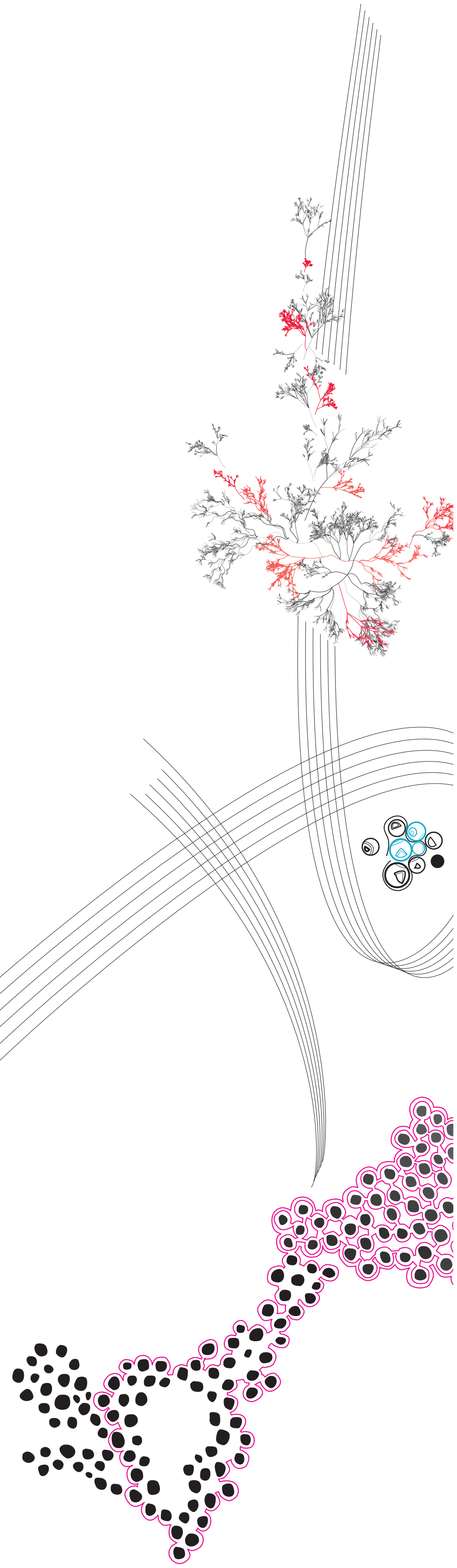

BSc Thesis Creative Technology

Creating Awareness of the Effect of Electric Devices on the Low-Voltage Power Grid: a Dedicated Study on the Dutch Situation

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July, 2024

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Abstract

Climate change is one of the biggest problems facing the world today. To reduce greenhouse gas emissions, it is essential to stop using fossil fuels as an energy source. A more sustainable energy source is electricity, which can be generated renewable. Switching all devices to electric equivalents does however come with a problem. The grid will need to supply way more power, something it does not manage in its current state, especially during peak demand. Expansion of the grid or using smart electronics for better power management both take a long time before full implementation. Another way to tackle this problem is to inform the consumer about these problems, making them aware of the problem and allowing them to make an informed decision about their power use. Therefore, this thesis aims to find an answer to the question: *"How can a communication method be designed to show data from the Dutch power grid to users, to help them understand the impact of their electric devices on the grid?"*

To answer this question, background research was performed including literature research and state-of-the-art analysis. Thereafter, the Creative Technology Design Process was followed, consisting of four phases. Starting with the ideation phase, a stakeholder analysis was performed and a final concept was selected based on the concept generation. Then, in the specification phase, both functional and non-functional requirements were set for the concept. Additionally, further details of the concept were worked out and interactions were analyzed using time sequence diagrams and personas. In the realization phase, the prototype was realized and an intermediate evaluation pitch was performed for experts of the Energy Group. Finally, the evaluation phase assessed the functionality and usability of the prototype through user tests and questionnaires.

Based on these four phases, a prototype tool was developed to inform members of the general population about their impact on the local grid, and how this impact can be reduced. The final prototype is an interactive visualization that displays technical grid data in a neighborhood setting relatable to the user. the final evaluation shows an overall positive response from its participants. Additionally, the visuals and interactivity of the prototype were well received and helped to provide insight into the power grid. However, there is room for improvement. Future work could further develop the tool and look into implementing behavioral changing methods to increase the effectiveness of change in user power demand. Furthermore, more user tests should be performed to cover a bigger portion of the broad target audience to obtain more representative results.

Acknowledgements

First of all, I sincerely want to thank my supervisors Nataly Bañol Arias and Cora Salm for guiding me through the development of this thesis. I want to thank you for all the weekly meetings, time, valuable feedback, and enthusiasm for my project.

Additionally, I want to thank all the experts and participants that have participated in this research. I want to thank them for all their expertise and opinions, which helped to develop the project to where it is today.

Finally, I want to thank my family, girlfriend, and friends for being my support system throughout the project. I especially want to thank Floor Lieverse for all her support, encouragement, and endless help wherever needed. Also, my friends and graduation colleagues, thank you for helping me through this semester.

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Chapter 1

Introduction

Climate change is the long-term alteration in temperature and typical weather patterns of our planet [1]. Earth's climate has naturally changed throughout history, but recently this change has accelerated, with human activities being the main cause. Starting from 1800 [2], our industry-driven society has been heavily polluting the earth by extracting and burning fossil fuels, contributing tons of extra carbon dioxide to the ozone layer and causing the greenhouse effect.

Only since the 1980s have people started to think about the consequences of these emissions. On the 12th of December 2015, the Paris Climate Agreement was adopted internationally to limit global warming and the effects of climate change [3]. As a result of the Agreement, the Dutch government constructed the Dutch Climate Agreement (DCA) [4] in 2019. By the year 2050, Dutch greenhouse gas emissions must be reduced by 95 % compared to 1990 levels, with already a reduction of 49 % by 2030.

To achieve this common goal, multiple sectors need to change their current practices. In the DCA the six most contributing sectors are mentioned: industry, electricity, traffic and transport, agriculture, built environment, and land use. According to the Central Statistical Office (CBS), these sectors contributed 31 %, 19 %, 19 %, 15 %, 12 %, and 3 % of the total greenhouse gas emissions in 2022, respectively [5]. The national vision is to start making processes more efficient, focus on sustainable practices, and encourage innovation. A big part of this solution is to switch to electricity as a main energy source as it can be generated without fossil fuels by using sustainable wind and solar power. This transition is called electrification. Transportation, space heating, and cooking are perfect examples of recent electrification, given the heavily subsidized and growing amount of electric vehicles (EVs), heat pumps, and electric cooking devices such as ovens and cooktops [6], [7], [8].

Although this electrification is a step in the right direction, it also means that the Dutch electrical grid will have to endure much more power in future years. This has proven to be a problem, as the grid in its current state is reaching its capacity limits (grid congestion) [9]. This is a societal problem, causing both industries and smaller consumers to be denied access to the grid, as well as problems for households wanting to charge their cars or heat their homes. Past winter reports showed heat pumps shutting off due to under-voltage [10] during freezing nights. Grid operator Stedin has requested municipalities to turn off public charging points for electric cars between 4 and 9 pm to reduce strain on the power grid during peak hours [11]. These measures are taken with only 20 % of households using heat pumps [12] and about 6 % of all cars being EVs [13] in the Netherlands. If these numbers grow to meet 2030 goals, the grid will certainly need to be reinforced.

Besides this, data on electric cooking devices is not yet considered, as not much is known about them. These have the potential to also make a big impact, as they typically demand between 1 and 2 kW and are used mostly around the same time (e.g., to cook dinner), which also occurs during peak hours.

The solution of the government and the grid operators is to invest money to rapidly expand the grid. However, there are not enough qualified workers to realize this project, and it is projected to take several years, causing this transition to be referred to as “the largest renovation of the Netherlands” [14]. Another way to tackle the problem in the short term, is to make the general population aware of their energy demands and strain on the grid, hoping to spread demand over the day, also known as flexibility. Other devices that can help spread awareness of energy consumption, such as smart thermostats, have proven to effectively lower overall energy use [15]. Therefore, this study aims to design a tool to show the general population their impact on the grid regarding their electric devices (especially electric cooking) to reduce the strain on the grid.

1.1 Research questions

Based on the section above the following research question is formulated:

> *How can a communication method be designed to show data from the Dutch power grid to users, to help them understand the impact of their electric devices on the grid?*

To answer this question three sub-research questions are formulated:

1. What problems are occurring on the grid due to electrification and what share does electric cooking have?

2. What methods or tools are used to present information to the general population and what works best for technical data?

3. Which part of the general population would benefit most from this technical overview?

4. To what extent can the prototype have an impact on the user demand of the electricity grid?

1.2 Outline

This paper consists of nine chapters. chapter 2 focuses more thoroughly on background research, including literature research, state-of-the-art analysis, and field research. chapter 3 discusses the methods and techniques used during the design process. chapter 4 covers the ideation phase and concept generation. chapter 5 specifies the concept from the ideation phase and works out the right visuals, target audience, and contents. Next, the concept is made into a functional prototype in chapter 6. This prototype is evaluated by two user tests in chapter 7. chapter 8 discusses the performed research as a whole, including strengths, limitations, and future recommendations. Finally, chapter 9 provides a conclusion to this research.

Chapter 2

Background research

An essential part of the design process is to gather background knowledge of the topic. The goal of this chapter is to find answers to the first and second sub-research questions, and it consists of four parts: First an introduction to the Dutch energy grid, looking at how it is constructed and what share of electricity is for residential use. This information will serve as a foundation to examine the size of the problems occurring. Secondly, a literature review is used to answer the first sub-research question *What problems are occurring on the grid due to electrification and what share does electric cooking have?*, zooming in on the most harmful devices and their impact on the Dutch grid. The third part focuses on electric Cooking (eCooking) specifically, as it is not covered much in literature, and it reviews its benefits, downsides, and significance to the grid. Following up is a state-of-the-art section that describes some existing communication devices used to show technical data. This chapter concludes with an overview of household devices that significantly impact the grid, and opportunities/challenges of current solutions. Both will be taken into account further in the design process.

2.1 The Dutch Power Grid

The Dutch power grid makes use of 3 different voltage levels: high-, medium-, and low-voltage grids as seen in Figure 2.1 [16]. The high-voltage grid is owned by the government and operated by Tennet, which is the transmission system operator (TSO). It varies between 380 - 110 kV and is responsible for long-distance transportation. The middle and low-voltage are operated by regional distribution system operators (DSO), such as Liander and Enexis. The medium voltage varies between 23 and 3 kV before it is transformed to low voltage for residential use. In the Netherlands, about 22% of total electricity is used in the residential sector, according to 2021 data from CBS [17]. Industry and transportation use 31% and 24%, respectively. Residential electricity is primarily used for heating, lighting, and appliances. Over the last decades, the average residential electricity consumption has been decreasing. This is mostly caused by devices becoming more energy-efficient, homes being better isolated, and people being more focused on saving energy costs.

The low-voltage power lines consist of three-phase wires and one neutral wire. Most Dutch households are connected to a single phase, as this was the standard before 2010 [18]. However, it is unclear exactly how many household three-phase connections there are. A single-phase connection is rated for 25 to 35A (Ampere) via just one of the live wires and the neutral wire. A three-phase connection consists of all three of the live wires, together with the neutral wire, resulting in either a 3x25 or 3x35A connection. Inside the household, this grid connection is split over multiple power groups, rated for a max of 16A each and 230V (so about 3.6 kW). The purpose of these groups is to protect electrical devices from power loss. If one group is consuming more than 16A because of a short circuit or too many devices being connected, the group will pop a breaker and shut down the power on that group. The other power groups in the house remain operational. The groups isolate the problem and prevent a total blackout of the household.

As visible in Figure 2.1, renewable energy sources are connected on multiple levels on the grid, including households at the bottom. This means that the energy flow is no longer in one direction, from power plants to households, but is allowed to flow in both directions, downstream to upstream at any point of the power grid. This bidirectional electricity flow is a huge challenge for the grid because it was not initially designed to operate under these conditions, resulting ultimately in operational issues such as poor power quality, grid congestion, or even power outages [19].

2.2 Literature Review

This section discusses the conducted literature research, which first focuses on what household low carbon technologies (LCTs) influence the LV-grids most, and in what way. The next section zooms in on smart grids, and what technologies this new grid infrastructure uses to deal with the grid's problems.

2.2.1 Impact of High Demand LCTs

Three LCTs come forward when reading literature about the most significant devices impacting the power grid. The first technology thoroughly researched is electric vehicles (EVs). According to Damianakis et al. [20], studying both individual and combined with other LCT cases on different LV-grids, EVs are prone to cause increased power peaks, energy consumption, and voltage deviations, harming the grid. This is backed up by Senol et al. [21]. Both studies found the impact of EVs most significant during winter, as more energy is needed for cabin heating and higher transportation load. The cold weather increases energy consumption by about 30%, as stated by both papers. Senol et al. [21] also mention an increase in harmonics and phase imbalance, similar to what is mentioned by Tavakoli et al. [22]. These harmonics are caused by the conversion of AC to DC voltage, leading to voltage distortions. Phase imbalance is the result of multiple EVs simultaneously charging on a single phase, causing power losses in the distribution transformer. Tavakoli et al. [22] do not take the effects of winter into account, in comparison to the other two papers. They are however the only ones to mention the effects of fast charging. Most of the phenomena mentioned above are linked to the relatively high and short-term demand for charging an EV. Power peaks occur mostly when people come back home and start charging their cars. If this is done with a fast charger, the impact

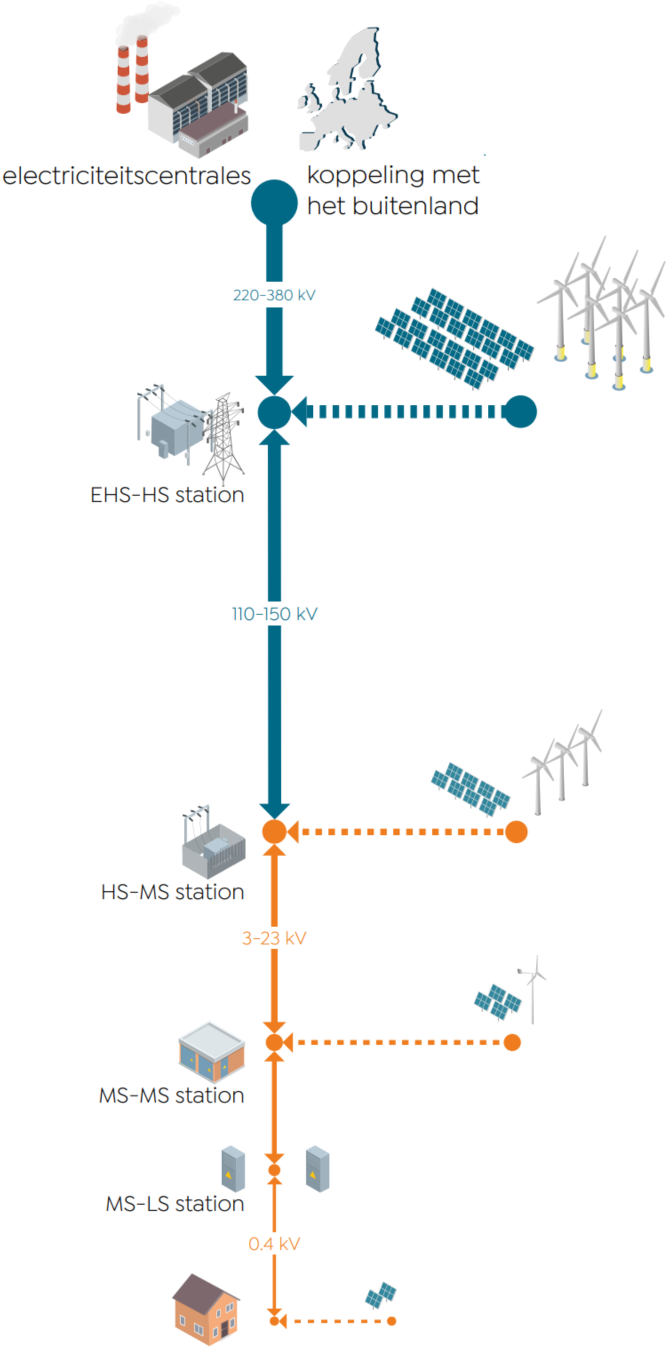


Figure 2.1: Dutch power grid layout

is even bigger. One thing to note is that fast chargers are often connected to the medium voltage grid and do not affect low voltage grid sections.

Another increasingly more common LCT is the photovoltaic (PV) panel. These are also covered in the papers of Damianakis et al. [20] and Tavakoli et al. [22]. Like the EV, PVs cause voltage deviations, but the most significant impact is their intermittent nature. Unlike a traditional power plant, a PV panel is dependent on the sun and therefore hard to predict regarding power delivery. In the research of Olowu et al. [23], the 2015 solar eclipse is discussed, where Germany lost 9 GW (about 20% of their solar capacity) within a 75-minute timeframe. These fluctuations in solar energy supply make it hard to match the demand. As the eclipse blocked sunlight, the PV supply dropped rapidly. This resulted in demand exceeding supply on the grid, leading to a voltage drop. After the eclipse sunlight suddenly returned, the PV generation increased, leading to more supply than demand on the grid and provoking a voltage peak. PV panels are also prone to cause reverse power flow, where the voltage rises so much that current flows backward in the grid over the transformer. Passey et al. [24] mention some negative impacts, such as damage to grid control systems and higher loss of PV-generated power.

The final LCT with significant impact is the heat pump (HP). Most papers focus on air-source heat pumps, which are more common in households. Since a HP can be used for both cooling and heating, they are used frequently throughout the year, both in summer and winter. HPs have a relatively high energy demand, but this is more consistent throughout the day compared to an EV. These long periods of high energy demand cause mostly overloading, even with low penetrations of HPs, according to Damianakis et al. [20]. Heat pumps consume more power during colder periods of the day, such as the morning and the evening. Most are also fitted with an instant backup heater for really cold days, causing unwanted peaks in demand. This is covered by Protopapadaki et al. [25]

2.2.2 Smart Grid Solutions

The power grid is built using the older idea of centralized generation and one-directional energy flow. Since consumers are now prosumers, meaning they both produce and consume electricity, new technologies are needed to deal with this huge demand and generation. These technologies are implemented in the smart grid, which is an increasingly more adopted form of grid infrastructure. In the literature, three main technical parts of a smart grid are mentioned. The first is advanced metering infrastructure. As mentioned by Thakur et al. [26], this consists of smart meters communicating with the DSO, providing real-time data on the demand and status of the network. These meters allow the DSO to monitor the grid better and respond quickly to peak demand. Some processes can even be automated such as detecting and resolving faults, which can reduce downtime, or using machine learning and algorithms to predict consumption and form energy demand strategies. Promises and challenges of these algorithms are discussed by Esfandi et al. [27]. When demand can be predicted correctly the DSO can start up power plants to increase energy supply in time. In case of a detected grid fault, the area could be disconnected from the main grid, isolating a faulty part of the grid. The connected smart grids can be self-sufficient using PVs and batteries.

Another solution within a smart grid is demand-side management. Via communication with connected devices to the smart grid, such as the meters, EV chargers, and HPs, the DSO can manage the consumption of these devices. According to Xiang et al. [28], smart charging strategies reducing simultaneous charging times during a peak load period can reduce network expansion investment by 60-70%. This is also backed up by Thakur et al. [26], stating the benefits of flexible consumers in comparison to the still very inflexible power generation plants such as big fossil fuel or biomass steam turbine power plants. The ability to read and control the demand of (a part of) the grid leaves it vulnerable to cyber-attacks. Multiple research articles about smart grids mention cyber security, with Alsuwian et al. [29] stating it is the top power industrial security target. Centralized grid management systems can also greatly benefit the quality of power on the grid. Both studies of Damianakis et al. [20] and Tavakoli et al. [22] look at the benefit of using PVs and EVs together, to balance the voltage level of the grid. In an ideal situation, EVs will be charged during the afternoon as PV generation is at its peak. Combining these technologies can cancel both technologies' voltage fluctuations and harmonic generation, resulting in a stable grid.

Last is energy storage. This can consist of larger batteries powering the grid during high demand or taking up energy generation from renewable sources such as PVs. A new idea is vehicle-to-grid (V2G) technology, where EVs start to function as mobile batteries for the grid when plugged in. A benefit of these local batteries mentioned by Esfandi et al. [27] and Thakur et al. [26] is the very fast demand response times to fluctuating demand or generation from the LCTs. This means that if demand suddenly peaks, these batteries can supply enough power before centralized power plants can increase their power output and take over, keeping supply and demand in balance. The local placement of these batteries reduces transport costs and losses, increasing power efficiency. Esfandi et al. [27] also mention the downsides of these batteries, such as high implementation cost, the need for very secure and precise control, and the potential reduction in battery life with poor energy management systems. This is especially a problem for V2G technology, as large parts of these costs are for the EV owners. Leippi et al. [30] go further into the participation of EV owners to demand response with V2G technology, stating that most people do not want to risk battery degradation and decreased driving range, even when receiving monthly compensation for it.

2.3 eCooking

In the literature not much is known of eCooking. However, it is mentioned briefly in multiple articles and the report of Netbeheer Nederland [16]. Here different amounts of electric cooking together with EV charging are compared to get insight into the necessary increase of grid infrastructure. The report suggests that eCooking has a fair share of grid impact, but eCooking devices are not mentioned on their own.

Due to the lack of literature on this subject, an attempt to magnify the impact of eCooking devices on the power grid is made in this section. Some of the findings and discussions included in this chapter are supported by the knowledge of one expert in the field (an employee of Alliander, the parent company of the Dutch DSO Liander), via an interview (see Appendix B).

According to Eurostats figures of 2021 [31], 6% of Europe's electricity is used for electric cooking. Here it is also stated that about 50% of energy used for cooking is electric. Zooming in on the Netherlands, 35% of households have electric cooking devices. This is backed up by the Dutch CBS [32], stating that about four in ten households use electric cooking devices in 2021. Adding to this, the interest and adaptation of eCooking have grown constantly over the last few years, with another 13% of people considering their next cooktop to be electric within the next two years [32]. This means the current eCooking penetration will be even higher.

This growth is caused mainly by government subsidies and initiatives, but eCooking also has other benefits. Compared to natural gas, electric cooking equipment is better for health, as it does not burn fuel creating fumes harming air quality. If eCooking is compared to other unclean cooking fuels such as kerosene and coal, used by about 2.3 billion people worldwide, the difference is even bigger. The World Health Organisation (WHO) [33] estimates about 3.2 million people die annually because of the health risks cooking on fuels causes. These fuels are mostly used in middle- to low-income countries and do not apply to the Dutch case. Still, the comparison shows how important it is to have access to clean cooking fuel, and natural gas is not as risk-free as eCooking is. Another benefit of some eCooking technologies such as the induction cooktop is the fact that the plate itself does not heat up, so one cannot burn themselves on it. This improves safety in the kitchen, especially compared to the open flame of a gas cooktop.

Costs of eCooking

An interesting difference is found in the cost of eCooking compared to the gas-fueled equivalent. Considering the price of a kWh of electricity being lower than one m^3 of gas does not necessarily mean eCooking is cheaper. A study by Bilich et al. [34] constructed a list of energy needed to cook food in Haiti using an electric pressure cooker (EPC) and induction stove in 2020. A variety of foods, such as stews, pastas, and rice were cooked for a year, resulting in an average of 1.58 kWh per day for induction and 0.79 kWh per day for EPC. The food cooked in Haiti differs from that in the Netherlands, as in the Netherlands mostly stir-fried foods are made, but it can be seen as a ballpark figure. Considering the current average Dutch electricity price of € 0.35 per kWh [35] means eCooking costs between € 0.28 and € 0.55 using an EPC or induction stove respectively. Compared to gas, knowing that 1 m^3 contains about 9.8 kWh of energy, cooking with gas is about 60% efficient, and 1 m^3 of gas costs €1.38, this same cooking on a cooktop would cost €0.36 instead of €0.55 making cooking on gas cheaper. This contradicting fact was discussed with the expert, whose calculations had the same outcome. His explanation for this was the pricing of electricity in the Netherlands. For example, the price of 1 kWh straight from a windmill or solar park might only cost €0.10, but the DSO will charge the same amount of money it costs to produce 1 kWh using a gas-fueled power plant, even if 80% of energy produced at a given moment comes from renewable sources. This makes the price of electricity dependent on the price of gas. He mentioned the difference with neighboring countries, where the electricity price is calculated on the actual costs of producing it, making it less connected to the price of gas. Over the last few years, the price of gas has seen big fluctuations, especially around the start of the war between Ukraine and Russia. If the price of electricity can be disconnected from the price of gas, only depending on actual renewable production costs, the costs of cooking and heating using electricity would be greatly reduced. In that case, only the weather influences the price of electricity, which can be omitted using battery storage.

Grid Impact from eCooking

Another important aspect of eCooking is its impact on the grid, with the most significant impact being the increased evening power peaks on the grid with higher penetrations. To investigate this, the tool ALPG developed by G. Hoogsteen, which is an open-source artificial load profile generator was used [36]. The tool creates an average load profile of ten households per day for over a year and incorporates real device data of EVs, PVs, HPs, and eCooking equipment. For these examples the following penetration rates were set: 10% EVs, 30%PVs, 20% HPs, and different levels for eCooking as seen in Figure 2.2. These values follow the current penetrations of these LCTs in the Netherlands, rounded to the nearest 10% [37], [38], [12]. The induction cooktop is rated at 1.8 kW of power. As each simulation generates a random energy profile, demand during the rest of the day differs each time. The line from 0% eCooking penetration would apply to a neighborhood cooking on gas, and the 100% line from one with all houses on eCooking. The current situation, with 40% eCooking penetration, is included as a reference. From the graph in Figure 2.2 the difference in power peaks between 17:00 and 20:00 is visible, especially for 100% eCooking penetration, with an overall energy increase of 6.7% between 0% and 40% eCooking penetration. This is similar to the 6% that was found by Eurostats [31]. When the current 40% is compared to a potential 100% penetration rate, the increase of energy used is about 7.9%. At first sight, this increase does not seem significant, but the fact that the power demand only seems to increase between 17:00 and 20:00 is interesting. This highlights that eCooking occurs mostly in this time slot during the entire year, and always adds extra power demand to the power peaks already experienced by the grid. However, the amount of power needed for eCooking is way less than the amount of power needed for charging an EV. This is highlighted in Figure 2.3, where only a single day is considered for both a household with only eCooking devices, and a household with only an EV. In this graph, a power peak of about 2kW is demanded for eCooking between 18:00 and 19:00, and the peak of 11kW is demanded for an EV between 17:30 and 19:30. The peak of the EV is way bigger than the one of eCooking, and will therefore impact the grid significantly more. Yet, this peak could be shifted and is not always at the same moment of the day, which is not the case for eCooking devices.

