NTNU – Trondheim
Norwegian University of
Science and Technology

Visualizing Energy Use in Smart Grids

Developing a User Display for the Dynamic Microgrid Tariff

Kristina Voll

Master of Science in Computer Science
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Supervisor: Dag Svanæs, IDI
Co-supervisor: Erica Löfström, SINTEF

Norwegian University of Science and Technology
Department of Computer and Information Science

Preface

This thesis has been conducted during the spring of 2015, and completes my Master's degree in Computer Science at the Norwegian University of Science and Technology (NTNU). The work has been done for the Department of Computer and Information Science in cooperation with SINTEF and NTE.

The thesis has been done in cooperation with Øystein Molnes, special thanks are thus given to him for sharing good ideas and thoughts, and for being a good working partner and motivator.

I would also like to thank my supervisor, Professor Dag Svanæs at NTNU's Department of Computer and Information Science, for his invaluable assistance and guidance throughout the project.

In addition, I would like to thank Erica, researcher at SINTEF, for sharing her experience and expertise of great relevance, and for valuable guidance during the project.

Special thanks are also given to Nord-Trøndelag Elektrisitetsverk (NTE), represented by Thor Gunnar Steinsli and Therese Troset Engan, for engaging in the project and for providing access to test data and information regarding the Dynamic Microgrid Tariff project.

Finally, great thanks are given to all the participants in the questionnaire, focus group and usability tests, for taking their time to participate, for giving useful feedback and for contributing in interesting discussions.

Kristina Voll

Kristina Voll

Trondheim, June 11, 2015

Note from supervisor

This thesis is a cooperation between two students from different study programmes at the Department of Computer and Information Science. Kristina Voll is on the master in Computer Science, while Øystein Molnes is on the master in Informatics programme. The structure of the two programmes are a bit different in that Informatics students have a full year on the thesis (60 ECTS fall+spring), while Computer Science students only have one semester (30 ECTS in the spring). In addition Computer Science students have a 15 ECTS specialization project course in the fall that is often done as a preparation for the 30 ECTS thesis (TDT4501). In this case the project course TDT4501 for Kristina was done in cooperation with the first part of Øystein´s 60 ECTS master in the fall of 2014. The project work resulted in a project report that was handed in, but with information that this was done as part of a cooperation between the two students. It was graded accordingly. A revised version of the findings from the work in the fall has been included here as chapters 6 and 7. They are part of Øystein´s 60 ECTS thesis as they document the work he did in the fall, while strictly speaking they are not part of Kristina´s 30 ECTS thesis as she has already used this in her 15 ECTS project report (TDT4501).

Abstract

Increasing demands for energy in Norwegian households are stretching the capacity of the electrical grid to its limits. To avoid having to expand the electrical grid, peak loads must be reduced, and power companies are dependent on energy consumers to distribute their energy use more evenly throughout the day. Smart Meters are to be installed in every Norwegian household within January 1st, 2019, and can help provide customers with the information and control needed in order to achieve peak reductions.

Demo Steinkjer is a national project testing new solutions for energy usage, and is currently running a project testing a tariff which focuses on increasing electricity prices when the grid is heavily loaded. They plan to use a tablet display to inform users about consumption and pricing. However, it is not determined what kind of, and how, this information should be communicated.

This thesis explores how such a display tool should be developed in terms of context of use, user requirements, and design. Based on findings obtained from literature reviews, a survey and a focus group, a prototype has been developed and tested on potential users. The research has been carried out following the Design and Creation strategy and Human-centered design for interactive systems.

The research showed that a majority of our participants to a little extent reflect upon their energy consumption. However, many expressed a willingness to adapt their energy consumption according to information given to them. In order to take action, users should be provided with concise information, and a visualization of energy consumption should focus on readability rather than detail in data. Test participants found the display tool useful for handling the tariff and gaining better control of their energy consumption and costs. Appliance control, preferably automatic, was considered the most interesting and useful feature.

A display tool should cover the needs of its potential users, and not simply force them into solving the needs of the power companies. Users show willingness to change behavior and adopt new technology, but only if they are provided with the appropriate tools that help them achieve their goals in their everyday lives.

Sammendrag

Et stadig økende strømforbruk i norske husholdninger har ført til at belastningen i strømnettet har nådd grensen for hva strømnettet er bygget for. For å redusere behovet for utvidelse av strømnettet, må effekttoppene reduseres. Strømselskapene er dermed avhengige av at kundene deres fordeler strømforbruket sitt jevnere utover døgnet. Innen 1. januar 2019 skal alle husstander i Norge ha fått smarte strømmålere installert. Smarte strømmålere kan bidra til at kundene får informasjon om, og bedre kontroll over, forbruket sitt. Dette gir de mulighet til å kunne redusere effekttoppene.

