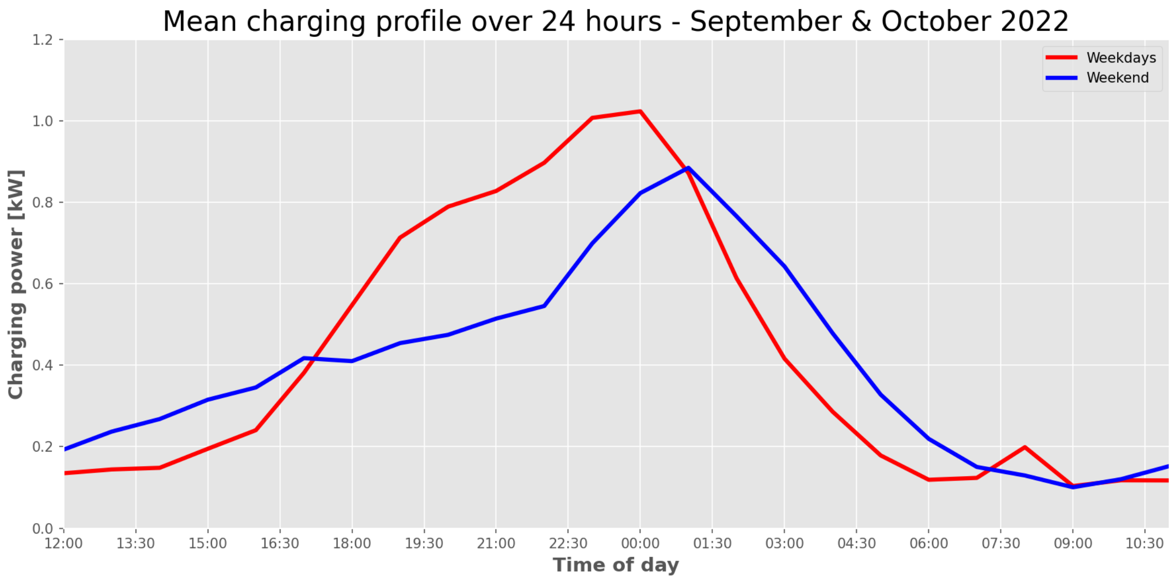

Figure 3.9: The average daily charging profile per charging station during the uncoordinated months.

But looking at the day with the peak charging load over these two months, this number becomes even higher, reaching over 1.5 kW charging power per station simultaneously. This is exactly the effect that EV charging can have.

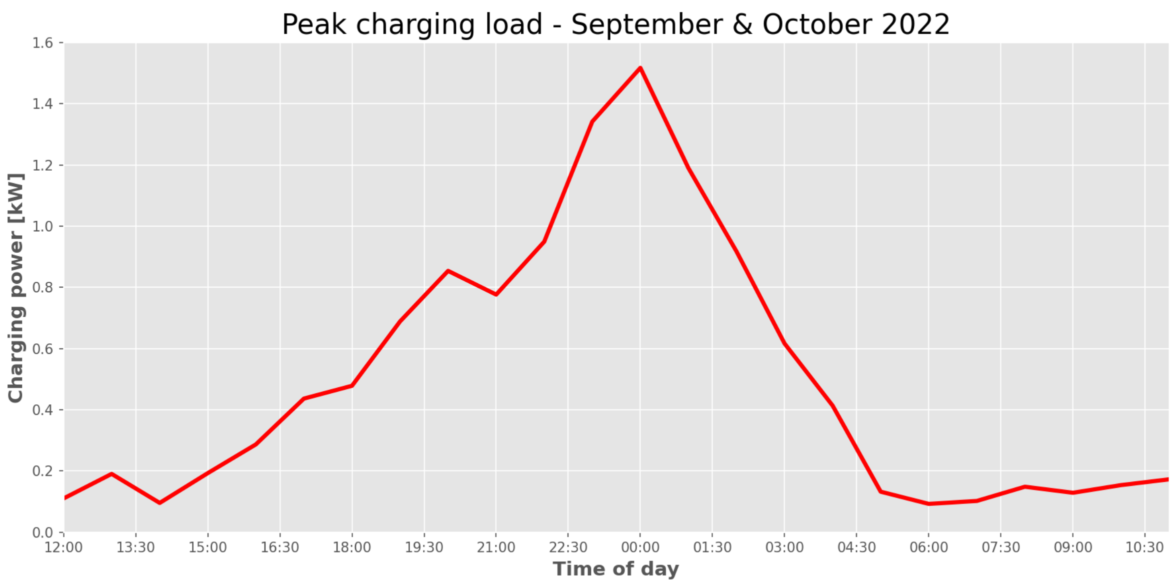

Figure 3.10: The charging peak during the uncoordinated months.

3.2.2. Household consumption

In order to really see the effects this charging load has on the distribution grid, the household consumption must be taken into account. In figure 3.11 below, stacked demand profiles of the charging and the household consumption can be found, divided by the number of participants. The household consumption largely follows the same profile as the charging and in turn a peaking effect is apparent between roughly 19:00 and 22:00, before the households lower their consumption as well as the EVs. At 20:00, the average peak increase caused by EV charging is around 75%.

What can also be seen is that there is a big valley in the night before the morning heating of the EVs starts at around 7:30 and 8:00. The main focus of the different DR programs was to try shift the charging load so it would fall in the region where the household consumption is either lowering or at its lowest.

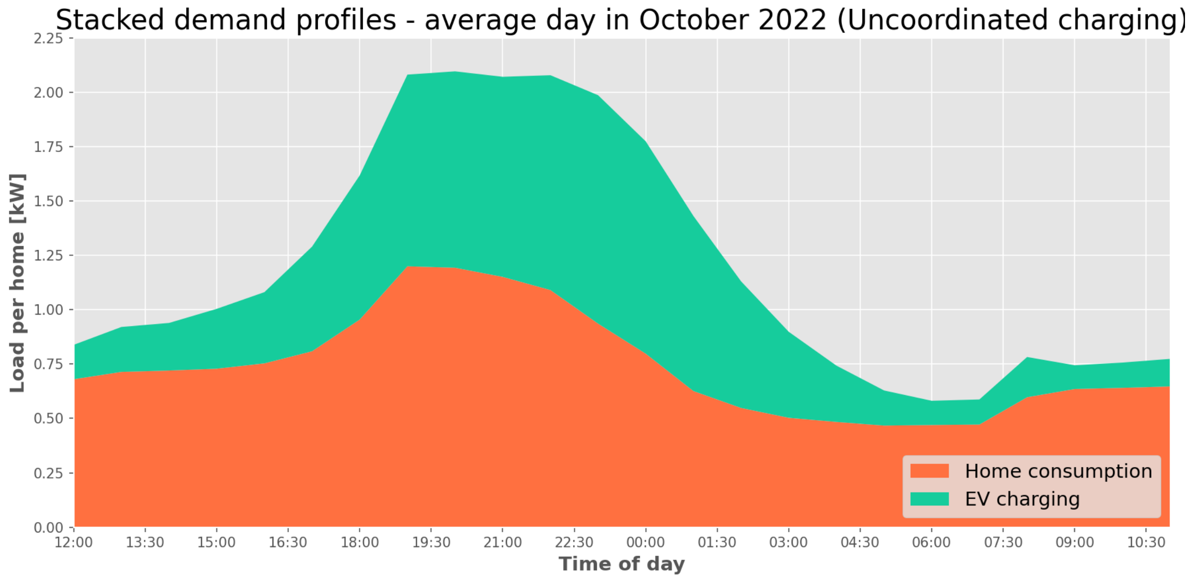

Figure 3.11: The home consumption and charging load on an average day in October 2022 with uncoordinated charging.

As with the charging data, it also helps to look at the extremes, i.e. the peak of these combined profiles. In figure 3.12 below, the same month, October 2022, can be seen but now the highest peak over that month is examined. The peaking effect becomes even bigger and at 23:00, the peak increase from the new total peak compared to the peak of only the household consumption is almost 120%.

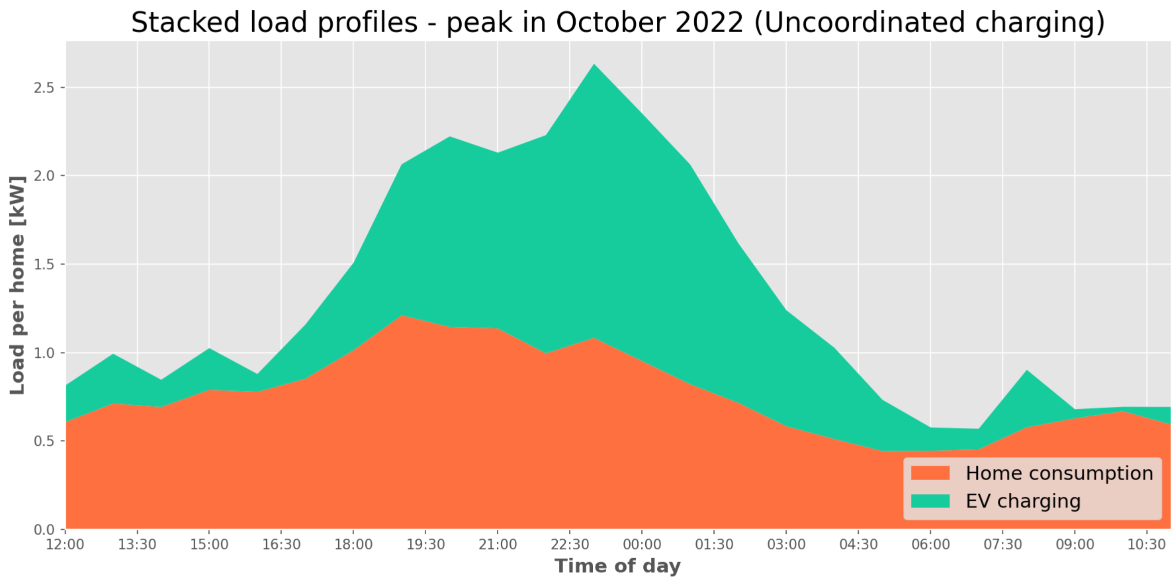

Figure 3.12: The home consumption and charging load on the peak day in October 2022 with uncoordinated charging.

What is very important to note in this analysis and all the analyses that follow in this chapter, is that they are based on the exact circumstances and conditions in this pilot project, which is a very small subset of EV owners in Iceland. More importantly, the effects of EV charging in relation to the household consumption and the peak reductions through the different DR programs are based on the EV ownership in this project, which as mentioned before in section 3.1 was around 58%.The peak reductions that are determined in this project are therefore dependent on this EV ownership scenario.

The future goals of Iceland in terms of the energy transition in transport and thus EVs, is an eventual EV ownership close to 100%. This comes from the Icelandic government's ambitions of carbon neutrality in 2040 and the phase out of fossil fuels, with a planned ban on new registrations of internal combustion engine (ICE) vehicles from 2028 (Ministry of the Environment & Climate, 2024). The anticipated load impact of the future when EV ownership is closer to 100% will be much more than in this project, with its 58% EV ownership. On this same point, the current EV ownership as of September 2024, is 22.4% for both BEVs and PHEVs combined (Icelandic Transport Authority, 2024) and thus the current load effects overall on the distribution grid are lower. These other scenarios, the current EV ownership and future ownership closer to 100% and its anticipated impact on this load effect is discussed in greater detail in section 4.1.1 in the Sensitivity analysis chapter.

3.3. Time-of-use (TOU)

For the analysis of the effects of the TOU DR program, three main analyses will be conducted. First the charging profiles by months will be analysed based on the different scenarios from various tariff price reductions and structures. Secondly, the relationship between the charging and the household consumption will be analysed based on the average days of the uncoordinated charging months compared to the TOU months. Lastly, the peak days of the months, will be analysed and compared.

3.3.1. Charging profiles

When taking a look at the effects of the TOU DR program, the effects on the charging profiles was mainly that they delayed the peak timing. In figure 3.13 below, the mean daily charging profiles can be seen for the first pilot phase, November until April as well as the uncoordinated months. In this observation, the aim is to see the effects the TOU tariff has on the timing of the charging profiles. It is important note that the profiles in this graph have been scaled so that the total electricity consumption over the month is the same for these 8 months in comparison, to be able to compare the profiles equally, taking out seasonality and other factors which affect EV charging efficiency.

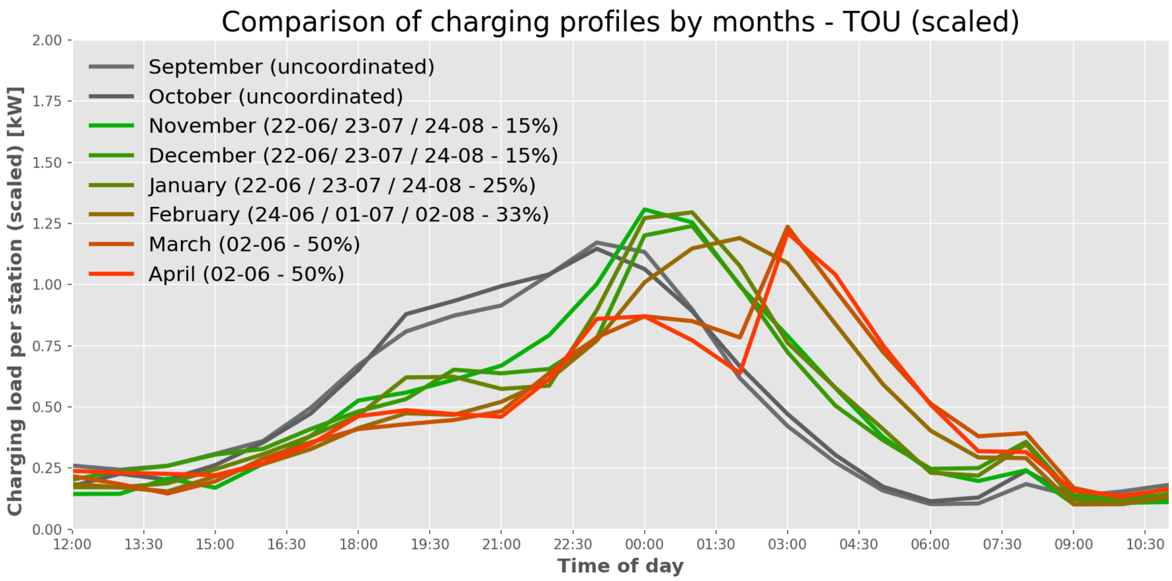

Figure 3.13: The daily average charging profile by months for the TOU DR program for the first pilot phase.

On the upper left part of the figure the tariff structures as well as price reductions can be seen. In November and December a moderate 15% price reduction was put into place which shifted the peak from around 23:00 for the uncoordinated months until 00:00 and 01:00. In January the same structure was in place but with an increased price reduction which resulted in more or less the same profile. In February however, the off-peak window was shortened down to 6 hours and the price reduced even more. This shifted the profile further into the night. In March and April the off-peak window was shortened down to four hours, from 02:00 - 06:00 and the price reduction increased moved all the way up to 50% and as mentioned before, this was for the whole electricity price so essentially in these hours the electricity was half off. In those two last months, two peaks emerged, one around 00:00 and another one at 03:00. This resulted in the main peak moving well into the night. In all these profiles, the morning heating of the EVs can be observed.

From November until February, there were three groups with different starting points. In figures 3.14 and 3.15, the breakdown of the charging profiles between groups can be seen for January and February. What can be observed are the starting times for the off-peaks for each group, which results in different times of peaks.

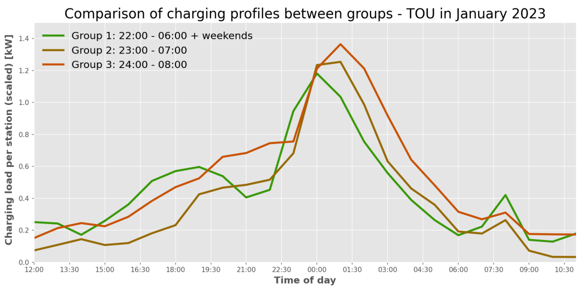

Figure 3.14: Breakdown of the daily average charging profiles by groups for January 2023.

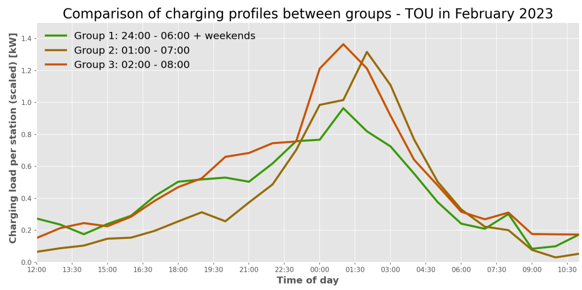

Figure 3.15: Breakdown of the daily average charging profiles by groups for February 2023.

In addition to these nuances to the groups and changes over the months in the first pilot phase, a special Christmas price was put into place for Group 3. This tariff was active from December 20th until midnight of December 23rd and offered 25% discount all 24 hours of those days. In figure 3.16 below, a timeline from December 20th until midnight of December 25th can be seen.

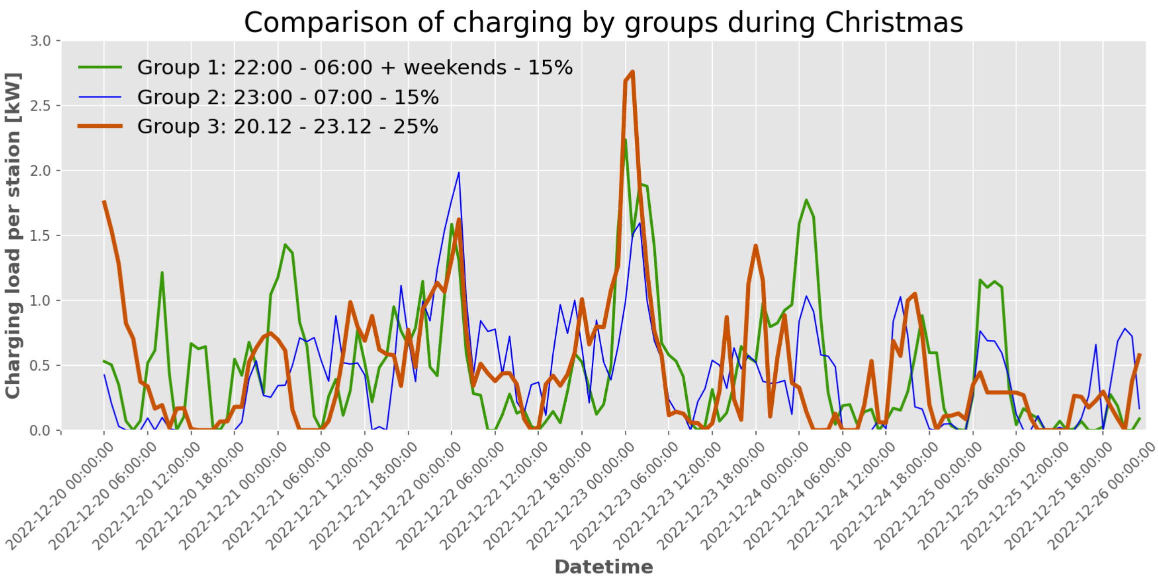

Figure 3.16: An overview of the charging profiles by groups from 20.12 2022 to 25.12 2022.

The group that was offered this special tariff, that applied both to charging and the home, can be seen in the red line in the graph. It did not seem to have much effect on the evening peak on 24th of December, which generally has been one of the peak times for Veitur Utilities' distribution grid. However, it did increase charging the day before and lowered the charging after midnight on the 24th of December as can be seen in the graph. However, it also has be kept in mind that group 1, which had an off-peak window over the weekends seemed to utilise that because the 24th and 25th of December fell on a weekend which explains why their charging is much higher compared to groups 2 and 3 on those days.

In figure 3.17, the second pilot phase, where groups 1 - 3 switched to DLC and groups 4 - 6 were in the TOU DR program can be seen. The structure of the TOU tariffs and price reductions were exactly they same as in the first pilot phase, with one slight change, increased price reduction in October all the way to a 75% reduction. Some similarities between the first and second pilot phase can be seen but the changes between charging profiles over the months are far less visible. For this group, the DLC had been in effect for 6 months, where the control methods and algorithms scheduled the charging for the participants. However, in TOU, the charging and scheduling of the charging has to be done by the participant. Most often this is done by using an app with the car or in the car itself.

What can be seen is that May until August all look very similar, but the peak is moving later into the night. For September and October, the shifting of the profiles is much less apparent than in first pilot phase. In October, when there was 75% reduction on the price, the charging peak was still outside of the off-peak reduction hours. The monthly surveys on these months will be analysed later in this chapter.

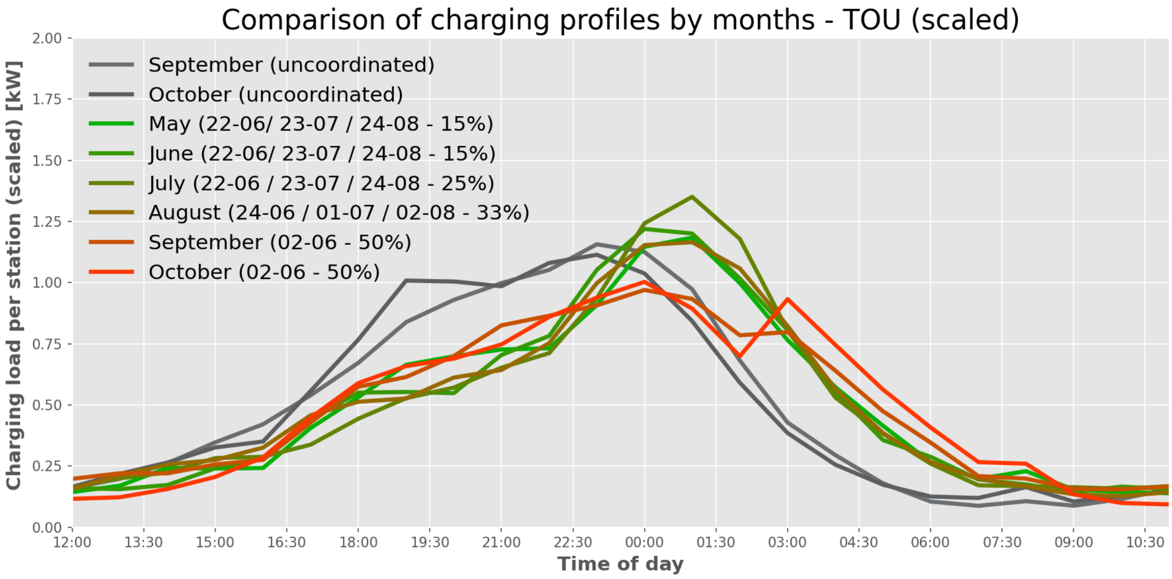

Figure 3.17: The daily average charging profile by months for the TOU DR program for the second pilot phase.