The graphs were discussed with the expert, and he recognized the data. eCooking does add to the evening peak, which is the worst time of day for the grid. EVs would be more averaged out over the day, or in a wider time range in the evening, as people might plug their car in later in the day or not charge their car every day. This is referred to as chaotic behavior, as not everyone does the same thing at the same time. This level of chaos is higher for EVs than for eCooking, as EVs are likely to charge over a wider time range of the day than eCooking. Alliander once ran a test where an entire neighborhood baked a pizza and charged EVs at exactly 7 pm, which resulted in a local power outage [39]. In a real-life scenario, people do not use the same appliances at the exact same time. Some people arrive early from work, or later as they deal with traffic, meaning they do not plug in their EVs at the same time.

Another impacting factor is the phase imbalance eCooking devices may cause. The average induction cooktop uses easily more than one power group can provide, which is about 3.7 kW. To solve this, it can either be connected to at least two power groups via a Perilex connector or a three-phase connection. Induction cooktop manufacturers make sure their cooktops can work with both connections. This is done by providing each cooking zone with its own AC-to-DC converter and thereafter a DC-to-high-frequency-AC inverter and connecting a single phase or group to each cooking zone. It would be more efficient to use only one of both these components and connect all zones to it, but this can only be done for a three-phase connection. When such an induction cooktop is connected to three phases, often the biggest and most frequently used cooking zone is connected to phase 1, causing phase 1 to experience more peak power than the other phases. Adding to this phase imbalance problem, the multiple con- and inverter construction causes more harmonics on the grid, as these components are known to do this.

Conclusion

Not a lot of literature covers eCooking. Yet, eCooking is becoming more popular and adopted. Compared to the most popular cooking fuel in the Netherlands, which is gas, it has significant health and safety benefits. Because electricity can be generated sustainably, the government stimulates households to switch to eCooking. This has proven to be successful as about 40% of households have adopted it and more are expected to consider it. Besides these benefits, the cost of cooking on electricity is not yet competitive with gas prices, but this may change in the future due to an increase in renewable energy generation, internationally connected grids, and technical advances. Regarding the grid, an increased penetration of eCooking devices causes higher power peaks between 17:00 and 20:00. Power peaks are small compared to charging an EV, but the fact that cooking occurs every day results in a significant increase in average daily power peaks measured over a year. The way eCooking devices such as the induction cooktop are constructed and connected introduces phase imbalance problems and harmonics on the grid. For these reasons, eCooking must be considered as a significant grid impacting LCT. However, since cooking is a primary necessity and a habit, low consumer flexibility of this LCT is expected and not much can be done to change when people cook. Some advancements that could be made considering eCooking is to provide the technology with smart control and battery storage to deal with this inflexibility. To provide an overview of the LCTs considered in this background information chapter, Table 2.1 is constructed.

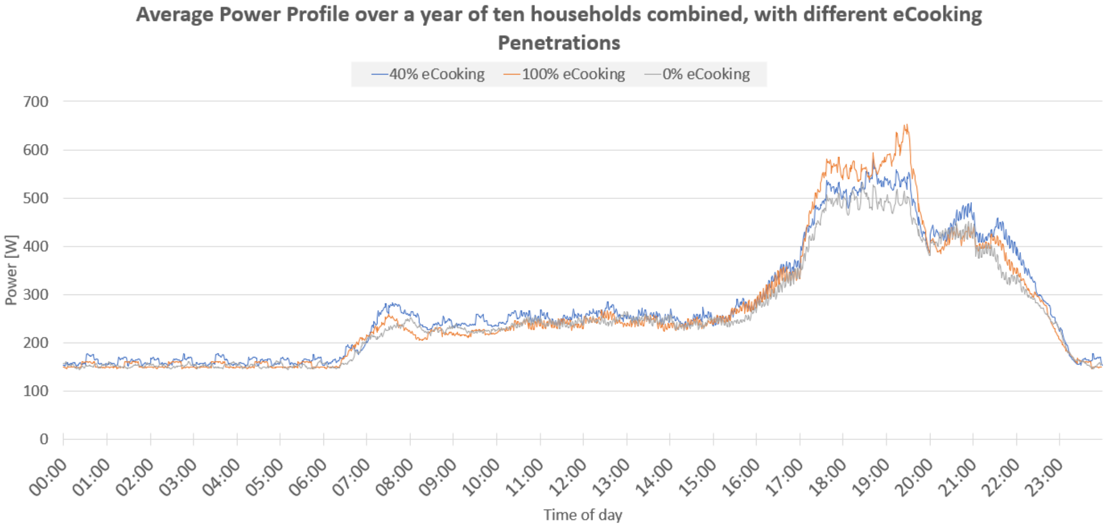


FIGURE 2.2: Average power profile over a year of ten households combined with different eCooking penetrations

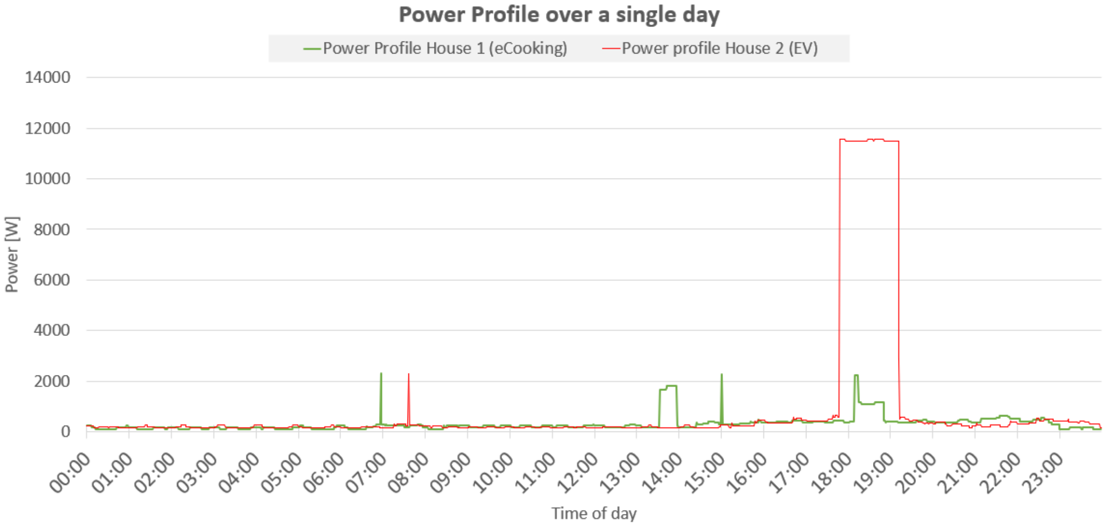


FIGURE 2.3: Power profile of a single day, comparing an only EV household vs an only eCooking household

LCT	**Impact on Grid**
EV	- Voltage drop - Cable and transformer overloading - Harmonics due to AC-DC converter
PV	- Voltage rise - Energy backflow - Harmonics due to DC-AC inverter
HP	- Voltage drop - Cable and transformer overloading - Harmonics due to AC-DC converter
eCooking	- Peak power in the evening - Phase imbalance - Harmonics due to AC-DC converter

Table 2.1: Overview of significant LCTs and their impact on the grid

2.4 Preliminary Household LCTs

Based on the findings of subsection 2.2.1 and section 2.3, the following electric devices have been chosen as the most significant household LCTs impacting the Dutch power grid: EV, HP, eCooking, and PV. An overview of these devices and their impacts are presented in Table 2.1.

2.5 Communication Methods for Technical Data

This section aims to formulate an answer to the second sub-research question, which is: *What methods or tools are used to present information to the general population and what works best for technical data?* Since the general population of the Netherlands is a large variety of people, communicating technical data to a non-technical audience is essential in this project. Lots of research has studied effective methods to tackle this problem, with the most interesting techniques listed below [40].

The first method is to provide context to the audience. Explain why things are happening and focus less on how it exactly works. As the user and the producer of a tool can differ a lot in technical knowledge, the producer has to level with the knowledge of the audience. When context is provided on why something works as it does, the audience can relate to it and better understand what the product aims to do.

Visualizations are another great way to communicate technical details to a general audience. Instead of only listening to a story and trying to think of what is meant by the speaker, a visualization can help provide a reference to which the story can be followed. It uses more senses to interact with data and makes it more relatable. Physicalization goes one step further and lets the audience physically feel and experience the data firsthand, creating more interest and making it easier to understand.

A third effective method is to avoid assuming the audience knows what the data represents and help them by providing additional basic information. The target audience of this project is not likely to know industry-specific terms, and therefore these should be avoided. Together with providing context and visualizing the data, an easy explanation or extra information improves the audience's ability to understand this technical topic.

2.6 State of the Art on Energy Consumption Devices

In this section, existing technologies used to communicate technological information to the general public will be highlighted. First is Toon, the smart thermostat of Eneco, which provides energy consumption data to Eneco's customers, as well as the option of smart energy consumption. As these customers are a large mix of different people, it serves as a good example of how to inform people about their energy demands. Homewizard is similar to Toon as it provides energy demand data to its users, but is focused on spreading awareness and does not have extra features for smart control. Both technologies tackle the problem of educating people on their energy consumption and can provide valuable answers to the second sub-research question. Another program related to this report is the Landelijk Actieprogramma Netcongestie (LAN), aimed at solving grid congestion on multiple sides of the problem. It serves as a roadmap for the energy transition. Since the other technologies in this state-of-the-art review used for providing energy consumption data and energy saving only consider the connection of the user, they lack any information on a system level such as congestion, power peaks, and probability of local blackouts. This information on the status of the grid is very important for the DSOs and needs to be included in such communication technologies.

2.6.1 Toon Smart Thermostat

Toon is the smart thermostat made by Eneco, who developed this thermostat to give their customers insight into their energy consumption, on both gas and electricity, and a way to control this remotely or via custom schedules [41]. The device is linked to the customer's Eneco energy contract and warns them when consumption is higher than estimated. The focus of this product is on energy saving, achieved by providing the consumer with energy usage per day/week/month and how much they paid for this energy. Toon itself is the screen shown in Figure 2.4, which can be mounted on the wall as a normal thermostat. Via WiFi it is connected to the central boiler and smart electricity and gas meter. This does require these devices also to be compatible with Toon and have WiFi capabilities. Eneco uses a monthly subscription to access Toon's data, which is €4.50, with the device itself costing €275. Toon users generally like the product because of the ease of use and providing them with a good insight into their energy consumption. Smart features like geofencing, sensing when the user leaves the house after which it stops heating the house, improves their experience. Compared to other popular smart thermostats Toon excels in informing and involving the user on energy saving, rather than autonomously doing this for them. One such example is the Nest learning

FIGURE 2.4: Toon smart thermostat by Eneco

thermostat from Google. Toon is a great example of visualizing data on its screen for the user to understand, and because it shows live consumption data of the users own home the data is relatable to the user. The only downsides is that Toon is only available for Eneco customers, and the fact that it requires a monthly subscription for the best features.

As found in the study of Lee et al. [15], smart thermostats can provide significant energy savings of 10-15% on average according to manufacturers, academic studies, and the US Department of Energy. However, this study also found that smart thermostats tend to start at roughly the same time in the morning to heat the house back up again, which causes load synchronization. This behavior increases the daily peak heating electrical demand. They highlight the importance of widespread energy management initiatives, such as the smart thermostat, to not only look at the local energy savings but also at the effects at the system level.

2.6.2 Homewizard

Homewizard is a company that specializes in helping people monitor their energy consumption at home, covering electricity, water, and gas [42]. They aim to help people understand how much and where energy is consumed, so they can start taking measures to save money. To do this, they manufacture sensors, displays, software for devices, and smart sockets as seen in Figure 2.5. Some of their main benefits over competitors are their relatively low pricing and the simple yet insightful way of displaying the technical data. Similar to Toon, homewizard povides live visual representations of ones energy consumption, making it relatable to their situation and easier to understand the data. They are different from a smart thermostat, as their software only monitors and does not use actuators for control.

FIGURE 2.5: Homewizard products

2.6.3 Landelijk Actieprogramma Netcongestie (LAN)

The Dutch Landelijk Actieprogramma Netcongestie (LAN), or national action program grid congestion, is an action program focussing on grid congestion [9]. It was formed in 2022 when two provinces had to reject all new organizations in need of a grid connection as the grid was too congested. LAN has three main goals:

- Rapid realization of grid expansion
- Stronger direction towards better utilization of the grid
- Increasing flexible capacity through public and private actions for smart solutions

The first goal is focused on streamlining the construction procedures needed for new equipment and grid expansion. The government, DSOs, and industry work together in these projects to ensure improved procedures and faster realization. Still, this means grid expansion will take multiple years, and thus the other goals are necessary to improve energy and grid capacity usage. To improve grid utilization, DSOs are allowed to demand different organizations to use more or less electricity at a certain time of day, in exchange for money (i.e., provision of flexibility) [43]. This allows better planning of energy use, so the grid is more equally loaded during the day and more organizations can be connected. The DSOs also inform them on how to make better use of the grid. The report states that it is essential that all parties involved are aware of the rules on congestion management. Currently, this is not the case as grid congestion has never been a problem before. Some ways to deal with better utilization of the grid is to charge extra for electricity during peak demand and to make priority lists of organizations based on energy profiles and importance. The last goal is also centered around improved energy use. Since renewable energy sources are of intermittent behavior, demand needs to be flexible as well. The challenge is to match demand with local generation, energy use, and energy storage to keep the electricity price low and make grid use future-proof. This flexibility is especially hard for organizations that use a lot of electricity on tight schedules. LAN aims to help them adapt to a flexible energy supply, providing favorable rates and conditions to those who adapt. It is essential to set up clear rules for energy use, to educate organizations and households on their energy use, and to support smart solutions to increase flexible capacity.

Important to note from LAN is the fact that energy use will react to supply, as opposed to supply reacting to demand. This is because of the intermittent behavior of renewable energy sources. Adding to this, organizations need to be informed to adapt to flexible energy demand, as this can contribute to congestion management and save a lot of money.

2.7 Conclusion

Based on the information in this background research, a couple of conclusions can be formulated. First, the implementation of grid expansion and smart grids will take multiple years. Consumers need to be aware of their energy use and its impact on the grid to deal with congestion and allow DSOs to connect more users. Second, the LCTs of a household with the most impact on a grid are EVs, PVs, and HPs. eCooking devices only consume peak power for a short period of time, and these peaks are therefore less significant compared to the peaks of HPs and EVs. Yet, since people generally cook only for a few hours in the evening, these peaks are more concentrated at this time of the day. This means that their impact on the grid must be considered in this project. Finally, devices such as Toon and homewizard can improve user awareness of energy use and significantly reduce their consumption. Their visualization of one's consumption data and situation helps the user understand how to improve their consumption behavior and relate it to their situation. However, These devices only focus on energy savings for the consumer and lack a system overview, insight into power peaks, or information on the status of the grid as mentioned by LAN. This information will be used further in the design process of the communication method to be proposed in this graduation project.

Chapter 3

Methodology

For this graduation project, the Creative Technology Design Process will be used as the main design method [44]. This process was developed by two professors of the bachelor program Creative Technology, Mader and Eggink. The process consists of four phases: the ideation phase, the specification phase, the realization phase, and the evaluation phase. Each phase will form a chapter of this report and is explained here.

Each phase of the process starts with a divergent process, followed by a defining convergent phase. The idea of a divergent process is to explore the design space, focused on quantity and not necessarily quality [45]. Various methods can be used for this. The convergent phase is used to analyze all ideas found and qualify the best ones [45]. The entire design process has two spiral phases, the ideation and specification phase. All processes and phases are visualized in the Creative Technology Design Process model, to be seen in Figure 3.1.

3.1 Ideation

The ideation phase is the first step of the design process and starts with the design question [44]. For this report, the design question is equal to the research question. Ideation is a spiral phase, consisting of user needs/stakeholder requirements, technologies, and creative ideas.

To investigate stakeholder needs, background research was conducted as seen in chapter 2. Together with a literature review, an answer was found for the first sub-research question, which is formulated: "*What problems are occurring on the grid due to electrification and what share does electric cooking have?*". A power-interest matrix will be constructed to get an overview of stakeholder requirements. The background knowledge also covered existing methods to communicate technical data to a less technical audience. In the ideation the target audience will be further defined and one of the important stakeholders of this project. The state-of-the-art analysis was used to investigate different technologies similar to the goal of the main research question, and answered the third research question on "*What methods or tools are used to present information to the general population and what works best for technical data?*". Here, both strengths and weaknesses were found, useful for the further design process. Further ideas for useful technologies will be gathered

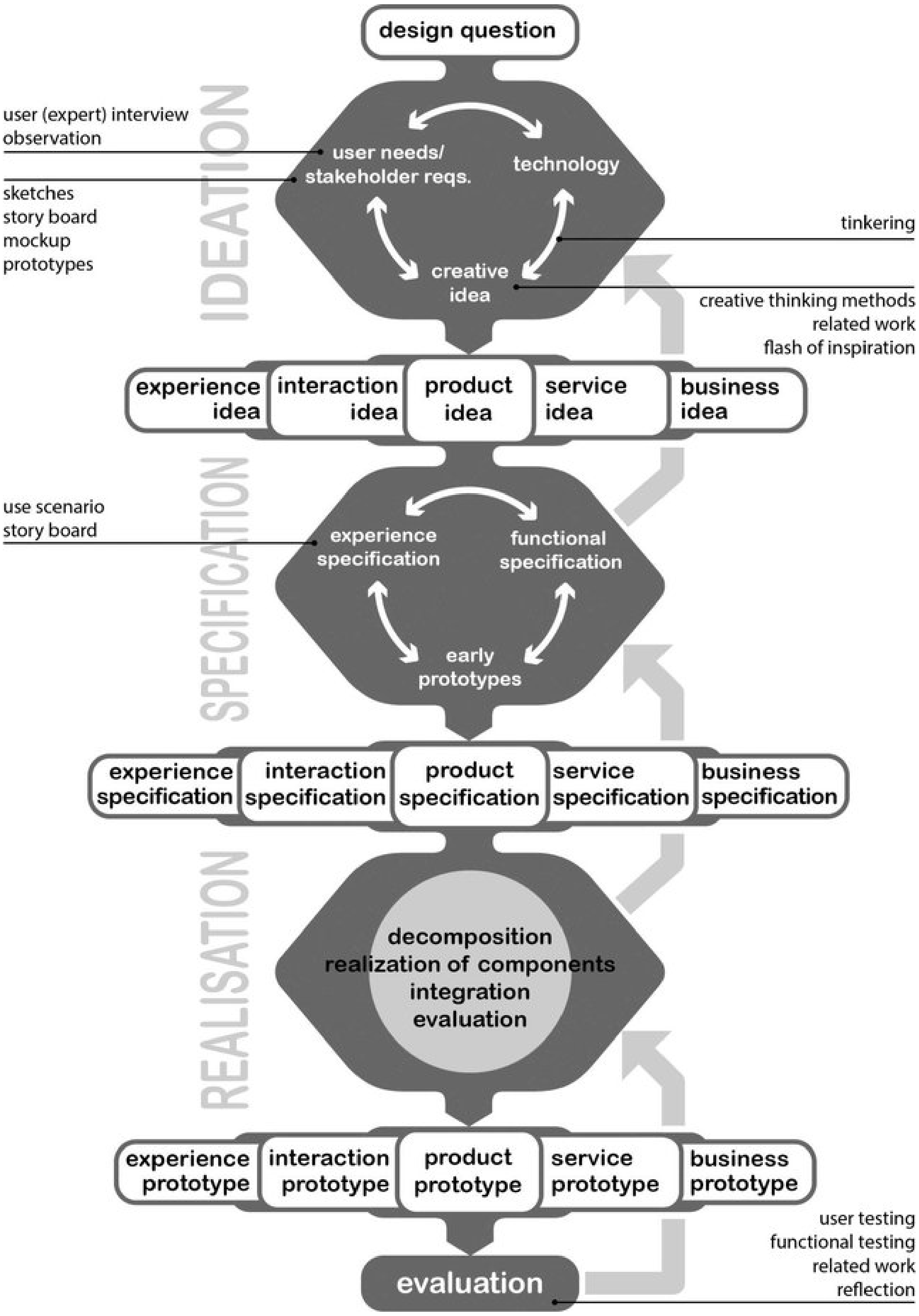


Figure 3.1: A Creative Technology Design Process

using some tinkering. A couple of brainstorming sessions with different techniques will be used To create a list of ideas and concepts. The first session will provide an overview of the design space, and the second one will help generate ideas and use cases for different technologies. Finally, some concepts will be worked out and the chapter ends with the best concept and a list of requirements for it.

3.2 Specification

The second step in the design process is the specification phase [44]. This phase is characterized by the use of numerous low-fidelity (lo-fi) prototypes and an evaluation and feedback loop to explore the design space further. The goal is to evaluate the functionality of a prototype together with the user and get to know the user experience, after which a new prototype can be made and tested to implement all feedback.

In this phase, the ideas from ideation will be analyzed by constructing a list of requirements, whilst categorizing them using the MoSCoW method [46]. Using this list the final concept will be specified by content, design, and back-end coding. Designs will be made as lo-fi prototypes and adapted using the feedback of the supervisor and fellow students. To create the right user experience, time sequence diagrams [47] and personas [48] will be used.

3.3 Realisation

In the realization phase the proven methods and product specification from the specification phase can be used to realize a high-fidelity (hi-fi) prototype [44]. For this hi-fi prototype, the final components will be selected and integrated. Evaluation within this phase is used to validate whether the end product meets the subsequent specifications.

In this phase, a final prototype will be made. The process started with creating the front end similar to the one from the designs of the specification phase. First, the user interface is implemented, then the neighborhood, and finally the graph. Alongside this process, the back-end functionalities are created for interaction with the tool. An intermediate evaluation pitch was held to prepare the tool for the first user tests. The results from these user tests were used to improve the tool to a final prototype for the final user tests.

3.4 Evaluation

The evaluation phase is used to validate the functionality and user experience of the final prototype [44]. This phase focuses mostly on whether all the original requirements identified in the ideation phase are met.

In this phase, user tests will be conducted to validate the usability of the final prototype from the realization phase. The tests will be performed using participants who represent the target audience, ranging in technical knowledge level, age, and LCT devices owned. The interaction with the tool will consist of observations by the researchers, and feedback from the participants via a questionnaire. Finally, the results will be summarized.

Chapter 4

Ideation

4.1 Stakeholder Analysis

This section discusses the different stakeholders that play a role in this project. First, an explanation of stakeholders is given. Thereafter, relevant stakeholders are categorized as primary or secondary stakeholders, To conclude this section a power-interest matrix is presented.

4.1.1 What are Stakeholders?

A stakeholder is either an individual, group, or organization impacted by the outcome of a project or a business venture [49]. They have an interest in the success of a project and can be part of or external to an organization sponsoring it. The decisions or support of a stakeholder can have a crucial impact on the project, both positively and negatively. Since multiple stakeholders can be involved with the project with different requirements, managing them is essential. Stakeholder mapping can help with identifying the key stakeholders of a project so their needs can be prioritized.

Stakeholders in a project can be divided into two categories: primary and secondary [50]. Primary stakeholders are those directly involved with the project's results. They have a strong interest in its success and can significantly influence its progress. Secondary stakeholders are less directly connected to the project and may have less interest in it. However, they can still influence the project's course.

A good method for stakeholder management is to start with making a list of these primary and secondary stakeholders, after which a visual overview such as a power-interest matrix can be made. This matrix has 4 quadrants, indicating the course of action for these stakeholders [51]. The quadrants are:

- **High-power, high-interest**: These stakeholders are decision-makers and have the biggest impact on the project. They need to be closely managed.
- **High-power, low-interest**: These stakeholders need to be kept in the loop. As they yield power they need to be handled with caution and stay satisfied.
- **Low-power, high-interest**: These stakeholders need to be kept informed to make sure no major issues arise. They are often helpful with the details of the project.

- **Low-power, low-interest**: These people must be monitored, but are of least interest, and not much time must be spent on them.

4.1.2 Primary and Secondary Stakeholders

For this project, the primary and secondary stakeholders can also be identified, as listed below.

Primary Stakeholders

The most obvious primary stakeholder of this project is the end user, who will be using it to get more insight into the status of the grid and their own energy and power usage. Their feedback will be most valuable and their willingness to work with the eventual device will be of great impact and influence to the project. User testing will monitor them closely and is beneficial for the product.

Another primary stakeholder is the DSO, as energy demand and peak power influence the grid. Their data on the grid is needed to provide accurate readings, and the results will be of importance to the functionality of their grid. This means they are of high interest and high influence and must be closely involved in this project.

Similar to the DSOs, the energy providers are of high interest to this project, since better use of the grid would mean more energy consumers can be connected. This would allow the energy suppliers to sell more energy via the existing grid. They would be of lower power than the DSOs, as less of their data is required to make the project work. However, since a lot of money can be made by selling this extra energy they will be managed closely during the project.

Investors of the project will be the last primary stakeholders. Currently, this project is a graduation project, but when it is released on the market it is essential to have enough investors to cover the costs for this full-scale release. They are of high influence, but medium interest. Their main interest is profit and therefore must be kept satisfied with the aim of the project.

Secondary Stakeholders

Competitors are often secondary stakeholders, as their main interest will be what the product does better than theirs. Examples are Toon of Eneco and other smart thermostats aimed at involving the end user in reducing energy demand. They have low interest and influence on the project but must be monitored.

Another secondary stakeholder is the government. They made the climate agreement to meet the Paris Agreement and are actively motivating people to electrify their appliances and save on energy. Their subsidies encourage people to be aware of energy use, and this motivation is essential for this project. However, the government is not necessarily heavily interested in this specific product. It is important to keep them updated and satisfied with the results of the project so they do not change their support.

The last secondary stakeholders are the manufacturers of LCTs. If people are more involved with these technologies, interest will also grow. With more interest in sustainable electric alternatives such as these LCTs, sales might grow even more. Developments on their side, such as increasing the efficiency of these devices are also of interest to the goal of this project. Therefore, their influence might be minimal but their interest is large. These manufacturers need to be kept informed about the status of the project.

4.1.3 Target Audience

Since the aim of this graduation project is to communicate information to the general Dutch population, and one of the most important stakeholders is the end user, it is important to analyze who these people will be. This tool is necessary to make consumers aware of something they are likely very unfamiliar with; the Dutch power grid. Therefore, the message of the tool must be clear to people of multiple technical knowledge levels, ages, and interests. The importance of the problem is the best message, not so much the technical details of it. Additionally, electricity is a widely misunderstood subject, as it is not as visible or tangible as water or mechanical gears, and therefore hard to perceive its workings. To design the right tool for technical communication, these ideas must be taken into account and the target audience should be reflected by the participants of the evaluation phase.

4.1.4 Power-Interest Matrix

With the knowledge of the different stakeholders involved a power-interest matrix can be made to visualize the results. The matrix is presented in Figure 4.1

4.1.5 Stakeholder Requirements & User Needs

To conclude the stakeholder analysis, their requirements and user needs need to be summed up. These must be taken into account: the user wants to pay as little as possible for their electricity, have power available when needed, and use more energy in future years for their LCTs. If they have to be made aware of their energy use, the data should be presented in a non-technical way and it must spark their interest in the workings of the grid. Important to include is the risk of what happens if the grid can not handle all demand in a future scenario, to stress the impact this future has on the users themselves. DSOs want to connect more users to the grid so they can sell more energy from the energy suppliers without the need to reinforce the grid, as this takes multiple years. To do this, the power peaks must be reduced or well-managed, otherwise, these peaks cause grid congestion, and power outages may occur. They want their consumers to be flexible in their energy consumption. The energy suppliers are mostly interested in selling more energy to customers on the grid.