Demo Steinkjer er et nasjonalt prosjekt som tester ut nye løsninger i forbindelse med smarte målere og strømforbruk. Våren 2015 startet de et prosjekt som tester ut en nettleietariff som øker nettleieprisen betydelig når strømnettet er tungt belastet. De planlegger å benytte et nettbrett for å informere forbrukere om strømforbruk og priser, men per i dag er det ikke bestemt hvilken informasjon som skal vises, eller hvordan den skal presenteres, i nettbrettet.

Denne masteroppgaven utforsker hvordan en slik løsning bør utformes, både med tanke på konteksten den skal brukes i, krav fra brukere, og design. Basert på funnene fra litteraturstudier, en spørreundersøkelse og en fokusgruppe, har en prototype blitt utviklet og testet på potensielle brukere. Arbeidet har vært brukersentrert, og fulgt forskningsstrategien Design and Creation.

Resultatene viser at de fleste deltakerne i studiet i liten grad er opptatt av eget strømforbruk, men mange var likevel villige til å flytte strømforbruk bort fra effekttopper på bakgrunn av informasjon. For å kunne gjøre endringer bør forbrukerne motta konsis informasjon tilpasset deres husholdning, og visualiseringer av strømforbruk bør fokusere på lesbarhet fremfor detaljert informasjon. Deltakerne i brukbarhetstesten syntes display-løsningen var nyttig for å kunne forholde seg til tariffen, og for å få bedre kontroll over eget strømforbruk og -utgifter. Styring av elektriske apparater ble ansett som mest interessant og nyttig, og automatisk styring ble foretrukket fremfor fjernstyring.

En display-løsning bør tilby funksjoner som dekker de potensielle brukernes behov, og ikke tvinge brukerne til å løse strømselskapenes behov. Brukere viser villighet til å endre forbruksvaner og ta i bruk ny teknologi, men bare dersom de tilbys de riktige verktøyene som hjelper dem med å oppnå sine mål i hverdagen.

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Part I

Introduction

1 Introduction

This chapter introduces the motivation for conducting this research, and places it in a context. Further, the research questions driving this research are formulated, and the scope of the thesis is defined. Finally, this chapter provides some guidance for the reader by explaining relevant terms and presenting the chapters to come.

1.1 Motivation

Since the days of Thomas Edison and his invention of the first commercially viable light bulb in 1878, electricity has been one of the most valuable assets to mankind. Today electricity is so integrated into our daily lives that rarely do we stop to think about its remarkable ability to light up our homes, cook our food, heat our living rooms, and today even charge our cars. Not a day goes by without the use of electricity, and for most of us it has become an invisible asset that is always at our disposal whenever needed. Its constant availability and increasing invisibility allow us to focus on carrying out our daily tasks, such as washing clothes, cook dinner, or charge our electric car.

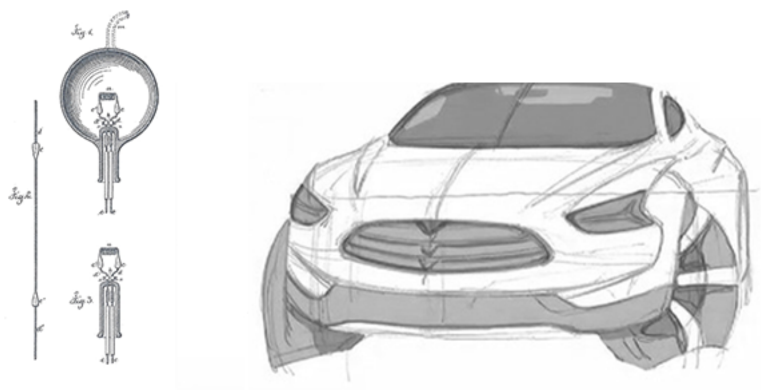


Figure 1.1: Edison's lightbulb from 1880 and the new Tesla Model X from 2015.

However, just because some activity is part of our daily routine does not mean it cannot be reflected upon and improved. Ten years ago going for a jog would only include strapping on a pair of sneakers and going out the door. Today, however, going for a jog will for some people also require strapping on a smartphone logging every move, such as calories burned, route taken, distance covered, and the amount of sweat drops lost. Having this information brings about the ability to reflect upon the activity of going for a jog. Either driven by burning more calories than last week, taking a route not already taken, or running a few meters longer than your friend, the information changes the daily routine of jogging. This is not to say that every jogger will be interested in logging sweat drops, but it is saying that just because a routine is the way that it is, does not mean it should or will be like that in the future. This indicates that either A) new technology is capable of changing our behavior and routines, or B) we create and start using technology that better fits our desired routines and needs, or perhaps somewhere in between.

The future is best predicted by the past, and looking back at the past decades, our daily routines have drastically changed as new technology has emerged. Wherever we go, our smartphone is there, and whenever we have a question, the internet is there to enlighten us. Perhaps the future will also show a change in how we relate to electricity use, as new technology makes it visible once again. New technology bears the potential of providing us with information and control, in order for us to achieve our goals, whether they include reducing costs, saving the environment, improving control, or simply maintaining comfort.