3.3.2. Load reduction - average day

To be able to understand the effects the load has on the distribution grid, the household consumption has to be taken into account and more importantly how these two load profiles interact. To do that, the combined profiles of the different months of the TOU tariff will be compared to the total load in the uncoordinated months. In the figure below, this can be seen. The black line represents the total load from the participants, divided down to each home and the orange and green areas are the breakdown.

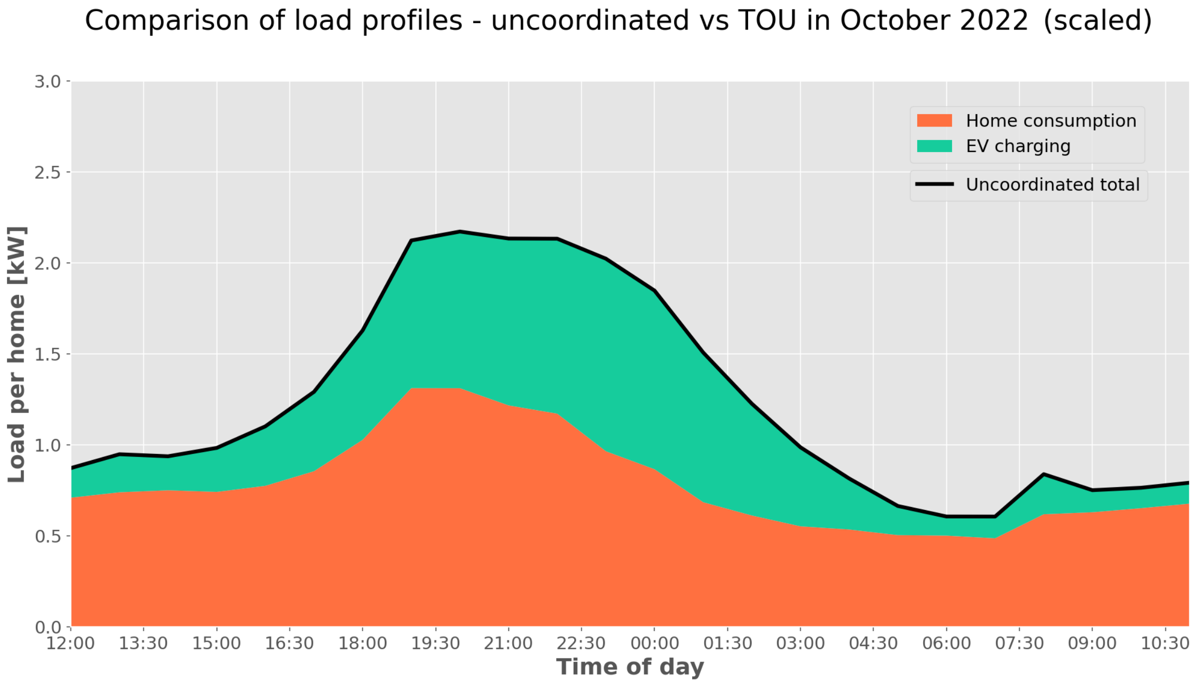

Figure 3.18: An overview of the home consumption and the charging load for the average day in October 2022.

From this establishing graph, the months where the TOU was in place can be examined. In figure 3.19 below, the uncoordinated charging is compared to January in 2023. In these graphs, and in fact all graphs in the results chapter, the total electricity consumption over these two comparison months have been matched. This is to take out variability such as seasonality, weather and other factors that affect EV charging efficiency. It is also done to be able to compare effectively the peak reduction, with only these two factors in play, the tariff changes between the two months. Figure 3.20 shows February of 2023, which resulted in the most peak reduction of all the TOU scenarios, 19.7%. This was when there were 6 hours of off-peak pricing, starting at different times depending on the groups.

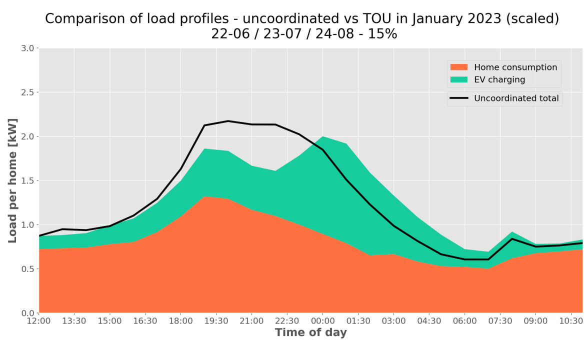

Figure 3.19: Comparison of the uncoordinated total load to the combined home consumption and charging load for the average day during the TOU in January 2023.

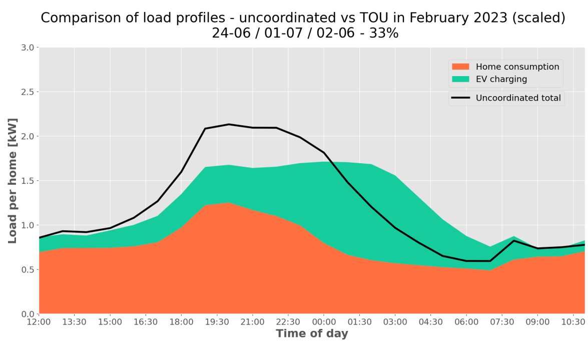

Figure 3.20: Comparison of the uncoordinated total load to the combined home consumption and charging load for the average day during the TOU in February 2023.

As mentioned before, the TOU tariffs had less of an impact on the charging profiles in the second pilot phase.

However, the peak reduction when overlaying those charging profiles on the household consumption the peak reduction was similar to some of the months of the first pilot phase. In Appendix A.2, the peak reductions for these average days of the month for all the TOU DR program months can be found in table A.4. In figure 3.21 below, the last month of the second pilot phase can be seen. As with the other graphs, the months have been scaled to match in electricity consumption to be able to compare equally. In this month, where the price reduction was 75%, the peak was reduced by 13.2%, which is a fair reduction, but still much less than the best month of the first pilot phase as mentioned before, which had much less of a price reuduction.

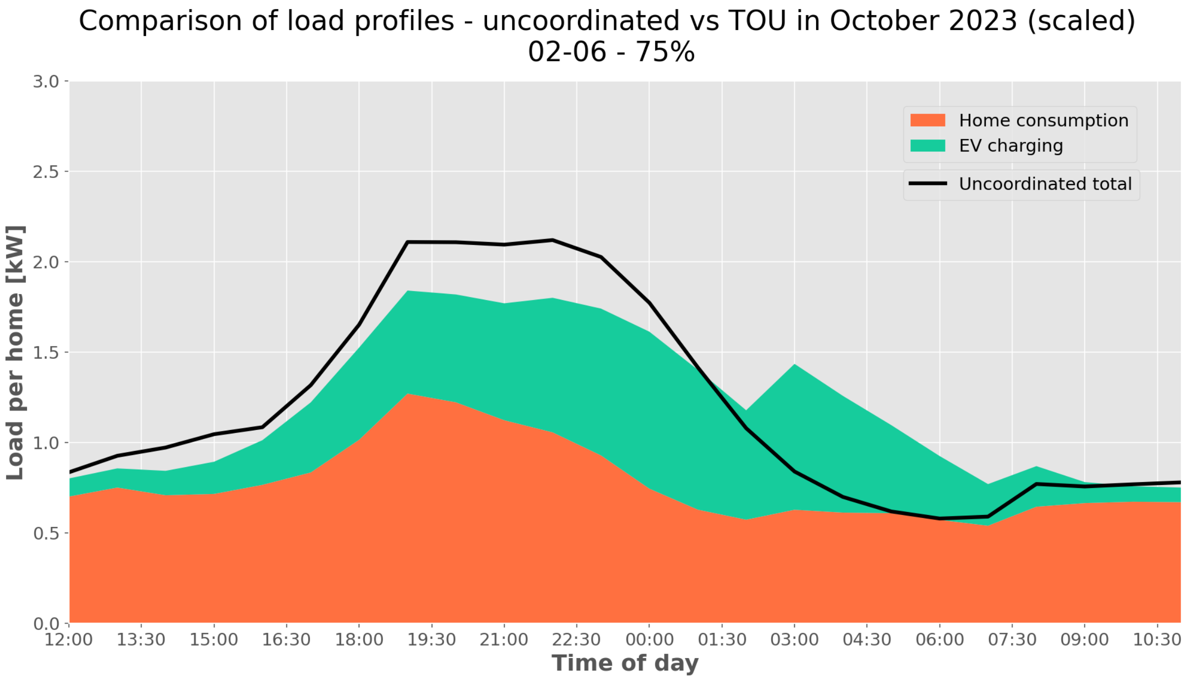

Figure 3.21: Comparison of the uncoordinated total load to the combined home consumption and charging load for the average day during the TOU in October 2023.

3.3.3. Load reduction - peak days

The ability of the DR programs to lower the peaks on average days, as was done in the previous section, is a good indicator on the overall effects on load and charging profiles that the TOU DR program can have. But to truly understand the effects on the distribution grid, the peak days, i.e. the peaks of each month have to be examined. In figure 3.22, the peak load of October 2022, the baseline month and the peak load in February 2023, when the TOU was active can be compared. As before, the total electricity consumption has been matched to be able to effectively compare the TOU in terms of profiles and timings. This was done by scaling, down in this instance, the total electricity consumption of this day in February to match the peak day in October 2022. Based on this, the peak was reduced by 18%, mainly by shaving a chunk of charging which would have happened between 19:30 and 22:30 as can be seen in October and moving it into the night. In April, there was also a good peak reduction, 15.6% when the same scaling is applied. This can be seen in figure 3.23. The late charging window helps with spreading some of the charging to that time, while another peak is also around 00:00.

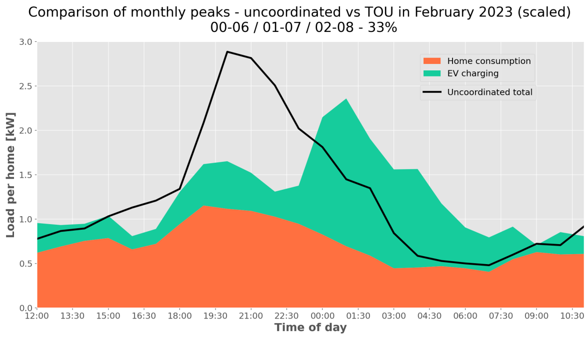

Figure 3.22: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the TOU in February 2023.

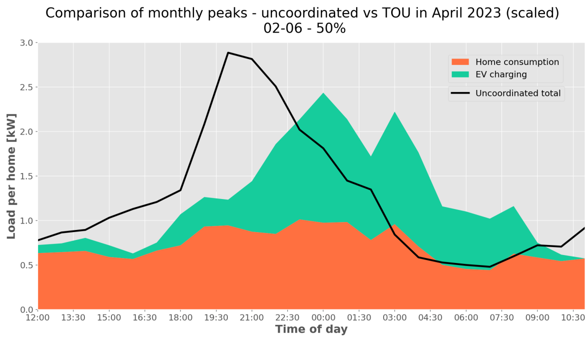

Figure 3.23: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the TOU in April 2023.

For the second part of the pilot phase, the peak reductions were much less on the peak days of each month. Over the 6 months in the second pilot phase for the TOU DR program, the highest peak reduction in this analysis was only 8% and three months either had no peak reduction or actually increased the peak. In figure 3.24, August 2023 can be seen, where the new peak based on the TOU was 2% higher than the uncoordinated peak. Similar to the average days, an overview of the peak reductions based on these peak days of each month can be found in table A.5 in Appendix A.2.

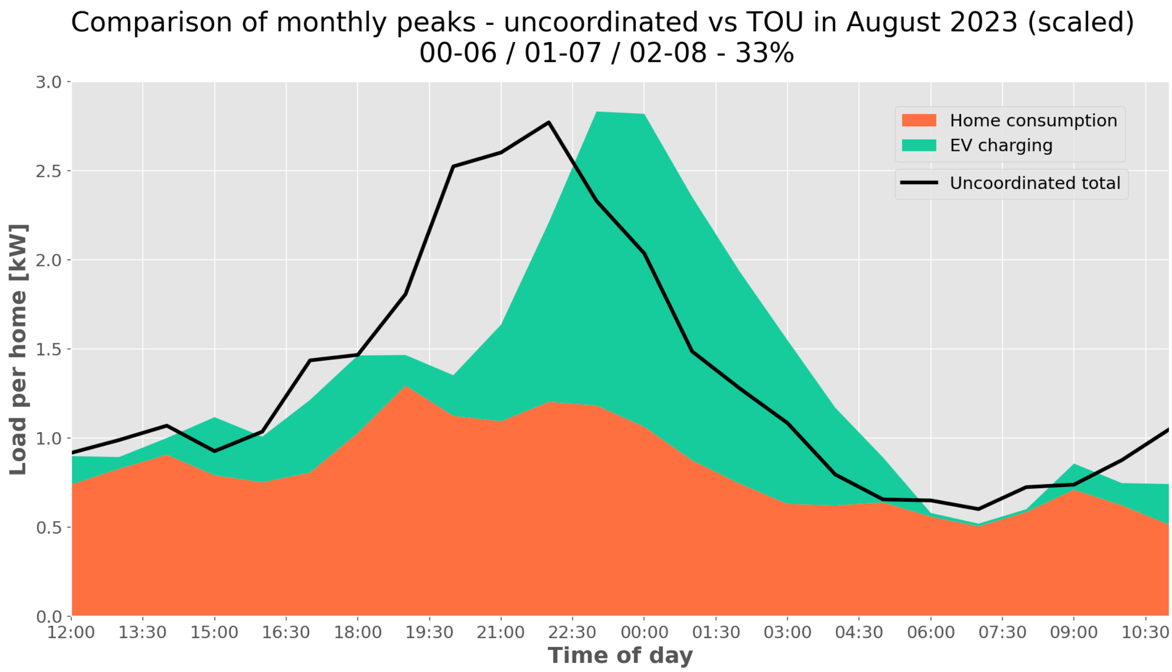

Figure 3.24: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the TOU in August 2023

3.4. Time-of-use (TOU) - apartment building

For the TOU tariff, not only were the participants in the single family homes participating in that DR program, but also the apartment building as described before. In figure 3.25 below, the uncoordinated months for this group of participants can be seen. As with the analyses for the TOU for the single family homes, the charging profiles have been matched by electricity consumption to be able compare effectively. The peak on the three uncoordinated baseline months happened at the exact same time, 19:00. The charging profiles in fact look almost identical, there is a ramp up early in the afternoon, peak is reached at 19:00 and a slight drop off into the night and from around 4:00 there is almost no charging load. This also shows the potential for distributing the charging load later into the night. As mentioned earlier in this chapter, the share of PHEVs out of the EVs in the apartment building was almost 50%, much higher than for the participants in the single family homes.

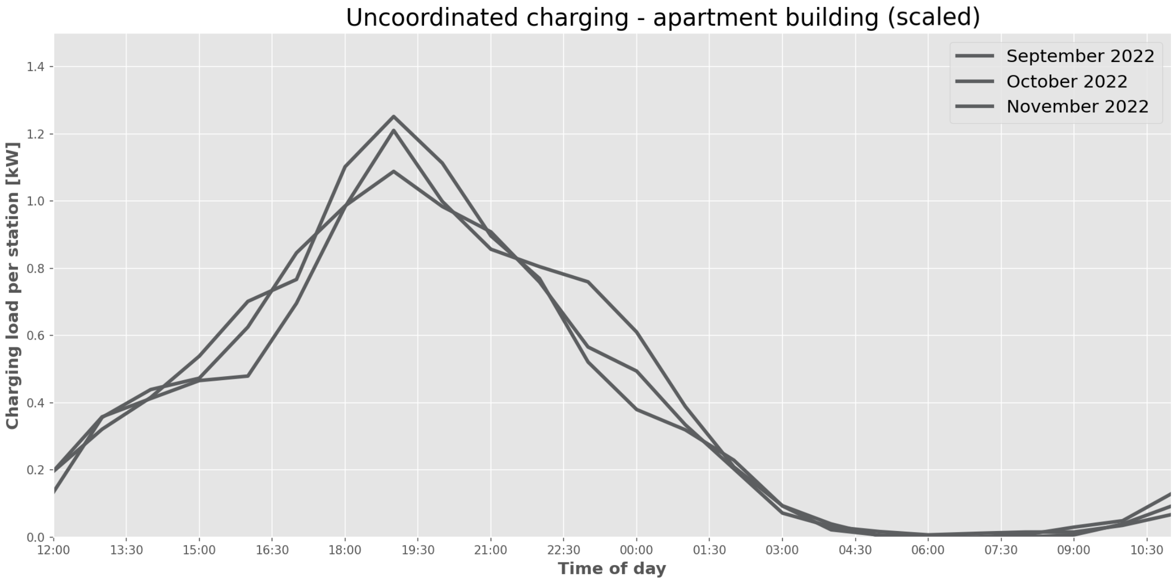

Figure 3.25: The daily average charging profile for the three uncoordinated charging months in the apartment building.

With the TOU tariff introduced, the charging profiles are slowly delayed and another peak emerges in the night. The TOU tariff was active for a total of 14 months and the exact structures can be found in tables A.1, A.2 and A.3 in Appendix A.1. The first four months, December 2022 until March 2023 the window of the off-peak was 22:00 - 06:00 with a price reduction of 15-20%. From April to June, the off-peak window was from 00:00 - 08:00 with a 20% price reduction. This was shortened to 01:00 - 08:00 in July and August with a 25% price reduction. From September 2023 and onwards there was 33% price reduction and the off-peak window was from 02:00 - 08:00. What is important to note here is that the charging consumption of each month is scaled as was done with the analyses of the single family homes, so they are equal in electricity consumption. This is done to be able to analysed effectively only the changes to the profiles based on the TOU tariff but not external factors.

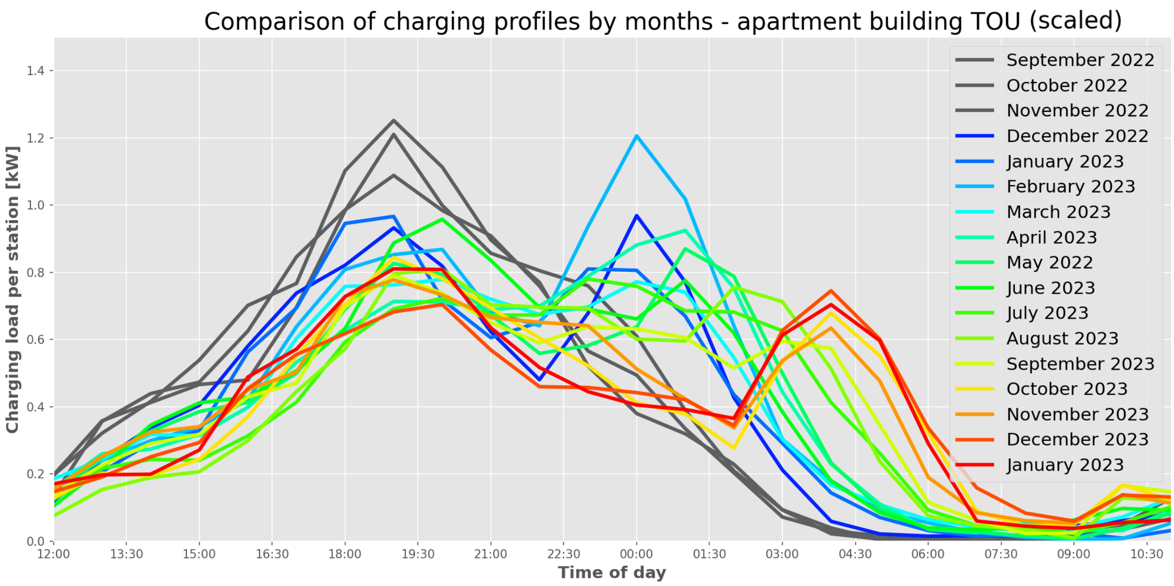

Figure 3.26: The daily average charging profile by months for the TOU tariff in the apartment building.

What can be seen in terms of the charging profiles is that they are delayed into the night but also two peaks form, one around the usual peak charging time, between 18:00 and 20:00 and then another peak at either around 00:00 or 4:00, depending on the off-peak window timing. This in fact lowered the charging peak substantially, most by 40.5% in December 2023, compared to November 2022, based on the peaks of the average days of those months.

There was no smart meter installations for the participants in the apartment building so the interaction to the household profiles was not researched specifically, the aim was rather to see the effects of the TOU tariff on the charging profiles.

3.5. Direct load control (DLC)

For the analysis of the DLC DR program, the same approach will be taken. First the effect on the charging profiles, then the average days of the active DR months and lastly the peak days of each month.

3.5.1. Charging profiles

In the first pilot phase, the first month of the DLC was moderate, reducing maximum charging power by 25% between 17:00 and 0:00. In figure 3.27, the charging profiles for these first 6 months of the DLC can be seen, along with the two uncoordinated months. As with the previous analyses, the total electricity consumption of each month is matched to be able to compared effectively. The full structure of the tariffs for pilot phase one and two can be found in tables A.1 and A.2 in Appendix A.1.