4.2 Concept Generation

In this section, the concept generation of the ideation phase is covered. The user needs and stakeholder requirements as mentioned above are taken into account. The

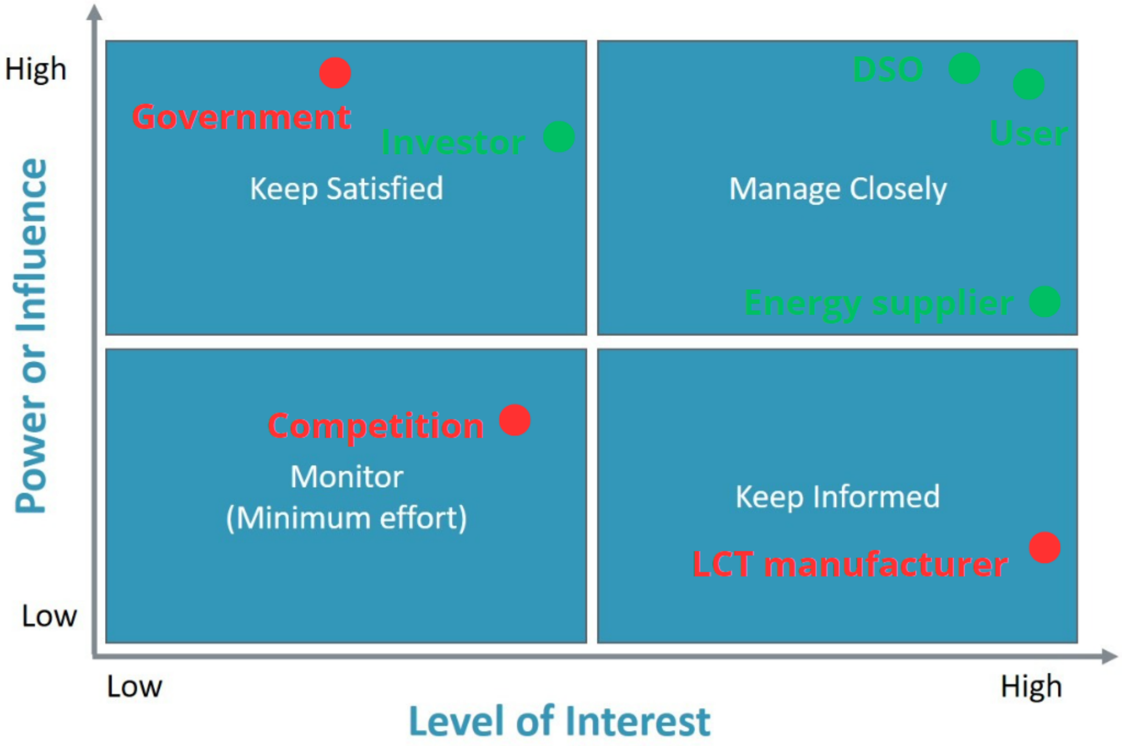


FIGURE 4.1: Filled in power-interest matrix

results of both brainstorming sessions can be found in Appendix C.

4.2.1 Brainstorm Sessions

In this section two brainstorming sessions are presented, used to explore the design space of the research question, and a way to come up with different technologies that can be used in the concept generation section.

Brainstorm 1

The first brainstorming session was centered around the research question and had a special focus on *Communication tools*, *Impact*, *Household electric devices*, and *Dutch power grid users*. The resulting mind map can be seen in Figure C.1 and was created using the online tool Coggle [52]. This mind map was not necessarily focused on generating creative ideas, but on getting an overview of the design space and breaking down the design research question.

Brainstorm 2

In the second brainstorming session, the focus was put on finding as many technologies as possible and coming up with ideas for this project. The resulting mind map can be seen in Figure C.2 and was also made using [52]. The technologies can be covered in three different concept categories. The first category is an interactive screen, such as the one found on a laptop, tablet, phone, or smartwatch. The design concept would revolve around an app or website and be able to be used by many people at home. The second category is creating a new device, such as an extra screen or device with lights, that would only show data in different ways. This is less interactive, but can passively influence the user's behavior. The final category is to make an interactive physical installation. This triggers a lot of senses, which is beneficial for conveying technical knowledge to non-technical users, as found earlier in chapter 2. The ideas from this brainstorm will be combined with the user needs and stakeholder requirements in the concept generation section.

4.3 Concepts

In this section, the two best concepts as mentioned above are worked out more elaborately into different sketches.

4.3.1 Interactive Website/App

The first concept is in the form of interactive visualization, implemented in a website or an app. The main goal of this concept is to focus on experimentation and spark people's interest in the idea of power peaks and power peak shaving. The first concept for this application can be seen in Figure 4.2. Using the buttons and sliders at the bottom, the user can interact with the energy profile seen above, and see what the impact of their changes is to the grid. For example, if the eCooking slider is moved to a 100% penetration rate, an increase in the evening peak would be visible in the graph. The graph helps with conveying technical data and visualizes what happens, creating a game-like experience for people with less technical knowledge. One benefit of this idea is the accessibility to users, as it can be searched for on the internet.

4.3.2 Interactive Physicalisation

Similar to the first concept, this one focuses on people's interaction with the available data on the grid. It does not necessarily show live data but aims to spark the interest of people and let them interact with it. As this concept is a physical form of showing data, it is even more interesting to use and triggers more senses during the interaction, such as feeling, hearing, and observing movement. As found in chapter 2, physical contact is a great way to interact with data and experiment with different scenarios. One downside of this concept is the fact that it would result in one physical installation and is therefore less likely to be used by a lot of people. It could however be located in a newly built neighborhood or at the headquarters of one of the Dutch DSOs. An example of the physicalisation can be seen in Figure 4.3. This image was made using Microsoft Designer and the prompt *"a physicalisation that people can interact with to learn about electric cars, heat pumps, solar panels, and electric cooking equipment"*

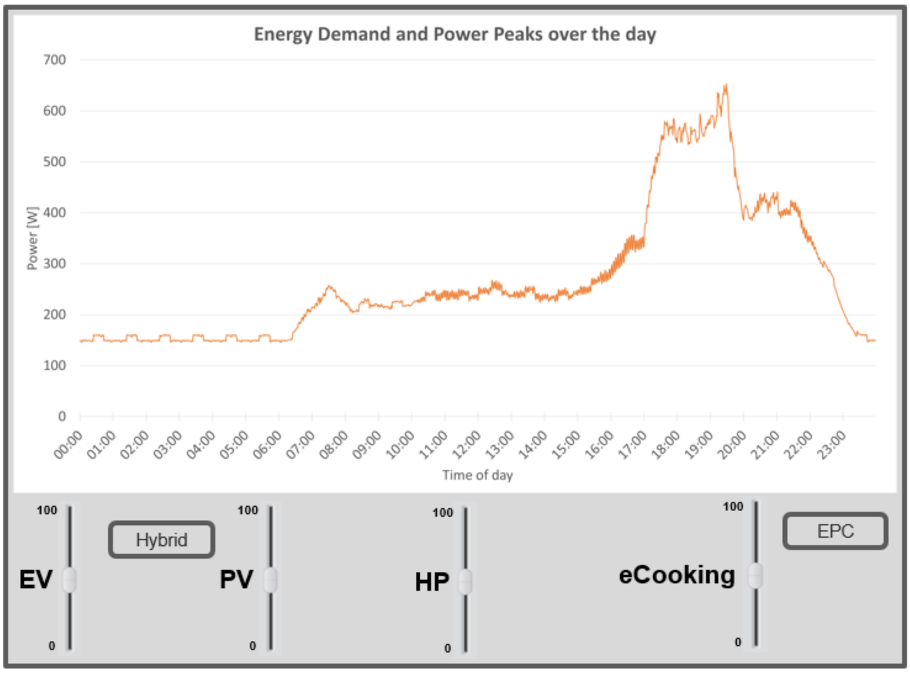


FIGURE 4.2: Concept: Interactive Website/App

4.3.3 Interactive Website/App of Neighborhood

This last concept is a combination of the ones above. Since the project must cover a lot of people to be functional, an online website or app might be preferred over a physical installation. However, the graph as seen in Figure 4.2 might be still too technical for people not used to working with graphs. Another option is worked out in this concept and can be seen in Figure 4.4. Similar to the interactive website in subsection 4.3.1, buttons and sliders can be used to change the penetrations and type of LCTs in the neighborhood. The visualization will respond to the input of the user and can show the status of the grid using colored cables and transformers due to peak load, altering sine waves due to harmonics, and power outages when the grid fails. The visualization of the neighborhood will be more familiar and appealing to users and allow them to understand what is happening to the grid.

4.4 Results

The concepts presented above were discussed with the expert from Alliander, interviewed in Appendix B, and with the supervisor Nataly.

4.4.1 Expert Input

When the expert was asked what he thought about the concepts, his immediate reaction was to focus on a technical solution. His experience with people interacting with pilots from Alliander was poor, with them only actively participating for the first few days, after which their interest was lost and reverted to their habits. However, and he also mentioned this himself, he is a technical person and therefore

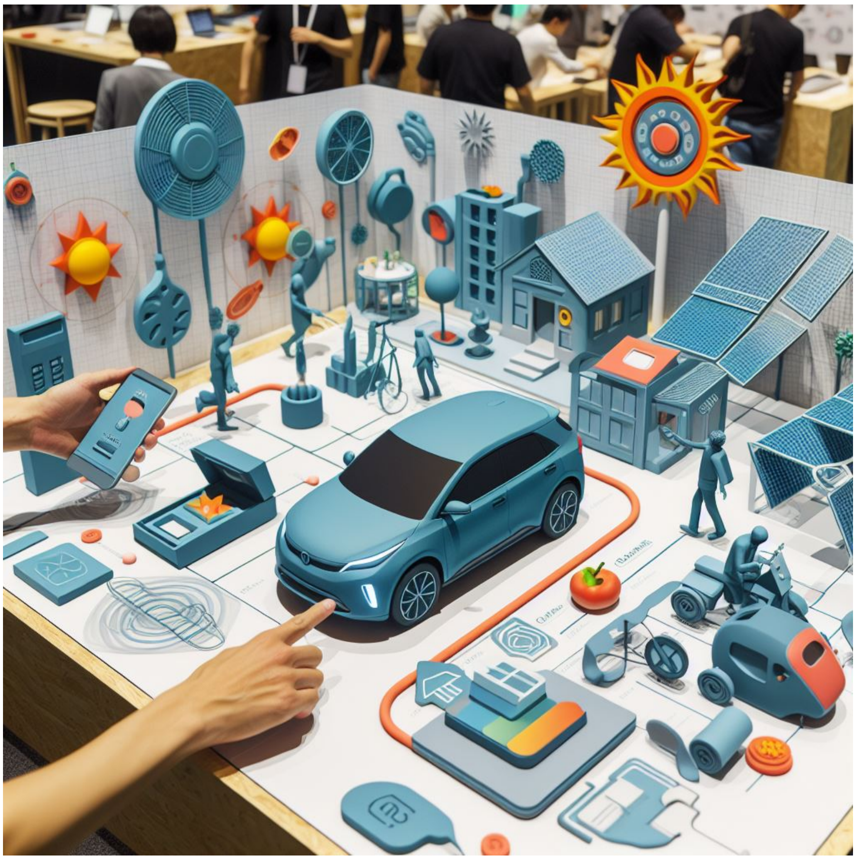


FIGURE 4.3: Concept: Interactive Physicalisation

likes technical solutions better, as these are easier to control than people. A person can be told what to do, but this does not mean they will do it. Despite the expert's opinion, this report will focus on the need to spread awareness about one's energy use impact on the grid, as was concluded in the background research. Therefore, this will remain the goal. Because the problem of the energy transition is so big and important over the next decade, it should be attacked from all sides, so via grid expansion, technical advancements in smart devices, and better understanding amongst consumers

4.4.2 Supervisor Input

As the main supervisor of this project, Nataly also looked at the three concepts in this chapter. The last concept was favored in particular, but there were some remarks. The fact that the third concept is a combination of the first and second one worked great, but the focus on power peaks was lost in the process. Since these power peaks are the main focus of this project, they must be included in the visualization. This can be done via a similar graph seen in the first concept in Figure 4.2. One other concept the visualization covers is harmonics, and Nataly remarked on the importance of explaining what it is, as it is not easy. This should also be included in the design process.

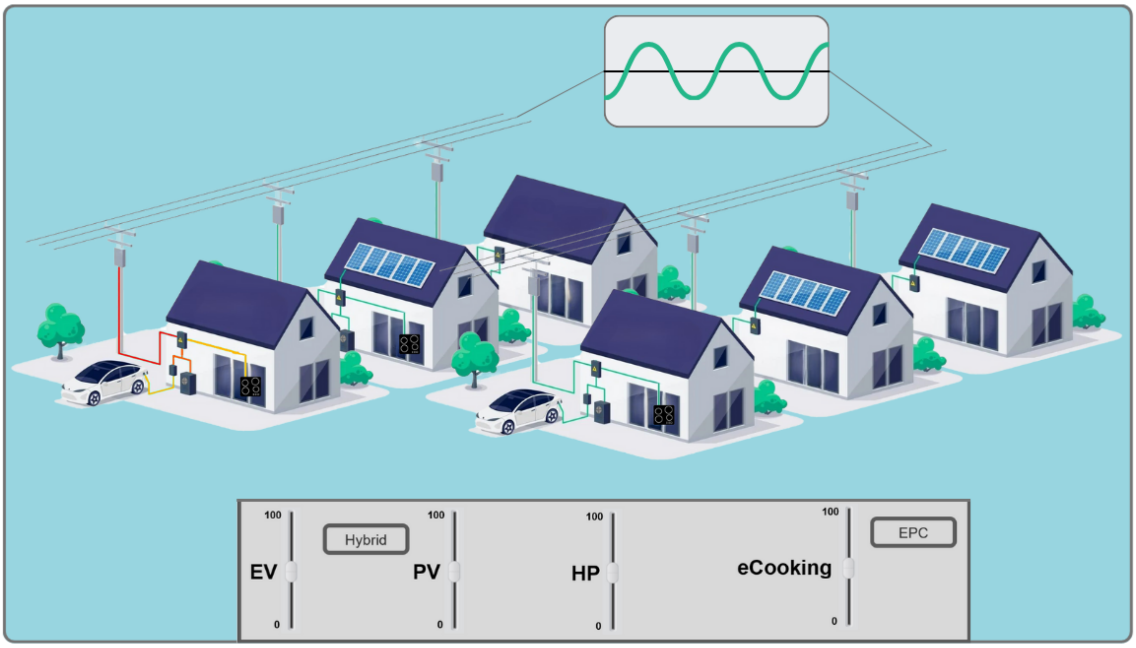


FIGURE 4.4: Concept: Interactive Website of Neighborhood

4.4.3 User Needs

Finally, the user needs as discussed in section 2.5 are of importance in all the concept designs. All three concepts are already focused on visualizing technical data, but not all do this in a familiar setting to the average person. The first concept only uses the graph to explain the status of the grid, but the houses, EVs, and PVs of the second and third concepts manage to do this in a familiar setting, such as a neighborhood. This makes those two options more preferred.

4.4.4 Online or Physical

Adding to this, an online communication tool is preferred over a physical one, as more people can be reached this way. The threshold to interact with the tool must be as low as possible to reach the most amount of people. Since an app must be downloaded before it can be used, it takes additional steps and creates a bigger threshold to use compared to a website, as this can be accessed easily via the web browser on one's laptop, PC, or tablet. A website with a simple link or QR code is therefore preferred.

4.5 Final Concept

Based on the concepts generated and the results in this chapter, the third design was chosen to be the best. The fact that it is an online website allows more people to use the tool without having to visit a fixed physical location, as opposed to an app that has to be downloaded and installed before using it. A simple hosted website will be sufficient and is more easily accessible via the internet or a link / QR code on one's laptop, PC, or tablet. Another benefit of this design is the familiar setting that is created by the illustrated neighborhood. In this setting the technical data is directly presented and the user can interact with buttons and sliders to experiment with the status of the grid. After the feedback from Nataly, the final concept could be formed, as seen in Figure 4.5.

In the top right corner, the energy profile of the neighborhood is shown to the user. At the bottom a toolbar is placed to let the user interact with the neighborhood, changing the penetrations and the specific type of all LCTs. Additional information, such as harmonics and voltage fluctuations can be shown in the top left corner, but can also be left out if this is too overwhelming for the user. This way the tool can be interesting for both non-technical and technical users. Cable and transformer overloading can be implied by changing the color of these components, signaling the status of the grid. Additional information and specific parameters can be provided by clicking the houses or the graph to gain more inside knowledge on the visualization.

This final concept matches all of the requirements identified in this report and will therefore be worked out further in the next chapter.

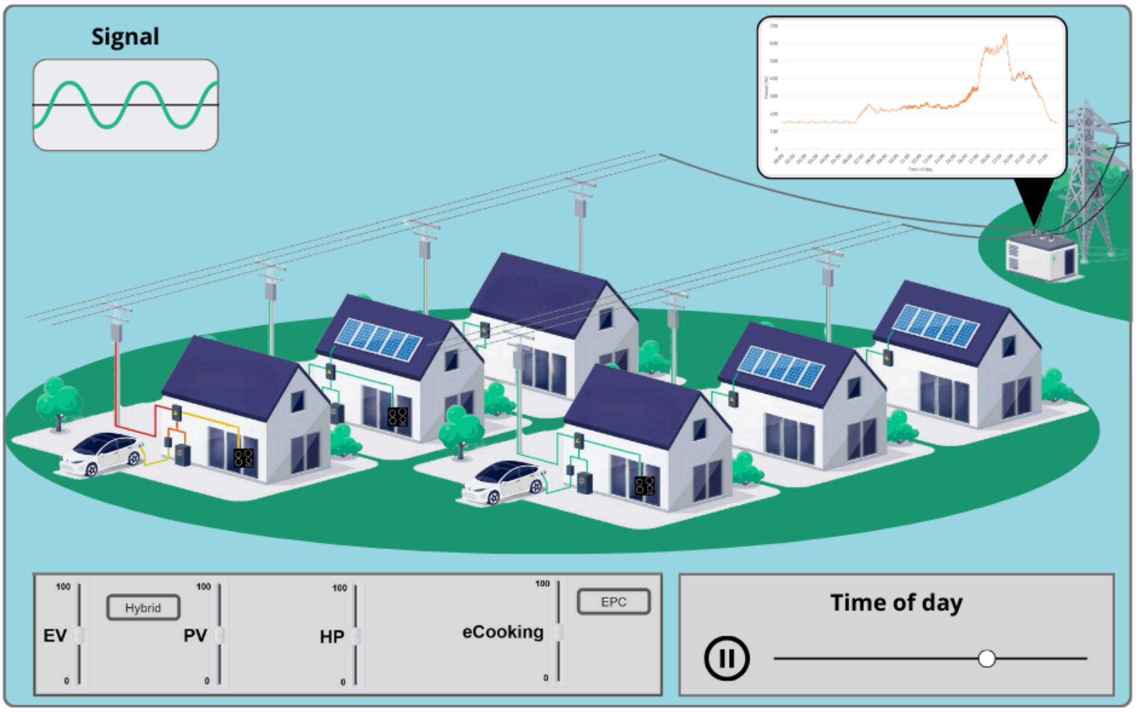


FIGURE 4.5: Final Concept: Interactive visualization of neighborhood

Chapter 5

Specification

5.1 Requirements

A list of requirements is formulated in the specification phase to make sure the prototype meets the user's needs and requirements. The requirements used here are already mentioned in chapter 4.

The requirements can be split into two categories: functional and non-functional requirements. The functional requirements are focused on parts that are specifically requested by the user, or in this case the things that must be included to meet the design question. They have an impact on whether the software does what it is intended for, for example responding to different inputs [53]. Non-functional requirements focus on how the software performs. They specify what a system will do to respond to user input. An example of this is the speed of performance or the usability of the software [53].

To order the overview of all requirements the MoSCoW [46] method will be used. This method helps to identify the importance of each requirement by labeling them: Must have, Should have, Could have, and Will not have.

5.1.1 Functional Requirements

In Table 5.1 the functional requirements for this graduation project are formulated and prioritized using the MoSCoW method [46].

5.1.2 Non-functional Requirements

Additionally to the functional requirements, Table 5.2 contains the non-functional requirements for this graduation project. The MoSCoW method was used to prioritize them [46].

5.2 Target Audience Specification

This section will specify the target audience of the concept tool. Together with subsection 4.1.3 from the ideation phase, this will formulate an answer to the third

#	**Functional Requirements**	**MoSCoW**
1	The prototype must be tailored to the needs of the target audience and stakeholders and educate them on the discussed impacts of LCTs on the grid.	Must have
2	The prototype must be interactive and respond to user inputs.	
3	The prototype should be easily accessible (online) via a computer.	Should have
4	The prototype should provide realistic data on power peaks and energy consumption of the shown LCTs.	
5	The prototype could provide additional in-depth information on the different impact factors.	Could have
6	The prototype could provide (live) data of the user's own neighborhood.	
7	The prototype could contain pre-made scenarios to highlight important future impacts.	
8	The application will not be available on a phone.	Will not have

Table 5.1: Functional requirements with MoSCoW prioritization

#	**Non-functional Requirements**	**MoSCoW**
1	The prototype must have a short delay between input and output.	Must have
2	The prototype must be visually appealing.	
3	The prototype must be easily accessible.	
4	The content of the prototype should be well-structured and clear.	Should have
5	The prototype should be coded in a widely accessible coding language.	
6	The prototype could be animated in the background.	Could have
7	The prototype could be connected to local grid databases of a DSO.	

Table 5.2: Non-functional requirements with MoSCoW prioritization

research question: *Which part of the general population would benefit most from this technical overview?*

Since the goal of the concept is to spread awareness of the status of the Dutch grid, the concept will be focused on the Dutch situation. Therefore, the language of the concept should be in Dutch. To account for users with less technical knowledge, easy language must be used and technical terms should be avoided where possible. Essential technical principles, such as the power profile of the neighborhood, should be provided with a clear explanation.

A small brainstorm was used to come up with different use cases for this specific tool, which can be seen in section D.1. The results of this brainstorming session are listed below:

- The DSO could use this tool as a first notification to a residential area that is experiencing grid problems or is reaching its limits. The DSO could send the link and help their consumer understand why these problems are occurring, and how they can help to improve their situation.

- The DSO could also send this to consumers who just moved into a newly built residential area. Since these consumers are new to their house and their devices, they would be more likely to change their consumption behavior.

- Consumers in social housing might be unfamiliar with the devices preinstalled in their homes, such as PV, HP, or eCooking. The DSO could send the link of the tool to them when moving in, to inform them about how to use and control them properly and beneficial for the grid.

- If people want to learn more about the Dutch power grid and the impact of high-power devices they could search for the tool on the internet and interact with it.

To summarize, and formulate an answer to the third sub-research question, the specific target audience of this tool would be both technical and non-technical people who fall under one of the use cases mentioned above.

5.3 Concept Specification

This section will cover the specific design and functionalities of the concept. First, the specifications of the presented content are discussed. After that, the design of the website is specified. Finally, the website infrastructure will be discussed.

5.3.1 Content

The website will focus on the four LCTs and their impacts as identified inTable 2.1. The user will be able to interact with the different penetrations of these LCTs and experiment what their impact on the grid is. The tool will visualize the impacts to the user as output. Another output will be a couple of preset scenarios, allowing the user to see the current status of the grid in the Netherlands, along with both the worst and best future cases.

LCTs

The four LCTs that will be covered by the visualization will be EVs, PVs, HPs, and eCooking devices. The user will be able to select different penetrations of each LCT using a slider bar. Since the impact of these LCTs on the grid can be influenced by the weather or simultaneous use, these parameters can also be changed by the user.

Impacts

In the visualization, three main impacts on the grid will be highlighted, as opposed to the four presented in Table 2.1. Phase imbalance will be left out of the visualization, as this is only depended on the grid connection of a house, and the user can do little about it. The first impact is cable and transformer overloading, which happens when a lot of power is used at once (e.g. during power peaks). The power profile graph together with visual cues in the form of colored cables will be used to visualize the load on these components. As an example, the cables of a house will vary in color from green to red, with green being optimal operating conditions, and red being peak load. The power profile of the entire neighborhood will be displayed in the graph next to the transformer. In this graph a red line will be present to signal the

FIGURE 5.1: Example of cable and transformer overloading in a visualization.

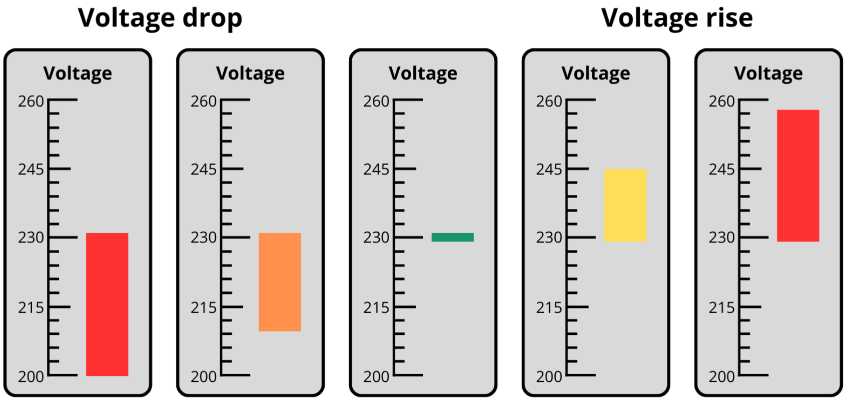


FIGURE 5.2: Voltage fluctuation meter with upper and lower limit

maximum power the transformer can supply before a breaker will pop, causing a blackout. Both visuals can be seen in the example in Figure 5.1

The second impact shown in the visualization will be voltage fluctuations. Voltage rises as generation is high with little load, and drops when load outweighs generation. Too high or low voltage will result in malfunctioning devices. To visualize this, a meter is shown in the top right corner. When supply and demand match, the meter will be left in the middle around 230V. The meter has two limits, a lower and an upper limit, and devices will shut down when these are surpassed. In Europe, the maximum allowed fluctuation range is +-10%, So in the Dutch case the operating range is between 207V and 253V. A concept for this voltage fluctuation meter can be seen in Figure 5.2.