1.2 Context

The electrical grid that brings heat and lighting to Norwegian homes was built in a time of simple needs. It was not designed for charging electric cars, distributing solar power to our neighbors, or controlling electric appliances. It is safe to say that today's needs for electricity differ from the needs we had a hundred years ago, and perhaps will the needs of tomorrow differ even more. One of the most urgent weaknesses in the electrical grid is its limited capability to distribute electricity to an increasing demand from consumers [68]. When consumers use more electric appliances, they use more electricity, which in turn requires a grid capable of distributing that electricity in a safe and secure way. This weakness became apparent when in February 2010, cold weather and failing power supplies resulted in some of the northern parts of Norway experiencing electricity prices of 11 NOK per kWh [37]. The average price for the same period in 2014 was about 0,85 NOK per kWh [75].

The electrical grid can be thought of as a highway with a limited number of lanes, and thus capable of carrying a limited number of cars at the same time. If more cars are trying to run on the highway than there is room for, either the traffic-flow breaks down or the highway has to be expanded. An effective way to avoid having too many cars drive on the highway at the same time is getting drivers to be more flexible. The highway will probably be pushed to its limits when people are going home from work at four, and it will be hard to dictate when people should leave work. On the other hand, if we get some of those thinking about going out shopping at four to wait until six, the load on the highway is immediately reduced, the traffic flow does not break down, and the highway can carry the load without having to be expanded with more lanes.

The question then becomes *How do we get these people to go shopping at six instead of four*, and in this context, going shopping is replaced by turning on the washing machine. To avoid having to expand the electrical grid, power companies are dependent on electricity consumers to distribute their consumption more evenly throughout the day, and avoid using the most electricity when the grid is heavily loaded. They therefore depend on the average consumer taking action.

The implementation of smart technology into the electrical grid can help provide customers with the information and control needed in order to achieve peak reductions. Also, a change in how electricity is priced is emerging, focusing on increasing electricity prices when the grid is heavily loaded [Grete Coldevin, Smart Grid Seminar]. These innovations can also help Norway meet EU's 20-20-20 objectives, a legislation aiming at reducing greenhouse gas emissions, raising the share of renewable resources, and improving energy efficiency within the year of 2020 [78].

1.3 Research Questions

Demo Steinkjer is a national project testing new technology and solutions for energy usage and measurement in full scale. In these days, they are running a project testing a tariff that focuses on increasing prices when the grid is heavily loaded, and they depend on communicating this tariff to their users. They plan on using a tablet display to inform users about consumption and pricing in order to enable them to take action. However, it is not determined what kind of, and how, information should be communicated, how the display can achieve user friendliness, and most importantly how and why the display should be adopted and used by the consumers. These are the objectives of this thesis.

The research is carried out in the context of Smart Grid, data visualization and user centered development, and is done in cooperation with Demo Steinkjer. In the following we use the term *display tool* to denote a visual tool enabling customers to acquire information and control electricity usage, e.g. as an application on a tablet or a smartphone, or simply a web application on a PC. The following list states the four research questions that this research sets out to answer.

Research question 1: What is the context of use for the display tool, and what is the initial motivation and attitude towards it?

Research question 2: What are the user requirements for a display tool supporting this kind of tariff, in terms of what data to visualize and functionality?

Research question 3: How should the display tool be designed, in terms of data visualization and usability?

Research question 4: How do users evaluate the display tool?

1.4 Scope and Limitations

The goal of this thesis is to determine how a display tool related to energy consumption can be designed in terms of what kind of information to communicate and how the information should be communicated. The thesis also investigates motivations and attitudes towards such displays, how they can achieve user friendliness, as well as how and why the display should be adopted by users.

When these questions are answered a functional prototype will be developed with the use of HTML, CSS and JavaScript. The prototype will be evaluated by users, and allow them to interact in order to achieve goals enabled by the display tool.

Although several aspects may be deemed relevant when discussing display tools regarding energy consumption, the research questions take a user centered approach, asking how a display tool should be designed for the user. Hence, several limitations have been made. These include:

- **Potentials of Smart Grid**
  This thesis does not evaluate the potential of Smart Grid and all of its technologies.
- **Grid and Pricing Complexity**
  Neither does it outline the complexity of the electrical grid, with all of its components, or the various pricing systems that exist in the Norwegian electricity market.
- **Business Model**
  The business model may affect the success of such display tools, but is not deemed

relevant in order to answer the research questions.

- **Technology Requirements**
  The display tool will be placed in a technological environment, but integration in terms of security and internet and appliance communication lies beyond the scope of this research.

- **Technology Platforms**
  Answering the research questions does not depend on the evaluation or selection of technology platforms, such as Android vs iOS.

1.5 Term Clarifications

This section is included in order to explain a set of terms, and clarify how they are used in this thesis.

Electrical Grid - An interconnected network for delivering electricity from suppliers to consumers.

Smart Grid - An electricity network that can integrate the actions of all users connected to it in order to efficiently deliver sustainable, economic and secure electricity supplies.