In November, the change was very minimal and the profile was nearly the same. in December and January the price reduction was the same, starting at 15% in the beginning of the month and reducing by 3% with each opt-out action. As with the TOU, during the first and second pilot phases the participants in DLC were divided into three groups. In December and January the first group had power reduced by 50% between 17:00 and 00:00. The second group got no power between 17:00 and 20:00, then reduced power by 25% from 20:00 and 00:00 and then full power onwards. The third group had no power between 18:00 and 22:00 and then full power onwards. This structure resulted in a reduced charging load between 17:00 and 23:00 as can be seen in the graph.

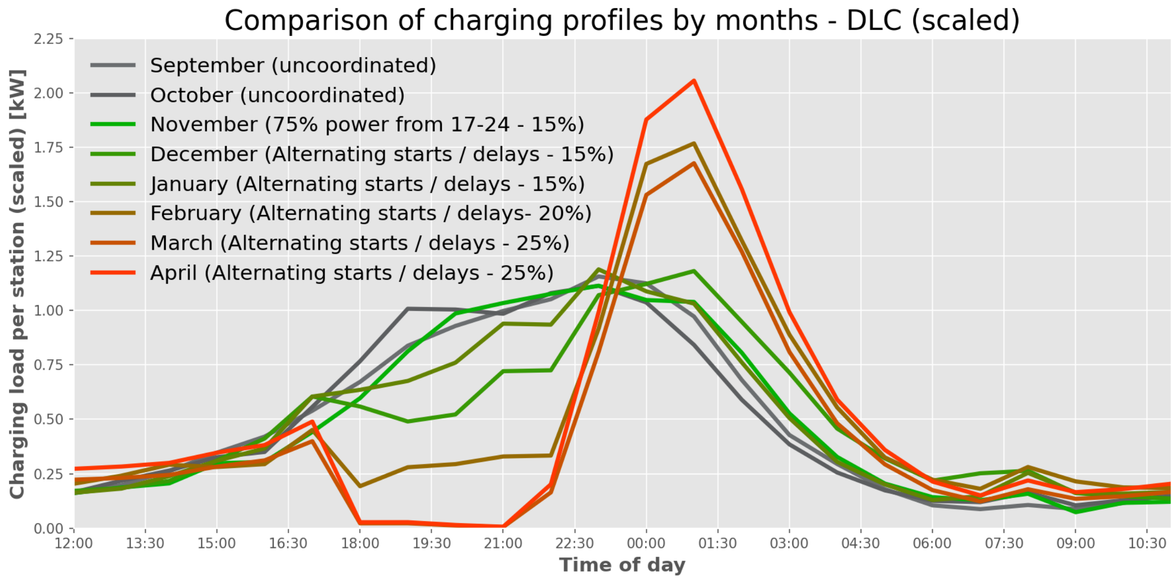

Figure 3.27: The daily average charging profile by months for the DLC DR program for the first pilot phase.

In February, all the groups had no power from 17:00 and the first group regained it 22:00, the second at 22:30 and the third at 23:00. The first group then had 50% from 22:00 - 00:00, the second 75% power from 22:30 - 00:00 and the last got full power from 23:00. This structure was kept in March and April and the price reduction was increased. This resulted in a substantial charging load reduction between 17:00 and 22:00 with almost no charging load between 18:00 and 21:00. However, a new charging load peak is created around 00:00

and 01:00, which becomes significantly bigger than the former charging peak.

For the second pilot phase, the DR stucture for the first three months were very similar to the first pilot phase. This was both done to ease the participants into this DR program but also, as mentioned before, to see if there were any noticeable differences when going from TOU to DLC. In the first month, with the moderate 25% power reduction, the profile is very similar to the uncoordinated months. The second month, June, the first group had power reduced by 50% between 17:00 and 00:00. The second group got no power between 17:00 and 20:00, then reduced power by 25% from 20:00 and 00:00. The third group had no power between 18:00 and 22:00 and then full power onward. This second month in the second pilot phase had a greater effect on the charging profile compared to the first pilot phase. What it also noticeable is that the ramp up of the charging around 16:00 - 18:00 is much less. This might be due to the fact that some participants still had some charge-delay settings on their cars. To note, it was however communicated to participants to remove such charge delay settings during the DLC months.

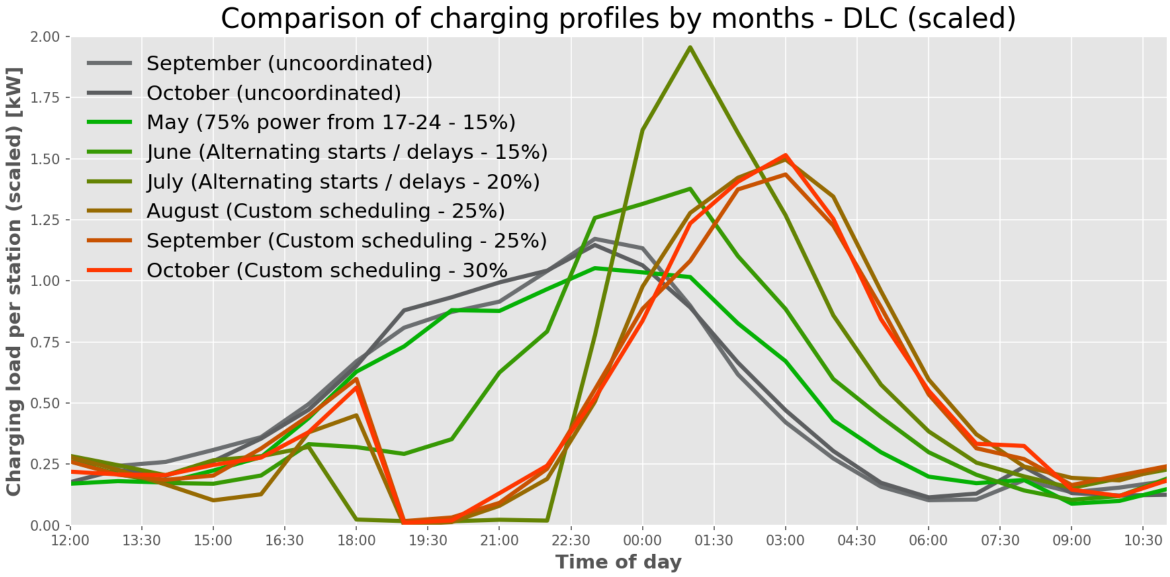

Figure 3.28: The daily average charging profile by months for the DLC DR program for the second pilot phase.

In the third month, July, the price reduction was increased to 20%, which was earlier than in the first pilot phase. In this month the structure was like the last three months of the first pilot phase. This resulted in a large charge reduction between 18:00 and 22:00 which made a substantial peak at 1:00. From August, a new approach was taken with the DLC and another control method was used, custom scheduling. This method was explained in detail in section 2.3.4, but in short, it used the battery sizes of the EVs provided by the participants as well as charging speed statistics, to try to start the charging as late as possible but still offering up to 95% of the charging energy they needed at the most. In these months, the charging has a sharp drop off from 18:00 but begins for some participants around 19:00, by those who have very long charging needs. Slowly, the charging picked up as more and more participants' stations began to charge and the peak was reached at 3:00. From there there was a decline in charging need towards the morning, which almost connects with the morning heating of the cars. As can be observed in the graph, this method produced a much smoother charging profile compared to the first method.

3.5.2. Load reduction - average day

Like previously done for the TOU DR tariff, the interaction between the charging profiles and the household consumption is important to examine. In figure 3.29 below the comparison of December 2022 to the uncoordinated baseline in October can be seen. The same process has been applied here, the total electricity consumption for the comparison month has been matched with the uncoordinated month. The DLC DR program reduces and delays the charging during the evening peak and thus manages to move more charging into the night. The peak on the average days of those comparison months, was lowered by 11.7% by the DLC

DR program.

When the structure of the DLC became more aggressive towards reducing the evening peak, the accumulated charging need can became substantial. In April of 2023, as shown in figure 3.30 below, this charging need became bigger than the former evening peak of the uncoordinated charging. This resulted in an 18% increase in the peak.

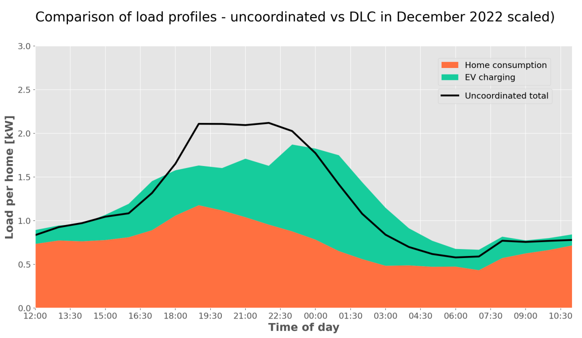

Figure 3.29: Comparison of the uncoordinated total load to the combined home consumption and charging load for the average day during the DLC in December 2022.

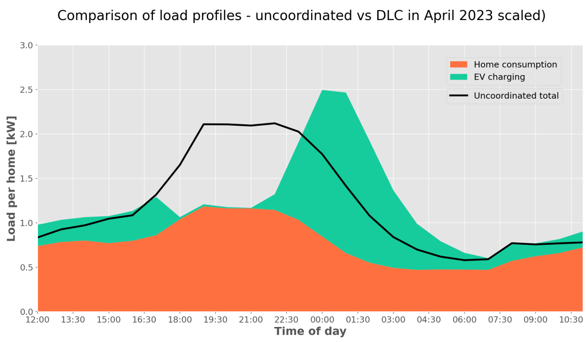

Figure 3.30: Comparison of the uncoordinated total load to the combined home consumption and charging load for the average day during the DLC in April 2023.

In the second pilot phase, the last three months; August, September and October of 2023, which used the custom scheduling method, achieved the greatest peak reduction. The last month, October 2022 reduced the peak on the daily average comparison by 14.7%, the highest of all the DLC months. This can be seen in figure 3.31 below. As with the TOU peak reductions, the full results of the DLC peak reductions for the average days can be found in table A.4.

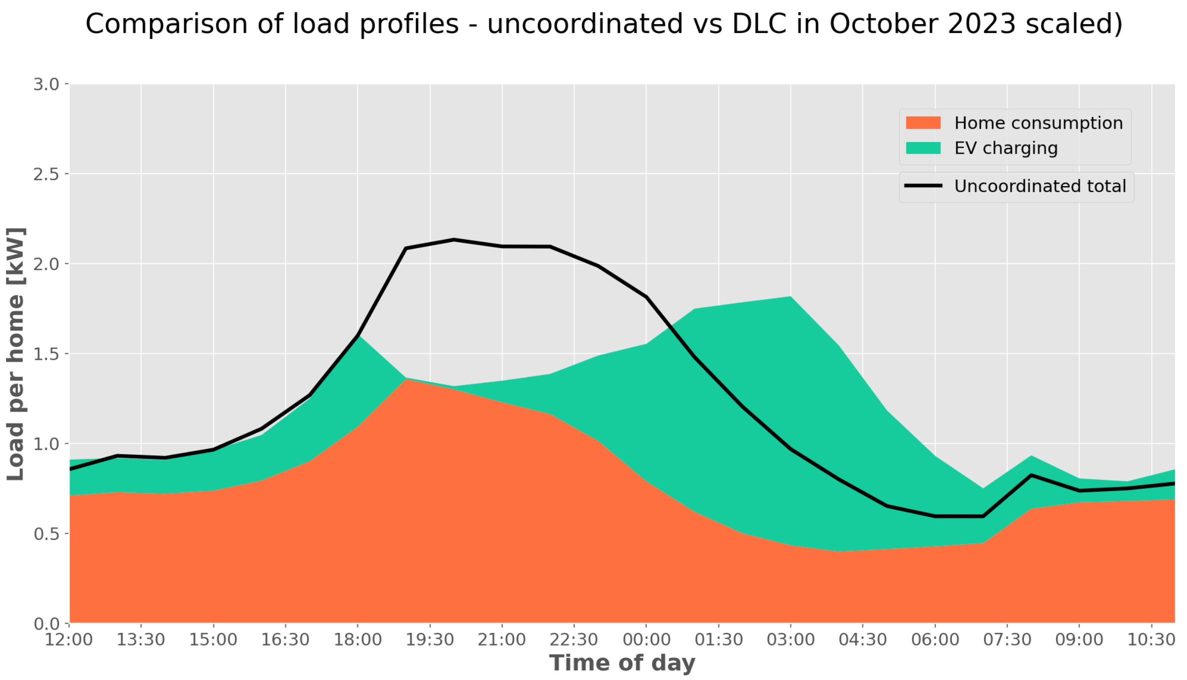

Figure 3.31: Comparison of the uncoordinated total load to the combined home consumption and charging load for the average day during the DLC in October 2023.

3.5.3. Load reduction - peak days

To see the effects on the load reduction on peak days, the same method was used as for the TOU DR program analyses. The highest peak on the uncoordinated month of October in 2022, was compared to the highest peaks in the DLC months. In the first pilot phase, there were some months that reduced the daily peak in this comparison form but other that increased it. In the figures below, these analyses can be seen for December 2022 and April 2023. In December, when the DLC control method was still fairly moderate, the peak on the peak day was reduced by 12.6%. However, in April 2024 when the DLC allowed no charging over the evening peak, the new charging peak exceeded the older peak by far and increased the load peak by 28%.

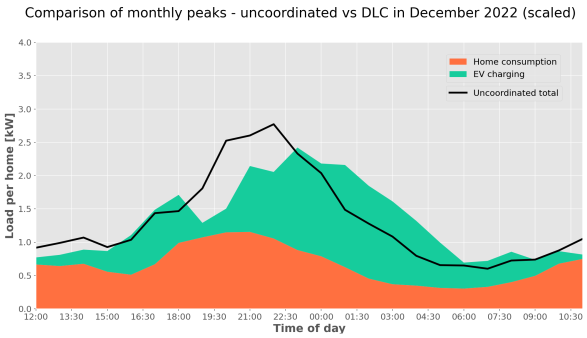

Figure 3.32: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the DLC in December 2022.

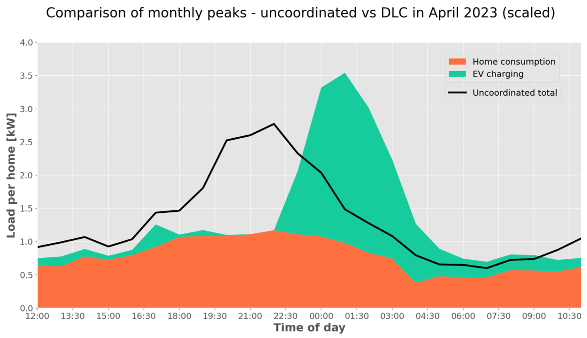

Figure 3.33: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the DLC in April 2023.

In addition to December 2022, as shown above, a few of the months during the DLC DR programs lowered the peaks, but 6 out of the 12 months actually increased the peaks or had no effect. The custom scheduling however did have some reduction effects on the peak. In figure 3.34, September of 2023 can be seen. In that case, the majority of the charging happens overnight and is well distributed apart from a minor peak at midnight, resulting in a 9% peak reduction.

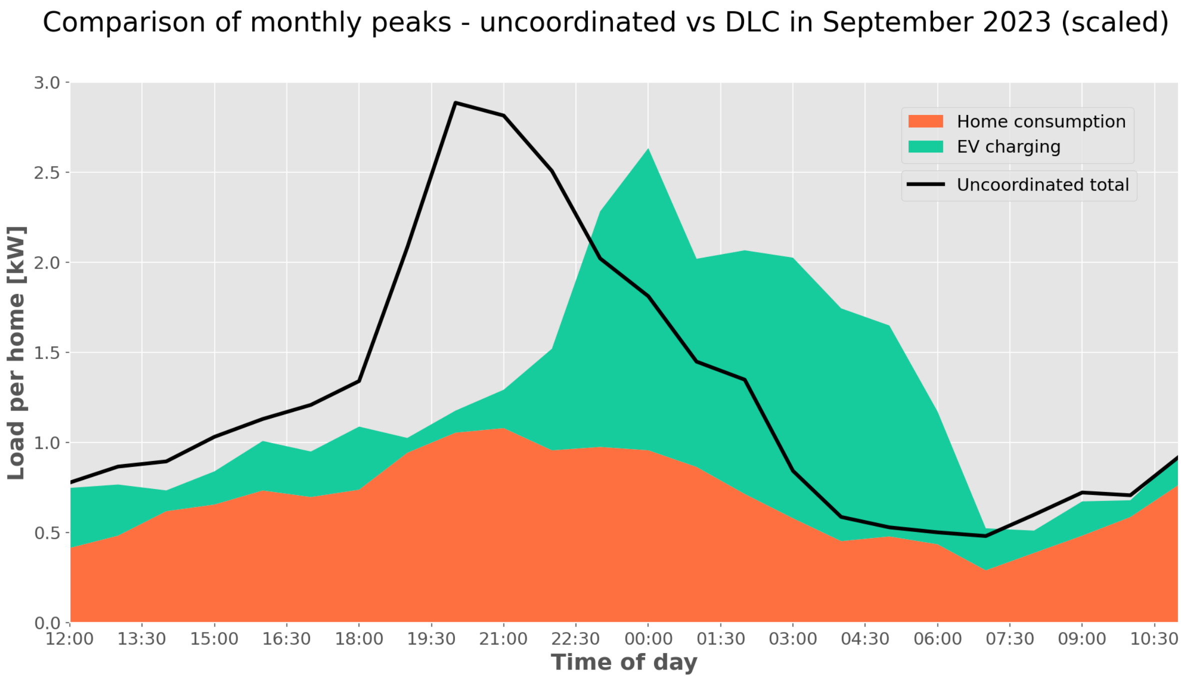

Figure 3.34: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the DLC in October September 2023.

3.5.4. Opt-out actions

As previously mentioned, during the DLC DR program, the participants could at any time opt-out of the charging control by using a opt-out button in the project's customer portal. This was explained in section 2.3.3 and seen in figure 2.3. By doing this however, the monthly price reduction was lowered every time this button was used. Overall, the button was used 98 times by 41 different participants over the 12 months of the DLC program. This number is an adjusted number, because it happened numerous times that the same opt-out action was recorded multiple times, as the participants either pressed the button many times or it was recorded multiple times. This number is thus found by filtering out multiple opt-out actions within the same hour by the same user. Overall, only 35% of the participants actually used the button.

In figure 3.35, the breakdown of opt-out button usage per participant can be found. Of those who used the button, most used it 1-2 times. Each participant was in the DLC DR program for 6 months, either starting in pilot phase one or the second one.

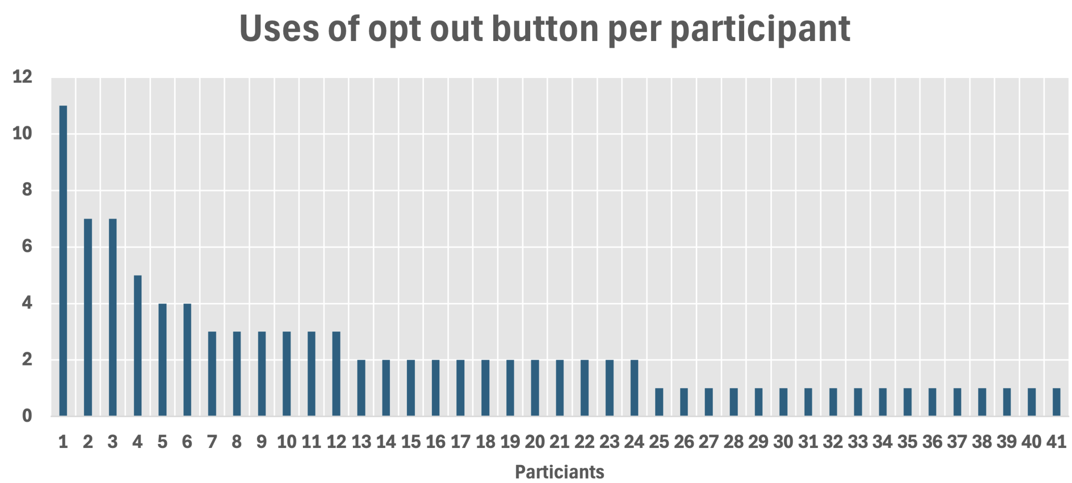

Figure 3.35: An overview of the number of opt-out actions per participant that used the button. Out of 115 participants, only 41 used the button, as can be seen.

In figure 3.36 below, the usage statistics of this button by months can be seen. During the first months of the DLC for each pilot phase, i.e. November 2022 and May 2023, very few opt-out actions were performed. In the first pilot phase, this ramped up quickly and in February when the DLC control method became more aggressive and for most of the evening, no charge power was offered, the opt-out button was used 14 times. In November 2022 to February 2023, the participants were only informed that the charging would be affected most between 17:00 and 23:00 and that a full charge could be completed within the night, when the schedule method would start charging. However, in the end of February 2023, the participants were informed about the exact structure of their schedule, i.e. that group one would have no power between 17:00 and 22:00 and from then 50% power until midnight when full charging power was regained. This detailed communication affected the usage of the opt-out action which lowered by 57% between February and March.

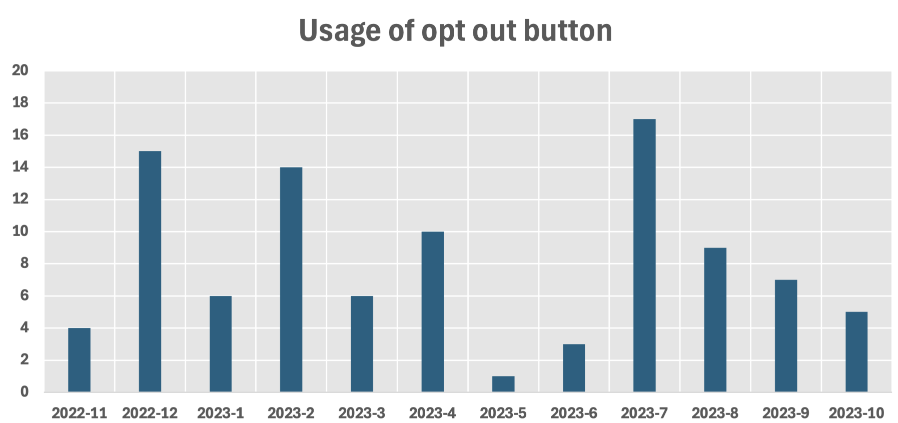

Figure 3.36: The usage of the opt-out button by months.