Harmonics are the last impact presented in this visualization and are visible in the top left corner. The sine wave will be pure and green when little devices are used

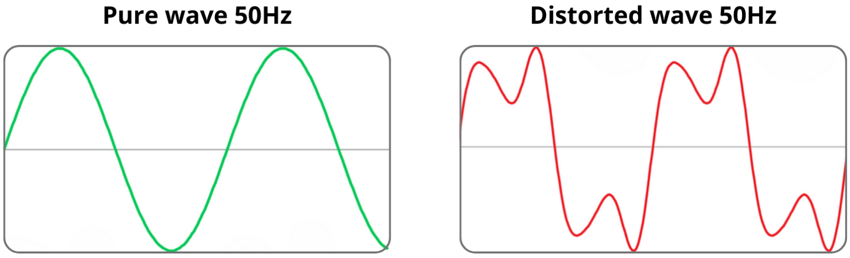


FIGURE 5.3: Pure AC sine wave and sine wave distorted by harmonics.

simultaneously and will become more deformed and red when lots of devices are used at once. The tab in the bottom left corner allows the user to edit the schedule of the neighborhood, and shorten or lengthen the period where consumers charge their car and use the heat pump. Since PV harmonics and EV/HP/eCooking harmonics can cancel each other out, the importance will be shown of balance between these LCTs. An example of the grid's AC signal can be seen in Figure 5.3.

Scenarios

The tool allows users to play with different penetrations of the LCTs and change parameters to see the resulting impact on the grid. To make sure the tool is not just a game but also of educational value, different preset scenarios can be selected to see their (realistic) results. Some interesting scenarios would be to look at the current situation, the worst case, and the most ideal situation. The Current scenario would be using penetrations of about 10% EV, 10% HP, 30% PV, and 40% eCooking. Regarding the general load profile of the residential sector, the load will reach its maximum peak during the evening. As people come home from work, EVs will start charging, food will be cooked, and homes will be heated for comfort. Alongside this rise in electricity demand, generation from PV decreases as the sun goes down. This piled-up power demand and low local energy generation in the evening puts the grid under lots of stress. Adding to this the overall voltage of the grid will drop significantly. Harmonics will be present, but not yet in a significant way.

The worst way the grid could be used is to increase the penetrations of all LCTs to 100% without changing electricity consumption behavior. Similar to the current situation the demand is concentrated in the evening, producing a large power peak. Since the entire neighborhood needs electricity for their EV, HP, and eCooking devices, the grid will most definitely fail to supply all this simultaneous power. Blackouts can be used to visualize the consequences of this scenario. The voltage will fluctuate during the day, as PV generation and low load in the afternoon will make it increase, and high load together with lower PV generation will decrease it. Harmonics will be present over the entire day, as PV and high demand will mostly alternate with each other instead of balancing out. Both voltage fluctuations will cause devices to shut down or stop working properly.

The last presented scenario would be an ideal future case, where even with high penetrations of all LCTs the local transformer will manage all power demand. To do this some demand can be moved to the afternoon when power peaks are lower and PV generation is at its highest. As discussed earlier, eCooking cannot be moved

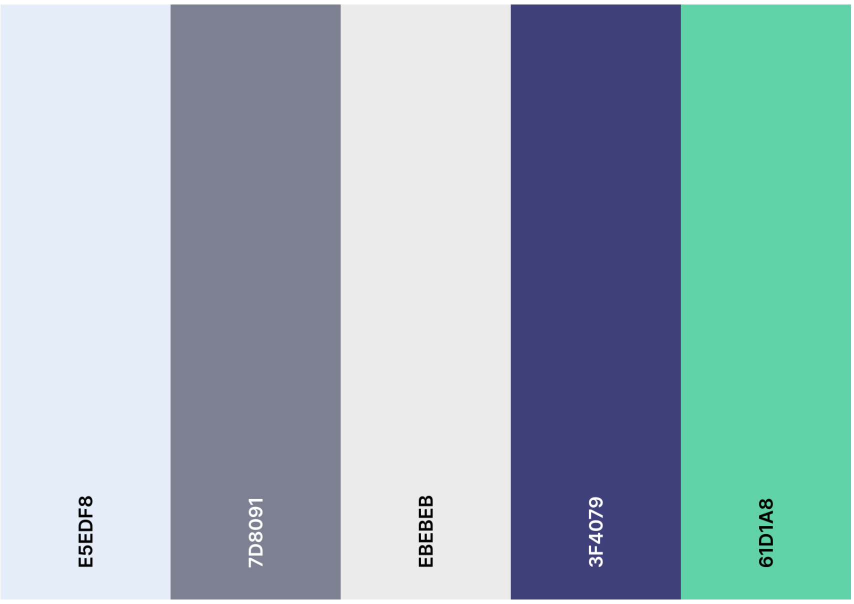


Figure 5.4: Color Palette

from the evening, as cooking is a necessity and too much of a habit. HP demand can be moved to the afternoon, preheating the home to maintain comfort in the evening, especially if it is well insulated. EV charging could also be done in the afternoon either at work or at the house if it is plugged in. Another option is to move it to the late evening or even during the night. When PV and high demand are combined during the day, voltage fluctuations and harmonics can be more balanced and therefore improve the status of the grid even with high LCT penetrations.

5.3.2 Design

The design of a website is also known as the front end and regards both the graphic design (the looks) and the user interface (the feel) [54]. These will be discussed in this subsection such as the color palette, user interface, and website layout.

Color Palette

An important aspect of a good website visualization is the color palette. The online tool Coolors [55] was used to select the palette seen in Figure 5.4, which is based on the colors used for the final concept houses in Figure 4.5.

User Interface

The user interface allows the user to interact with the website and serves as a control panel for the visualizations where all parameters can be altered. In Figure 5.5 a concept for the user interface can be seen. Different colors are used for the different LCTs of which the penetrations can be changed using sliders. Weather can also be changed, affecting the performance of the solar panels. The last part of the interface will allow the user to change or schedule when EVs and HPs will be used by sliding these over the day.

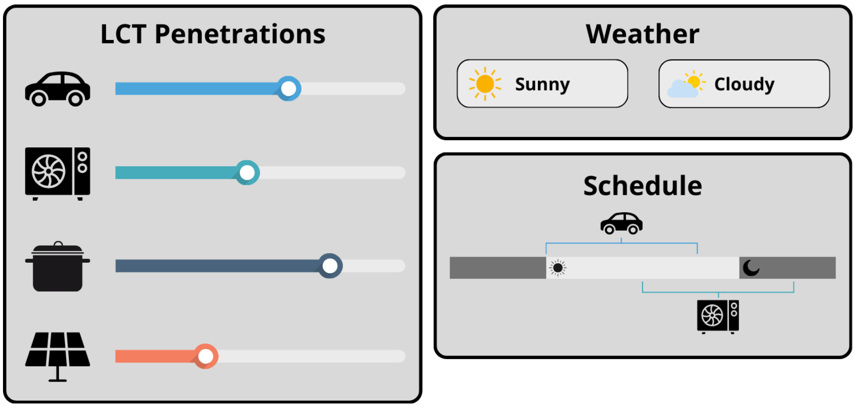


FIGURE 5.5: User Interface of concept.

Website layout

The website will mainly focus on the effects of the LCTs on the local grid of the neighborhood. Therefore, the visualization of the neighborhood should be most apparent on the site, accompanied by the power profile graph. Since the website will be made for a rectangular laptop screen, The controls can be put on the left side of the screen. This leaves a lot of room on the right side for the neighborhood and the power profile graph up top, since a laptop screen is rectangular.

5.3.3 Website infrastructure

The infrastructure of a website, or back end, regards how the website will function [54]. The specific coding language, the database, and the server hosting the website will be discussed in this subsection. The visualization will be coded using Processing, as this is a familiar language and can be easily implemented in a simple HTML website.

The data the website will be using can be generated using the aforementioned ALPG tool [36]. Data of a single simulation with all penetrations on 50% will be split over the different LCTs and can be shifted over the day using the sliders. To account for increased penetrations, the scale can be adjusted between 0 and 2 for each LCT. Voltage fluctuations and harmonics will be based on the simultaneous use of PV and the other LCTs.

5.4 Interaction and Experience

To define the user interaction and experience of the visualization, three time sequence diagrams (TSD) are constructed. The first section discusses the TSDs. Additionally, two personas are created in the second section, where they will be used in a user scenario, describing what their interaction could look like.

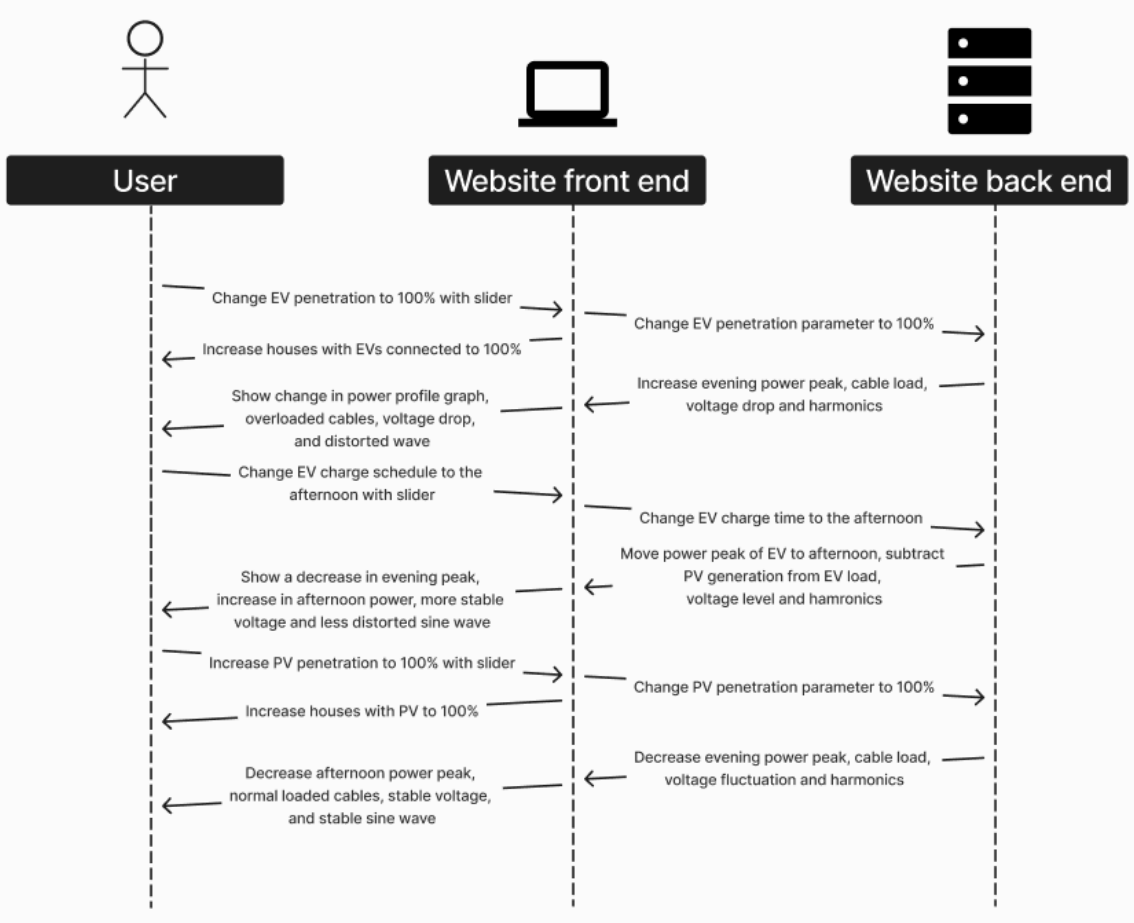


FIGURE 5.6: TSD - Normal interaction

5.4.1 Time Sequence Diagrams

Time Sequence diagrams can be used to detail how operations of a website are carried out [47]. In this case, it shows what inputs the user will give to the website, and what the website will request from the back end to present in the visualization. The diagram also specifies when these operations are carried out. Three different interactions are specified in this section. Figure 5.6 shows normal interaction, where the user changes different parameters of the visualization using the sliders and buttons. In Figure 5.7 the user wants additional information on the presented impacts on the grid, which can be requested by clicking on the diagrams. Finally, Figure 5.8 shows a user selecting one of the preset scenarios of the visualization, and learning about why these scenarios represent the worst and best situations for the grid.

5.4.2 Personas

In this subsection, two personas are created to investigate the potential users of the product. Personas can help the researcher to take the point of view of their target audience and get a more detailed insight into their needs and improve user experience [48].

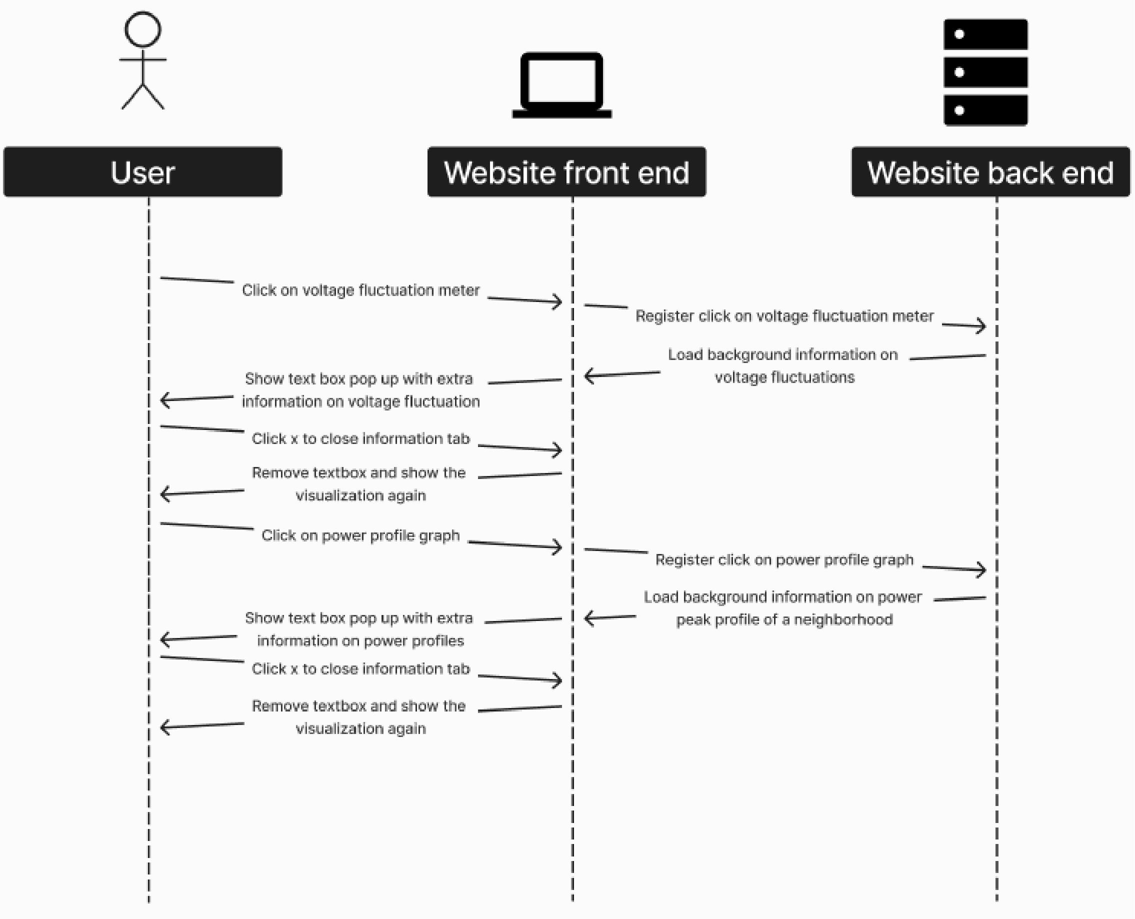


Figure 5.7: TSD - Providing additional information

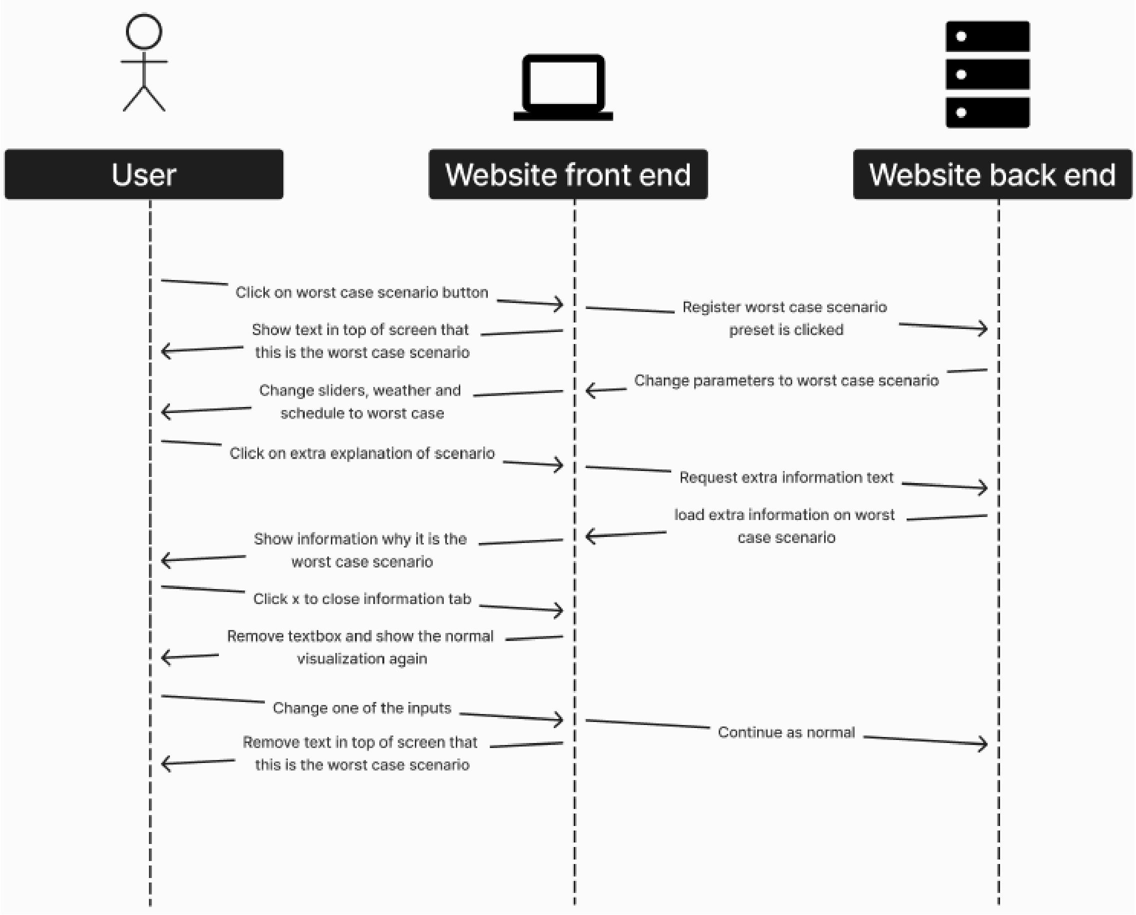


Figure 5.8: TSD - Selecting scenarios

Persona 1

The first persona is Anna de Vries, as described in Figure 5.9. She has a high interest in sustainability and is thinking about getting an EV and PV in the near future. However, she does not have a lot of technical knowledge and therefore wants to learn more about the pros and cons of these devices. Either via the internet or via her DSO she gets the link to the visualization of this project. Since she is eager to learn and curious, she starts to experiment with the tool by changing the penetration values of the LCTs, and their consumption schedule. The visual cues give her a rough idea of what is better and worse for the grid, but does not fully understand terms such as ‘harmonics’ and ‘voltage fluctuations’. She clicks on the graphs, providing her with additional information on these topics. She does not fully understand what is happening but knows how to prevent these effects. Using the preset scenarios of the ideal and worst case for the grid, she feels she has a better understanding of the local grid and knows what to do with her EV and PV in the future to prevent any unwanted power outages.

BIO

Anna de Vries is a 52-year-old primary school teacher living in Utrecht, Netherlands. Dedicated to her students, she finds joy in sparking curiosity and fostering a love of learning in the next generation. Outside of school, Anna enjoys spending time with her family, tending to her vegetable garden, and cycling along the scenic canals of Utrecht.

She is comfortable using everyday electronics as her phone or laptop, but struggles with anything more complex.

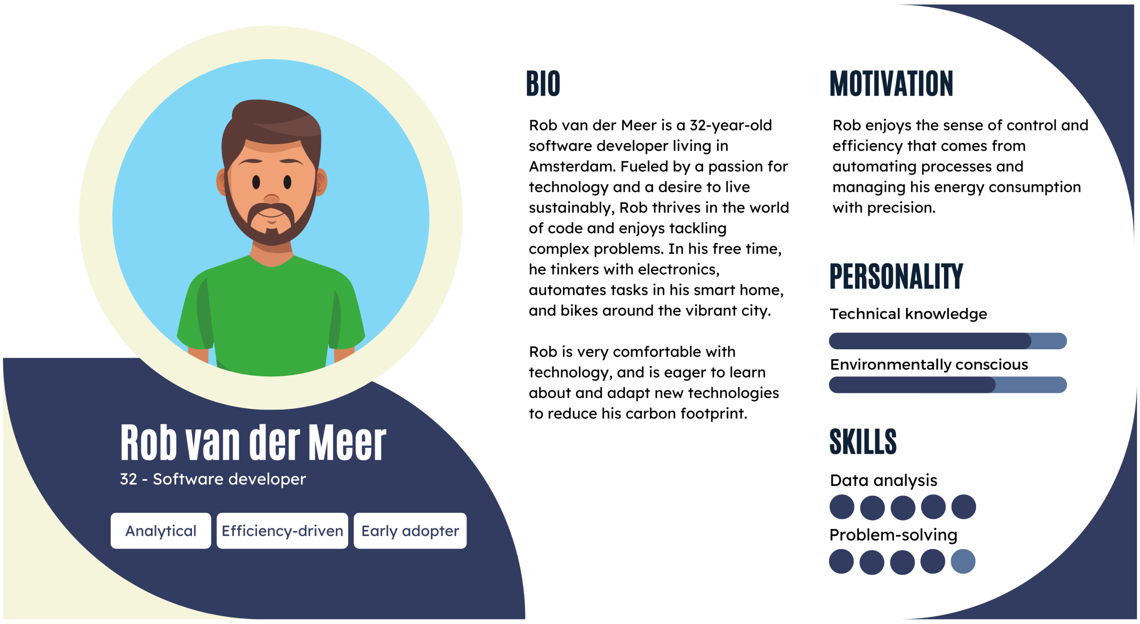
MOTIVATION

Anna has an inherent desire to learn and understand how things work. She also values living a sustainable lifestyle because it benefits her family and the environment for future generations.

Figure 5.9: Persona 1 - Anna de Vries

Persona 2

Rob van der Meer is the second persona and his profile can be seen in Figure 5.10. Similar to Anna, Rob strives to reduce his carbon footprint and is eager to learn about the functioning of the grid. As a software engineer, he knows a lot about code but has less in-depth knowledge of electronics. Nevertheless, he is quite comfortable with technology. He also reaches the website via either the internet or a link he got from his DSO since he is an early adopter and owns all LCTs covered in the tool. Rob immediately starts to experiment with the sliders and buttons and tries to understand what is happening in the visualization. He likes the graphs and tries to move the power peaks over the day and in- and decrease them. By clicking on the graphs, he learns more about the electrical properties such as harmonics and voltage fluctuations. After this interaction with the tool, he understands how the local low-voltage grid operates and how he can change his EV and HP schedule to use the grid more efficiently and sustainably.



Rob van der Meer is a 32-year-old software developer living in Amsterdam. Fueled by a passion for technology and a desire to live sustainably, Rob thrives in the world of code and enjoys tackling complex problems. In his free time, he tinkers with electronics, automates tasks in his smart home, and bikes around the vibrant city.

Rob is very comfortable with technology, and is eager to learn about and adapt new technologies to reduce his carbon footprint.

Rob enjoys the sense of control and efficiency that comes from automating processes and managing his energy consumption with precision.

Figure 5.10: Persona 2 - Rob van der Meer

Chapter 6

Realization

This chapter will cover the realization phase of this graduation project. Here, the final concept as specified in chapter 5 will be made to a high-level prototype such that all functions and interactions can be evaluated in the evaluation phase. The tool will be built using Python instead of HTML since Python in combination with the Pygame library is optimized for such a visualization using data manipulation in the back end. Additionally, the final prototype does not have to be hosted online to evaluate it. The coding process was sped up by using ChatGPT wherever possible [56]. The designs made in the specification phase using Canva [57] were uploaded in the chat, resulting in the quick generation of a base code that could easily be added to as needed.

6.1 Front end

6.1.1 User Interface

The first challenge in the prototype realization was to make a functional user interface, similar to the one seen in Figure 5.5. To start the dimensions of the tool were set resulting in a screen size of 1600 by 900 pixels, which is the same as the full-screen resolution of my laptop. The interface was split up into four different parts: the LCT penetration slider block, the weather block, the schedule block, and the scenario buttons at the bottom. These blocks turned out very similar to the Canva designs, as can be seen in Figure 6.1. During the coding process, the choice was made to use Dutch as the main language of the tool, since it is tailor-made to the Dutch situation. ”LCT Penetrations” was changed to ”Aantal Apparaten” (amount of devices), and each LCT icon and slider was accompanied with text explaining what the icon resembles, so ”Elektrische Auto” (Electric Car), ”Warmtepomp” (Heat Pump), ”Electrisch Koken” (Electric Cooking) and ”Zonnepanelen” (Solar panels). The sliders can be dragged by clicking and moving the white dots, and the percentage below corresponds to its position. The weather block, or Weer in Dutch, allows the user to change the weather from sunny to cloudy. The block is similar to the concept design, with the addition of a blue color to whichever button is active/pressed. The schedule block is also similar to its concept design. The slider uses the same icons as used in the LCT penetrations block above for consistency, and should resemble morning, afternoon, and evening. The car slider and the heat pump slider can be moved between these three options and will snap to the one closest to where it is positioned by the user. Finally, the best and worst-case scenario buttons are added. Clicking these buttons will update the LCT penetrations, weather, and schedule to the preset values for these scenarios. The best-case scenario will set the penetration percentages to 90, 80, 90, and 100% from top to bottom, make the weather sunny, and move car and heat pump demand to the afternoon. The worst-case scenario will preset the percentages to 100, 90, 80, and 90%, with cloudy weather and both car and heat pump demand in the evening. The scenario buttons do not get a blue color as the weather buttons do since they are not always active and the preset can easily be adjusted once clicked.

Elektrische Auto 10%
Warmtepomp 10%
Elektrisch Koken 40%
Zonnepaneel 30%

FIGURE 6.1: Prototype interface implementation

6.1.2 Neighborhood

The second step in the prototype realization was to construct a Neighborhood of ten houses, resembling the penetration percentages set by the user. Since four variables can be controlled by the user, sixteen different houses with different LCTs can be displayed. For the base image of the house, the one from the final concept design in Figure 4.5 was used, as it was already equipped with an electric car, PV panels, and a grid pole. This base image was found via the internet [58] and edited using Adobe Photoshop [59] to make it better suited for the prototype, such as a turned car, added heat pump, and an eCooking connection. In Photoshop sixteen different images were exported and imported in the prototype code. A few examples can be seen in Figure 6.2. The ten houses drawn are supported by a green ellipse to serve as the ground, as well as a grid connection and a transformer station on the right side of the screen. The different power lines from the homes are joined using cables, which connect to the transformer station. To provide the user with feedback on the current selected weather, either a sun or one covered by a cloud is shown next to the controls on the top left side. The result of the entire neighborhood implementation is shown in Figure 6.3.