Smart Meters - Electronic device that records consumption of electric energy in intervals of an hour or less, and communicates that information at least daily back to the power company for monitoring and billing. Smart Meters enable two-way-communication between customers and energy provider.

Network Tariff - The price paid by customers to the owner of the electrical grid for transporting electrical power from the main grid to the individual customer.

Critical Peak Pricing - Pricing scheme aiming at controlling electricity demand by substantially increasing the price for electricity during periods of high use.

Microgrid Tariff - Pricing scheme based on the load on a local sub-part of the electrical grid; a microgrid.

Power vs Energy - Power is the ongoing usage measured in kW, whereas energy is the accumulated usage over time, measured in kWh.

Display Tool - A visual tool enabling customers to acquire information and control electricity usage, e.g. as an application on a tablet or a smartphone, or simply a web application on a PC.

1.6 Thesis Outline

Part II Background

Chapter 2 - Background explains the situation in today's electrical grid, and how the introduction of smart technology and new pricing systems aim at improving it. The chapter presents Demo Steinkjer and two of their projects, before finally listing a few existing solutions for display tools.

Chapter 3 - Adopting Display Services examines the fields of human-computer interaction, data visualization, and motivations for adopting new technology.

Part III Methodology and Research Design

Chapter 4 - Methodology outlines methodologies applied when conducting the research.

Chapter 5 - Research Design describes the strategy, process and the activities conducted in this research.

Part IV Visualizing Energy Consumption Data

Chapter 6 - Prestudy Charts presents several charts designed for usability testing during a prestudy.

Chapter 7 - Prestudy Testing presents the execution of six usability tests conducted in order to evaluate the charts developed during the prestudy.

Part V Requirement Elicitation

Chapter 8 - Questionnaire addresses the completion of a survey, and presents its results.

Chapter 9 - Focus Group presents sketches, execution and results of conducting a focus group.

Part VI Prototype Development

Chapter 10 - Prototype Implementation explains the implementation of a prototype in terms of framework, architecture, design, and a user manual.

Chapter 11 - Usability Testing presents a session of usability tests conducted in order to evaluate the implemented prototype, as well as their results.

Part VII Discussion and Conclusion

Chapter 12 - Discussion discusses the results obtained through conducting the activities, in terms of the research questions.

Chapter 13 - Conclusion concludes the study by answering the research questions and suggesting possibilities for future research.

Part II

Background

2 Smart Grid Research

This chapter provides insight into the context in which this research takes place. Section 2.1 explains the situation of emerging needs in the electrical grid, and outlines the introduction of smart technology. Further, Demo Steinkjer and two of their projects are described. Finally, existing solutions for meeting the requirements of a changing grid are presented.

2.1 An Electrical Grid in Change

The triggering cause for this research is the emerging need to reduce peak consumption in the electrical grid. Hence, this section starts with clarifying the situation and its implications. The section further explains the introduction of smart technology into the electrical grid, actors affected by the situation are identified, and previous research on Smart Meters is presented.

2.1.1 Emerging Needs

The current electrical grid was built between 80 and 120 years ago [76], when the electricity needs were simple, and households had small energy demands, such as a few light bulbs and a radio. The grid has been improved upon as technology has advanced, but with the increasing demand for electric power the capacity is now stretched to its limit. [79]

In 2013, Norwegian households constituted about 30 percent of all electricity consumed [74]. When most of these households share the same routines of getting up in the morning and getting home from work in the afternoon, they also share the same routines for electricity usage throughout the day, as shown in Figure 2.1.

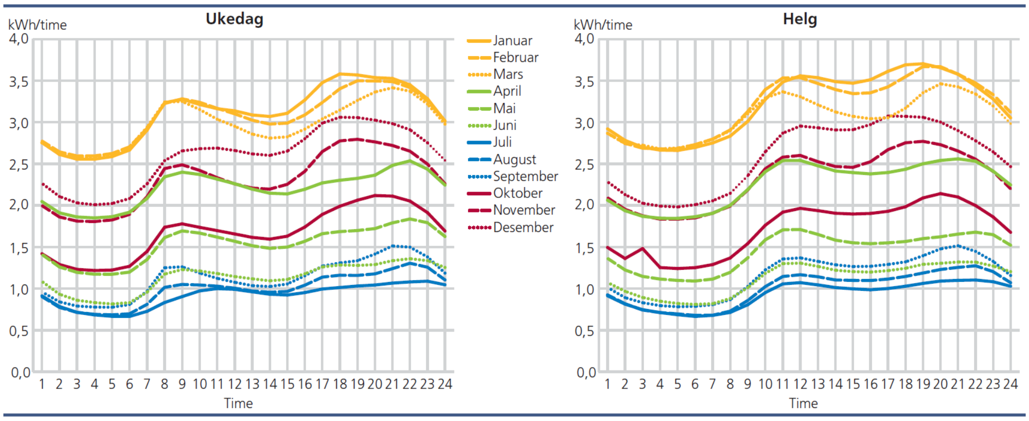


Figure 2.1: Average hourly consumption in Norwegian households.To the left: week days. To the right: weekend. [21]

These shared routines cause peaks in the demand for electricity, which in turn cause power plants having to work harder and deliver less efficient, more polluting power at higher costs [68]. The sudden increase in simultaneous power demand may also lead to decreased voltage quality, outages and the need for importing electricity. Due to these implications and limitations, the electrical grid is in need of an upgrade, and an introduction of new technology is required [79].