For the second pilot phase, July had the most usage of the opt-out button, 17 times. Like before, the participants were only informed that the charging would be affected the most between 17:00 and 23:00. In August, the DLC method changed, as the custom scheduling method was implemented. However, the information provided was not very detailed, just that the charging would be randomised by days and most affected between 17:00 and 23:00. However, the usage reduced quite a bit between July and August.

3.6. Load based pricing (LBP)

The third and last DR program in this pilot project was explored for a shorter duration of four months. This was because all the participants were in this LBP program together and more data was not considered to be needed. The analysis of this DR program will follow the same structure as before with the TOU and DLC DR programs, first going over the charging profiles, secondly the peak reduction on the average days of the month and lastly the peak days of the months.

3.6.1. Charging profiles

When examining the monthly charging profiles like has been done with the TOU and DLC programs, as can be seen in figure 3.37 below, the variability in profiles between months is much less compared to the other two DR programs. In the graph, the uncoordinated months can be seen as well as the four months of the LBP program along with the load steps and the reductions.

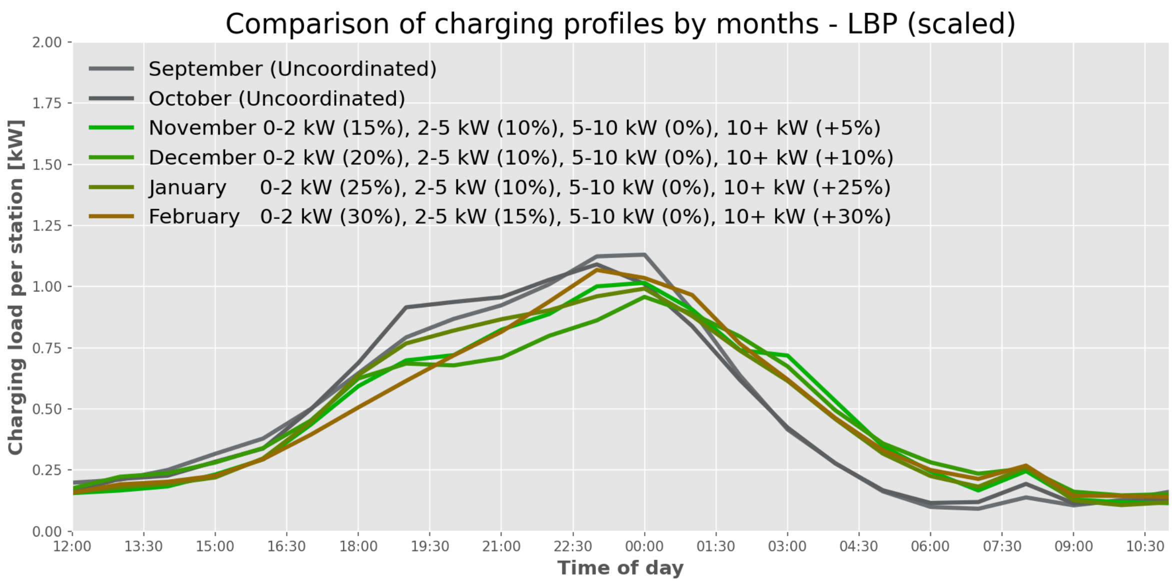

Figure 3.37: The daily average charging profile by months for the DLC DR program.

As was mentioned earlier in section 2.2.4 on the tariffs, the highest load step actually has an increased price. This was done to incentivise the participants to charge during off-peak hours or to lower the charging power themselves. What can be seen is that the charging profiles are very similar to the uncoordinated months, however there is a slight reduction between 19:00 and 00:00 which results in increased charging load during the night.

3.6.2. Load reduction - average day

In the figures below, two out of the four months that the LBP DR program was active in are shown. As with the two other DR programs, scaling is applied to those comparisons so the months being compared match in electricity consumption. The LBP tariff reduced the total load over the evening hours, from around 19:00 - 00:00, as was observed earlier in the changes to the charging profiles. This change resulted in peak reductions based on the average day for all of the four months where the LBP DR program was active, most at 14% in December and 8.8% on average. In table A.4, the results for all of the months can be found.

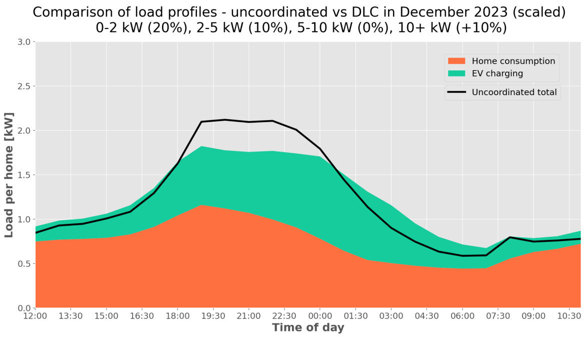

Figure 3.38: Comparison of the uncoordinated total load to the combined home consumption and charging load for the average day during the LBP in December 2023.

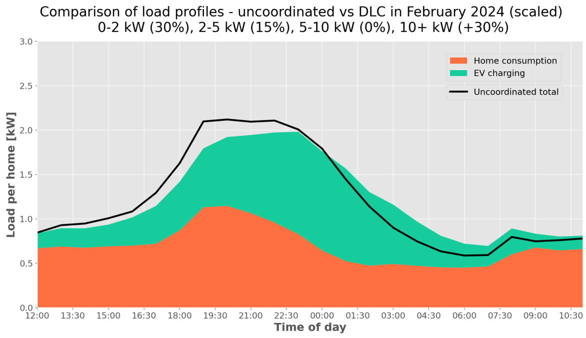

Figure 3.39: Comparison of the uncoordinated total load to the combined home consumption and charging load for the average day during the LBP in February 2024.

3.6.3. Load reduction - peak days

For the peak days of the LBP months, peak reductions were also achieved in all four months. In figures 3.40 and 3.41, November and January can be seen. In both those months, a part of the charging profile was spread into the night which lowered the peak in comparison with the former peak at 22:00. Considerable peak reductions based on those peak days were achieved, 18.8% in November and 14.3% on average. The peak reductions of each month based on the peak days can be found in table A.5.

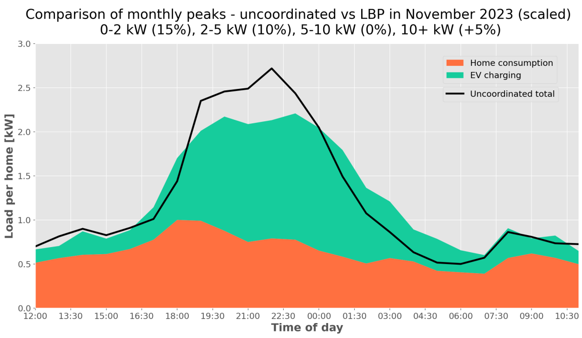

Figure 3.40: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the LBP in November 2023.

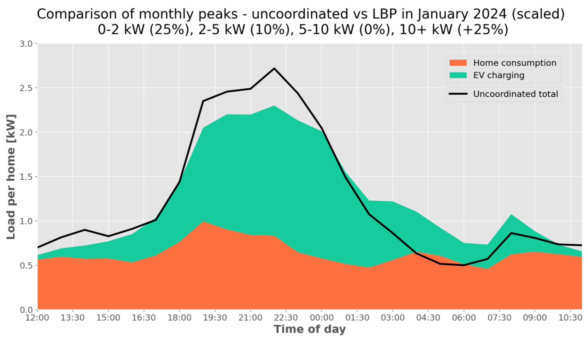

Figure 3.41: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the LBP in January 2024.

3.7. Survey data

The participants in the project were sent a survey after each month, asking a series of questions about the DR structure, tariffs and their impression of the DR program. After the research phase ended, a final survey was sent out which asked the participants about their attitude towards these DR programs in real world circumstances as well as their liking of them in the project. In this chapter these surveys for the three DR programs will be summarised and finally the last survey will be analysed. In the questions for the programs, an overview of the answers will be given for both the first and second pilot phase together in a graph and analysed. Some questions will only be summarised in this chapter but the full answers to all the questions that are not included in this chapter can be found in Appendix A.2.

3.7.1. TOU surveys

The TOU surveys were sent out after each month of the TOU DR program. In the first few months, the answer rate was very high, around 70-90% but gradually dropped down to around 50%. The first question in the surveys following the TOU months was a question that analysed the overall impact of the DR program and asked if TOU affected the charging behaviour of the previous month. In figure 3.42 below, the answers by months can be seen for both the first and second pilot phase. To the left of the months, the timing of the off-peak windows can be seen for each month as well as the price reduction in the off-peak windows. As can be seen in the graph, the participants in the first pilot phase thought the TOU DR program affected their charging much more than the participants in the second pilot phase.

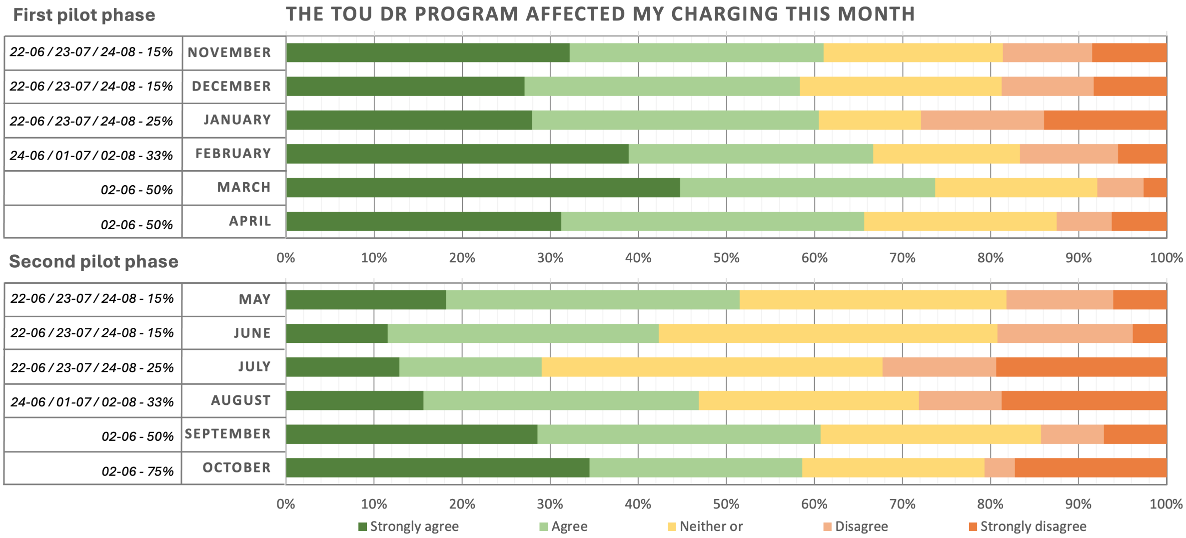

Figure 3.42: The results of the survey question on if the TOU DR program affected the charging behaviour of the participants.

When asked about the timing of the off-peak window, less satisfaction came with later windows. The first off-peak window at 2:00 - 6:00 in the morning got the least likeness for both pilot phases, but in the second month with that same structure, the affinity to this window grew.

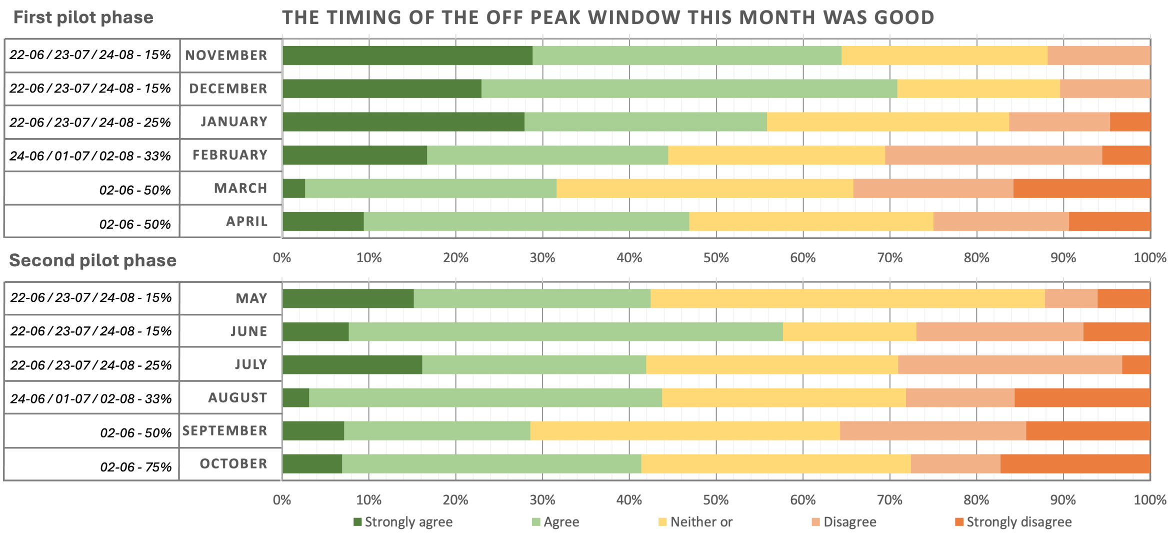

Figure 3.43: The results of the survey question on if the timing of the off-peak window during the TOU DR program.

Another question asked the participants about the price reduction in the off-peak windows. As mentioned before, the price reduction for each month can be seen on the left side of the graph. In the first pilot phase, the price reduction satisfaction increased slowly over the months, topping at almost 70% in March and dropping down again in April for the same exact price reduction. In the second pilot phase, the price satisfaction fluctuated more during the first four months but the fifth month, just as in the first phase had the highest score, around 65%. In the last month, where there was a reduction of 75% of the total electricity price during those hours, more participants strongly agreed to the price reduction being enough but when taking into account those who agreed, the overall satisfaction was still less than the previous month, which had a lower price reduction.

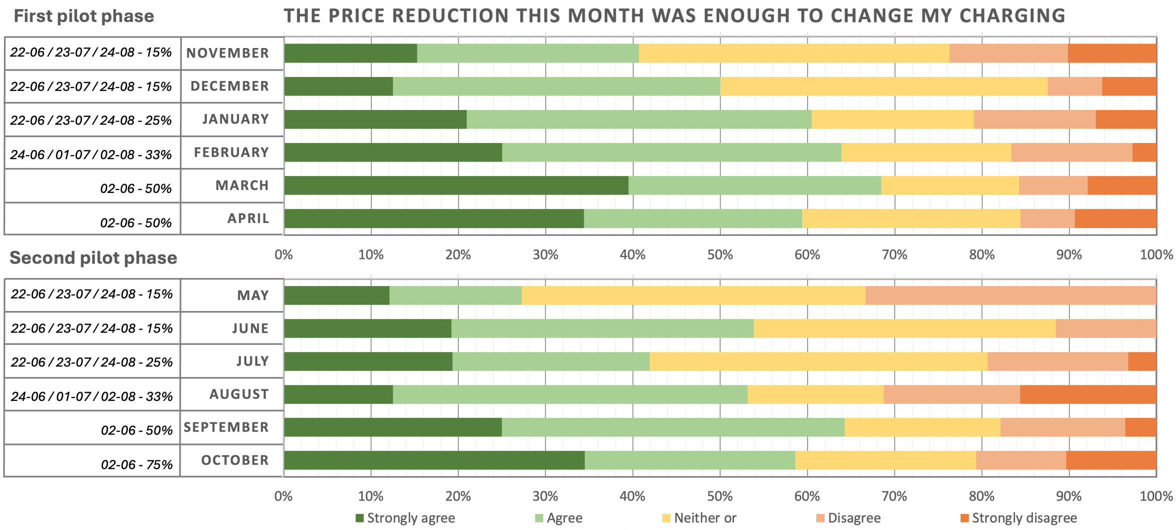

Figure 3.44: The results of the survey question on if the price reduction was enough to change charging behaviour during the TOU DR program.

The participants were also asked each month if they tried to charge in the off-peak window. The results of that question can be seen below in figure 3.45. There was a notable difference between the first and second pilot phase. In the first pilot phase, those who strongly agreed to that question were around 40-45% over all of the months, in total with those who agreed, it was around 65% on average. In the second pilot phase, those who strongly agreed were between 20% and 30% in all of the months except September which was a little higher. Overall, those who agreed or strongly agreed in the second pilot phase to this question were much fewer than in the first pilot phase.

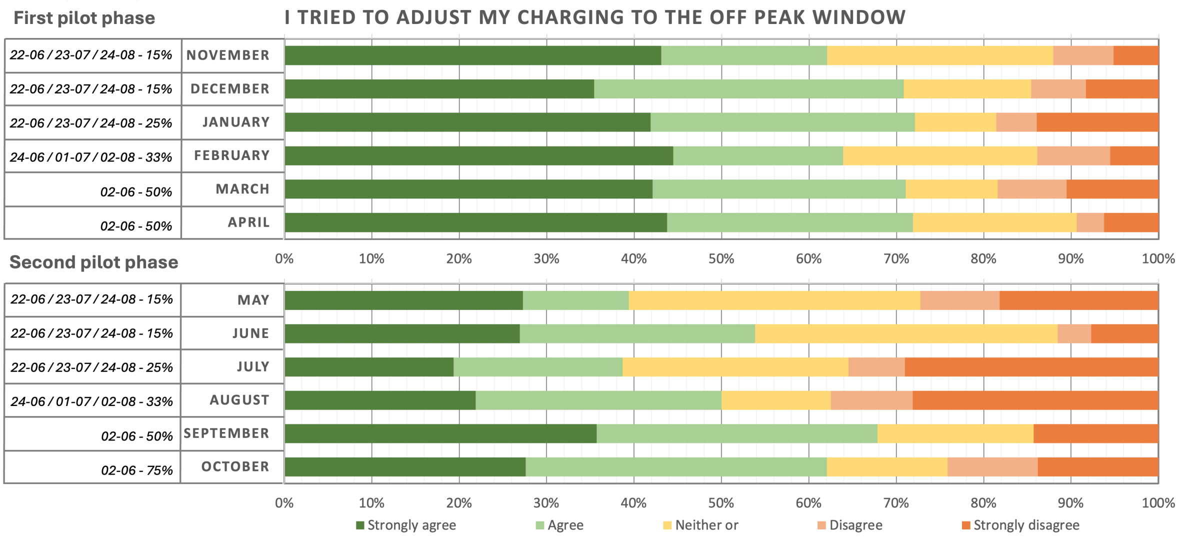

Figure 3.45: The results of the survey question on if the participants tried to adjust their charging to the off-peak window during the TOU DR program.

A few other questions were asked, here they will be summarised but the graphs can be found in Appendix A.2.3. Participants were asked if it required little effort to charge in the off-peak window. Generally, the answers indicated that a little bit more effort was required when the off-peak window was later into the night. Overall, 60% agreed or strongly agreed in the first pilot phase and 50% in the second pilot phase. When asked about if the participants observed their charging in the project's customer portal, the first pilot phase agreed overall to that around 50-60%. The second pilot phase had variable answers, from 20% all the way up to nearly 70%. Lastly, when asked about the method they used to charge in the off-peak window, in car settings as well as an app for the car were they most popular answers, as well as "other" which was not specified specifically.

3.7.2. TOU surveys - apartment building

For the apartment building participating in the TOU tariff, the same questions were asked. However, as the TOU had less variability and it was only one group, the surveys were not sent out monthly, but rather after a period with the same structure before a new structure was implemented. The answer rate for the surveys was between 30-50%. In figure 3.46 below, the first question of the surveys sent out to this group of participants can be seen. Similar to the graphs for the TOU tariff for the single family homes, the timing of the off-peak window and the price reduction can be seen on the left hand side of the graph. The participants found the TOU tariff to have the most effect on them in the last months but still there were around 40-50% that answered to that in the first half of the research phase.

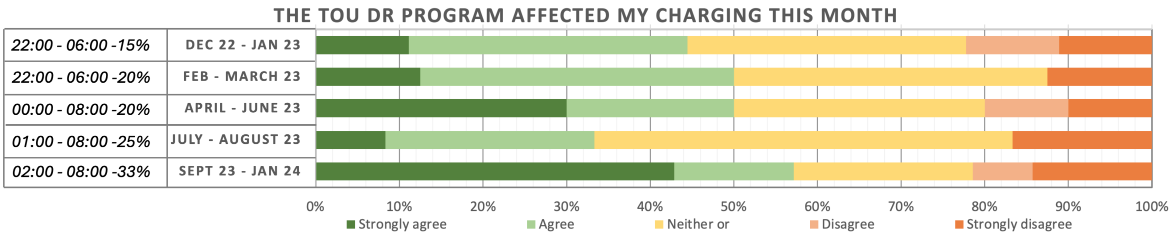

Figure 3.46: The results of the survey question on if the TOU DR program affected the charging behaviour of the participants in the apartment building.

When asked about if the price reduction was enough to change their charging behaviour, no one strongly agreed in the first two surveys. In the next two months, the satisfaction increased but the last survey which was based on the period with the most price reduction got by far the highest satisfaction, as seen below in figure 3.47.