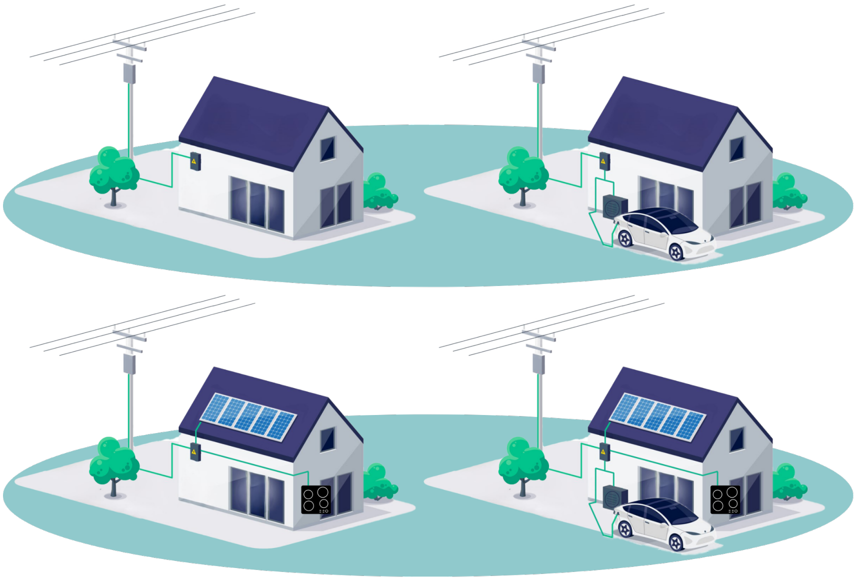


FIGURE 6.2: Examples of houses used in the prototype

6.1.3 Graph

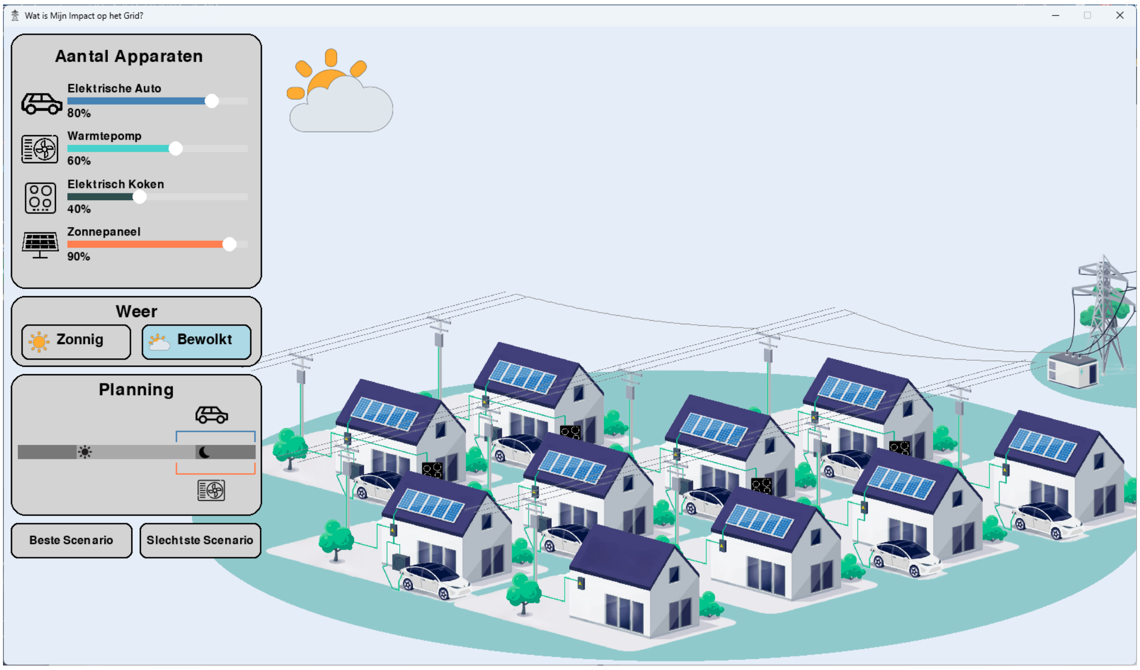
The final visual step is to draw the power profile graph (or ”vermogensprofiel”) of the neighborhood. The profile is drawn at the top right corner of the screen, above the transformer station. A black triangular shape is used to indicate that the profile is measured from this transformer station. The graph displays the power profile data, which is a combination of five data sets: an EV, HP, eCooking, PV, and a base load dataset. The x-axis displays the time of day, spanning the entire 24 hours. The y-axis shows the amount of used power at a given moment of the day, in kW. a bar of 100% is placed to resemble the maximum amount of power the transformer can supply, and surpassing this value will result in a power outage. The graph can be seen in Figure 6.4, finalizing the first visual representation of the prototype.

6.2 Back end

While constructing the visual representation of the prototype, back-end variables were introduced to interact with the visualization. These are listed bellow.

6.2.1 LCT Penetrations in the Neighborhood

The first interaction implemented was control over the amount of electric devices present in the neighborhood, and the corresponding visual feedback in the ten



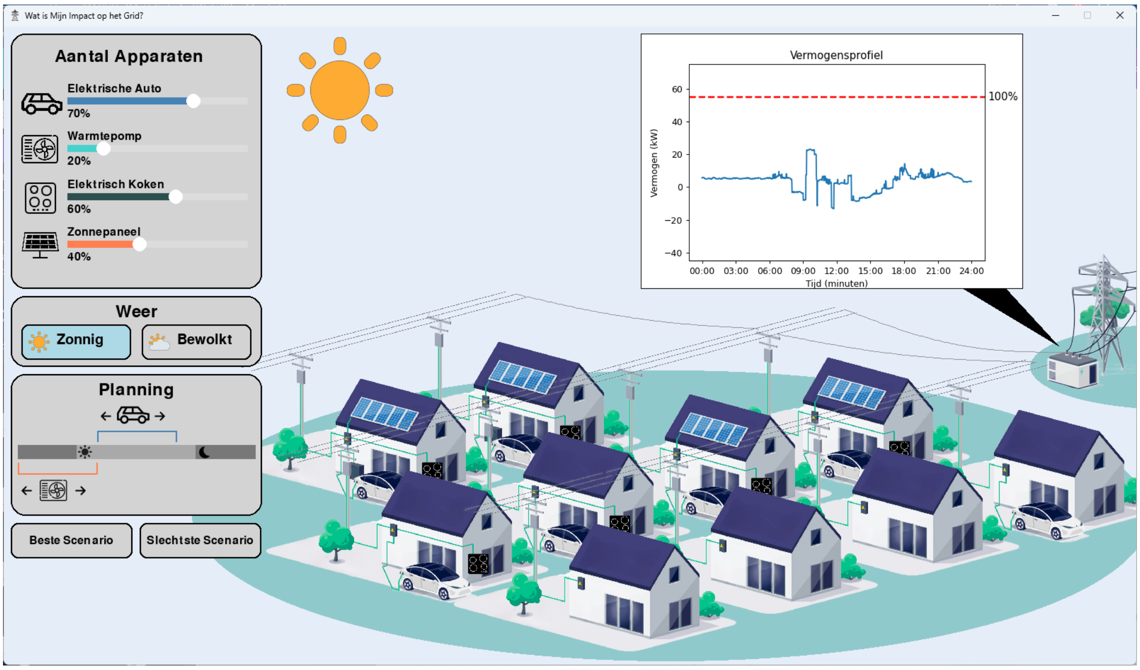
Elektrische Auto 80%
Warmtepomp 60%
Elektrisch Koken 40%
Zonnepaneel 90%

FIGURE 6.3: Prototype neighborhood implementation

houses. The code registers every mouse down, mouse up, and mouse movement event. Each LCT penetration slider is checked whether the mouse down and dragged event collides with the position of each white slider circle, and if this is the case the position of the slider is updated. This position is also translated to a value between 0 and 1, representing the set percentage by the user. The previous state of each slider is stored so the code knows whether one is being adjusted. This prevents performance issues as the image displayed of all ten houses is only updated if values are changed, something which is checked also for the weather, planning, and updating the power profile. Once a penetration slider is adjusted, the code runs a loop to construct a neighborhood with the right amount of devices present as set by the user. This is done by checking whether all percentages are higher than 0. If this is the case, the image of the house with all LCTs present is added to one of the ten available spots, and every percentage is lowered by 0.1 in the code. If all values are still above 0, another one of these houses is added. If one of the percentages becomes 0, a house is added to the neighborhood containing only the other 3 LCTs. This cycle continues till all ten houses are added, where the neighborhood is drawn.

6.2.2 Schedule Sliders

The second interaction implemented in the code was the ability to adjust the planning of EV charging and HP use. The code checks whether the mouse is clicked around the EV or HP icons in the planning block, and if dragged from side to side the position is updated of the icons and their brackets. Both brackets can be set to either the morning, afternoon, or evening, and will snap to the closest position once the mouse button is released. Whilst sliding over the schedule, the position variable is updated every time it changes between these three possible times of day, and this


Wat is Mijn Impact op het Grid?

Aantal Apparaten

Elektrische Auto 70%

Warmtepomp 20%

Elektrisch Koken 60%

Zonnepaneel 40%

Weer: Zonnig

FIGURE 6.4: Graph added to prototype

is represented in the power profile graph. The weather variable changes every time either sunny or cloudy is clicked, which also updates the graph.

6.2.3 Graph Data

Finally, the graph is implemented. As mentioned earlier, the power profile graph as displayed is a combination of a base load and four different datasets, one for each LCT. The data is gathered using ALPG and DEMKit, both developed by dr.ir. G. Hoogsteen at the University of Twente [36], [60]. The datasets resemble ten houses with 50% penetrations of all four LCTs. Using the percentages as set by the user, the data is scaled by a factor between 0 and 2, representing 0 to 100% respectively. All data shown in the visualization was chosen to be the data from the first of June in order to make it consistent between the different datasets. Using the position variables of the schedule block the data in the EV and HP sets is shifted to either the morning, afternoon, or evening. The dataset of PV generation is halved if the weather is set to cloudy, or remains as is if the weather is sunny. All interactive variables of the code, with their possible values, can be seen in Table 6.1.

6.3 Intermediate Evaluation Pitch

About halfway through the realization of the prototype I was allowed to pitch it to the Energy Group of the University of Twente [31]. The meeting was arranged by my supervisor dr. M.N. Bañol Arias, who is also part of the group, and the goal was to receive technical feedback on the represented data in the visualization.

The first point of feedback received was about the mismatch between the target audience and the prototype in its current state. Generally, if one would want to

Table 6.1: Interaction variables of the prototype tool

Input	Variable	States	Notes
LCT sliders	self.slider_values	0-1 (increments of 0.1)	[0] = EV [1] = HP [2] = eCooking [3] = PV
Weather buttons	self.sunny_active self.cloudy_active	True/False True/False	Sunny Cloudy
Schedule sliders	self.EV_schedule_pos self.HP_schedule_pos	1,2,3 1,2,3	1 = morning, 2 = afternoon, 3 = evening
Scenario buttons	self.shared_state self.shared_state	"best case" "worst case"	Best case scenario Worst case scenario
Graph button	self.graph_toggle	0,1	0 = capacity bar, 1 = power profile

explain something technical to a random person in the population, graphs are not the best idea in their experience. A solution mentioned by the group was to start the visualization with a different kind of graphical feedback, such as a score or a measure of used grid capacity, where after the user can click on the graph to expand to the more technical graph as seen in Figure 6.4. A given example of such an approach is the Climate Science Special Report [61], which provides the user with a short summary at the beginning of the report, where after the reader can go to more detailed chapters and even more detailed chapters to receive more technical information. This method helps to provide information to multiple target audiences.

Another point of feedback was about the weather. The current idea to cut PV generation in half when cloudy weather is selected was covering only half the idea of cloudy weather. Another prominent difference between a clear sunny sky and cloudy weather is the fluctuation visible in PV generation as PV panels get covered by a cloud, as opposed to a single curve on a sunny day. One suggestion was to pick a day close to the first of June when fluctuations in generation were visible and use this for the cloudy day.

The last major point of feedback was about providing (more) information about what the user can do to improve the status of the grid. This would also help to form a clear general piece of information the user must be able to learn after interacting with the tool. Since the tool does not contain any additional text to help people steer in the right direction, or explain why their created situation is bad, the user can get stuck and no longer understand what they must do. One thing to consider is to add text corresponding to what the user is interacting with or to the situation they created in the neighborhood, steering them to make the "right" decision.

6.4 Prototype for First User Tests

After receiving feedback from the energy group and fellow students some changes were made to the prototype. In Figure 6.6 the final design can be seen. The biggest change is the capacity ("Capaciteit") bar on the right side, replacing the power profile graph. This bar lets the user know how much capacity is needed for their selected settings. If demand peaks too much at one point of the day and exceeds the limit of the local transformer, which is about 55 kW in this scenario, a warning will

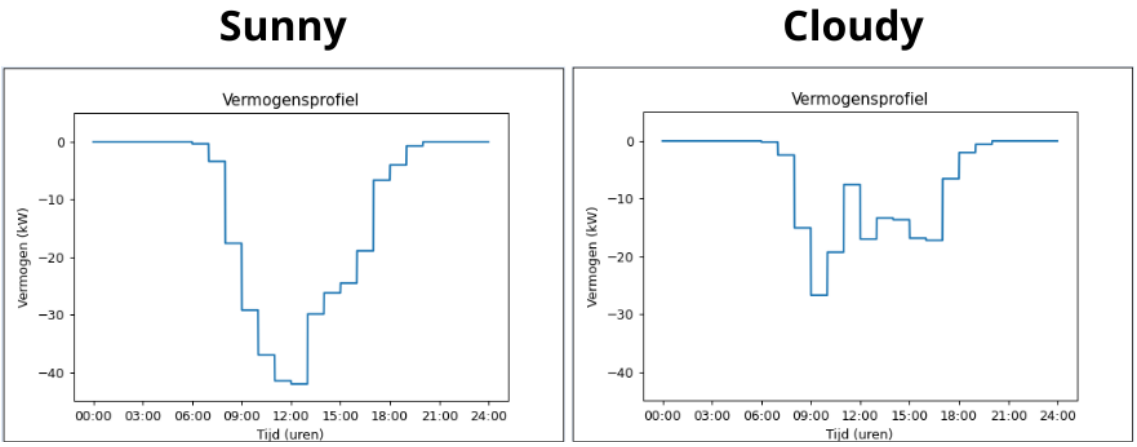


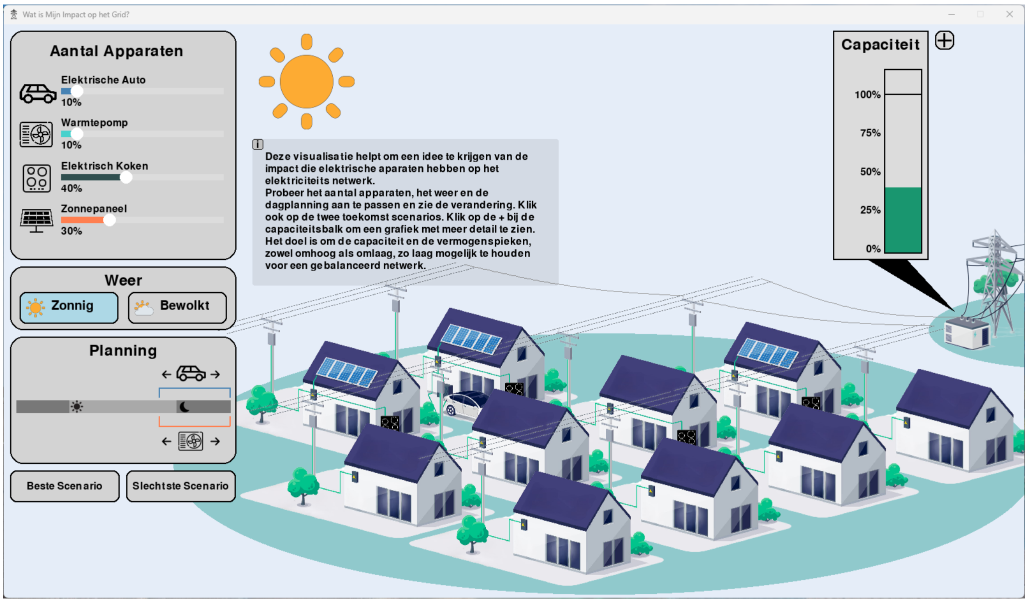
FIGURE 6.5: PV generation profiles for sunny and cloudy weather

show and the bar becomes red. Furthermore, the bar will be green when the capacity is low, yellow when 75% capacity is used, and orange with a capacity above 85%. The height of the bar is determined by the highest reached peak during the day. Therefore, it shows a big difference between evening demand and morning/afternoon demand. If people want a more detailed graph the + button can be clicked to show the power profile graph as can be seen in Figure 6.7

Another change has been made to the weather settings. As suggested by the Energy Group, a secondary dataset with fluctuating generation during the day was picked to show the difference in energy generation on a sunny and cloudy day. The new dataset was picked from the same ALPG data generation, but instead of the first of June as used for sunny weather the third of June was selected for cloudy weather. The difference in generated power and fluctuation over the day can be seen in Figure 6.5.

Another added feature to the prototype was the text box above the neighborhood. This text box first displays the goal of the tool, explains what can be changed, and how to change it to the more detailed graph. The text box will change according to what the user is interacting with to provide extra information on that interaction. For example, if the weather is changed by the user, the text box will explain why the weather has such an impact on the grid, and what to look for. This extra information is especially helpful for the best and worst case scenario presets, which can be seen in Figure 6.7 and Figure 6.8, respectively. This text helps the user to not only see the differences between the two scenarios but also learn why these situations are so different. Since the texts are hard to read in these images, go to section E.2 for enlarged versions of the text.

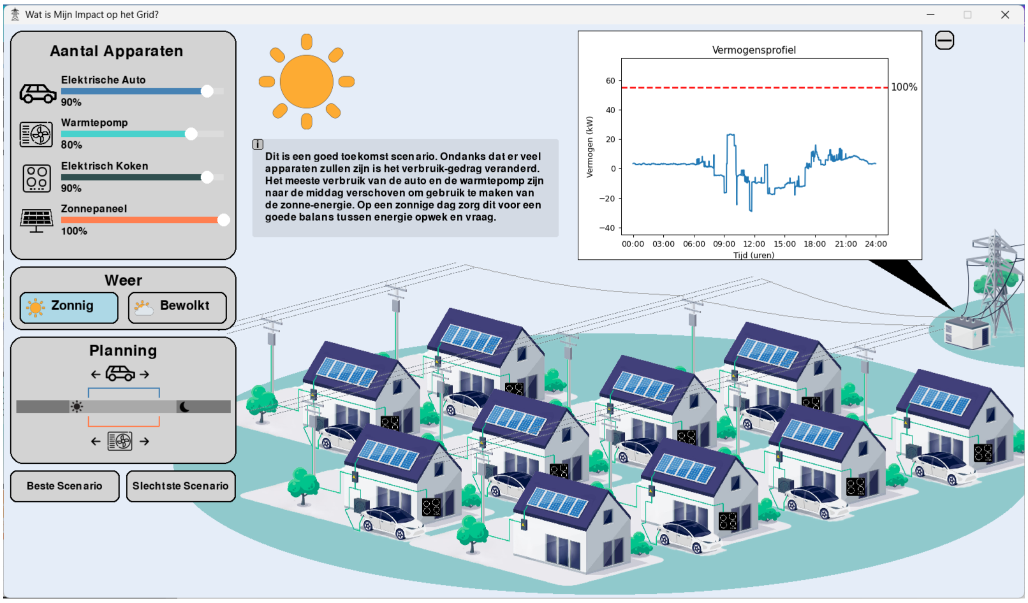
Finally, Some last changes were made to make it clear when the maximum capacity or the maximum power peak is reached, by adding a red border to the screen and adding a warning sign next to the graphs, seen in Figure 6.8. This prototype is ready for the first user tests, found in section 6.4.



Elektrische Auto 10%
Warmtepomp 10%
Elektrisch Koken 40%
Zonnepaneel 30%

Deze visualisatie helpt om een idee te krijgen van de impact die elektrische aparaten hebben op het elektriciteits netwerk.
Probeer het aantal apparaten, het weer en de dagplanning aan te passen en zie de verandering. Klik ook op de twee toekomst scenarios. Klik op de + bij de capaciteitsbalk om een grafiek met meer detail te zien. Het doel is om de capaciteit en de vermogenspieken, zowel omhoog als omlaag, zo laag mogelijk te houden voor een gebalanceerd netwerk.

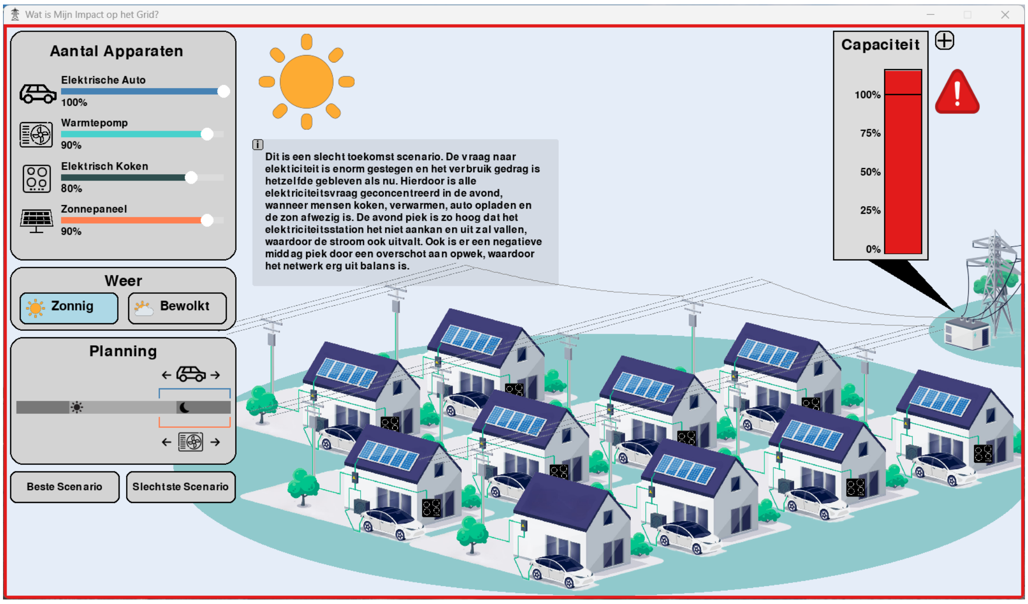
FIGURE 6.6: Final prototype after Energy Group feedback



Elektrische Auto 90%
Warmtepomp 80%
Elektrisch Koken 90%
Zonnepaneel 100%

Dit is een goed toekomst scenario. Ondanks dat er veel apparaten zullen zijn is het verbruik-gedrag veranderd. Het meeste verbruik van de auto en de warmtepomp zijn naar de middag verschoven om gebruik te maken van de zonne-energie. Op een zonnige dag zorg dit voor een goede balans tussen energie opwek en vraag.

FIGURE 6.7: Final Prototype with the best case scenario and power profile graph



Dit is een slecht toekomst scenario. De vraag naar elekticiteit is enorm gestegen en het verbruik gedrag is hetzelfde gebleven als nu. Hierdoor is alle elektriciteitsvraag geconcentreerd in de avond, wanneer mensen koken, verwarmen, auto opladen en de zon afwezig is. De avond piek is zo hoog dat het elektriciteitsstation het niet aankan en uit zal vallen, waardoor de stroom ook uitvalt. Ook is er een negatieve middag piek door een overschot aan opwek, waardoor het netwerk erg uit balans is.

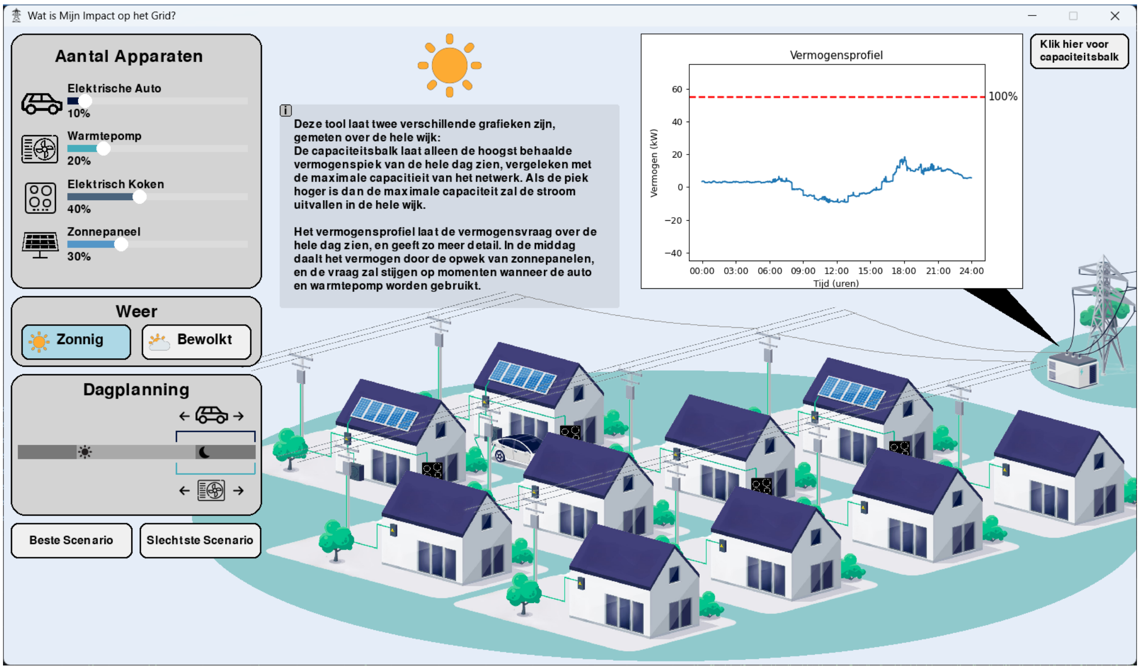
FIGURE 6.8: Final Prototype with the worst case scenario

6.5 Final Prototype

After the first batch of user tests, as described in section 6.4, some feedback points were frequently mentioned about the tool. Because of this, and the fact that the next set of user tests were scheduled a few days later, there was enough time to fix these flaws. This new iteration of the final prototype was used for the second batch of user tests, which can be compared to the first user test and is found in section 6.5.

The feedback about what the user did not like or could be improved about the tool highlighted two main components. The most mentioned point of improvement was about the graphs. Not every participant managed to find the power profile graph, and the capacity bar was confusing. The beginning text shown after the startup of the tool suggested how to switch to the other graph, and how both graphs must be interpreted, but this text disappeared as soon as the participant interacted with something else and did not come back later. Not all participants read the text and therefore were unaware of the other graph. This flaw was attempted to solve by giving the graph its own text which appears after clicking either the graph or the button of the graph. Additionally, the button of the graph in the top right corner was made bigger and shows text in it which says "Click here for power profile", instead of the minus or plus symbol. These changes can be seen in Figure 6.9.