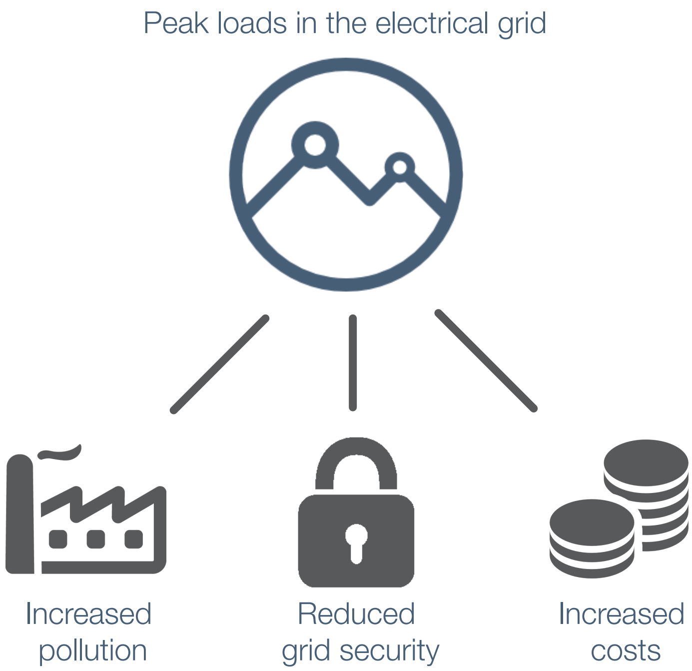


Figure 2.2: Implications of peaks in the electrical grid.

2.1.2 Smart Grid Technology

EU defines Smart Grid as: *"an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies."* [47]

Renewable resources such as wind and solar are sustainable and growing sources for electric power. However, these power sources are variable by nature and add complexity to the grid. The power production follows the access of resources, like the wind or sun intensity, which can not be controlled, increasing the demand for smart and flexible grids. Although electricity in Norway is mainly produced by hydropower, which is a power source more controllable through water reservoirs, periods of drought happen. In addition, Norway is part of the European power market, which implies both export and import of power to and from European countries.[69]

The Smart Grid provides the infrastructure needed to enable power plants to efficiently put energy on the grid and optimize its use. By having smart sensors along the transmission line power companies can be aware of any weaknesses in the grid caused by bad weather or sudden changes in electricity demand, and proactively prevent outages. The introduction of new tariff systems and infrastructure will also allow consumers to start produce and distribute electricity to the grid, and become prosumers. [69]

> *"The renewable society is taking form, and we need smart electrical grids to support it."*
>
> Grete Coldevin,
> Director of The Norwegian Smartgrid Centre (Smart Grid Seminar)

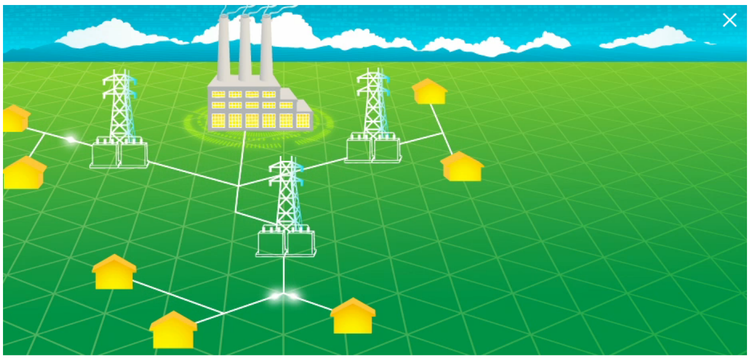


Figure 2.3: Smart Grid.

To keep up with constantly changing electricity demands, power companies must turn power plants on and off depending on the amount of power needed at certain times of day. Electricity is more costly to deliver at peak times because additional and less efficient power plants must be run, and power might be imported from other countries to meet with the higher demand. The Smart Grid will enable power companies to manage and moderate power use with the help from their customers, especially during peak demand times. By deferring the electricity usage away from peak hours and having devices run at other times, electricity production is more evenly distributed throughout the day, and power companies will be able to reduce their operation costs, and the need to expand the electrical grid is reduced. [69]

2.1.3 Stakeholders

The increasing problem of power peaks has implications on several levels, and hence the implementation of Smart Grid technology has several stakeholders. First, Norway is committed to EU's 20-20-20 objectives [78], and the Norwegian government has decided to invest 140 billion NOK in the electrical grid over the next ten years [39]. The EU legislation aims to ensure the European Union meets its ambitious climate and energy targets for 2020. The three key objectives are:

1. A 20 percent reduction in EU greenhouse gas emissions from 1990 levels.
2. Raising the share of EU energy consumption produced from renewable resources to 20 percent.
3. A 20 percent improvement in the EU's energy efficiency.