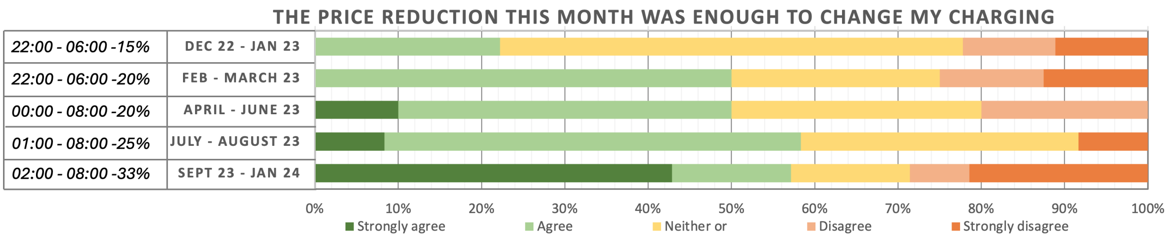

Figure 3.47: The results of the survey question on if the price reduction was enough to change charging behaviour during the TOU DR program for the participants in the apartment building.

The timing of the off-peak window was the subject of the next question, as seen in figure 3.48. Overall, the agreement to that statement was similar over the surveys, around 40% on average.

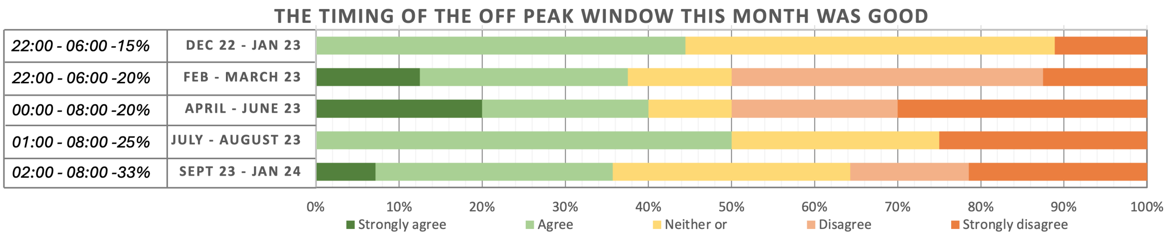

Figure 3.48: The results of the survey question on the timing of the off-peak window during the TOU DR program for the participants in the apartment building.

The participants in the apartment building were also asked about the effort needed to charge in the off-peak window. Over the five surveys those who strongly agreed increased but the overall agreement fluctuated a bit, as seen in figure 3.49.

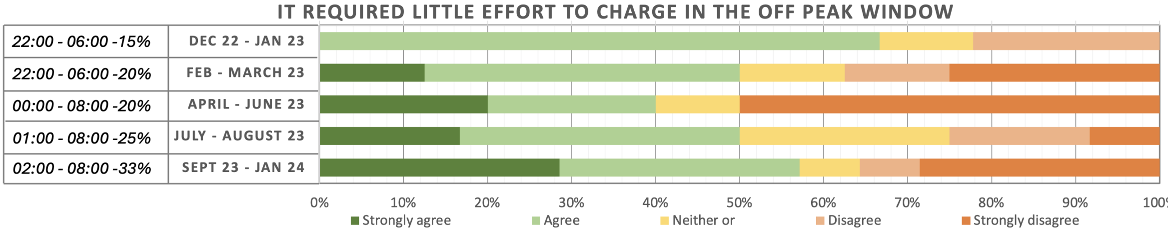

Figure 3.49: The results of the survey question on if it required little effort to charge in the off-peak window during the TOU DR program for the participants in the apartment building.

The participants were also asked about if they tried to charge in the off-peak window which also varied by months but was around 45% on average. The participants who observed their charging in the project's customer portal were around 30% on average, except the last months were there were almost no one which agreed to that. Regarding the methods to try to charge more in the off-peak window, the methods changed over the surveys and in the end, in car settings and car app along the ON Power app were the most popular methods. The full survey answers for these questions can be found in Appendix A.2.4.

3.7.3. DLC surveys

In the same way as the TOU surveys, the DLC surveys were sent out after each month, a total of 12 times. Similarly, the answer rate started off with around 70-90% in the first three months to around 50% by the sixth month. When the second group started in DLC, the answer rate started at around 60% and ended around 40%.

For the months with the DLC DR program, the first question was a bit different than in the TOU months. It asked the participants if they could charge like they wanted. In the same way as before, the answers for both the first and second pilot phase will be displayed in the same graph. On the left side of the graph there are explanations to the structure of the DLC DR program for each month as well as the starting price reduction for each month. The exact structures of the alternating starts and delays by groups can be found in tables A.1 and A.2 in Appendix A.1.

In figure 3.50 below, the answers to the first DLC related question can be seen. The results for the first and second pilot phase are very similar in some terms, especially the total agreement. However, those who strongly agree make up a bigger share in the first pilot. Still, the last month of the DLC, October 2023, had the highest satisfaction or 97%.

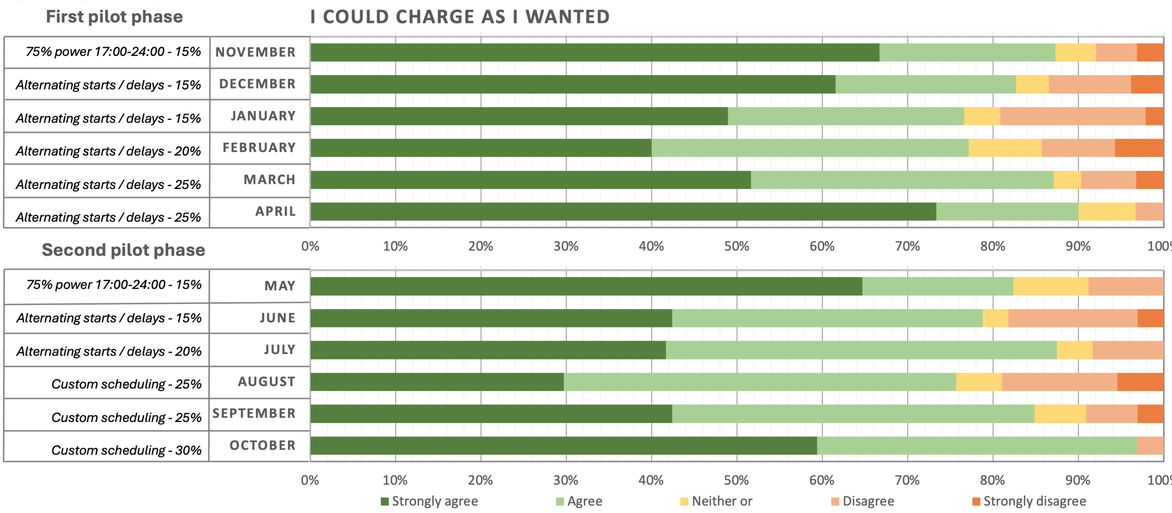

Figure 3.50: The results of the survey question on if the participants in the DLC DR program could charge as they wanted.

The participants were also asked about the price reduction in this DR program. In figure 3.51, the answers to that question can be found. Overall, the affinity towards that statement was around 40-50% in the first pilot phase. In the second one, the agreement was similar but September 2023 had a much higher one. Still in October 2023, when the price reduction was greater, the agreement towards the statement went down again.

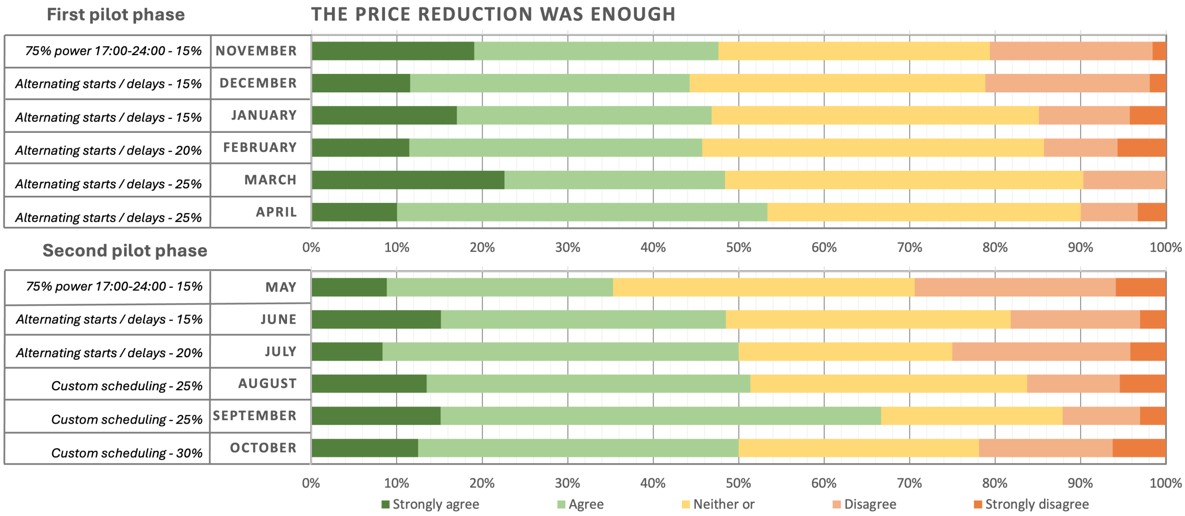

Figure 3.51: The results of the survey question on if the price reduction in the DLC DR program was enough.

Another question related to the price reduction was about the loss of price reduction with each opt-out action. As explained previously, each opt-out action lowered the starting price reduction of each month by 1/5. So in September 2023 for instance, with a 25% starting price reduction, each opt-out action lowered the price reduction by 5%. In figure 3.52 below, the results for this question can be seen. There was a big difference between the first and second pilot phase, even though the structure with the opt-out actions was exactly the same. In the first pilot phase, the agreement was about 40% on average but around 25% in the second one.

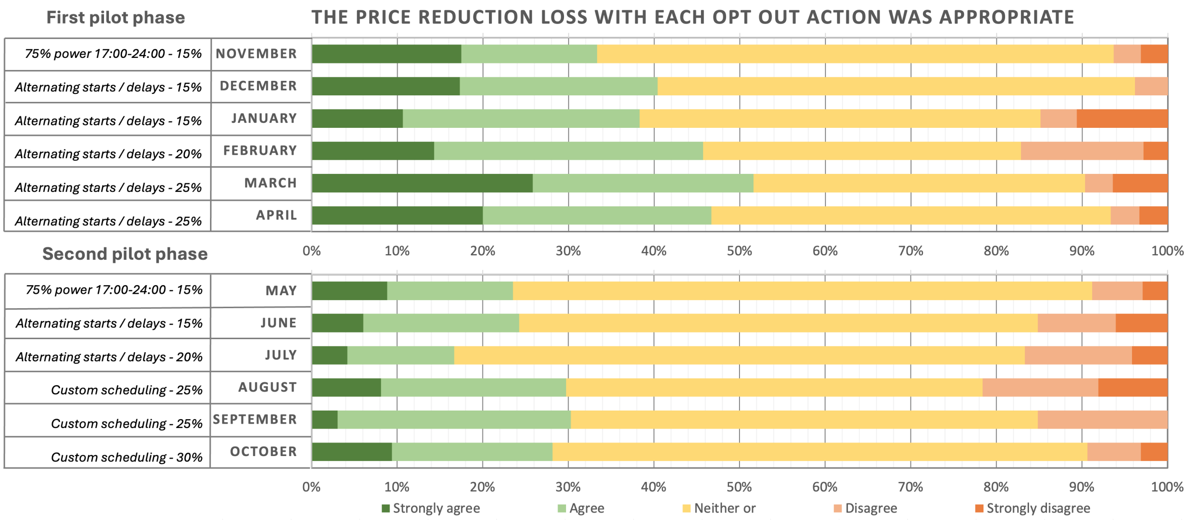

Figure 3.52: The results of the survey question on if the price reduction loss with each opt-out action was appropriate during the DLC.

Lastly, the participants were also asked if there were any problems with charging over the month. On average, 87% of participants reported no problems. Only about 1.8% found the EV too slow in charging on average, while another 1.8% on average reported that the EV was not fully charged in the morning. The additional 10% or so on average reported other minor problems. The breakdown of this by months can be seen in figure A.9 in Appendix A.2.5. When asked about if the participants liked the DLC tariff structure, around 60% agreed in the first pilot phase with more varied answers in the second phase, from 45-75%. When asked about if the participants observed their charging in the project's customer portal, around 50% agreed in the first pilot phase and around 40% in the second one. The full answers to these last two can also be found in Appendix A.2.5.

3.7.4. LBP surveys

For the LBP surveys, there was only one pilot phase that it applied to, the third and last one. To revise, the structure of the LBP tariff and price reductions were in four different usage steps. In table 3.1, an overview of the LBP tariffs by months can be seen. The answer rate was 50-60% for the first three months but 83% in the last one, as it was a part of the final survey, which will be covered later in this chapter.

Steps	November	December	January	February
0-2 kW	15%	20%	25%	30%
2-5 kW	10%	10%	10%	15%
5-10 kW	0%	0%	0%	0%
10+ kW	+5%	+10%	+25%	+30%

Table 3.1: An overview of the tariff structure and price reductions in the LBP DR program.

Like before with the TOU DR program, the participants were asked if the LBP affected their charging behaviour. In figure 3.53 below, the answers can be seen. The agreement to this statement grew over these four months and in the last month, just over 55% agreed to this.

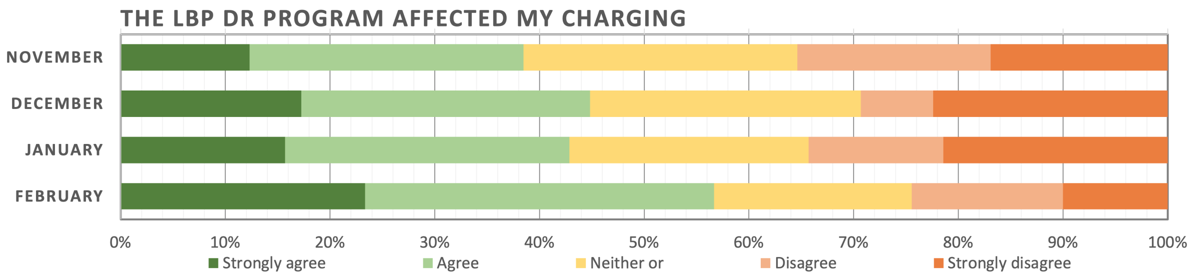

Figure 3.53: The results of the survey question on if the LBP affected the charging behaviour of the participants.

In addition to the effect on the charging, the participants were asked if the LBP DR program affected household electricity consumption. Those who strongly agreed to that were always very few, under 5% for all the months. Overall, only around 20% agreed to this statement on average.

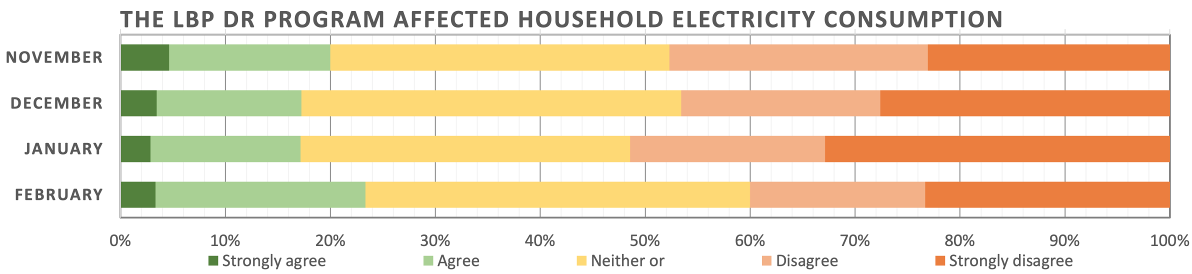

Figure 3.54: The results of the survey question on if the LBP affected the household electricity consumption of the participants.

For the price reduction during the LBP months, the overall satisfaction was around 30-40%. Those who strongly agreed were less then 10% every month.

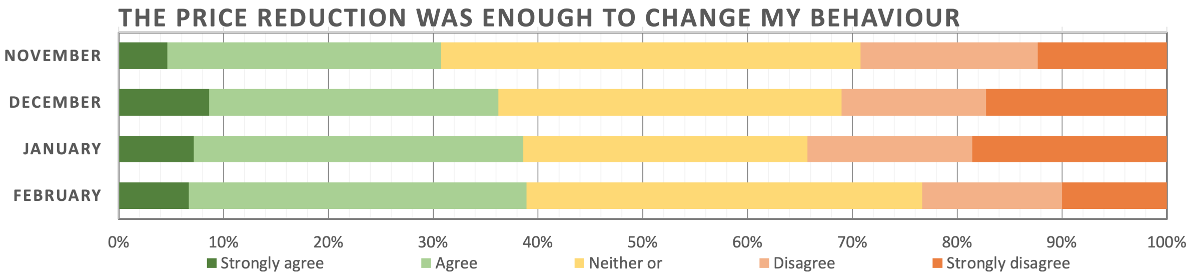

Figure 3.55: The results of the survey question on if the price reduction during the LBP was enough to change the charging behaviour of the participants.

When asked about the effort needed to try to use electricity in the lower steps, i.e. the steps that were with price reductions, the overall agreement to that statement grew over the four months. However, the share of those who strongly agreed reduced slightly.

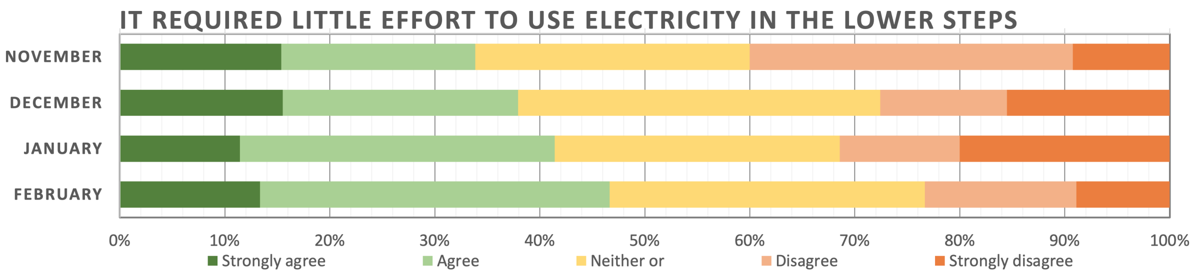

Figure 3.56: The results of the survey question on if it required little effort to use electricity in the lower steps during the LBP.

Four additional questions were asked that will be summarised shortly here. The graphs with answer breakdowns for these months can be found in Appendix A.2.6. The participants were asked about the setup of the steps, which were the same throughout the four months. The answers were quite even the first three months, around 35% overall agreement and in the last month it increased to nearly 50%.

When asked about if they observed their charging in the project's customer portal, about 40% agreed every month. For the method of trying to charge more in the lower steps, settings in the car and with an app accompanying the car were together responsible for around 40-50% of the answers each month. Additionally, "other" which was unspecified was around 40% in the first month and down to roughly 30% in the last month. The participants were also asked about how they tried to use electricity in the household in the lower steps. The vast majority, around 80% answered that they did in fact not do that. Around 15% used home appliances at other times than usual. The remaining answers were either other methods or by using settings of home appliances.

3.7.5. Final survey

The final survey was sent out in March 2024, a few days after the last month of the research phase concluded. Out of 115 remaining participants at that time, 96 answered or 83%. In this final survey, the first question was a simple one, *which of the three DR programs did you prefer?* In the graph below, the outcome of this question can be seen. The vast majority preferred TOU, nearly 73%, followed by LBP and then DLC, with 16.7% and 10.4% respectively.

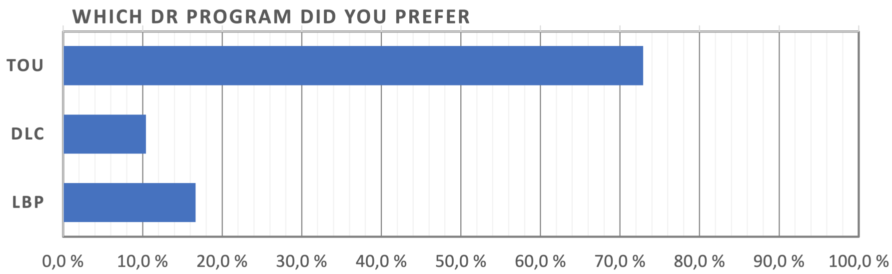

Figure 3.57: The results of the final survey, asking the participants which DR program they preferred.

A follow up question on the preference on the DR programs was also asked: *If the circumstances were not in a pilot project, but in the real world, how likely would be you to participate in these three DR programs?* This question was not eliminating the other possibilities by preference like question one. Similar results for the TOU DR program emerged, 86% would be likely or very likely to participate in TOU. For DLC, only roughly 10% are very likely and an additional 22% are likely. For the LBP, similar results were for the very likely answer but more very likely to participate overall.

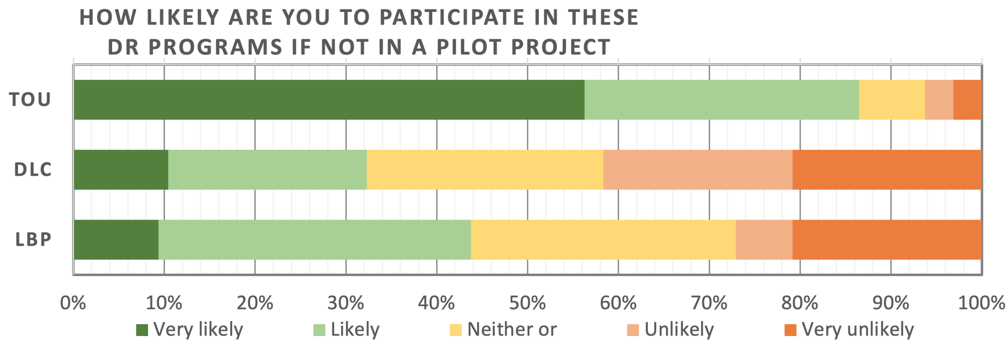

Figure 3.58: The results of the final survey, asking the participants how likely they were to participate in the DR programs if they were under normal circumstances, i.e. not in a pilot project.

Following these two questions on preference and likeliness towards the DR programs, the participants were asked more general questions about them. In figure 3.59 below, those three questions can be found. Just over 50% considered the cost savings to be adequate and another 30% were indifferent about it. A small percentage strongly disagreed and around 13.5% disagreed and thought the cost savings were inadequate.