Another improvement for the prototype was the text. Generally, the text was either hard to read or not read at all. Some participants pointed out this was because the text was a big block, and they wanted more information on what they could change or interact with. To solve this, the text block was made bigger to make more space for text in it. The text was split up into an informative part, and some additional tips or instructions that the user could do, split by an empty line. The idea is that these smaller sections of text are easier to read and provide more information for the tool. One example text can be seen in Figure 6.10. Here, the beginning text of the tool is changed and split for three different purposes: A



Elektrische Auto: 10%
Warmtepomp: 20%
Elektrisch Koken: 40%
Zonnepaneel: 30%

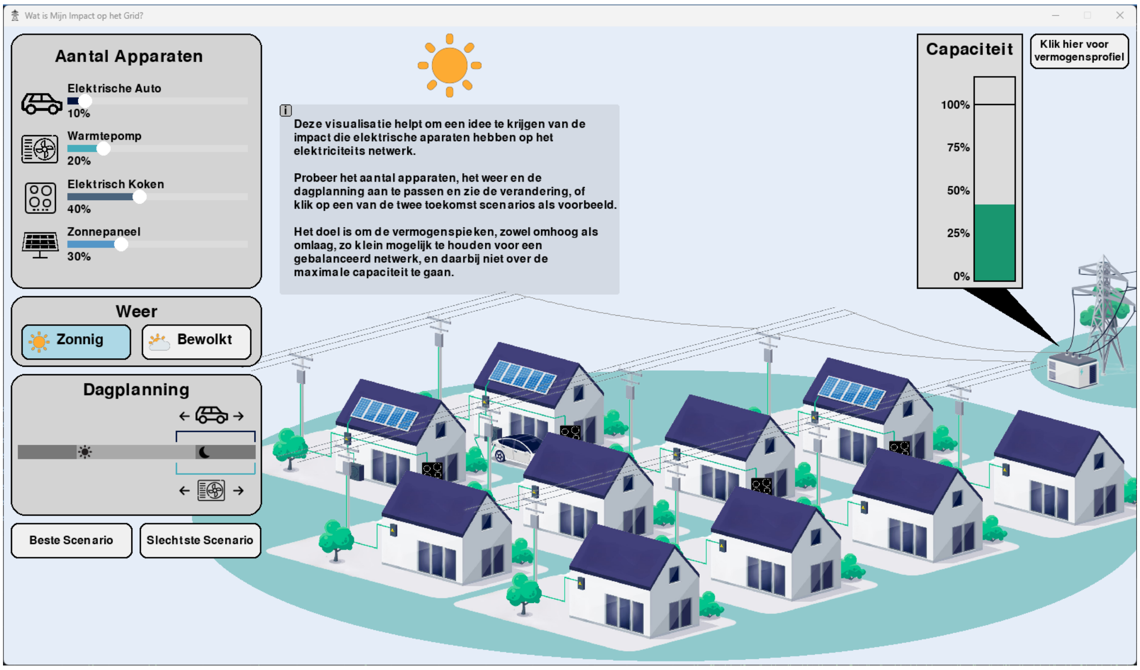
Deze tool laat twee verschillende grafieken zijn, gemeten over de hele wijk:
De capaciteitsbalk laat alleen de hoogst behaalde vermogenspiek van de hele dag zien, vergeleken met de maximale capacitieit van het netwerk. Als de piek hoger is dan de maximale capaciteit zal de stroom uitvallen in de hele wijk.

Het vermogensprofiel laat de vermogensvraag over de hele dag zien, en geeft zo meer detail. In de middag daalt het vermogen door de opwek van zonnepanelen, en de vraag zal stijgen op momenten wanneer de auto en warmtepomp worden gebruikt.

Figure 6.9: Improved graph button and text

small introduction, what can be changed, and the general goal. In Figure 6.6 the old version can be seen, for comparison.

In section E.1 a link to the entire code of the prototype can be found.



Elektrische Auto 10%
Warmtepomp 20%
Elektrisch Koken 40%
Zonnepaneel 30%

Deze visualisatie helpt om een idee te krijgen van de impact die elektrische aparaten hebben op het elektriciteits netwerk.

Probeer het aantal apparaten, het weer en de dagplanning aan te passen en zie de verandering, of klik op een van de twee toekomst scenarios als voorbeeld.

Het doel is om de vermogenspieken, zowel omhoog als omlaag, zo klein mogelijk te houden voor een gebalanceerd netwerk, en daarbij niet over de maximale capaciteit te gaan.

FIGURE 6.10: Improved text box for final prototype

Chapter 7

Evaluation

This chapter discusses the evaluation phase of the prototype tool. First, the design of the study will be covered, focusing on the aim, the targeted participants, how the data will be collected, and the procedure of the study. After this section the results will be discussed, looking at both the functional and user evaluation. Finally, a conclusion is formulated.

7.1 Study design

7.1.1 Aim

The main aim of the evaluation phase is to formulate an answer to the fourth sub-research question as mentioned in chapter 1, which is: *'To what extent can the prototype have an impact on the user demand of the electricity grid?'.* To do this, both the usability of the tool and the educational capability must be tested on a group of participants similar to the target audience.

7.1.2 Participants

Since the target audience of this project is quite broad, covering the entirety of the Dutch population, some key requirements must be set for the study participants. The first key requirement is people from multiple technical knowledge levels. This helps test whether the tool can educate both people with a lower base level of technical knowledge and ones who are already aware of the power grid's functions. Another requirement is covering a wide range of age groups, with both younger and older people. The last requirement of the participants is a variety of LCT owners. By also covering participants with only one or none of the LCTs mentioned by the prototypes, the tool's ability will be tested on people with no prior knowledge of the other LCTs. An owner or frequent user of an LCT can more easily recognize the behavior of these technologies without an explanation of the tool. These three conditions together form a wide base for the tool to be evaluated by the target audience.

7.1.3 Data Collection

The data of the participants will be collected in two main ways. During the interaction with the tool, the researcher will observe the participant's behavior and take notes accordingly. The second way to collect data will be a survey which the participant will fill out. This survey consists of three parts, starting with demographic questions covering age, technical knowledge, and LCTs owned/used. This is followed by the System Usability Scale (SUS) questions to evaluate the usability. Lastly, open questions about their perceived experience with the tool and additional remarks are asked.

Observations

The goal of the user observations during their interaction was to gather qualitative data in a controlled environment [62]. Before the first observation, some things to look for were thought of. For this research, it is important to know what the user is doing with the tool, instead of what is expected they do. For this reason, the order of interactions is tracked, as well as their reaction to certain feedback of the tool. After the user test was completed and the questionnaire had been filled out, the researcher asked some additional questions about what the user was thinking at different points of the user test, or what caused them to do a certain thing.

System Usability Scale (SUS)

The SUS was developed by J. Brooke in 1986 as a ”quick and dirty” usability scale and is still a widely used standardized questionnaire for the assessment of perceived usability [63], [64]. For its quick and valuable characteristics, it is also used during the assessment of this project's prototype tool.

The scale consists of ten statements, which can each be quantified with a scale from 1 to 5, strongly disagreeing or agreeing with the statement, respectively. This is also known as the Likert scale [65]. Afterward, the SUS score can be processed, resulting in a score from 1 to 100. Generally, a score of 68 is considered to be above average and therefore sufficient [66].

The score can be calculated with the following steps. First, the scores of the uneven questions are calculated. This is done by taking their value, between 1 and 5 for disagree to agree and subtracting 1 from it (X-1). Then the score of the even questions is calculated, which is a similar process, but now the value of the question is subtracted from 5 (5-X). Finally, the scores of all ten questions are added and then multiplied by 2,5. The answer is the SUS score [63].

7.1.4 Procedure

The user tests were carried out at the homes of the participants since the prototype only works on the researcher's laptop. After setting up the laptop with the tool, the information letter was presented to the participant. Some additional questions were answered after reading it and finally, the informed consent form was signed by the participant and the researcher. The information letter and informed consent form are visible in subsection F.1.1 and subsection F.1.2.

The user test consisted of two parts. First, the participant was provided with the prototype running and asked to start using it without any other instructions from the researcher. The researcher was looking at this interaction with the tool and taking notes of interesting behavior, such as where the participant starts interacting, and comments they make during the interaction. Input from the researcher was avoided to make sure no extra help was needed for using the tool. The researcher kept track of the interaction time to limit it to about 10 minutes, but the participants were also free to indicate they had seen enough of the tool. In some instances, the researcher would provide a last hint to participants who thought have seen everything about the tool but did not interact with all things, such as the power profile or the schedule sliders.

Once the participant was finished with the tool, they were presented with an anonymous questionnaire, consisting of demographic, SUS, and additional subjective questions. The questionnaire was primarily in English to make it easier to discuss findings with the supervisor, but the SUS questions were also provided in Dutch, and the open questions were allowed to be answered in Dutch. After the questionnaire, the researcher asked some final questions about the notes taken during the observation for clarification and their reasoning or some additional information on the topic. Finally, the user test was completed, and the participants were thanked.

7.1.5 Ethics

To carry out these user tests, approval from the Ethics Committee of Computer and Information Science (EC-CIS) of the University of Twente was needed [67]. This was done by submission of an ethics review, together with the used information letter and informed consent form, as seen in subsection F.1.1 and subsection F.1.2.

7.2 Results

The results of the evaluation phase will be discussed in this section. First, a functional evaluation is performed, reflecting on the requirements formulated in section 5.1. Afterward, both user tests are discussed regarding the user observations, the questionnaire, and the SUS score. A thematic analysis is performed on the qualitative data of the observations and the results from the questionnaire [68]. The SUS score is calculated for each test.

7.2.1 Functional Evaluation

The functional evaluation was performed by the researcher, and validated afterward by the project supervisor, who is considered to be an expert on smart grid technologies. The researcher went over all the functional requirements as formulated in the specification phase, and indicated if the prototype meets these requirements. The result of the evaluation can be seen in Table 7.1.

As highlighted by the table, only two requirements are not met by the prototype. This regards requirement number five, about providing additional information about different impact factors. The idea of this requirement was to include more technical

#	**Functional Requirement**	**Is this Requirement Met?**
1	The prototype must be tailored to the needs of the target audience and stakeholders and educate them on the discussed impacts of LCTs on the grid.	Yes
2	The prototype must be interactive and respond to user inputs.	Yes
3	The prototype should be easily accessible (online) via a computer.	Yes
4	The prototype should provide realistic data on power peaks and energy consumption of the shown LCTs.	Yes
5	The prototype could provide additional in-depth information on the different impact factors.	No
6	The prototype could provide (live) data of the user's own neighborhood.	No
7	The prototype could contain pre-made scenarios to highlight important future impacts.	Yes
8	The application will not be available on a phone.	Yes

Table 7.1: Results of functional evaluation

information in the prototype about impact factors such as voltage fluctuations and harmonics. However, as found in the evaluation pitch with the Energy Group, this would be too technical for the current state of the prototype and would be a better fit for later iterations of the project.

The other requirement not met by the prototype is about providing (live) data of the user's own neighborhood. This idea would help the tool to be more relatable to the user by providing them with their own data. However, for the scope of this project and the prototype, this would be too complicated and could be considered for a later iteration or final version of the tool.

Despite these two requirements, it can be stated that the prototype meets most of the functional requirements, which is a positive result for the functionality of this prototype.

7.2.2 Usability Evaluation by Users - Test 1

For the first user test, the prototype was used as described in section 6.4. The test consisted of eight participants. These participants differ in age, technical knowledge levels, knowledge levels of the Dutch power grid, and owned/used devices. Their characteristics are summed up in Table 7.2.

Table 7.2: Participants in User Test 1

Participant ID	Age Group	Technical Knowledge Level	Knowledge of Dutch Grid	Owned/Used Devices
1	50-59	Low	Low	EV, HP, eCooking, PV
2	50-59	High	Very High	EV, HP, eCooking, PV
3	50-59	High	Neutral	EV, HP, eCooking, PV
4	50-59	Low	Neutral	EV, HP, eCooking, PV
5	20-29	Low	Very Low	eCooking, PV
6	20-29	Very High	Very High	EV, HP, eCooking, PV
7	10-19	High	Neutral	EV, HP, eCooking, PV
8	60-69	Neutral	Neutral	eCooking

Observations and Questionnaire 1

To review the data from the first user test, a coding scheme was constructed using a thematic analysis, the result of which can be seen in Figure F.1. four themes were identified, which are listed below together with their sub-themes. The number of codes is based on the number of times these themes were mentioned during the user test, meaning higher codes were a recurring theme.

The first theme of the analysis is "Usability". This theme consists of six different sub-themes. The most occurring sub-theme is "Lots of control", as most participants enjoyed the interactive experience of the tool. These interactions and changing parameters allowed them to recreate a future scenario, or their own situation in their neighborhood, which leads to the second most mentioned sub-theme of "recreate own situation". sub-themes "Real-time feedback on input", "User friendly", and "Helpful text" were mentioned the same amount of times. A general remark for this is that the tool is easy to use despite the amount of control the user has, mostly because of the real-time feedback providing a clear idea of what the result is of each input of the tool. The additional text helps the user to understand what is going on. This is also suggested by the last sub-theme, "Clear overview".

The second theme is regarding "Visuals". It consists of four sub-themes, the most prominent being "Looks good". This sub-theme relates to "Liked the visualization", another sub-theme, and points out that the participants generally liked the design of the tool. This design, together with the "Quick response in the neighborhood houses" helps to relate the user to the topic, and to visualize a normally invisible topic such as electricity and power. The last sub-theme is "Like a game" as pointed out by one of the participants, immersing them in the interactive tool.

Another theme of the results is "Educational", referring to the educational capabilities of the tool. The "Electricity demand of these devices" was the most occurring sub-theme, as most participants were surprised by the huge power demand of EVs and the impact of high penetrations of PV, even if they owned these devices themselves. The fact that "The grid has limits" and "The scheduling of devices is important" was also a surprise for the participants. They never thought about these topics, which is understandable from a consumer perspective and interesting for this research. Finally, one participant mentioned that "All help is welcome" for education on the power grid.

The last theme of this user test is "Suggestions/ Improvements". The most often mentioned suggestion for the tool is "More instructions and easier to read text", as most participants either looked over the text, did not read it, or missed some instructions in it. The text displayed was one big block, which was not inviting to read according to the participants, they also missed some guidance for the interactions with the tool. The second most mentioned sub-theme was "Schedule sliders are unclear". The sliding design of the schedule sliders was not as intuitive as assumed, and the participant mistook the arrows for buttons, confusing them that this did not affect the slider. This confusion stopped some participants from experimenting further with the slider, preventing them from dragging and interacting with the slider. The graphs received some feedback, first of all, because of the "Hard to find power profile graph". The button for switching graphs was too small or not intuitive to suggest to the user there was another graph in the tool. Furthermore, the "Confusing capacity bar" meant participants did not come to the intended conclusion of the tool. This confusion was caused by a misunderstanding of what the bar was displaying, as this was not explained. Finally, participants would like to see more devices so they could relate even more to their situation.

SUS Score 1

The SUS score of the first set of user tests can be calculated using the method as described in section 7.1.3. The scores were calculated and added up per question. These ten scores were added and divided by the number of participants before multiplying by 2,5 to get the final average usability score. For the first user test, this resulted in a score of 73 out of 100, considered "Good", giving it a percentage score between 65-69% [69].

7.2.3 Usability Evaluation by Users - Test 2

After the first eight participants of the first user test, some slight changes were made to the tool to account for often received feedback. The changes made are described in section 6.5. This second user test is used to validate whether these changes improved the user experience and usability of the tool.

The second set of user tests consisted of five participants. These participants also differ in age, technical knowledge levels, knowledge levels of the Dutch power grid, and owned/used devices. Their characteristics are summed up in Table 7.3.

Table 7.3: Participants in User Test 2

Participant ID	Age Group	Technical Knowledge Level	Knowledge of Dutch Grid	Owned/Used Devices
9	20-29	Neutral	Low	HP, eCooking, PV
10	10-19	Very High	Neutral	EV, eCooking, PV
11	10-19	Very Low	Low	eCooking
12	50-59	High	Neutral	EV, eCooking, PV
13	50-59	Neutral	Low	EV, eCooking, PV

Observations and Questionnaire 2

Similar to the review of the first user test, a coding scheme for a thematic analysis was also constructed for the second user test, the result of which can be seen in Figure F.2. The same four themes were identified and listed below, together with different sub-themes.

The first theme of the analysis is "Usability". This theme consists of five different sub-themes. The most common sub-theme was "Find power profile on their own", which is an interesting change as opposed to user test 1 since this was one of the often mentioned suggestions. The other four sub-themes are evenly distributed, which are "Real-time feedback on input" "Helpful text", "Clear", and "Recreate own situation". These are similar to the ones mentioned in user test 1 and generally indicate that the tool's usability was pleasant.

The second theme is regarding "Visuals". It consists of four sub-themes, the most prominent being "liked the visualization". Together with the other sub-themes, "Looks good", and "Quick response in neighborhood houses", it indicates the tool was visually pleasing for the participants.

The third theme of the results is "Educational", referring to the educational capabilities of the tool. The most often mentioned sub-theme was "The scheduling of devices is important", which aligns with the main goal of the tool to better utilize the current capacity of the grid. Some participants pointed out that charging their car in the afternoon would be difficult, as the car would be at work, but also found using the tool that charging in the morning would relieve grid impact. "Electricity demand of these devices" and "learn about own situation" were the second most mentioned sub-themes. Participants found it interesting learning about the impact of their own devices, such as their EV, HP, eCooking, and PV, and did often not expect it to be this important. Participants that did not own the devices in the tool were also surprised by the impacts. "Why there are problems on the grid" and "How the grid works" refers to general knowledge the participants received from using the tool. Finally, "Gain more interest in the topic" came from a participant who pointed out she would like to start reading the news articles about problems on the grid, as this was first not in their interest but wants to learn more about it now.

The last theme of this user test is "Suggestions/ Improvements". The most often mentioned suggestion for the tool is "Likes the power profile more than capacity bar". This was not only mentioned by participants with high technical knowledge but also by less technical participants. The sub-theme ties in with the "Confusing capacity bar", as technical people were confused by getting a different response compared to what they expected to see, and less technical people mostly misinterpreted the bar. "Schedule sliders are unclear" and "More instructions and easier to read text" also occurred in this user test, again due to the schedule slider arrows being mistaken for buttons, and the text containing sometimes not enough information for the participant. Finally, "Hard to find power profile" was also mentioned in this user test.

SUS Score 2

The SUS score of the second set of user tests can also be calculated using the method as described in section 7.1.3. The process was similar to the SUS of the first user tests. This resulted in an increased score of 76 out of 100 for the second user test, an increase of 3 points. This score is also considered to be 'Good", but the percentage score rises to between 70-79% [69].

7.3 Conclusion

The evaluation of this project's prototype tool consisted of both a functional and usability evaluation. The functional evaluation indicated that 6 out of 8 requirements were met, meaning the functionality of the prototype has a positive result. The usability evaluation, considering both performed user tests, showed an overall positive response to the tool. Generally, the participants liked the interactive nature and the visuals of the tool and learned different things about the Dutch electricity grid. Both technical and non-technical people indicated to be surprised by the impact of their own devices and liked to be made aware of these effects. Yet, there were also a few suggestions about the tool to make it even more usable and understandable for the average member of the Dutch population. This is supported by the SUS analysis, as this resulted in a "Good" grade of 76 out of 100, and therefore leaves room for improvement. Generally, the tool showed a promising future prospect.

This evaluation aimed to formulate an answer to the fourth sub-research question: *'To what extent can the prototype have an impact on the user demand of the electricity grid?'*. Based on the results as presented above it can be stated that the tool of this graduation project can make a significant impact on the user's awareness and insight of their demand of the electricity grid. The tool, despite the room for improvements and refinements, is very usable and liked by the participants because of its interactive features and looks, and managed to educate both technical and non-technical users about the status of the local grid.

Chapter 8

Discussion

This thesis describes the design process of a communication tool to show data from the power grid to its users. The tool aims to provide insight and educate about the status of the grid. The Creative Technology Design Process was used as a guide for the development of the tool. Background research was performed to indicate the scale of the problem of the grid, which devices are mostly responsible for these problems, and look into existing methods to handle this problem. The impact of one device in particular, eCooking, was analyzed using data generation and an expert interview. The state-of-the-art analysis showed multiple devices for measuring one's consumption, however, these were all focused on the individual household and not on the status of the local grid. It was found that better utilization of the current grid can significantly improve the grid's status, without the immediate need for expansion. Based on the ideation phase a concept of an interactive visualization tool was formed and further specified. Together with an intermediate evaluation pitch the final concept was realised. The devices represented in the tool were based on the ones found in background knowledge, and the data was generated using a load profile generator. Finally, the prototype was evaluated with two user tests, consisting of eight and five participants respectively. The overall impression was positive, and the participants found the tool helped them gain insight into the problem on the grid. However, there is still room for improvement for further development of the tool.

8.1 Principle Findings

When comparing the designed prototype to other tools used for user insight in electricity consumption, the prototype distinguishes itself from others. First of all, the prototype displays data on a system level, e.g. the entire low-voltage grid, as opposed to only an individual household seen in devices such as Toon [41] and homewizard [42]. Furthermore, these devices inform the user about energy consumption, but not the power peaks induced on the grid. The prototype highlights the importance of spreading these power peaks over the day. Other technologies which target power peak shaving are demand response systems such as Honeywell Demand Response [70] and Siemens Demand Response System [71], Emissions-Optimized Energy Usage applications as WattTime [72], or peak load shaving home batteries such as the Tesla Powerwall [73]. These devices are focused on technology and autonomous peak reduction but fail to inform and include the user in the process. By providing the consumer with insight about the problem the prototype allows them to make an informed decision about their power use, closing the gap between now and the full-scale adoption of power peak shaving systems in Dutch households.

Another characteristic of this study's prototype is the combination of interactive and visual communication, as opposed to the purely visual communication of the devices mentioned above. M. Sorapure [74] constructed a framework of four key elements in information visualizations (infovis), such as the prototype of this project, which are text, image, data, and interaction. It is concluded that infovis distinguishes itself from infographics as it allows users to interact with the data, allowing them to relate it to their needs and interests. This is backed up by Perdana et al. [75], stating that Interactive Data Visualization (IDV) significantly enhances the user's understanding of data compared to using non-IDV methods, and IDV helps to mitigate the user's limitations (being not experienced) in informed decision making. Considering the prototype, its interactive visualization improves the user's ability to make an informed decision without needing technical experience/knowledge.

For the development of the tool, the Creative Technology Design Process was used as a main guide [44]. Additionally, experts and end-users were involved in the design process via an evaluation pitch during the realization phase and two user tests in the evaluation phase, which is a participatory design approach. Multiple studies highlight the involvement of potential stakeholders and end users has a beneficial influence on the development of a designed prototype [76], [77], [78]. By involving these experts and end users in the design process of the tool results in an end product that is more likely to fulfill stakeholder requirements and user needs. Additionally, it allows the researcher to construct solid arguments about the appropriateness of the design choices [78]. In this study's design process, the involvement helped to steer toward the right target audience, show data in different technical layers, and formulate a clear general message for the end user.

Finally, there was an unexpected outcome of the user evaluations. During the meeting with the Energy Group, the idea was brought up to replace the power profile graph with a more simple scoring system to prevent overwhelming non-technical users with a graph. This scoring system was expressed in the form of a capacity bar, displaying the highest reached power peak over the entire day compared to the highest capacity the local grid could handle. Contrary to what was expected, the participants of the user test found the capacity bar confusing and preferred to look at the power profile, since this displays the data over the entire day. However, when asked about the graphs, participants did like the idea of choosing the amount of detail in feedback. A recommendation for this would be to explore different forms of a simple scoring system for user feedback. This could be done by ideation of different designs and testing this with a new user test group.

8.2 Strengths and Limitations

8.2.1 Strengths

One of the strengths of this study was the participatory design approach that was used. By evaluating the design concept halfway through the realization of the prototype, via a pitch to experts of the Energy Group, some unforeseen flaws were improved. Additionally, conducting two separate user tests allowed the tool to be updated and improved to better-fit user needs. Both user tests led to valuable feedback and user requirements.

Another strength is the active involvement of the user in solving problems on the grid, especially by giving insight into the effect of power peaks on the local grid and how these could be spread better over the day. Unlike other educational electricity use devices, the tool has a wider scope that targets the entire low voltage grid on a system level and focuses on power peaks rather than energy use.

Finally, another strength of this research is the use of an interactive visualization as the communication method. Research and user testing have proven this is a successful method of communicating technical data to an audience with less technical knowledge. By allowing the user to interact and experiment with the data, they can relate it to their needs and interests.

8.2.2 Limitations

This study also has its limitations. The first limitation is the lack of time for realization of the prototype. The original idea for the prototype was to also include more in-depth technical details, such as harmonics and voltage fluctuations. After the evaluation pitch with the Energy Group, the decision was made to exclude these details from the prototype to make it easier to understand for the less technical target audience. Yet, similar to what is done with the power profile graph, extra graphs for harmonics and voltage fluctuations could be selected for a more technical audience, thus widening the target audience.

Another limitation of the study was the relatively small number of participants in the user tests. This is mostly caused by the very broad target audience, being the general Dutch population. To get a better understanding of the tool's usability and ability to educate users on their grid impact, more user tests should be performed. Additionally, the participants of the user test owned or used a lot of the four LCTs. This is on one side good since these people can immediately start altering their usage of these devices to improve the local grid. On the other hand, it is hard to decide if the tool would be as usable for users with little to none of these LCTs. This should be tested further.

Finally, SUS was used for quantifying the usability of the prototype. Despite being a "quick and dirty" way to effectively validate usability, it might not be the best fit for this graduation project. For example, the first question of SUS is about whether the user would like to use the prototype frequently. If the user agrees with this, the score gets higher. However, the goal of the prototype is to give the user insight into their effects on the local grid, which can be done by using the tool only once or twice. This tool is not meant for frequent use, and therefore this question does not fit the prototype. If this question were to be excluded, the SUS score would go from 76 to 79, which would raise the percentage score to 85-89%. Since this is about an increase of 10%, it is worth testing the prototype with a different scale.

8.3 Future Recommendations

Based on the principle findings, strengths, and limitations some recommendations for future research can be formulated. First and foremost, the tool in its current state can be further developed to improve the prototype and create a final product. As mentioned as a limitation, the prototype covered a relatively small number of participants for its broad target audience. Despite this, some feedback and recommendations could already be pointed out, such as an improvement for the capacity bar, a more intuitive design for sliders, and some additional information on more technical details. These suggestions could be worked out in a new study with a second prototype and more elaborate user tests to come to a more representative conclusion about the effectiveness and usability of the prototype.

Additionally, a recommendation can be made for the user tests of future studies to include users earlier in the design process of the tool. Despite the involvement of users in this study, it only happened during the realization phase of the prototype, which made it more difficult to implement suggestions that were very different from the current design of the tool. By conducting regular user evaluations starting from the ideation phase of the tool the involvement of the end user increases and would allow for a prototype better fitting to user needs. Additionally, regarding validating the usability of future prototypes, it is recommended to search for a different scoring system than SUS, as it might not be the best fit for this type of tool.