Further, a more efficient and secure electrical grid may allow for an increase in power export, benefiting both the Norwegian economy and the environment, as Norwegian power is almost exclusively based on hydropower [57].

Power companies have an interest in reducing peak loads to avoid spending resources on increasing net capacity and sporadic power production. Secure power transportation, and reducing the risk of breakdowns and outages are also in power companies' interest.

In order to solve the problem of consumption peaks, power companies depend on their customers to shift their consumption away from peaks. Electricity consumers are a very versatile group, with corresponding varying needs and interests. Customers' interests may include saving money, being environmental-friendly, do as they are used to, sustain comfort, do as others do, get information about their consumption, get an understanding of the electrical grid, adopt new technology, avoid having to think about consumption, get correct invoices, avoid spending money on equipment, and avoid sharing information with others.

Table 2.1: Stakeholders and their success criteria.

STAKEHOLDER	SUCCESS CRITERIA
Norway	**1**) Achieve EU's 20-20-20 objectives. **2**) Increased export and reduced import.
Power companies	**1**) Avoid electrical grid expansion. **2**) Secure power transportation.
Users	**1**) Reduce electricity expenses. **2**) Maintain comfort. **3**) Secure access to electricity. **4**) Achieve personal goals.

2.1.4 The Current Metering System

In order to understand the problem of consumption peaks, a separation between power (kW), the ongoing usage, and energy (kWh), the accumulated usage over time, must be made. Turning to the highway analogy, effect can be compared with the number of cars allowed on the road at the same time, while energy compares to the number of cars allowed on the road over time.

Today, Norwegian electricity consumers pay for the use of energy, and not power, which does not reflect the increased costs that come as a result of effect-use in periods of high load [38]. Although more and more consumers acquire contracts having varying electricity prices throughout the day, they have few incentives to adapt consumption according to short term changes in electricity prices. This is due to the workings of today's metering system and the lack of information given to customers. Most households report their consumption manually every month or so, and have no simple means for acquiring information about daily fluctuations in electricity prices. As a result, the current metering system does not award adoptions in consumption in order to reduce effect usage [25]. In order to encourage adaptions according to short time changes in electricity prices, a new metering system is needed.

> *"We are considering a change in the network tariff so that it better reflects how different consumption patterns affect the costs for the power companies." [51]*
>
> Ove Flataker,
>
> Deputy Director, NVE (Smart Grid Seminar)

2.1.5 Smart Meters

Smart Meters are part of the development of Smart Grid, and is to be installed in Norwegian households within 1st of January 2019 [56]. This means changing 2,5 million meters, at a total cost of over 5 billion NOK [55]. These Smart Meters replace the old energy meters in the fuse box, and introduce a two-way communication where electricity and information can be exchanged between the power company and its customers. Hourly readings from the energy meter are sent automatically to the power company, which gives quicker and more accurate retrieval of meter data, and provides a better basis for the invoices that are sent out to the customers. In addition, information about electricity prices and usage can be given to the customers. This exchange of more accurate and up to date data enables better control of the energy consumption, both for the customers and the power companies.

Figure 2.4: Smart Meter [42].

The Smart Meter alone only enables more accurate electricity bills for the consumer. Having Smart Meter technology installed does not in itself change the use of electricity. Neither does it raise awareness about the energy consumption in households. However, Smart Meter technology brings new possibilities for information exchange. Information about consumption and prices can be given through smartphone applications, web pages or in-home displays (IHD). This information provides users with more control over their energy consumption, and encourages changes in how customers use electricity. In addition, faults can be alarmed to both the power company and the private application allowing for proactive response, quicker recovery time and in general a better service from the power company.

The utility value of having Smart Meter technology installed therefore depends on how and what kind of information is given to the user.

Effects and Potential of Smart Meters

Smart Meters have now been tested in households for some time. Currently it is not specified what kind of, and how, information is to be communicated to users [NTE Demo Steinkjer, personal communication, October 1st, 2014]. Without sufficient knowledge about how information is best communicated to end users there is a risk of only utilizing a limited part of the potential use of the Smart Meter technology [24].

The potential of introducing Smart Meters are promising. Research has found that it is possible to reduce energy consumption by up to 30 percent by using information tools [27]. In addition, tailored and personalized information is shown to be more effective than general information for changing behavior [15].

Erica Löfström, senior scientist at SINTEF Building and Infrastructure, has studied what information should be communicated to households, and how it should be communicated [24]. Her research shows that users in Demo Steinkjer experienced a loss of control after installing the Smart Meter. Currently the statistics are available online, making users in need of logging into a website to get the information [NTE Demo Steinkjer, personal communication, October 1st, 2014], making the information less accessible. In addition, this data is 1-4 days old, and a wish for up-to-date information was expressed by users. This implies that using a website alone is not enough for communicating the information.