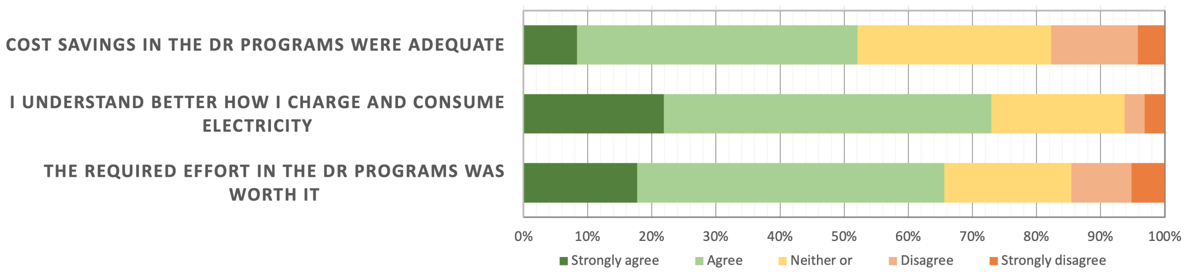

Figure 3.59: The results of three additional questions from the final survey.

Over 70% thought they understood better how they charged their EVs and consumed electricity on general. Only about 5% disagreed to that statement. The vast majority found the required effort to be worth it or about 65% but only around 18% strongly agreed. About 15% of participants disagreed to that and thus found the effort to be too much.

4

Discussion

In this chapter the outcomes of the pilot project are discussed. First, a sensitivity analysis on the results is performed, analysing the most important factors which can affect the outcomes of the project. Secondly, the perceived limitations in the pilot project are outlined and analysed. Finally, the findings of the project are summarised.

4.1. Sensitivity analysis

In this pilot project, three different DR programs were explored in multiple scenarios, based on program structure and tariffs. The results of the project are in the form of calculated peak reductions, based on both the average day of each month but also the peak day, i.e. the day where the load peak of the month occurred. Moreover, the results are also the observed changes to the charging profiles as well as the outcomes of the surveys sent out to the participants. Based on these results, several findings have been distinguished that will be explained in detail later in this chapter. However, the results of the peak reductions, both for the average day and the peak day of each month, are very sensitive to two main factors; EV ownership and DR participation. The comparison of the different DR programs in this report are based on the specific values of these factors. In this section, the sensitivity of these two factors are analysed and the different outcomes that come from their varying values are explored.

4.1.1. EV ownership

This pilot project explores the effects of EV load on the distribution grid and ways to reduce its impact. The ownership share of EVs compared to internal combustion engine vehicles is the main variable in in how much that added load is. As was explained in section 1.2 on EV development in Iceland, this share is growing rapidly and as of September 2024 it is 22.4% when taking into account both BEVs and PHEVs (Icelandic Transport Authority, 2024). In this project however, the EV ownership is 58%, and the ultimate goal of Iceland and its government is 100%. The results of the peak reductions achieved by the different DR programs explored in this project do in some ways change if other scenarios, such as the current EV ownership is considered or the full energy transition, with 100% EV ownership.

This sensitivity can be exemplified by one of the poor performing months for the DLC DR program, April 2023, where the peak actually increased by 18 % based on the peak on the average day of the month. In figure 4.1, the average day of that month can be seen, comparing the daily mean peak of the uncoordinated charging to the DLC DR program. In figure 4.2 however, this same month is shown but with the current EV ownership, 22.4%. This is done by simply scaling the EV charging profile from this month during the DLC down based on a different EV ownership scenario. This EV ownership is taken into account in both the uncoordinated charging and the DLC charging profiles and the household consumption is the same. What can be seen is that the overall load is much lower, since there is less EV load overall, but the DLC DR program performs much better this month and in fact lowers the peak by 6%.

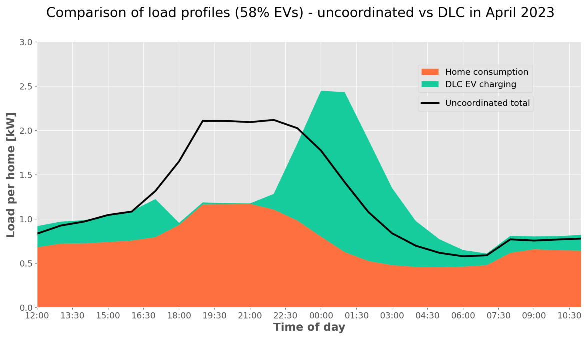

Figure 4.1: Comparison between the uncoordinated total load and the combined home consumption and charging load for the average day during DLC in April 2023 based on the circumstances in the pilot project, i.e. 58% EV ownership.

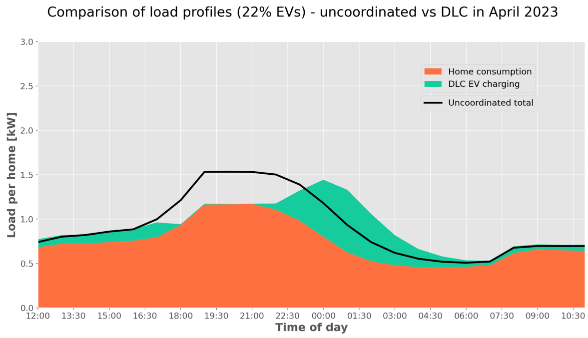

Figure 4.2: Comparison between the uncoordinated total load and the combined home consumption and charging load for the average day during DLC in April 2023, with the EV ownership scaled down to the current EV ownership in Iceland, 22%.

However, when the same methodology is applied to the future scenario, 100% EV ownership, the results get worse, which increases the peak on the average day by 31% in this scenario.

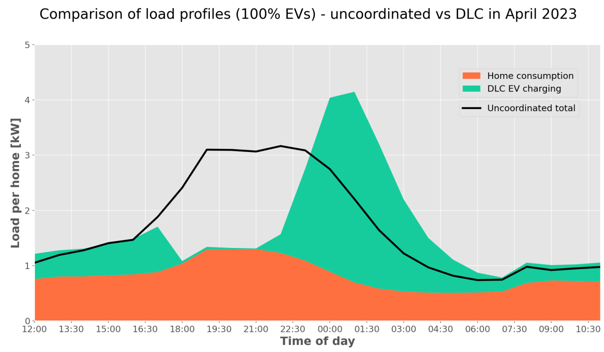

Figure 4.3: Comparison between the uncoordinated total load and the combined home consumption and charging load for the average day during DLC in April 2023, scaled up to the full energy transition for passenger vehicles, 100% EV ownership.

This same analysis can be done with the TOU DR program. To do this the "worst" performing month of the TOU tariff based on the peak day of each month can be taken as an example, which was August 2023. If the effects of the current EV ownership are put into that scenario, similarly as was done with the DLC in April, by scaling down the charging load but using the same behaviour, the peak would go from a 2% increase to a 2% peak reduction.

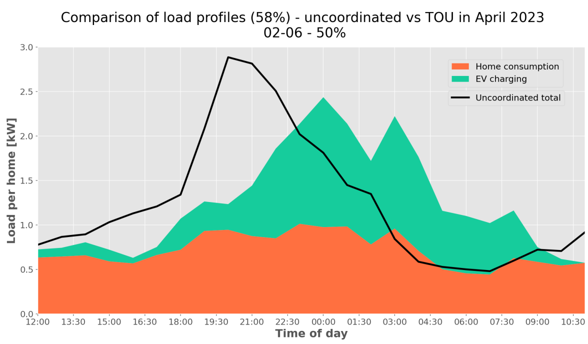

Figure 4.4: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the TOU in April 2023 based on the circumstances in the pilot project, i.e. 58% EV ownership.

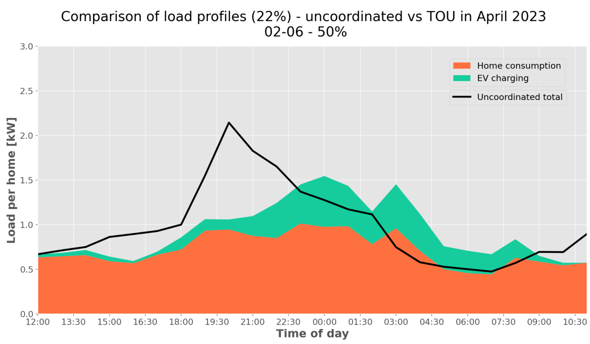

Figure 4.5: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the TOU in April 2023 with the EV ownership scaled down to the current EV ownership in Iceland, 22%.

Similarly, in months where the TOU tariff performed well, with the current EV ownership, it could perform even better. An example of this can be seen in figures 4.4 and 4.5 below, where the TOU DR program in April 2023 is shown. In that month, the monthly peak was reduced by 15.6% based on the 58% EV ownership in this pilot project. With the current EV ownership explore in this scenario in a similar comparison, the peak would have been reduced by 28%.

These scenario explorations showcase how sensitive the peak reduction values are to the EV ownership.

4.1.2. Participation

Another factor which highly affects the outcomes of the DR programs is customer participation. In this pilot project, the participants had high participation values, especially in the DLC DR program, where they were by default opted into the DLC. In the same way as was done for the EV ownership, some scenarios can be formulated to analyse the sensitivity of this factor to the results of the DR programs. The DLC was the least popular DR program in the project, according to the surveys and the final survey, as seen in figure 3.58 in section 3.7.5, where 32% agreed or strongly agreed to the statement of participating in such a DR program in real world circumstances. If the same month as was analysed for EV participation is taken, April 2023, the effects of decreased participation in DLC can be seen. In this analysis, 32% of the charging profile is from the DLC charging in April, while the remaining 58% of participants which are not participating in this scenario and thus charge as before, get charging profiles from the uncoordinated months. This results in a 6% peak decrease on this daily average comparison, instead of the 18% increase that was the result of the DLC with 100% participation.

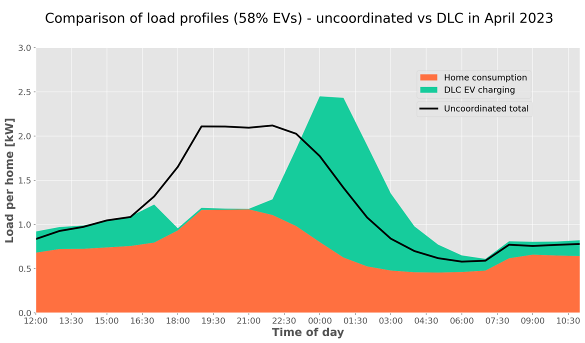

Figure 4.6: Comparison between the uncoordinated total load and the combined home consumption and charging load for the average day during DLC in April 2023 based on the circumstances in the pilot project, i.e. with almost 100% participation.

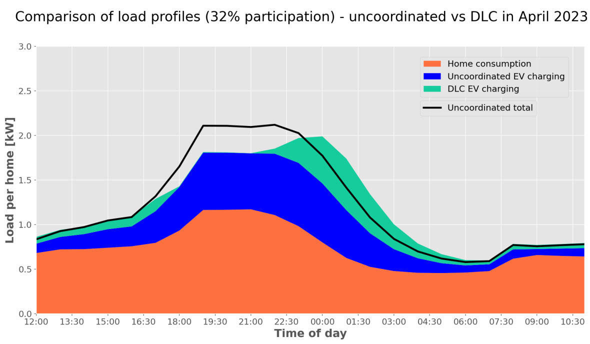

Figure 4.7: Comparison between the uncoordinated total load and the combined home consumption and charging load for the average day during DLC in April 2023 with the participation scaled down to 32%.

The results of the final survey regarding the TOU tariff can be analysed in a similar scenario exploration, as seen in the figures below. On the left, the peak day of February 2023 for the TOU tariff can be seen compared with the total peak in October 2022 where charging was uncoordinated. It is hard to estimate the exact participation in this month. It can be seen that it is not 100% as there is a small charging peak at around 20:00, well outside of the price reduced hours. However, the peak at 01:00 is much bigger. With rough calculations, the second peak is roughly three times bigger which might suggest participation around 70-80%, which is close to the results of the survey. In this month, with this estimated participation, there is a sizeable peak reduction, 18%, but when the participation is 40% less than was in February 2023 as seen in figure 4.9, where 40% of the charging comes from the uncoordinated months and 60% comes from the TOU tariff in this month, the peak is reduced much more, by 34%. The participation in these DR programs has a big impact on their outcomes and in some scenarios higher participation is optimal but in others, moderate or lower participation numbers are desirable.

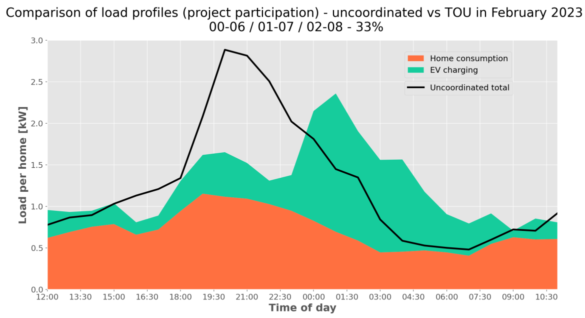

Figure 4.8: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the TOU in February 2023 based on the circumstances in the pilot project, i.e. high participation.

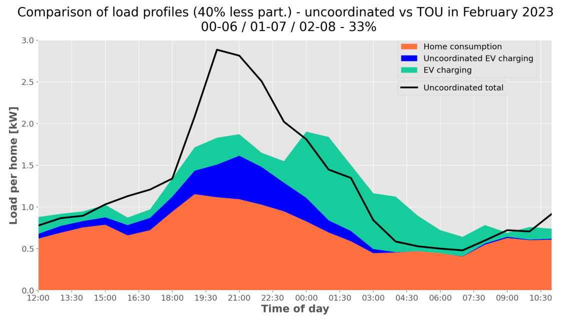

Figure 4.9: Comparison between the uncoordinated total peak and the combined peak of the home consumption and charging load during the TOU in February 2023 based on 40% less participation than in the pilot project.

4.1.3. Assumptions

During the project, several assumptions were identified that could affect the results and outcomes. However, they are not considered to have as great an impact as the two previously mentioned factors in terms of peak reductions and other results.

The main assumption related to the DR programs are that they do not affect each other sequentially. For example, for the participants that started in the TOU DR program in pilot phase one, are assumed to have stopped behaving towards that DR program once they entered pilot phase two with the DLC. In this example, this would mean that the participants would remove charge scheduling from their EVs at the end of the last TOU month. It is hard to evaluate how this assumption held up, but there were some indications of charge scheduling remaining in the first DLC month. The estimated impact of this is considered to be minor, as in the real world, a mixture of tariffs are already available, so the chances of this happening in real circumstances are possible.

Another assumption about the DR programs in general, is that the electricity market circumstances in the project are similar to the circumstances when they would be put into place. As mentioned earlier, during the research phase of the project, a few electricity retail suppliers started offering TOU tariffs. These are minor market changes and are not considered to affect the outcomes and relevance of the project results. However, if the electricity market would move towards a spot market, like is more widespread in Europe, the relevance of some of the results could be reduced.

Lastly, there was an assumption that the participants in the pilot project only used the charging stations supplied by the project. This was communicated to the participants very clearly in the beginning and while the project was ongoing. However, it became clear that some participants did that occasionally. In the final survey, the participants were asked if they had done this and around 15% said that they had done so. This affects the results in the way that the household consumption, which is found by subtracting the charging station usage from the meter usage, can contain some charging from these other chargers. From the standpoint of the DR programs, this does not affect the TOU and the LBP, but does affect the DLC. However, it can also be expected that during DLC in real circumstances, some EV owners might charge with another charging station or mobile connector additionally.

4.2. Limitations

In this pilot project, some limitations were identified. Some were technical, while others are due to the nature of this type of research project.

4.2.1. Technical limitations

The main limitations that are related to technology, both hardware and software, come from the charging stations in the project. The Easee Home charging stations used in the project offer 4G connectivity and two-way communication. However, the possibilities of controlling them are limited and constrained by the Charge Schedule feature as mentioned earlier in 2.3.4. The DLC methods explored in this pilot project are thus directly constrained by this feature. Therefore, the results of the DLC DR program are very much dependent on the specific type of DLC methods used in the project.

Additionally, some technical problems regarding the charging stations occurred over the research phase. The Charge Schedule feature deactivated at one point momentarily which did affect the results. This however, was in the beginning with the least aggressive DLC structure. Another problem that periodically happened, unrelated to the Charge Schedule feature but related to the specific charging stations used in the project, was that when certain EVs put a charge schedule on their cars, i.e. delayed charge starting time (during the TOU months) the charging station went down from three phase to one phase charging. This affected charging speeds greatly, affecting both the results but also the satisfaction of the participants.

Third, the state of charge (SOC) was not known when the participants plugged their cars into the charging stations. This however, is not a problem related to the charging stations in the project but a missing data point in the communication between the EV and the charging station, which is common with AC charging stations. This is also expected to change in the future and become available, with the support of the ISO 15118 standard. This missing data meant that when participants started a charging session during the DLC months, there was no way of knowing if they needed to fully charge their cars or just top up the charge and charge 15% for example. This was taken into account in the second DLC method, custom scheduling, but still it resulted often in charge sessions ending "too soon" and could have been timed much more accurately if the SOC was known at the start of each session.

Lastly, the data resolution in the pilot project also has effects on the results of the peak reductions. The time series data, from both the smart meters and the charging stations were not power based but energy based. The hourly data points were the consumption over the last hour. This also means, as explained before in section 2.2.4, that the energy over the hour is equal to the mean power over the hour. That way, the LBP DR program could be formulated with its tariffs based on this data. The limitation of this data is that the highest peak within each hour is not known. When a participant charges for 15 minutes at 10 kW, that charging is only registered as 2.5 kWh which results in a 2.5 kW mean charging power for that hour. This missing hourly peak information directly affects the results and the instantaneous peaks within the hour are probably much greater than the hourly mean power indicates. However, the aim of this project was to research if DR programs could reduce the load impact on the distribution grid. Load impact on underground cables and transformers is generally a function of time, so short unreported peaks within the hour have limited effects. Long, sequential hours under too much load is what causes distribution grid problems.

4.2.2. Pilot project circumstances

The nature of this pilot project itself also has some limitations. The goal of this research project was to try to imitate real world circumstances by recruiting typical EV owners in Iceland and aiming towards creating impartial conditions but the experience of participants is likely to be influenced by incentives by joining the project and other factors.

As was mentioned before in section 2.3.2, the participants got a free installation of a charging station and free use of that station while the project was ongoing, which was from installation time in April - August 2022 and until the research phase ended in February 2024. Additionally, the participants benefited from the price reductions in the project, which overall were much higher than could be expected in the real world. The pilot project got permission from the Icelandic National Energy Authority to lower the price for the participants on the notion that they would reduce the impact on the distribution grid during that time. Similarly, ON Power formulated special tariffs for the participants in the project to be able to effectively research different price reductions. If these DR programs would be implemented in reality, the "regular" price, i.e. the peak price for TOU or the starting price in DLC, would be higher than the current price. Therefore, the price reductions in this pilot project are unfeasible in some ways.

As a way of mitigating the possible effects of the pilot project circumstances on the results, a few steps were taken. First of all, information on the ways to effectively use each DR program in the best way, was kept quite limited. Information in the pilot project's customer portal displayed detailed information about the tariff structures and price reductions. Additionally, emails were sent out each month with that same information but tips on how to schedule EV charging or change charging behaviour to align to the DLC DR program in the best way was not given out in general. If participants contacted the project's team via the project's email or the customer service of the cooperating companies, information was given. Secondly, the participants' identities were not known to each other, therefore they could not contact each other, apart from the apartment building, where everyone knew that the whole building was participating. But for the single family homes, this was the case. This was done in an attempt to keep the influence of others to a minimum and let the participants figure things out on their own.

4.3. Findings

There were multiple outcomes of this pilot project based on its different parts. The goal was to explore different DR programs and their effectiveness in peak reduction but additionally and equally importantly, to get feedback from real customers on how they perceived them.

4.3.1. Customers

The main findings regarding the participants is that communication during a DLC DR program is vital. There were very few problems encountered due to technical difficulties and in almost all cases the participants got sufficient charge over the night, as was shown in the survey data from the DLC. Additionally, the participants were told that the charge would be carried out later in the evening and the charging would be most affected between 17:00 and 23:00, the usual peak hours. However, more information seemed to be necessary, as was illustrated by the usage statistics of the opt-out button as described in section 3.5.4. When more detailed information was given, usage of the opt-out button decreased drastically. For a successful DLC DR program, detailed and frequent information on how the control is carried out is important.

From the surveys, numerous findings were obtained. Firstly, there was a difference between the group that started in the TOU DR program as opposed to the group that started in DLC. The first group found that the TOU tariff affected their charging behaviour far more than the other group, which in a way had become accustomed to the DLC tariff, where they did not have to think about the charging times and off-peak windows. The second group, which started in DLC, found the TOU tariff overall to be less enjoyable than the first group. They found the timing of the off-peak windows worse, the price reductions less satisfactory (even though it was the same and in their last month far greater) and they reported that they tried less to charge in the off-peak window than the first group. There were much less drastic changes to the other way around, i.e. those who started in TOU and then moved on to DLC. When EV owners are used to not have to think about their charging, just plugging in and the charging happens automatically at the best time for the distribution grid, it may be hard to change from that into a structure where it is their own responsibility. This indicates that automating the charging procedure, finding the best price over the night, is something that EV owners appreciate.

From the final survey some important findings are identified. The TOU tariff was by far the most popular choice of the participants, at around 87% likeliness towards it in real world circumstances and 73% preferred it over the two other DR programs. This is most likely due to its simplicity, predictability and the fact that it does not restrict the charging of the EV owner in any way as opposed to the DLC and the LBP in some ways. This high satisfaction can however be worrisome with increasing EV ownership as it high participation levels were not always the best for peak reduction as illustrated in the previous section, 4.1.2, on the sensitivity analysis. Regarding price reductions and monetary incentives in regards to DR programs, only about 50% of the participants found the cost savings to be adequate in the project. This is also a key finding, as the price reductions in the project are far greater than what can be expected in real world circumstances, as explained earlier in section 4.2.2. Other survey outcomes indicated that over 70% of participants found that they understood their charging and electricity consumption habits better and around 65% thought the effort of the different DR programs were worth it, which was higher than the share of those who considered the savings to be sufficient.