A final recommendation would be to look into behavior change methods during future studies. In this study, only effective communication methods were researched and implemented in the tool design to allow a broad target audience a clear insight into the grid problem. Yet, by dedicating a study to behavior change methods and implementing them into the tool, the tool could influence the behavior of the user and become more effective in spreading power peaks over the day.

Chapter 9

Conclusion

This study aimed to design a communication method to show data from the Dutch power grid to its users, to help them understand the impact of their electric devices on the grid. By conducting background research the most significant grid problem was found to be power peaks, mostly caused by EVs, HPs, PVs, and eCooking devices. In this research, it was also found that an interactive visualization can be an effective method for presenting technical information to a broad target audience. This target audience was later characterized by people of different technical knowledge levels, highlighting the importance of the tool to be understandable for non-technical users. By combining the involvement of experts and end users, and effective communication methods a prototype of the designed tool was created. This tool aims to provide insight into the grid impact of users via an interactive visualization. The evaluation shows a positive response of both technical and non-technical participants, regarding the interactive visualization and the insight received by the tool. However, there is still room for improvement, in the feedback, intuitive design, and instructions. Future work could focus on improving the prototype. This includes more involvement of end users in a second design process, researching the implementation of behavior change methods, and including more details in the tool to make it relevant to an even broader target audience. Afterward, improved user testing with participants representing the target audience allows the tool to be tested on usability and effectiveness. Overall, the tool shows a promising future to improve users' insight into the grid's problems for the coming years of the energy transition.

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Appendix A

AI use

During the preparation of this work, the author used AI. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the content of the work. The tools used are:

- ChatGPT, for help with and speeding up the coding process, discuss different techniques/methods applicable to the project, and help with Overleaf problems.
- Microsoft Copilot, for generating Figure 4.3.
- Grammarly, to help with spelling and improve academic writing style

Appendix B

Background Research

B.1 Interview Expert from Alliander

Q: What is the efficiency of cooking with electricity compared to natural gas? If the electricity is from a renewable source, the efficiency of eCooking is very good. In this scenario, an induction cooktop is about 90% and a ceramic cooktop is 50% efficient. Natural gas is between 60-80% efficient in energy transfer, but this depends on how you cook, for example, using a lid, the size of the pan, having the right flame size, and using a pressure cooker. If the electricity is not from a renewable source but generated using gas fueled power plant, the efficiency of an induction cooktop drops to 37% and the ceramic cooktop to 21%. But the efficiency of eCooking can also be impacted by not selecting the right cooking zone, or not turning down the power when water starts boiling.
Q: What are the costs of eCooking compared to using natural gas? On average a household needs about 300 kWh to cook per year, with little difference between a household of 2 or 4 people. Gas costs about €1.38 per m^3, and one m^3 contains about 9.8 kWh, so considering an efficiency of 60% it would cost about €65. Compared to electricity, which costs €0.30 per kWh, the same cooking would cost €90. Currently, households in the Netherlands are allowed to use net metering, which means the energy generated by one's PV panels during the day or the summer can be used again at night or in winter. The cost of electricity then reduces to about €0.18, meaning eCooking would cost about €54.
Q: Why is the cost of electric cooking higher, even though it is the favorable and more sustainable option? The price of electricity produced by a renewable source, such as a windmill, might only cost the consumer about €0.10. However, during the day not all energy is generated by these renewable sources. Gas-fueled power plants are always used to provide a baseline energy supply, which is more expensive as gas is expensive. Energy providers will sell all energy for the highest production price, even if 50% comes from renewable sources. This means the price of electricity is linked to the gas price, and is higher than it needs to be. In other European countries, this is not the case, resulting in lower energy prices.
Q: How can cooking behavior be influenced, so people might start earlier or later with cooking? Multiple experiments/pilots in the past have shown the difficulty of changing people's cooking habits for an extended period.

Additionally, Dutch people want to cook when hungry or when they arrive home from work. They eat during the evening peak on the grid. Other countries are accustomed to eating during lunch or late at night, which would help with reducing the evening peak. Since cooking and eating are essential to a human being, it might not be the best option for grid improvement. Other technologies adding to the evening peak, such as EV charging and HPs, are better to delay in the evening as these can be considered ‘luxury’ items.
Q: What is the impact of eCooking devices on the Dutch electricity grid? eCooking does not consume a lot of energy but does require lots of power, which can overload the grid. An induction cooktop usually is rated for 7.2 kW of power, meaning it needs to be connected to at least 2 power groups or a three-phase connection. Manufacturers of these cooktops make sure their product works for both power groups or three-phase connections, and therefore provide each cooking zone with its own AC-DC converter and DC-high-frequency-AC inverter, instead of one central only for three-phase connection. Inverters and converters are known for introducing harmonics on the grid, so these ‘extra’ ones are not preferred by network operators. Adding to this, the biggest and most frequently used cooking area is connected to phase 1, causing this phase to be used more than the others. This phase unbalance is sometimes exacerbated by the phase connections of a new residential area, where all houses share the same phase 1 connection inside the house, instead of changing it with every house to a different grid phase. If all houses in such a residential area were to cook simultaneously, the phase 1 and neutral wire would be overloaded quickly. We experimented once where we told an entire residential area to bake a pizza at the same time, and this caused a blackout of that grid. The EV charging controller that was actually tested responded as expected, but the test showed that without the random spread of electricity use over the day and during peak demand the grid would not handle all demand.
Q: What do you think of the concepts I have now, so the interactive visualization and the physicalization? Personally, I have more confidence in technology as opposed to the behavior of the consumer, as past experiments have shown how hard it is to really change one’s behavior. We also performed an experiment once where we provided free washers and dryers and we would control when they would turn on. This worked for some weeks but then the consumers reverted to their habits. And besides this, devices are more efficient now, so it does not make a huge difference in price and the money initiative is not as effective anymore. However, every bit helps and if people were to maintain their peak demand awareness, it could help. As a technician, I would try to find a solution in the technologies used, such as actively cooling transformers with fans during peak evening hours, or raising the voltage at the output of a power plant if the voltage drops too low at the residential connections. This way, only the energy provider is responsible for providing carefree electricity, as they are paid to do by the consumer.

Appendix C

Ideation

C.1 Brainstorm session 1

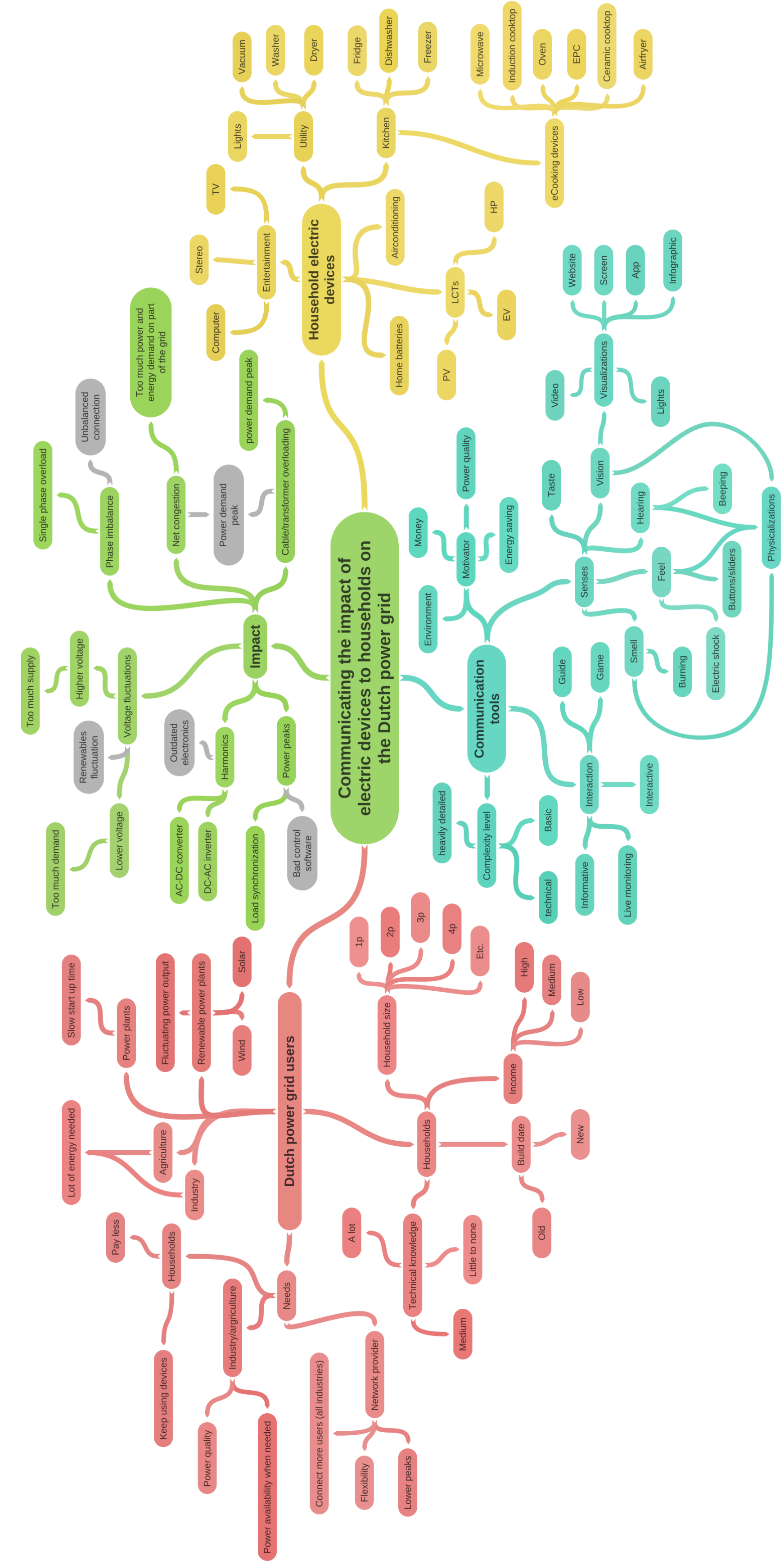


Figure C.1: Brainstorm 1 - Mind map Design Space

C.2 Brainstorm session 2

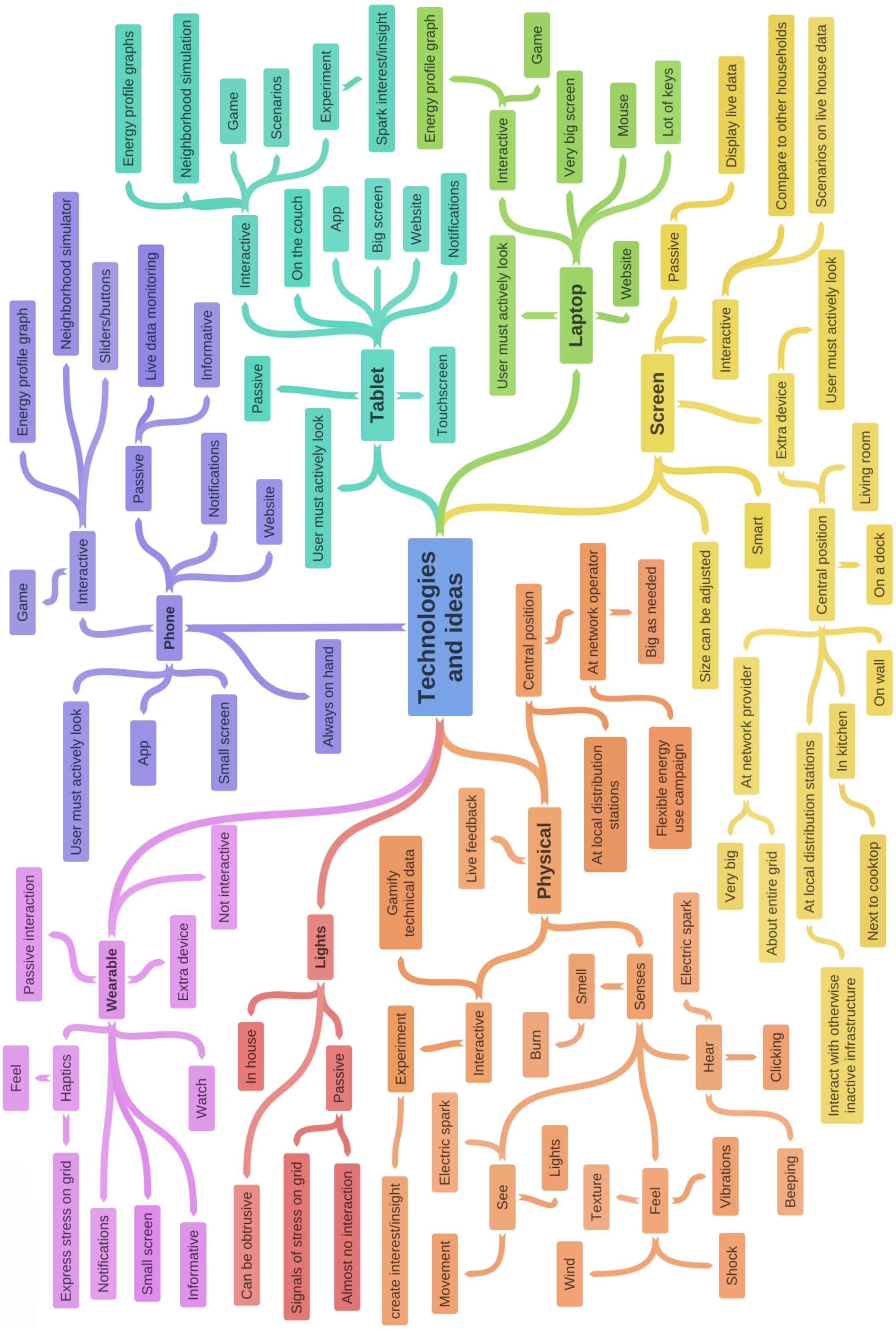


Figure C.2: Brainstorm 2 - Technologies and Ideas

Appendix D

Specification

D.1 Target Audience Use Cases

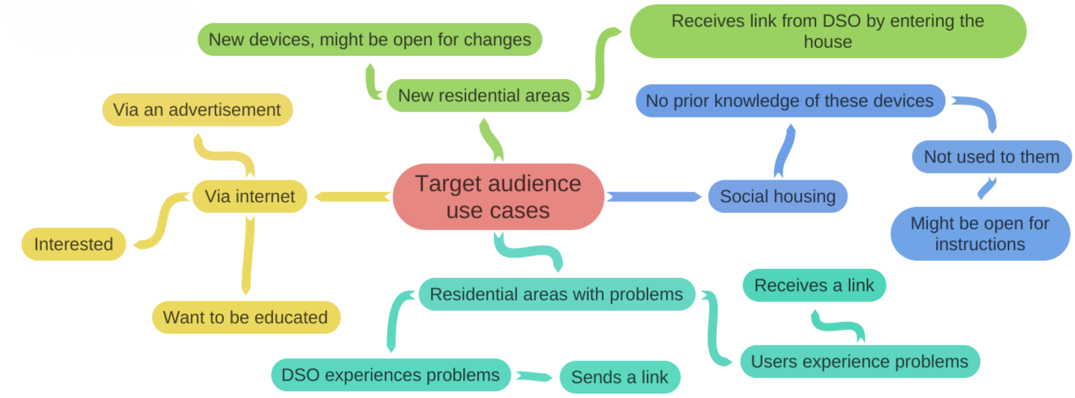


FIGURE D.1: Brainstorm of potential target audience use cases

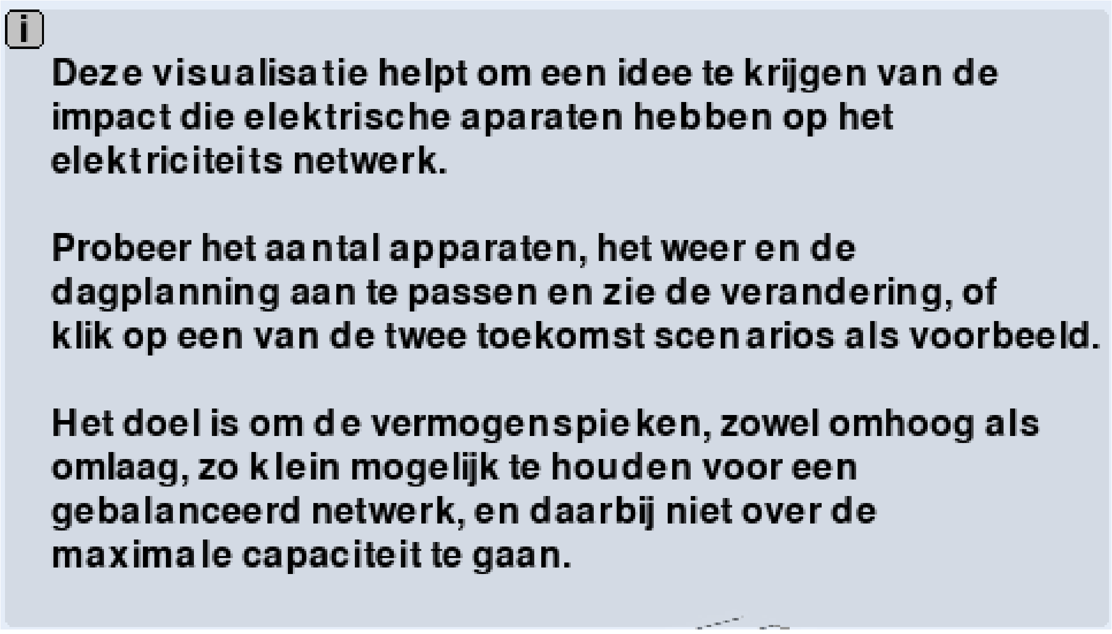
Appendix E

Realization

E.1 Code

To find the code for the prototype, visit: https://github.com/MrMaanix/GIVT

E.2 Texts

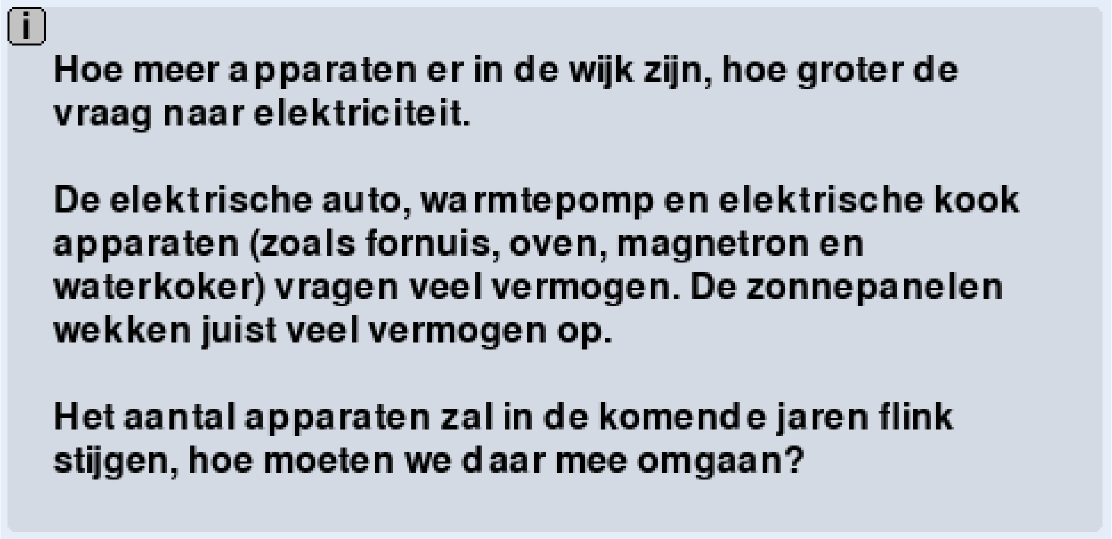


Deze visualisatie helpt om een idee te krijgen van de impact die elektrische aparaten hebben op het elektriciteits netwerk.

Probeer het aantal apparaten, het weer en de dagplanning aan te passen en zie de verandering, of klik op een van de twee toekomst scenarios als voorbeeld.

Het doel is om de vermogenspieken, zowel omhoog als omlaag, zo klein mogelijk te houden voor een gebalanceerd netwerk, en daarbij niet over de maximale capaciteit te gaan.

Figure E.1: Prototype start-up text

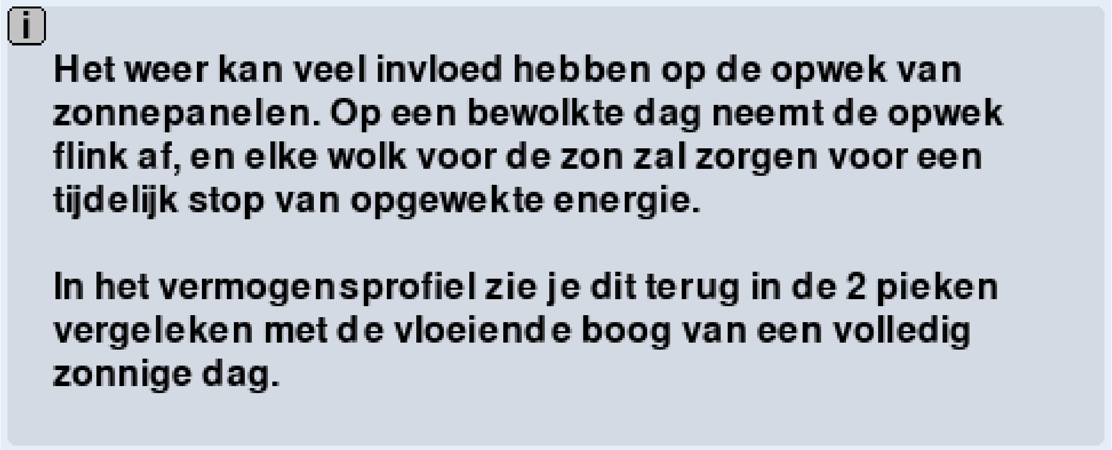


Hoe meer apparaten er in de wijk zijn, hoe groter de vraag naar elektriciteit.

De elektrische auto, warmtepomp en elektrische kook apparaten (zoals fornuis, oven, magnetron en waterkoker) vragen veel vermogen. De zonnepanelen wekken juist veel vermogen op.

Het aantal apparaten zal in de komende jaren flink stijgen, hoe moeten we daar mee omgaan?

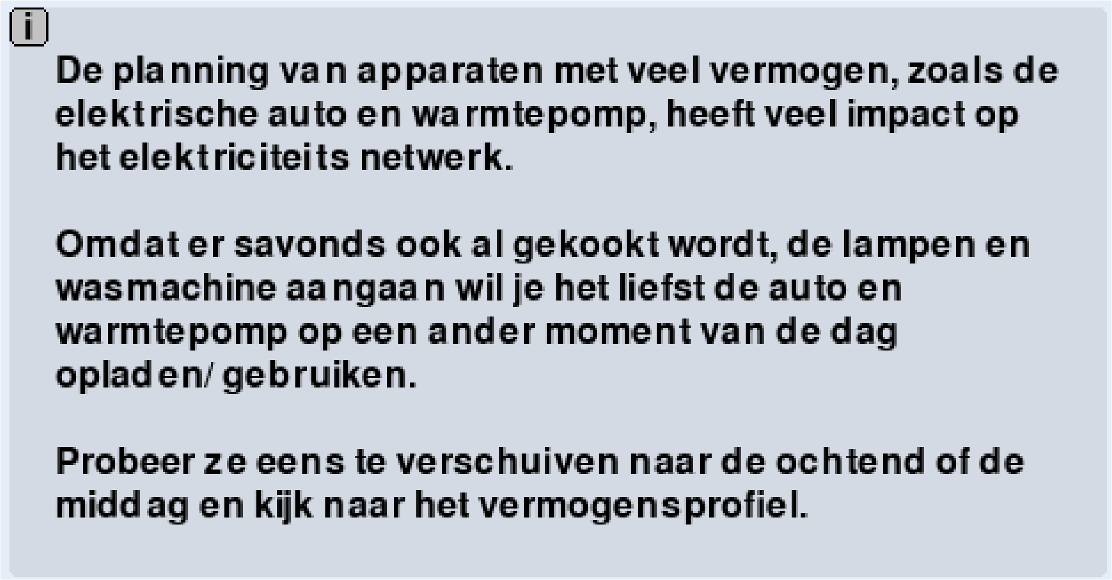
Figure E.2: Prototype LCTs text



Het weer kan veel invloed hebben op de opwek van zonnepanelen. Op een bewolkte dag neemt de opwek flink af, en elke wolk voor de zon zal zorgen voor een tijdelijk stop van opgewekte energie.

In het vermogensprofiel zie je dit terug in de 2 pieken vergeleken met de vloeiende boog van een volledig zonnige dag.

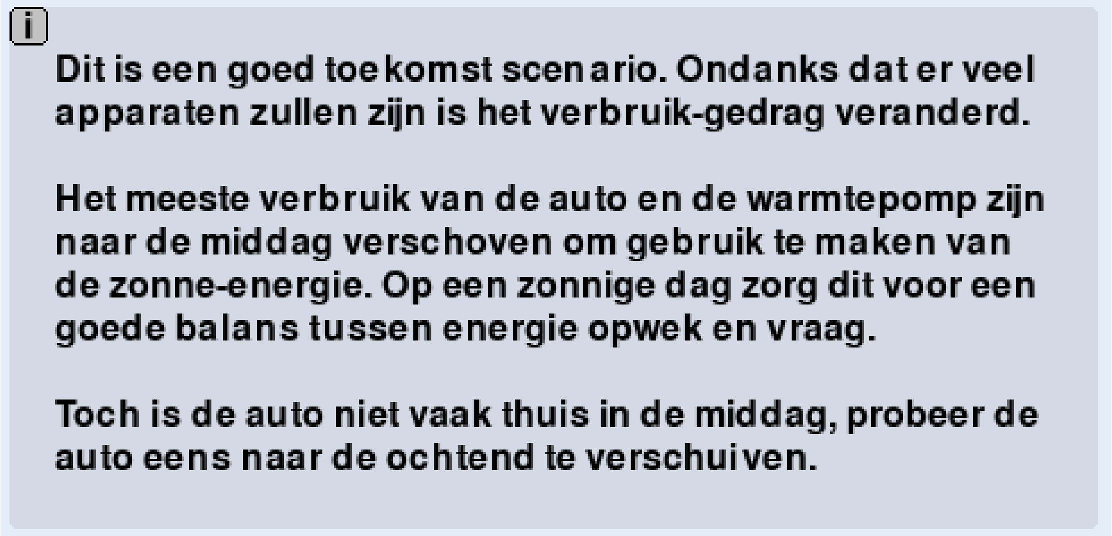
Figure E.3: Prototype weather text


De planning van apparaten met veel vermogen, zoals de elektrische auto en warmtepomp, heeft veel impact op het elektriciteits netwerk.

Omdat er savonds ook al gekookt wordt, de lampen en wasmachine aangaan wil je het liefst de auto en warmtepomp op een ander moment van de dag opladen/ gebruiken.