In her study, Löfström also found that households are able to understand the complexity of a Smart Grid, and may be willing to act in accordance to information in relation to it [24]. She suggests a solution having direct intuitive feedback on a daily basis and an overview of the household, enabling the possibility to make informed decisions based on this information.

Motivations and Attitudes

Energy usage is something Norwegian consumers to little extent reflect upon, as they do not consume energy itself, but instead they use appliances that consume energy. Energy consumption is linked to routine behavior, which is done unconsciously and automatically, and it is hence challenging to change such routines. [27]

Kristin Tønnesen explored in her master's thesis [26] possible motivational factors for energy saving with use of Smart Meter technology. Through focus groups with participants from

Demo Steinkjer she discovered findings both regarding motivation as well as wishes for a system presenting meter readings. She found that consumers want to decide for themselves how much to consume and when to do it. However, most consumers also want to participate in saving energy, but feel that their impact is too small to count and need to be sure that everyone else is doing the same. They also do not want too much to be required of them, and want a system that does not take too much focus and does not require a lot of effort to use. However, others wanted more control, such as the ability to remotely control electric appliances. Löfström and Palm [27] have found that new technology is adopted differently by various people, and that interest in technology, symbolic aspects, perception and values etc. influence how people perceive new technology. Systems should hence target different motivations and provide different strategies to influence energy behavior. Technology solutions should thereby preferably offer varying degree of information, with the possibility of selecting information of interest.

Research has found that only people with an existing interest in saving energy are willing to actively use and learn from the Smart Meter [19]. Not everyone has an existing interest in saving energy, and in order to create successful services it is necessary to be familiar with the Norwegian needs. Studies on user requirements for energy services show that Norwegian consumers want user friendliness, cost reduction, and predictability in display services [22]. Research also show that the connection between environmental awareness and practice is weak in Norway [11], indicating that knowing about environmental impacts is not necessarily sufficient to cause a change in behavior.

Combining Smart Meters with Visual Displays

Power companies are not required to install displays along with the Smart Meters [NTE Demo Steinkjer, personal communication, October 1, 2014]. On one hand, this is positive as consumers then can choose the preferable information channel. On the other hand, this leaves it up to the consumers to purchase displays, which may increase the threshold for accepting the technology.

Several studies in both Norway and other countries have been done on the effect of using visual displays for information and control of electricity consumption. Research at Hvaler found that consumers reduced consumption with up to 20 percent as a result of continuous information through a display combined with a power-based network tariff [40].

International studies on Critical Peak Pricing combined with display services resulted in 30 percent [17] to 50 percent [45] peak-shifting, implying a 50 percent power reduction in periods of high load. The study resulting in 50 percent peak-shifting was done in Sweden, and had prices of 3-10 NOK per kWh during peak hours. The tariff was created so that consumers would not loose money by maintaining their consumption. Information about peak hours was given one day ahead, and consumers reported the new CPP tariff as positive [45].

2.2 Demo Steinkjer

Demo Steinkjer is a national project in Norway where new technology and solutions for energy usage and measurement can be tested in full scale. The project enables the energy industry to test and pilot test Smart Grid related technologies, systems, and concepts in a real environment, in real homes, which is called The Living Lab [34]. In addition to being a venue for testing, large amounts of consumer data, demographics, and topological data are made available for developers and analysts. These data are linked to metadata, which gives a solid basis for research and analysis. Involved in the project are 800 households, schools and companies which all have Smart Meters installed and contributes with live data. 320 of these participants have agreed to being more involved in testing new solutions, and a customer panel of 23 customers have agreed to be even more included and available in the project.

One of the main occupations of Demo Steinkjer is to find ways to make efficiency improvements in the electrical grid in order to reduce peaks, bottlenecks and disrupts. Different technologies, as well as different products and services, are tested with partial involvement from the 800 households and companies that are involved in the project. The participants can choose which tests they want to contribute in. Demo Steinkjer is supported by NTE, the biggest power company in Nord-Trøndelag having a market share of 96 percent, and The Norwegian Smartgrid Centre, a national commitment established by initiatives from SINTEF and NTNU.

During its first phase, Demo Steinkjer's focus has been on the Smart Meter and installing the new meters in households. Now the focus is about to shift towards the data and information that are made available by the meters, and how this data should be visualized and utilized, both for the power companies and the consumers.

The 800 Smart Meters perform a meter reading every hour. These readings are uploaded once a day to a cloud service made by NTE. The data that are made available through an application programming interface (API) are thus at least one day old. In addition, there are ten meters sending meter readings every minute. These readings are uploaded to the cloud continuously and are thus live. The Smart Meters are equipped with an output for giving data to 3rd parties who wish to make a solution for connecting tablets, smartphones, and computers that read the data. The standard for this output has, however, not yet been set.