4.3.2. DR programs

For the different DR programs, the analysed results were threefold; changes to charging profiles, peak reductions based on average days of each month and the peak days of each month. Based on the outcomes of these analyses, various findings can be observed.

TOU

Beginning with TOU DR program, the charging profiles were shifted much later into the night, where there are more suitable times for the peak, both based on average days and the peak days. As mentioned before, the group that started in the TOU DR program liked it more based on the surveys, but the effects on the charging profiles were also more noticable for the first pilot phase. In the second one, a bigger share of charging still happened outside of the peak hours and on average, the peak reductions were much less as seen in detail in tables A.4 and A.5 in Appendix A.2. Overall, the peak was reduced for all the months based on average days, and in all but one months based on the peak days. These results indicate that TOU tariffs are a viable option for alleviating load during peak hours. This DR program is also quite simple in implementation, but for very high EV ownership and very high participation, the danger is that another peak emerges which exceeds the former peak. Ideally, multiple off-peak windows should be offered in such a tariff, as was done in this project based on groups. However, this might prove to be challenging due to energy equality, where some EV owners might "get" a off-peak window that they dislike as opposed to other EV owners getting more desirable off-peak windows.

For the TOU in the apartment building, the charging profiles had an even bigger shift than based on the participants in the single family homes. Over the 14 months that the TOU tariff was active for the apartment building, every single TOU month had a lower peak and in the end, the charging profiles had two separate peaks, one around 19:30 and another one at 4:00. The end result was that the peak could be reduced by up to 40.5%, based on the average day of each month. It was also observed that the participation in the later off-peak windows seemed less than for the group of participants in the single family homes, which is also one of the factors to the high peak decrease. This also supports the observation, which was explored in the previous section on the sensitivity analysis that the highest DR program participation is not always the best. It is also important to note that in the apartment building, the share of PHEVs was around 50%, as previously explained in section 3.1, as opposed to the single family homes where out of 154 EVs, only 9 were PHEVs. This might also be a contributing factor to the substantial peak reduction of the apartment building, where PHEVs typically need shorter charging times and are charged more frequently.

DLC

For the DLC DR program, the results fluctuated more, achieving peak reductions in some months but peak increases in other months. The effects to the charging profiles were mainly that a new and bigger peak emerged, around 1:00 for the first pilot phase, with the alternating starts / delays method and at 3:00 in the second pilot phase, utilising the custom scheduling method. The latter methodology had much better performance overall on the peak reduction, achieving peak reductions on all three months of that method based on the average day peak, compared to the former simpler method, where 4 out of the 9 months with that method actually increased the peaks. As was explored in the previous section on the sensitivity analysis, less participation increased the effectiveness of the DLC greatly, as well as lower EV ownership than the 58% in this project.

An important mention regarding the DLC, is that the formulation and methodology used in this project is only one version of DLC, as it can be done with other approaches or technologies. However, one key data point which would affect the performance of control methods greatly is the SOC, as explained earlier in the section on limitations. In this project, the SOC was unknown, so the charge schedule was in a way overly cautious, often starting too early for those who have bigger batteries or slow charging speeds, which need a long charging time when very high energy sessions are needed, leading to the majority of the charging taking place during peak hours for these specific EVs. This was mitigated partly by shifting the starting and stopping forwards and backwards by up to two hours, as explained in detail in 2.3.4 on the DLC methodology and technology. If the SOC would be known, as is expected with the ISO 15118 standard for EVs and charging stations, the DLC could be implemented in a nearly perfect way. A custom scheduling method, as used in this pilot project, is thus best suited towards scenarios with relatively low participation or low EV ownership. Based on the results from the surveys, where only about 30% of participants were interested in DLC, the DLC could in reality be more effective than perceived in this pilot project.

Lastly, DLC also offers more possibilities in terms of predictability and flexibility than both TOU and LBP. In TOU it could be observed on some of the peak days, that the participants did not try to charge in the off-peak windows, but rather when it suited them. En example of this is August 2023, when the peak was at 23:00, completely outside of the three off-peak windows. This happened less in the DLC, as most of the participants did not charge on their own accord, apart from the very few that used the opt-out button. This is the main strength of DLC, where on the peak days, the predictability is much more, especially with fine tuning of control methods and algorithms. However, the complexity of this DR program is much higher than the TOU, as well as the implementation cost, which calls for specialised workforce and software and higher overall operation costs.

LBP

For the third and last DR program explored in this pilot project, LBP, the effects on the charging profiles were far less than the DLC and the TOU DR programs. For the four months of the LBP DR program, little progression to the charging profiles occurred and the peak timing did not change much, which happened between 23:00 and 00:00. During the evening hours, a small reduction in charging load was noticeable that shifted into the night. This relatively small change in charging profiles still achieved fair peak reductions, where for both the average days and peak days of each month, the peaks were lowered. In fact, the peak reduction in November 2023 during the LBP, had the highest peak reduction based on the peak days of each month in the whole pilot project. This suggests that small changes, as observed in the LBP, can still produce desirable peak reductions. According to the surveys, around 40% of the participants thought the LBP affected their charging behaviour, much less than the TOU DR program and overall the participants liked it worse than the TOU, but still more than the DLC DR program.

5

Conclusion

5.1. Research questions

In the beginning of this pilot project, a main research question was formulated, that guided the research process along with three sub-questions. In this section, they will be answered.

How can demand response programs be used to reduce the load impact of EV charging in the low-voltage distribution grid?
The three different DR programs in this project were explored in multiple scenarios, with varying structure and price reductions. The ability to reduce the load impact was measured both based on average days of each month as well as the peak day, i.e. the peak load of each month. From the results of this pilot project, it is clear that DR programs can help alleviate load on the distribution grid, both overall, as was analysed for the average days of each month, as well as the peaks of each month. For the former analysis, time spent under less load can increase the lifetime of underground cables and transformers, as time under load close the to capacity speeds up the breakdown of these components and can cause blackouts and outages if the capacity is exceeded. For the system peaks, which the distribution grid has to be able to withstand, reducing those can help utilise the existing infrastructure better and delay and even reduce grid strengthening and therefore saving on investment and operating costs.

Importantly, this load reduction ability is very dependent on two factors; EV ownership and the participation in the DR programs. In this pilot project, there was 58% EV ownership and various participation levels for the three DR programs. For the DLC, the participation was close to 100%, since by default the participants were opted into that DR. For the TOU, it is hard to estimate accurately the exact participation, as it differed between months. Overall, it was quite high. For the LBP, the estimated participation levels were relatively low.

The TOU tariff reduced load peaks over all the months (both average days and peak days) except one month, where a small peak increased occurred. The LBP produced fair peak reductions in all its months while the DLC reduced peaks in some months but increased them in others. To answer the main research question, DR programs can be used to reduce the load impact by offering TOU and LBP at the EV ownership and participation levels in this project, but with DLC by reducing participation or at lower EV ownership levels. Importantly, lowering the participation can easily be done with adjusting the DLC itself, while in this project, all participants were controlled to gather the most data. Overall, all these DR programs can be used to reduce the load impact, but taking these factors into account is vital.

Do price-based DR programs suffice to reduce EV load impact?
The price-based DR programs explored in this project, TOU and LBP, could both reduce peak loads, based on average days as well as the peak days of each month. However, with very high EV ownership or participation, TOU tariffs can become problematic and produce a secondary peak that can exceed the former peak. Additionally, these price based DR programs do not ensure peak reductions on any given day, as it depends entirely on the customers and their reaction to the price reduction and tariff setup. This was exemplified in the project, where in August of 2023, the TOU exceed the uncoordinated peak and the peak timing was actually outside of the off-peak and price reduced hours.

At the current EV ownership in Iceland and with the expected participation, price based DR programs can be sufficient to reduce EV load impact, but with very high EV ownership, an alternate structure, e.g. with different off-peak window timings should be considered or combining the TOU with other DR programs such as DLC or LBP.

Can direct load control be used while maintaining customer satisfaction?

In this pilot project, DLC was the least popular DR program. Although a cautious control method was implemented, giving opportunity for big charging sessions every time the charging control was carried out, it seems that with less control over one's charging the less the overall satisfaction. The opt-out button was not used very often, but there was a noticeable difference between months where more detailed information about the structure was communicated. To answer the question, DLC can indeed be used to reduce load peaks, especially with the second control method. Customer satisfaction overall was not very high but the problems encountered were very few. In the last month of the DLC, October 2023, 97% of the participants said they encountered no problems with their charging but only around 55% said they like the tariff structure, i.e. the DR program in that month. This can be seen in figures A.7 and A.9 in Appendix A.2.5.

DLC can be used while maintaining some customers satisfied, but not others. The share of satisfied customers is around 30% based on the final survey but closer to around 50% from the monthly surveys. However, as was discussed in the sensitivity analysis, relatively low participation levels are sometimes desired.

What is the tariff reduction needed to ensure participation in DR programs?

Although the effects of the price reduction alone on the DR programs is hard to observe exactly, some observations can be seen. For the TOU tariff, the surveys indicated that with higher price reductions, the participants found that the price played a bigger role in changing their behaviour. For the lowest price reduction, 15%, only around 40-50% thought the price reduction was enough to change their mind. Interestingly though, months with 25% or 33% price reductions, scored similarly to the months with 50% price reductions, according to this surveys. Another question, asking about if participants tried to adjust their charging to the off-peak window, has little correlation to the price reductions. Therefore, based on this, very high price reductions are not needed and 25-35% discount seem to be sufficient.

For the TOU DR program in the apartment building, there seemed to be similar participation over almost all the months and thus different price reductions. The first price reduction of 15% did not get very high scores in the survey but the subsequent months, where it went from 20% to 33% all had very similar answers when the participants were asked about if the price reduction was enough to change their charging behaviour. Therefore it can be concluded that 20% would be enough to ensure good enough participation to produce desirable peak reductions.

For the LBP DR program, the changes in price reductions did not seem to have much effect on the charging behaviour, the reduction in charging over the peak hours actually was more with less price reductions. When the participants were asked if the price reduction was enough to change theur charging behaviour, there were little changes in answers with increased price reductions. Overall, it can be concluded that the tariff reduction for the LBP does not have to be very high and with the smallest price reduction, which was 15% and 10% in the first and second step, 0% in the third and a 5% surcharge in the third step produced desirable results, with diminishing returns in tariff structures with higher price reductions.

For the DLC DR program, the price reduction was in another form, where it started as a certain percentage at the beginning of each month and lowered with every opt-out action. As analysed in section 3.5.4, the opt-outs were not used very frequently and thus most of the time, participants got the full monthly starting price reduction, which was also for all the electricity consumption over the month, not just EV charging. Based on the answers on the survey question on if the price reduction was enough, 15% price reduction had very similar answers as 20%, 25% and 30% price reductions. The performance of the DLC did not correlate highly to the price reduction. Therefore, a 15% price reduction for the DLC seems to be sufficient.

5.2. Recommendations

From the results and findings of this pilot project, recommendations for future implementation of DR programs can be given, as well as recommendations on future research.

DSOs

From the results of the project it is clear that DR programs can be of great benefit to DSOs, helping them to increase utilisation of the distribution grid as well as lower investment costs. The TOU and LBP tariff are deemed to be best suited for the DSO to operate, as the DLC requires control over charging stations, either via backend systems or with other ways. The simplicity of the TOU tariff along with sizeable peak reductions, as illustrated in the project, make it an easy way for DSOs to reduce the load impact of EVs. At the current EV ownership in Iceland, the potential of a secondary peak exceeding the uncoordinated charging peak is small but with high EV ownership and/or high participation, this could become an issue. In those circumstances, different off-peak window timings could mitigate the effects.

Electricity retail suppliers / charging station operators

The price-based DR programs; TOU and LBP can also be used by electricity retail suppliers or charging station operators to reduce load during evening hours and increase electricity use during the night. This might be done in cooperation with a DSO or independently, but these parties might also be well suited to carry out these services for the DSO, helping them increase distribution grid utilisation. These parties are better suited for the DLC than the DSO as they have access control over the stations. The DLC could also be used as a service towards the DSO, as it can ensure load reductions with greater confidence than the TOU and LBP tariffs, as it is carried out by these parties but not by the participants behaviour towards pricing. This could be an opportunity for the retailers or charging station operators to supply grid services that also greatly helps the DSO.

Future research

In this pilot project, the focus was on exploring how different DR programs could be used to reduce the load impact on the distribution grid but more importantly how real EV owners would respond to these DR programs. The focus was not to find the best DR program or the best version of each DR program. However, based on the data from this project, which is publicly available, more detailed analyses can be made on the DR programs and an in-depth sensitivity analysis could be used to find out the best version of each DR program based on the two factors that affect them the most; EV ownership and participation. Additionally, the charging profiles and household profiles can be used for further research in the field of EV charging and distribution grid research.

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A
Appendices

In this section, the various appendices that contain additional or complementary information to the main content can be found.

A.1. Methodology

In this section, additional data and information on the methodology can be found in greater detail.

A.1.1. Tariff structures

Month	**November**	**December**	**January**	**February**	**March**	**April**
Year **Nr.**	**2022** **1**	**2022** **2**	**2023** **3**	**2023** **4**	**2023** **5**	**2023** **6**
Time of Use (TOU)						
Group 1	22:00 - 06:00 + weekends *15% reduction*	22:00 - 06:00 + weekends *15% reduction*	22:00 - 06:00 + weekends *25% reduction*	00:00 - 06:00 + weekends *33% reduction*	02:00 - 06:00 *50% reduction*	02:00 - 06:00 *50% reduction*
Group 2	23:00 - 07:00 *15% reduction*	23:00 - 07:00 *15% reduction*	23:00 - 07:00 *25% reduction*	01:00 - 07:00 *33% reduction*	02:00 - 06:00 *50% reduction*	02:00 - 06:00 *50% reduction*
Group 3	24:00 - 08:00 *15% reduction*	24:00 - 08:00 + Christmas special tariff *15% reduction*	24:00 - 08:00 *25% reduction*	02:00 - 08:00 *33% reduction*	02:00 - 06:00 *50% reduction*	02:00 - 06:00 *50% reduction*
Direct Load Control (DCL)						
Group 4	75% power between 17:00-23:59	50% power between 17:00 - 23:59 15% reduction	50% power between 17:00 - 23:59 15% reduction	No power between 17:00-21:59, 50% power between 22:00 - 23:59 20% reduction	No power between 17:00-21:59, 50% power between 22:00 - 23:59 25% reduction	No power between 17:00-21:59, 50% power between 22:00 - 23:60 25% reduction
Group 5		No power between 17:00 - 19:59, 75% power between 20:00 - 23:59 *15% reduction*	No power between 17:00 - 19:59, 75% power between 20:00 - 23:59 *15% reduction*	No power between 17:00 - 22:29, 75% power between 22:30 - 23:59 *20% reduction*	No power between 17:00 - 22:29, 75% power between 22:30 - 23:59 *25% reduction*	No power between 17:00 - 22:29, 75% power between 22:30 - 23:60 *25% reduction*
Group 6	*15% reduction*	No power between 18:00 - 21:59, full power from 22:00 *15% reduction*	No power between 18:00 - 21:59, full power from 22:00 *15% reduction*	No power between 17:00 - 22:59, full power from 23:00 *20% reduction*	No power between 17:00 - 22:59, full power from 23:00 *25% reduction*	No power between 17:00 - 22:59, full power from 23:00 *25% reduction*
Time of Use (TOU)						
Apartment building	Uncoordinated	22:00 - 06:00 *15% reduction*	22:00 - 06:00 *15% reduction*	22:00 - 06:00 *20% reduction*	22:00 - 06:00 *20% reduction*	24:00 - 08:00 *20% reduction*

Table A.1: The structures of the first pilot phase, i.e. the first 6 months. The structures and tariffs of the TOU and DLC can be seen as well as the tariffs for the TOU DR program of the apartment building

<table>
<tr><th>Month</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th><th>October</th></tr>
<tr><th>Year</th><th>2023</th><th>2023</th><th>2023</th><th>2023</th><th>2023</th><th>2023</th></tr>
<tr><th>Nr.</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th></tr>
<tr><td colspan="7">Direct Load Control (DCL)</td></tr>
<tr><td>Group 1</td><td rowspan="3">75% power
from 17-24
15% reduction</td><td>50% power reduction
from 17:00 - 00:00
15% reduction</td><td>50% power reduction
from 17:00 - 00:00
20% reduction</td><td>Custom scheduling
25% reduction</td><td>Custom scheduling
25% reduction</td><td>Custom scheduling
30% reduction</td></tr>
<tr><td>Group 2</td><td>No power from
17-20,
25% power reduction
from 20-00
15% reduction</td><td>No power from
17:00-22:30,
25% reduction from
22:30 - 00:00
20% reduction</td><td>Custom scheduling
25% reduction</td><td>Custom scheduling
25% reduction</td><td>Custom scheduling
30% reduction</td></tr>
<tr><td>Group 3</td><td>No power from 18-22
15% reduction</td><td>No power from
17:00 - 22:59,
full power from
23:00 - 23:59
20% reduction</td><td>Custom scheduling
25% reduction</td><td>Custom scheduling
25% reduction</td><td>Custom scheduling
30% reduction</td></tr>
<tr><td colspan="7">Time of Use (TOU)</td></tr>
<tr><td>Group 4</td><td>22:00 - 06:00
+ weekends
15% reduction</td><td>22:00 - 06:00
+ weekends
15% reduction</td><td>22:00 - 06:00
+ weekends
25% reduction</td><td>00:00 - 06:00
+ weekends
33% reduction</td><td>02:00 - 06:00
50% reduction</td><td>02:00 - 06:00
75% reduction</td></tr>
<tr><td>Group 5</td><td>23:00 - 07:00
15% reduction</td><td>23:00 - 07:00
15% reduction</td><td>23:00 - 07:00
25% reduction</td><td>01:00 - 07:00
33% reduction</td><td>02:00 - 06:00
50% reduction</td><td>02:00 - 06:00
75% reduction</td></tr>
<tr><td>Group 6</td><td>24:00 - 08:00
15% reduction</td><td>24:00 - 08:00
15% reduction</td><td>24:00 - 08:00
25% reduction</td><td>02:00 - 08:00
33% reduction</td><td>02:00 - 06:00
50% reduction</td><td>02:00 - 06:00
75% reduction</td></tr>
<tr><td colspan="7">Time of Use (TOU)</td></tr>
<tr><td>Apartment building</td><td>24:00 - 08:00
20% reduction</td><td>24:00 - 08:00
20% reduction</td><td>01:00-08:00
25% reduction</td><td>01:00-08:00
25% reduction</td><td>2:00 - 08:00
33% reduction</td><td>2:00 - 08:00
33% reduction</td></tr>
</table>

Table A.2: The structures of the second pilot phase, i.e. the first 6 months. The structures and tariffs of the TOU and DLC can be seen as well as the tariffs for the TOU DR program of the apartment building

<table>
<tr><th>Month</th><th>November</th><th>December</th><th>January</th><th>February</th></tr>
<tr><th>Year</th><th>2023</th><th>2023</th><th>2024</th><th>2024</th></tr>
<tr><th>Nr.</th><th>13</th><th>14</th><th>15</th><th>16</th></tr>
<tr><td colspan="5">Load based pricing (LBP)</td></tr>
<tr><td>Groups 1 - 6</td><td>T1:0-2kW (15%)
T2:2-5kW (10%)
T3:5-10kW (5%)
T4:>10kW (+5%)</td><td>T1:0-2kW (20%)
T2:2-5kW (10%)
T3:5-10kW (0%)
T4:>10kW (+10%)</td><td>T1:0-2kW (25%)
T2:2-5kW (10%)
T3:5-10kW (0%)
T4:>10kW (+25%)</td><td>T1:0-2kW (30%)
T2:2-5kW (15%)
T3:5-10kW (0%)
T4:>10kW (+30%)</td></tr>
<tr><td colspan="5">Time of Use (TOU)</td></tr>
<tr><td>Apartment building</td><td>2:00 - 08:00
33% reduction</td><td>2:00 - 08:00
33% reduction</td><td>2:00 - 08:00
33% reduction</td><td>No DR</td></tr>
</table>

Table A.3: The tariff structures during the last phase, from November 2023 to February 2024.

A.2. Results

A.2.1. Peak reductions - average days

Year-Month	2022-11	2022-12	2023-1	2023-2	2023-3	2023-4	2023-5	2023-6	2023-7	2023-8	2023-9	2023-10	2023-11	2023-12	2024-1	2024-2
TOU	6,3%	9,2%	7,9%	19,7%	12,5%	12,6%	12,8%	8,9%	8,1%	12,0%	13,0%	13,2%	-	-	-	-
DLC	3,3%	11,7%	7,1%	-7,0%	6,6%	-18,0%	7,7%	-1,0%	-28,0%	5,4%	13,3%	14,7%	-	-	-	-
LBP	-	-	-	-	-	-	-	-	-	-	-	-	8,5%	14,0%	6,3%	6,5%

Table A.4: An overview of the different load reductions achieved with the three DR programs, based on the average day of each month.

A.2.2. Peak reduction - peak days

Year-Month	2022-11	2022-12	2023-1	2023-2	2023-3	2023-4	2023-5	2023-6	2023-7	2023-8	2023-9	2023-10	2023-11	2023-12	2024-1	2024-2
TOU	2,0%	13,0%	4,0%	18%	16%	15.6%	2,5%	0,0%	0,0%	-2,2%	8,0%	2,3%	-	-	-	-
DLC	1,0%	12,6%	3,0%	-7,2%	-17,7%	-28,0%	2,5%	0,0%	-6,0%	-12,0%	9,0%	2,0%	-	-	-	-
LBP	-	-	-	-	-	-	-	-	-	-	-	-	18,8%	12,0%	15,4%	11,0%

Table A.5: An overview of the different peak reductions achieved with the three DR programs, based on the peaks of each month.