Probeer ze eens te verschuiven naar de ochtend of de middag en kijk naar het vermogensprofiel.

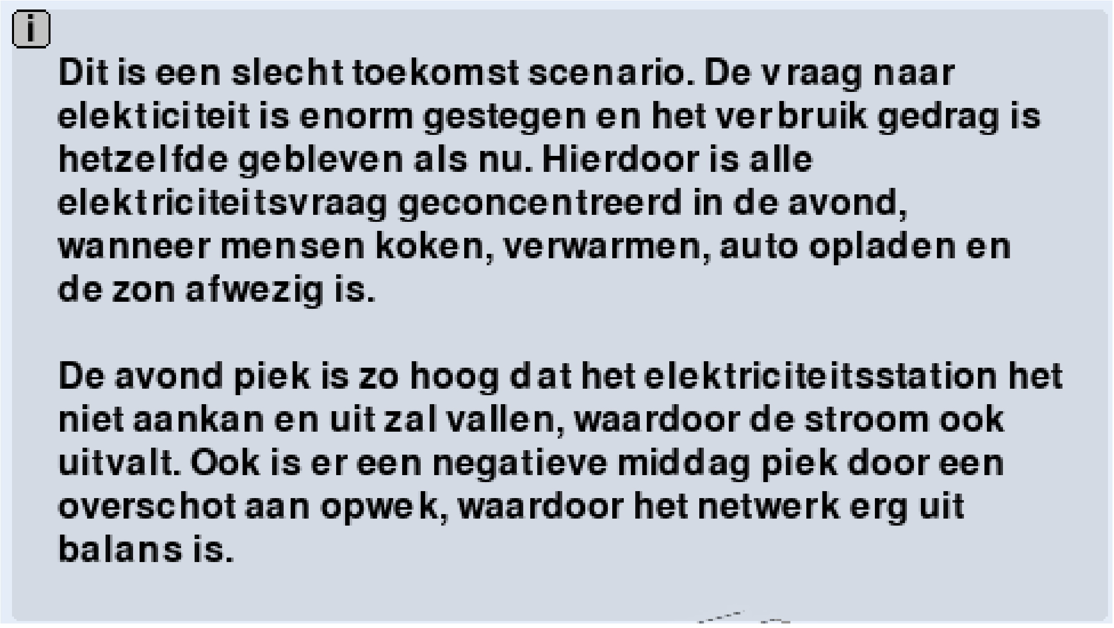
Figure E.4: Prototype schedule text


Dit is een goed toekomst scenario. Ondanks dat er veel apparaten zullen zijn is het verbruik-gedrag veranderd.

Het meeste verbruik van de auto en de warmtepomp zijn naar de middag verschoven om gebruik te maken van de zonne-energie. Op een zonnige dag zorg dit voor een goede balans tussen energie opwek en vraag.

Toch is de auto niet vaak thuis in de middag, probeer de auto eens naar de ochtend te verschuiven.

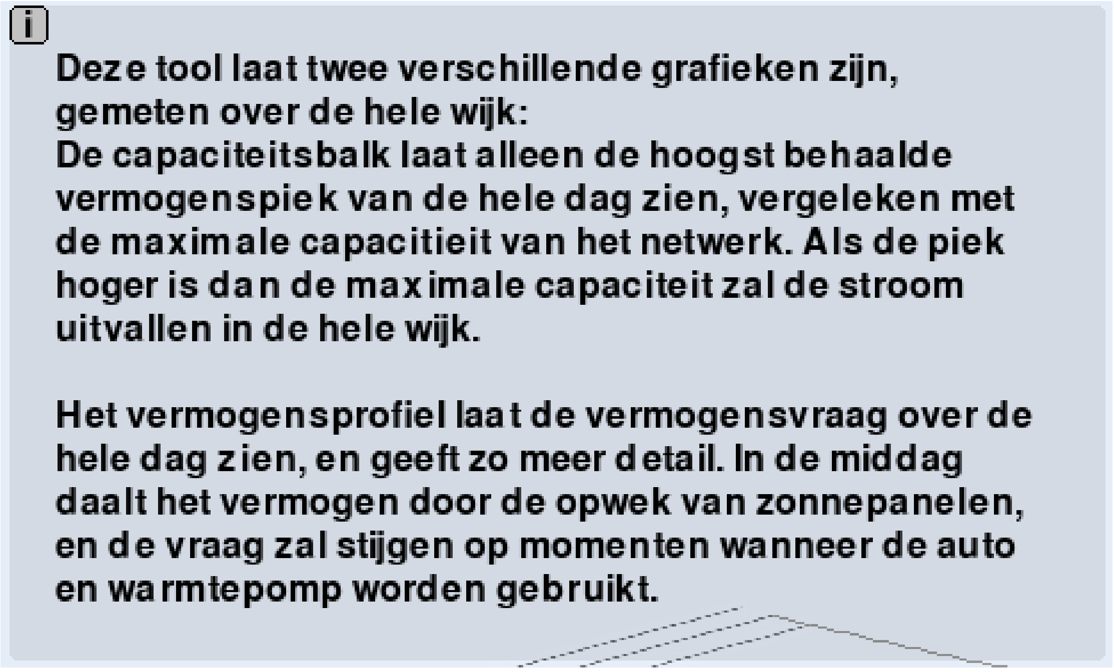
Figure E.5: Prototype best scenario text



Dit is een slecht toekomst scenario. De vraag naar elekticiteit is enorm gestegen en het verbruik gedrag is hetzelfde gebleven als nu. Hierdoor is alle elektriciteitsvraag geconcentreerd in de avond, wanneer mensen koken, verwarmen, auto opladen en de zon afwezig is.

De avond piek is zo hoog dat het elektriciteitsstation het niet aankan en uit zal vallen, waardoor de stroom ook uitvalt. Ook is er een negatieve middag piek door een overschot aan opwek, waardoor het netwerk erg uit balans is.

Figure E.6: Prototype worst scenario text



Deze tool laat twee verschillende grafieken zijn, gemeten over de hele wijk:
De capaciteitsbalk laat alleen de hoogst behaalde vermogenspiek van de hele dag zien, vergeleken met de maximale capacitieit van het netwerk. Als de piek hoger is dan de maximale capaciteit zal de stroom uitvallen in de hele wijk.

Het vermogensprofiel laat de vermogensvraag over de hele dag zien, en geeft zo meer detail. In de middag daalt het vermogen door de opwek van zonnepanelen, en de vraag zal stijgen op momenten wanneer de auto en warmtepomp worden gebruikt.

Figure E.7: Prototype graph text

Appendix F

Evaluation

F.1 Ethics Request

F.1.1 Information Letter

Information letter participating in a study

Title: Developing a communication tool to increase awareness of energy use and the impact thereof on the electricity grid.

Written by: Marnix Lueb

Date: 16-06-2024

Dear participant,

Due to an increase in electric devices over the last few years, such as electric vehicles, heat pumps, solar panels, and cooking on electricity, Dutch households are consuming and producing more electricity. The current Dutch electricity grid is not ready for this capacity and must be upgraded, but this will take multiple years. Because of the limited capacity new connections must be put on a waiting list.

However, the amount of electricity used is not the main problem, but mostly when it is used. Since people are often away from home during the day for work and use their devices once back, most of the power is requested at the same time in an evening peak. If this peak were to be flattened over the day, the grid could be used much more efficiently and more households could be connected.

This research aims to spread awareness of electricity use in Dutch households and educate them about the consequences of careless electricity use in future scenarios. To do this, an interactive visualization will be made to show the different devices and impacts in a nontechnical way for easy understanding and to spark interest in the topic.

What do I have to do when participating?
The study will consist of a user test with the visualization. You will be asked to interact with it, this will take about 10 to 15 minutes. During this session, the researcher will be looking at how you interact with the website. Afterward, you can fill out a survey form to rate the user experience and elaborate on these ratings (about 5 minutes). Finally, some questions will be asked by the researcher to check what you liked, disliked, or did not understand about the visualization (about 10 minutes).

All data will be used to improve the visualization and increase understanding of the topic.

What are the risks of participating?
This research does not come with any risks. You are allowed as a participant to leave whenever you want and participation is fully voluntary.

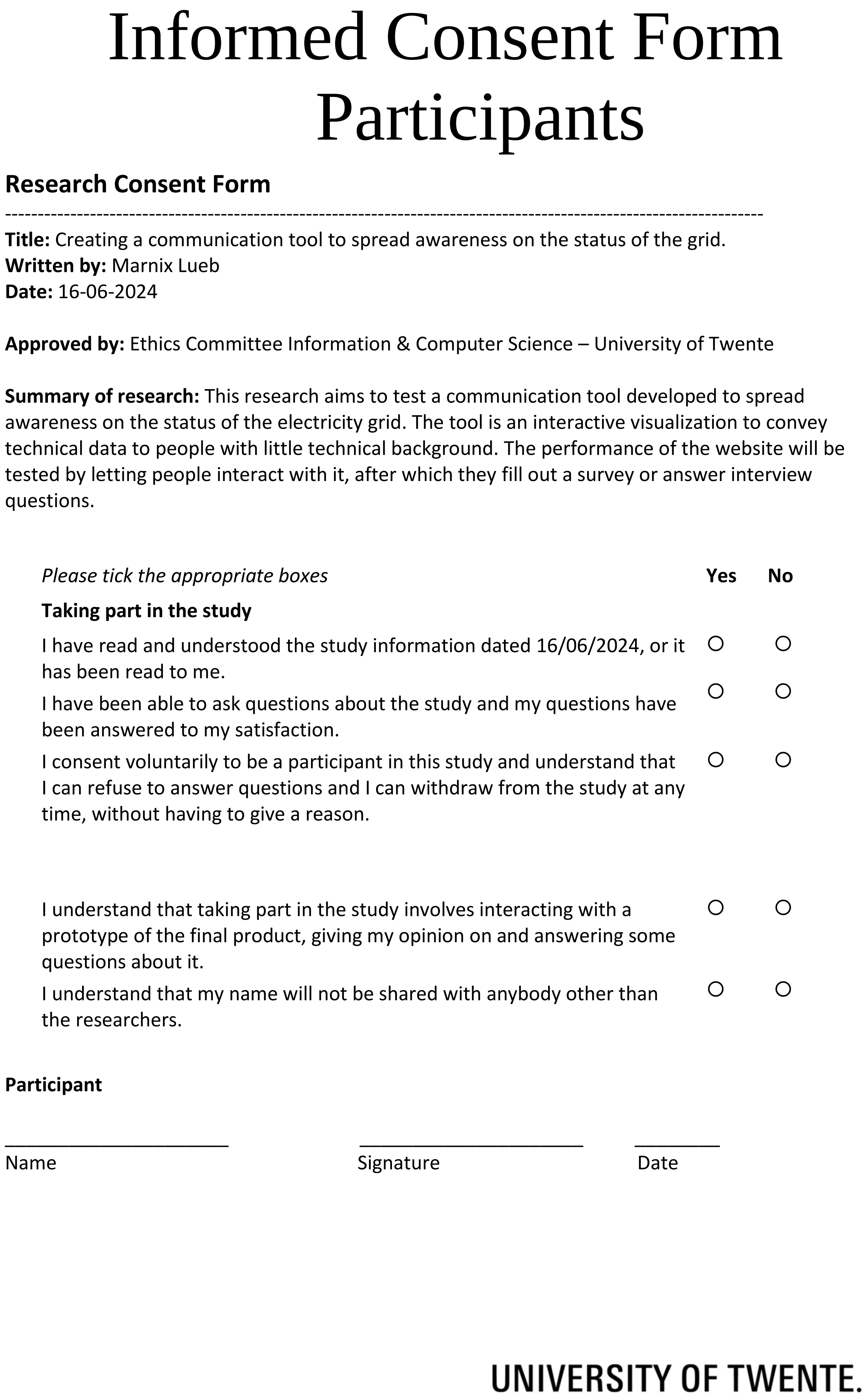
What happens to my data?
The interviews will be recorded to make sure everything is documented. Only this recording and your name will be saved after the participation. Your name is needed to approve your participation in the study. Only the researcher knows your name and it won't be shared with others. You can ask about your data and have it removed whenever you want.

Contact information researcher
Marnix Lueb, m.j.lueb@student.utwente.nl

Contact information committee University of Twente
If you have questions about your rights as a research participant or about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

Thank you for your participation!

F.1.2 Informed Consent Form



Informed Consent Form Participants

Research Consent Form

Title: Creating a communication tool to spread awareness on the status of the grid.
Written by: Marnix Lueb
Date: 16-06-2024

Approved by: Ethics Committee Information & Computer Science – University of Twente

Summary of research: This research aims to test a communication tool developed to spread awareness on the status of the electricity grid. The tool is an interactive visualization to convey technical data to people with little technical background. The performance of the website will be tested by letting people interact with it, after which they fill out a survey or answer interview questions.

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 16/06/2024, or it has been read to me.	○	○
I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves interacting with a prototype of the final product, giving my opinion on and answering some questions about it.	○	○
I understand that my name will not be shared with anybody other than the researchers.	○	○

Participant

______________________ ______________________ ________
Name Signature Date

UNIVERSITY OF TWENTE.

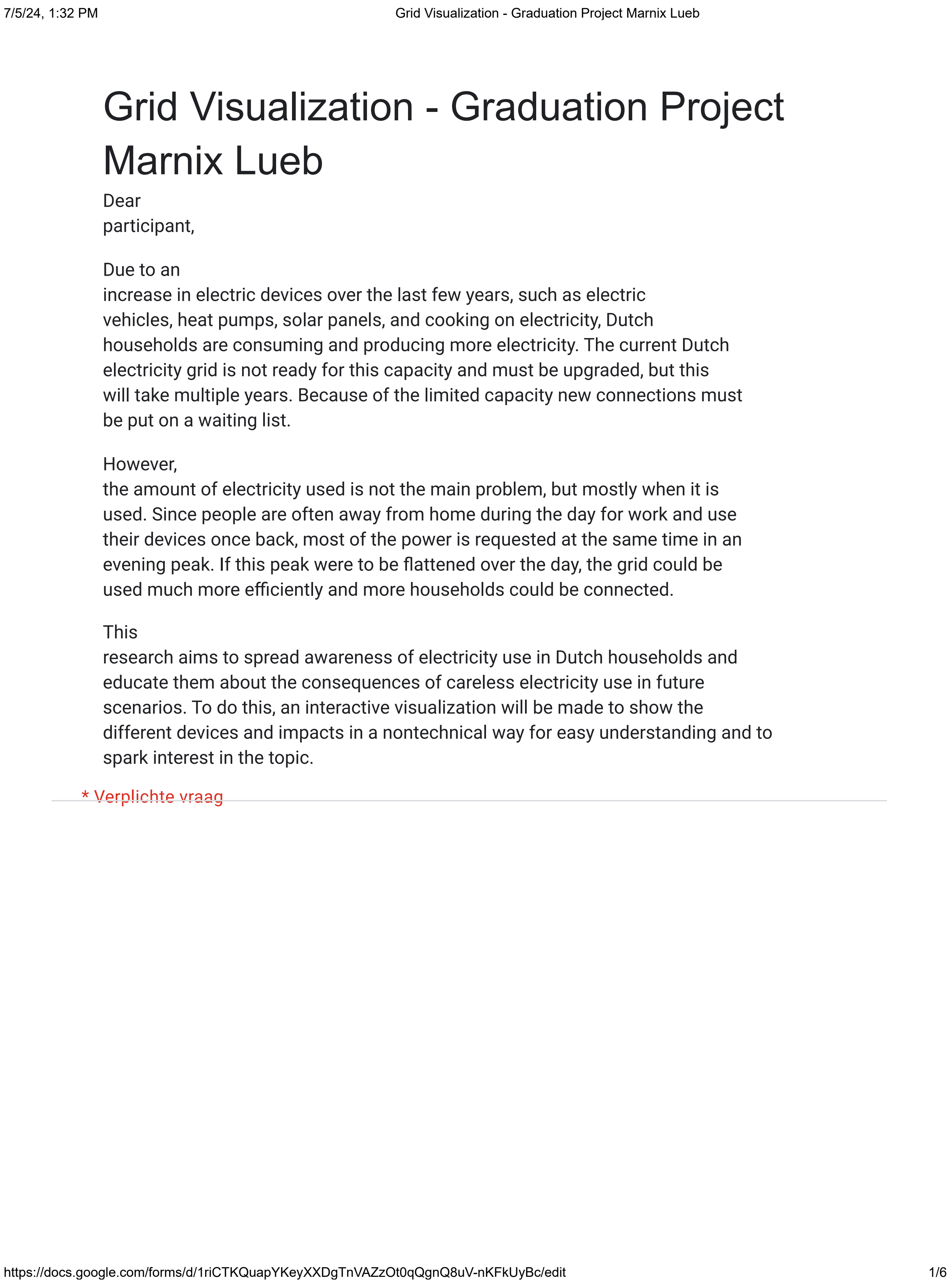
Researcher
I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands what they are freely consenting.

____________________________	________________________	_________
Name	Signature	Date

Contact details Researcher: [Marnix Lueb, m.j.lueb@student.utwente.nl]

If you have questions about your rights as a research participant or about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

F.2 Questionnaire



7/5/24, 1:32 PM Grid Visualization - Graduation Project Marnix Lueb

Grid Visualization - Graduation Project Marnix Lueb

Dear
participant,

Due to an
increase in electric devices over the last few years, such as electric vehicles, heat pumps, solar panels, and cooking on electricity, Dutch households are consuming and producing more electricity. The current Dutch electricity grid is not ready for this capacity and must be upgraded, but this will take multiple years. Because of the limited capacity new connections must be put on a waiting list.

However,
the amount of electricity used is not the main problem, but mostly when it is used. Since people are often away from home during the day for work and use their devices once back, most of the power is requested at the same time in an evening peak. If this peak were to be flattened over the day, the grid could be used much more efficiently and more households could be connected.

This
research aims to spread awareness of electricity use in Dutch households and educate them about the consequences of careless electricity use in future scenarios. To do this, an interactive visualization will be made to show the different devices and impacts in a nontechnical way for easy understanding and to spark interest in the topic.

* Verplichte vraag

https://docs.google.com/forms/d/1riCTKQuapYKeyXXDgTnVAZzOt0qQgnQ8uV-nKFkUyBc/edit 1/6

1. What is your age group? *

Markeer slechts één ovaal.

○ 10-19
○ 20-29
○ 30-39
○ 40-49
○ 50-59
○ 60-69
○ 70+

2. How would you rate your technical knowledge level? *

Markeer slechts één ovaal.

	1	2	3	4	5	
Low	○	○	○	○	○	High

3. What is your knowledge level of the Dutch electricity grid? *

Markeer slechts één ovaal.

	1	2	3	4	5	
Low	○	○	○	○	○	High

4. Which of these devices do you own/use? *

Vink alle toepasselijke opties aan.

☐ Electric car
☐ Heat pump
☐ Electric cooking equipment (Induction stove, electric stove, oven, microwave, kettle)
☐ Solar panels
☐ None

System Usability Scale Questions

5. I think that I would like to use this system frequently - Ik denk dat ik het graag regelmatig wil gebruiken *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

6. I found the system unnecessarily complex - Ik vind het onnodig complex *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

7. I thought the system was easy to use - Ik vind het makkelijk te gebruiken *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

8. I think that I would need the support of a technical person to be able to use this system - Ik denk dat ik ondersteuning nodig heb van een technisch persoon om het te kunnen gebruiken *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

9. I found the various functions in this system were well integrated - Ik vind dat de verschillende functies erg goed geïntegreerd zijn *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

10. I thought there was too much inconsistency in the system - Ik vind dat er teveel tegenstrijdigheden in zitten *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

11. I would imagine that most people would learn to use this system very quickly - Ik kan me voorstellen dat de meeste mensen het zeer snel leren om dit te gebruiken *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

12. I found the system very cumbersome to use - Ik vind het erg omslachtig in gebruik *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

13. I felt very confident using the system - Ik voel me er erg vertrouwd mee *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

14. I needed to learn a lot of things before i could get going with the system - Ik moest erg veel leren voordat ik ermee aan de gang kon gaan *

Markeer slechts één ovaal.

	1	2	3	4	5	
Disa	○	○	○	○	○	Agree

Additional questions

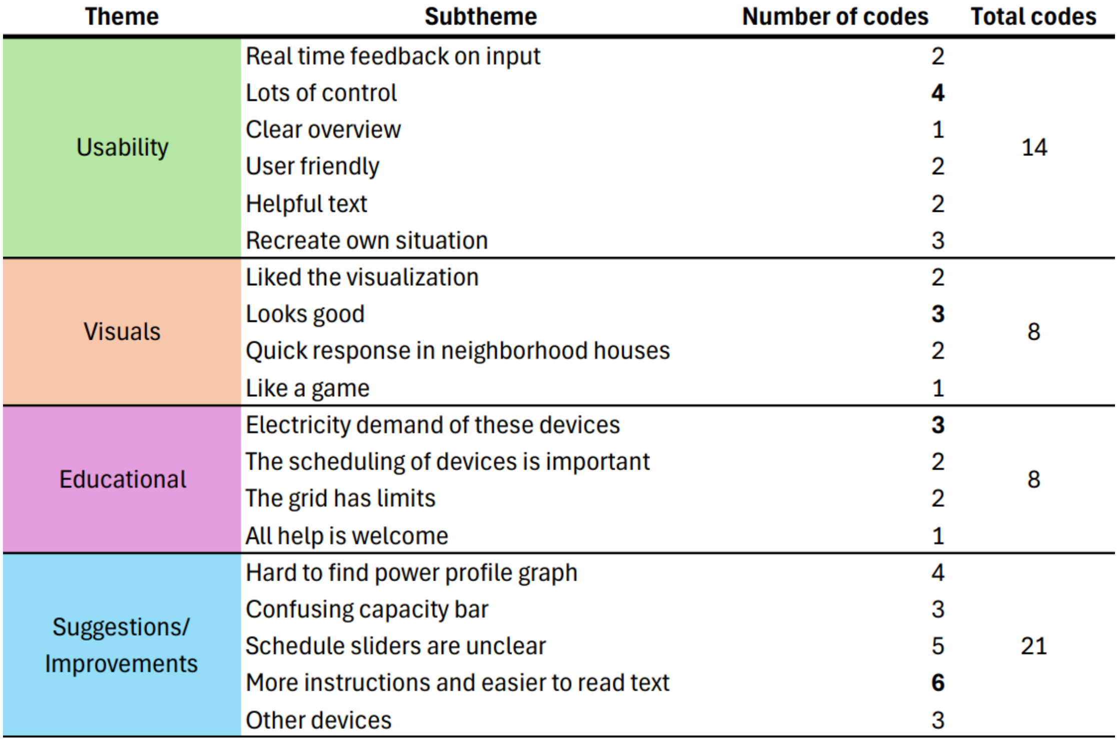
15. What did you like about this tool? *

16. What didn't you like about this tool? *

17. What did you learn from using this tool? *

18. Do you have any other remarks?

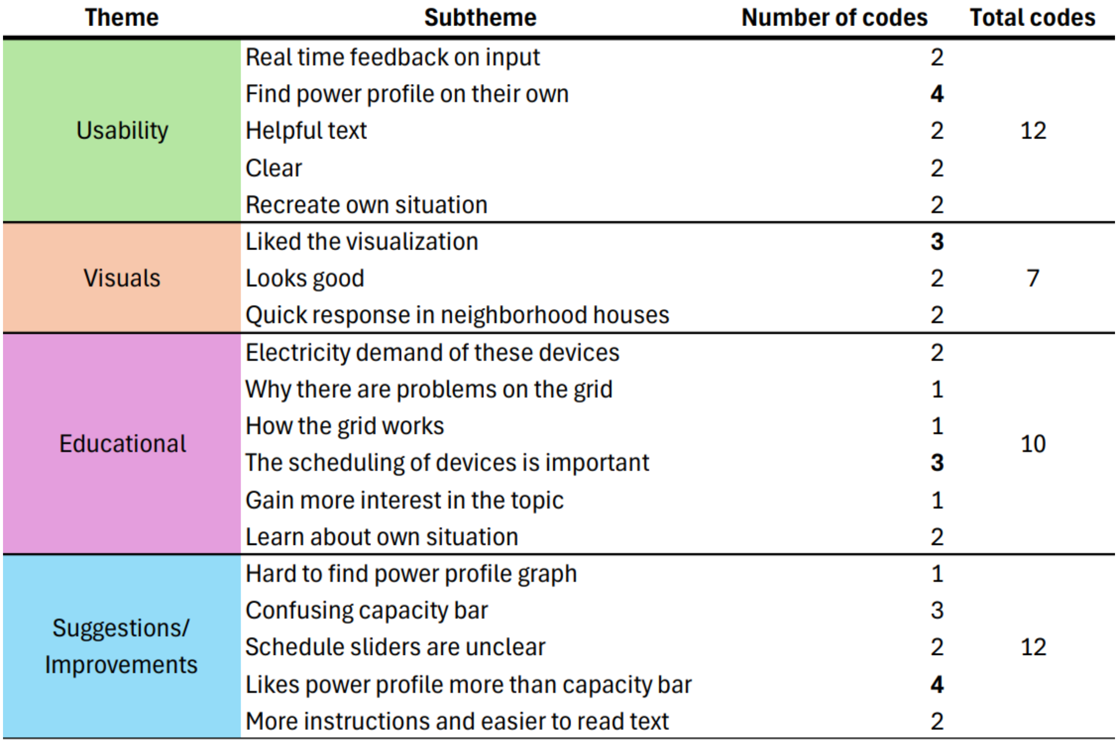
F.3 User Test 1 Coding Results



Theme	Subtheme	Number of codes	Total codes
Usability	Real time feedback on input	2	14
	Lots of control	**4**	
	Clear overview	1	
	User friendly	2	
	Helpful text	2	
	Recreate own situation	3	
Visuals	Liked the visualization	2	8
	Looks good	**3**	
	Quick response in neighborhood houses	2	
	Like a game	1	
Educational	Electricity demand of these devices	**3**	8
	The scheduling of devices is important	2	
	The grid has limits	2	
	All help is welcome	1	
Suggestions/ Improvements	Hard to find power profile graph	4	21
	Confusing capacity bar	3	
	Schedule sliders are unclear	5	
	More instructions and easier to read text	**6**	
	Other devices	3	

Figure F.1: Coding results of user test 1

F.4 User Test 2 Coding Results



Theme	Subtheme	Number of codes	Total codes
Usability	Real time feedback on input	2	12
	Find power profile on their own	**4**	
	Helpful text	2	
	Clear	2	
	Recreate own situation	2	
Visuals	Liked the visualization	**3**	7
	Looks good	2	
	Quick response in neighborhood houses	2	
Educational	Electricity demand of these devices	2	10
	Why there are problems on the grid	1	
	How the grid works	1	
	The scheduling of devices is important	**3**	
	Gain more interest in the topic	1	
	Learn about own situation	2	
Suggestions/ Improvements	Hard to find power profile graph	1	12
	Confusing capacity bar	3	
	Schedule sliders are unclear	2	
	Likes power profile more than capacity bar	**4**	
	More instructions and easier to read text	2	

FIGURE F.2: Coding results of user test 2