A.2.3. TOU surveys

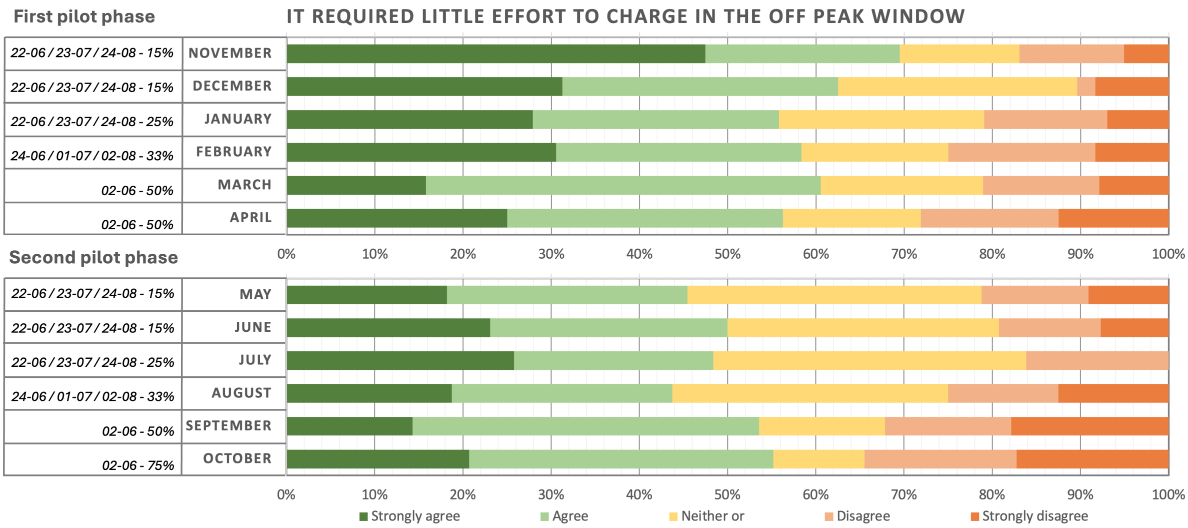

Figure A.1: The results of the survey question on if it required little effort to charge in the off peak window during the TOU DR program.

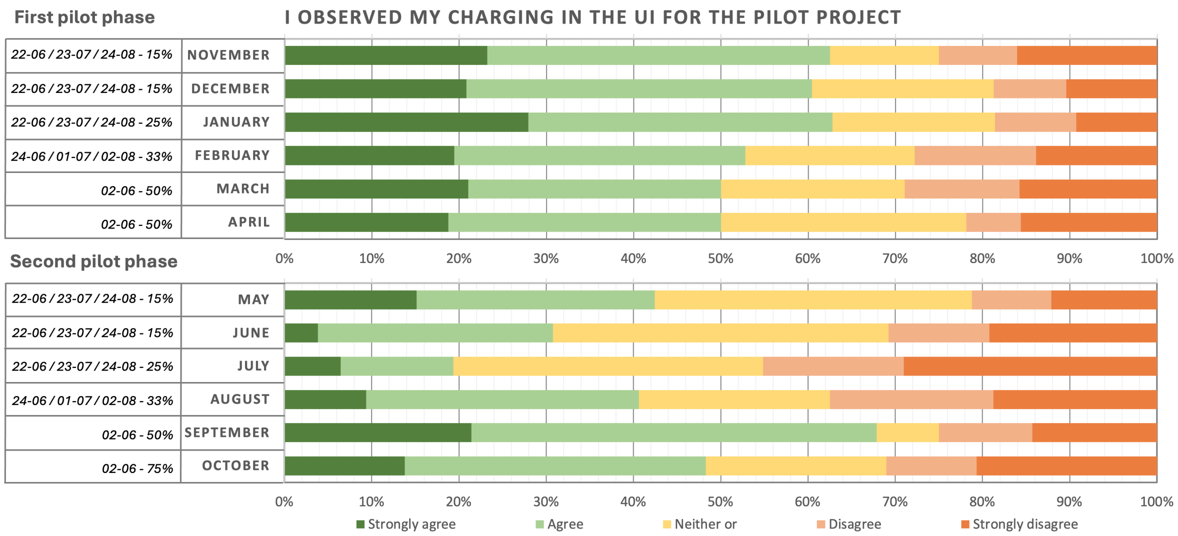

Figure A.2: The results of the survey question on if the participants observed their charging in the project's customer portal during the TOU DR program.

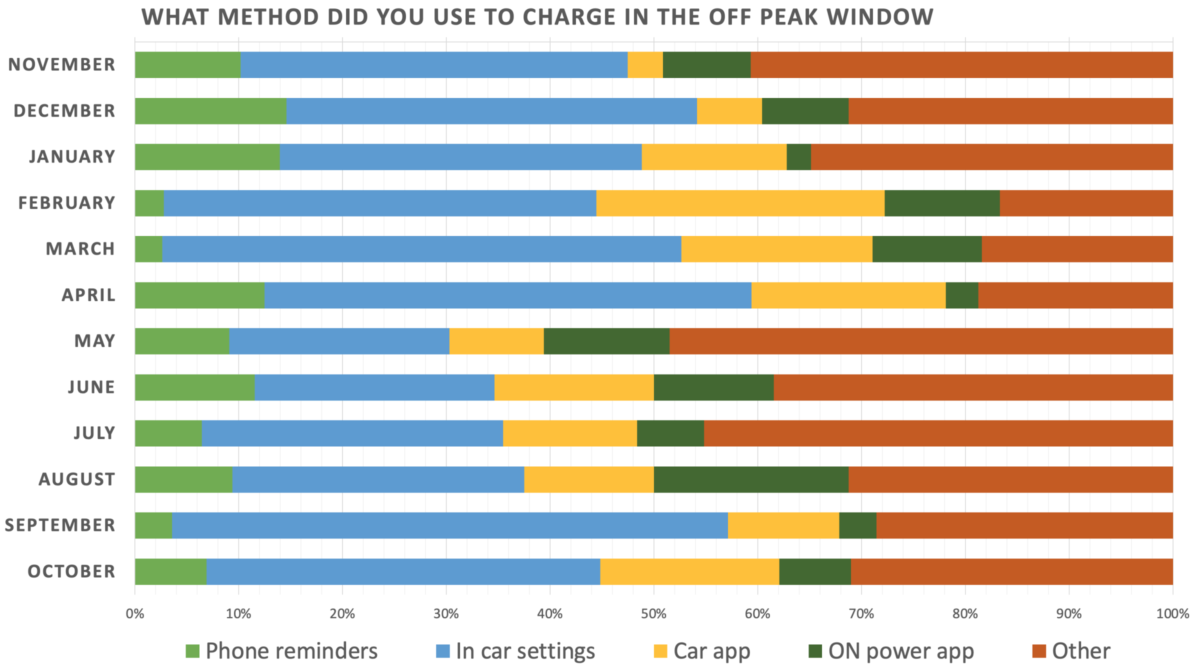

Figure A.3: The results of the survey question on the method the participants used to charge in the off peak window during the TOU DR program.

A.2.4. TOU apartment building - surveys

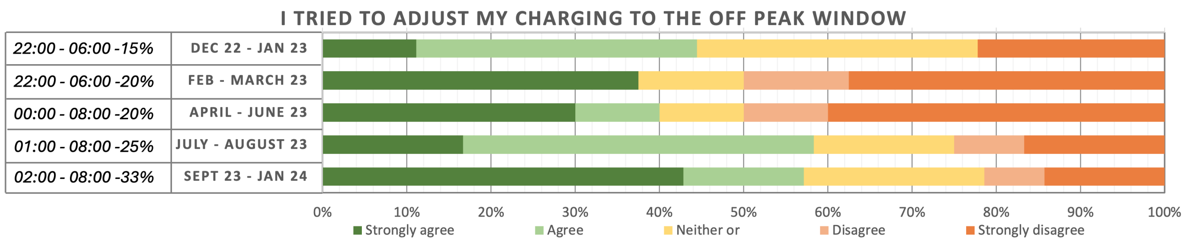

Figure A.4: The results of the survey question on if the participants in the apartment building tried to adjust their charging to the off peak window in the TOU DR program.

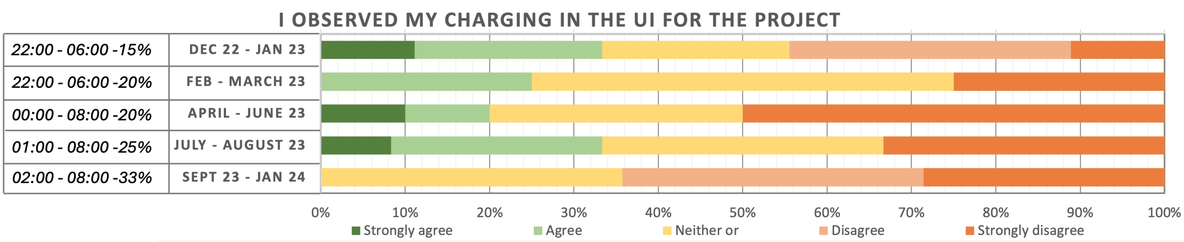

Figure A.5: The results of the survey question on if the participants in the apartment building observed their charging in the pilot project's customer portal.

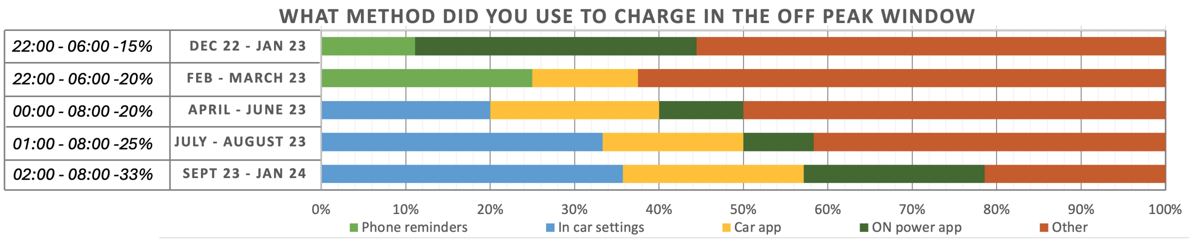

Figure A.6: The results of the survey question on the method the participants in the apartment building used to charge in the off peak window in the TOU DR program.

A.2.5. DLC surveys

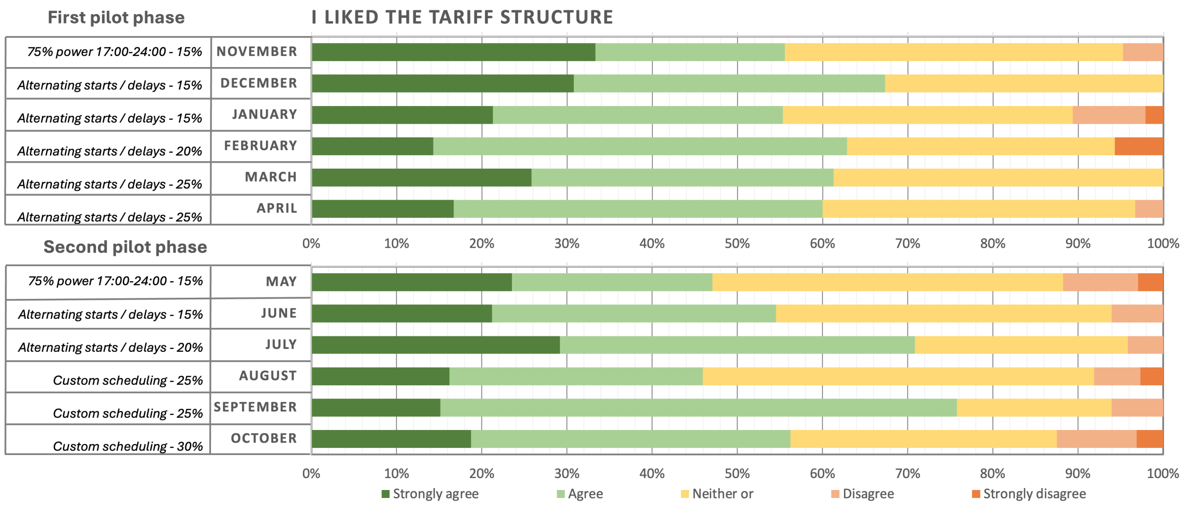

Figure A.7: The results of the survey question on if the participants like the tariff structure during the DLC DR program.

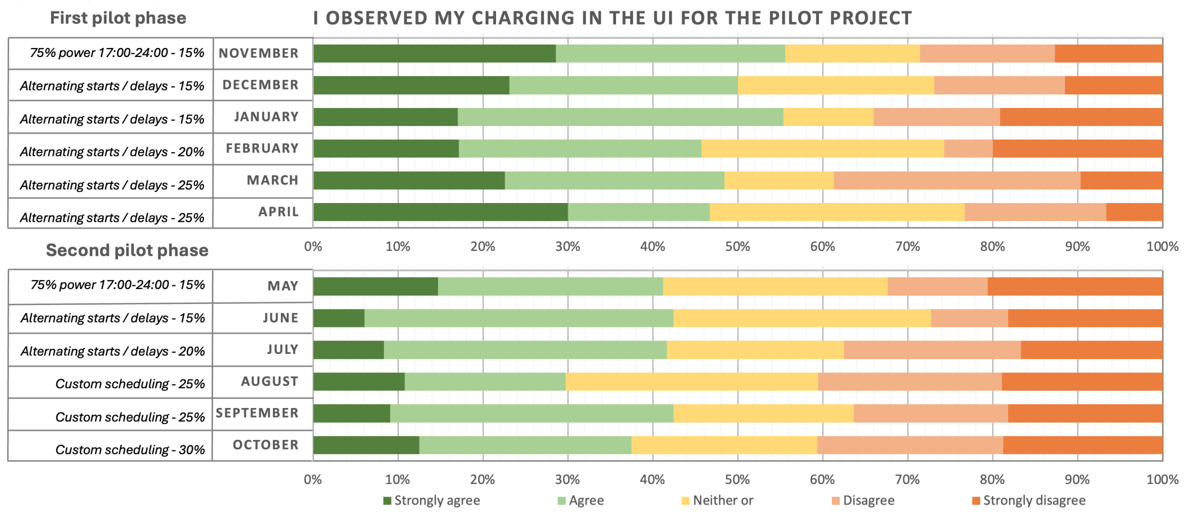

Figure A.8: The results of the survey question on if the participants observed their charging in the project's customer portal during the DLC DR program.

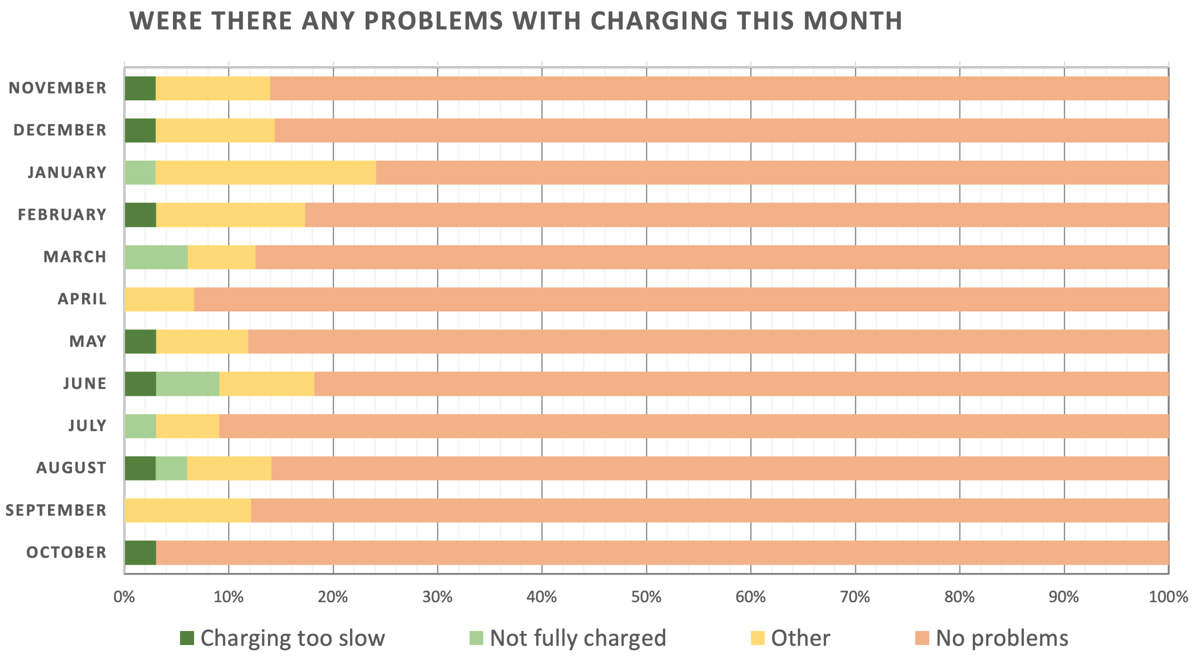

Figure A.9: The results of the survey question on if the participants encountered any problems with charging during the DLC DR program.

A.2.6. LBP surveys

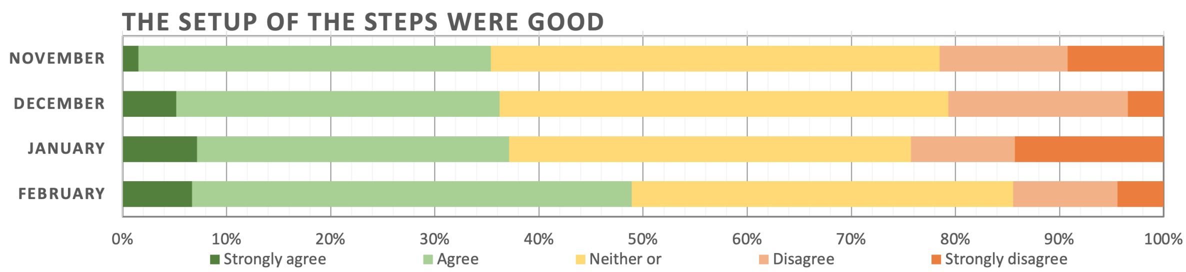

Figure A.10: The results of the survey question on if the setup of the steps were good during the LBP DR program.

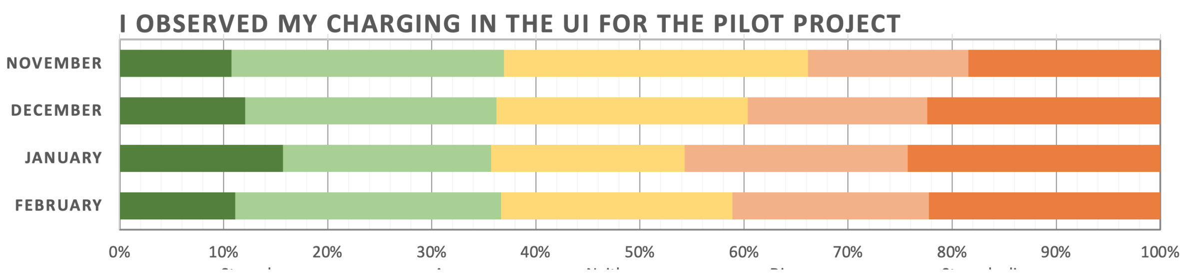

Figure A.11: The results of the survey question on if the participants observed their charging during the LBP DR program.

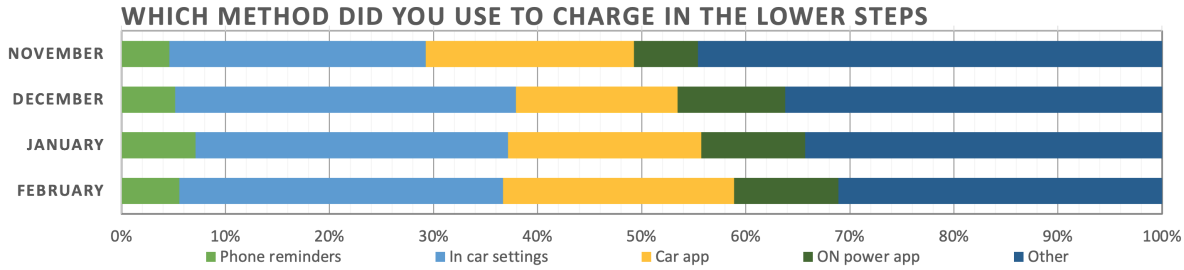

Figure A.12: The results of the survey question on which method the participants used to charge in the lower steps during the LBP DR program.

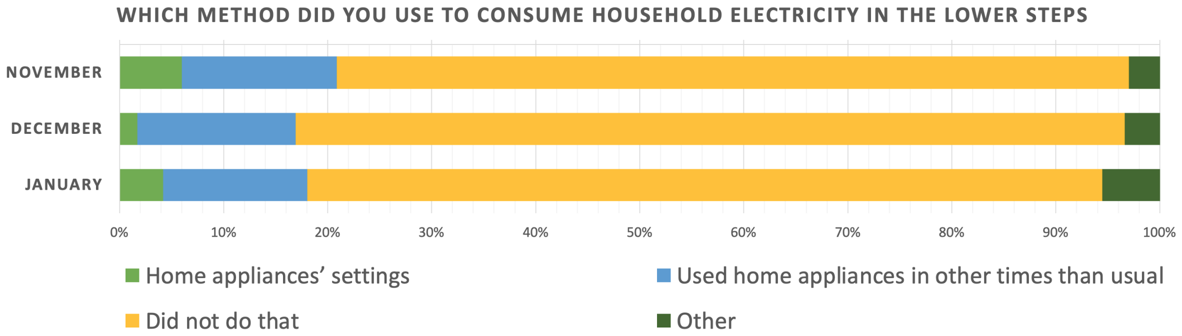

Figure A.13: The results of the survey question on which method the participants used to consume household electricity in the lower steps during the LBP DR program.