NTE predicts that in the future the average consumption will be lower, but with many, much higher peaks [NTE Demo Steinkjer, personal communication, October 1, 2014]. This change is caused by additional charging of electric vehicles, use of induction hobs, and other consumer appliances that draw a considerable amount of power.

In order to avoid these consumption peaks, power companies rely on providing information about this challenge to their customers, and point out that these peaks cause an increase in the network tariffs.

> *"Effect efficiency will be important, but how do we communicate this to customers?"*
>
> Grete Coldevin,
> Director of The Norwegian Smartgrid Centre (Smart Grid seminar)

2.2.1 Demo Steinkjer Projects

Demo Steinkjer is host for EU projects and has conducted several projects in conjunction with the Smart Meters. The projects include testing how consumers respond to new network tariffs that charge for power rather than consumption. This kind of tariff has already been used in the past. One example is the mixed tariff called H3, which included a fixed subscription fee, which depended on the size of the power limit. Consumption beyond the power limit was penalized with a considerable higher cost [1].

Two of Demo Steinkjer's projects are described in the following sections.

Subscribed Power

One project, which ended in December 2014, called "Abonnert Effekt", subscribed power, considered a new network tariff where each consumer subscribed to a certain amount of power. If the consumption exceeded the agreed power limit the price pr kWh increased considerably. The goal of this project was to test if the tariff could encourage consumers to adjust their energy consumption and lower the peaks.

Figure 2.5: Subscribed Effect.

Results show that changes were made. 85 percent of the participants in the Demo Steinkjer area reduced their energy consumption, and even more reduced the maximum power load [40]. Several households reduced their consumption by 20 percent compared to the previous year, when taking differences in temperature into account [35].

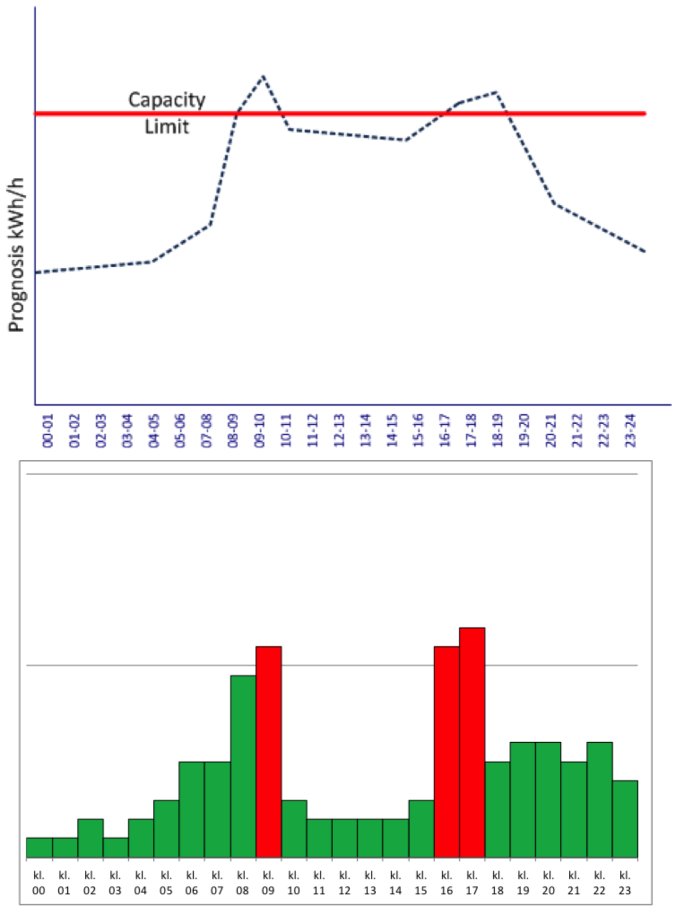
However, in spite of these good results, the context in which the project was done must be taken into consideration. The customers involved were volunteers and might hence have been more motivated than the average consumer. In addition, the project lasted one year, which is a relatively short time for testing long term change. It is thus unknown if the results had been the same after running the project for several years.

Dynamic Microgrid Tariff

Demo Steinkjer has now started a new tariff project called "Dynamisk Microgrid Tariff" or Dynamic Microgrid Tariff, from now called the *Microgrid Tariff*. The project is to be carried out from March 2015 to March 2016. This tariff aims at stimulating reduction in the power load in hours of high total load on the network station. Hence, as opposed to the "Abonnert Effekt" tariff, this tariff directs towards times of peak, and does not stimulate load reduction in hours where the total network load is low.

The tariff has two electricity price levels, green and red. Green price occurs when the power load is low and there are no problems in the electrical grid. Red price occurs in times of peak hours when the grid load is high. Price levels are based on 24 hour prognoses, but it has not been determined when price information will be given to the customers. Details regarding the tariff has in time of this writing not been finally set. However, the red price is estimated to be at least ten times higher than the green price.

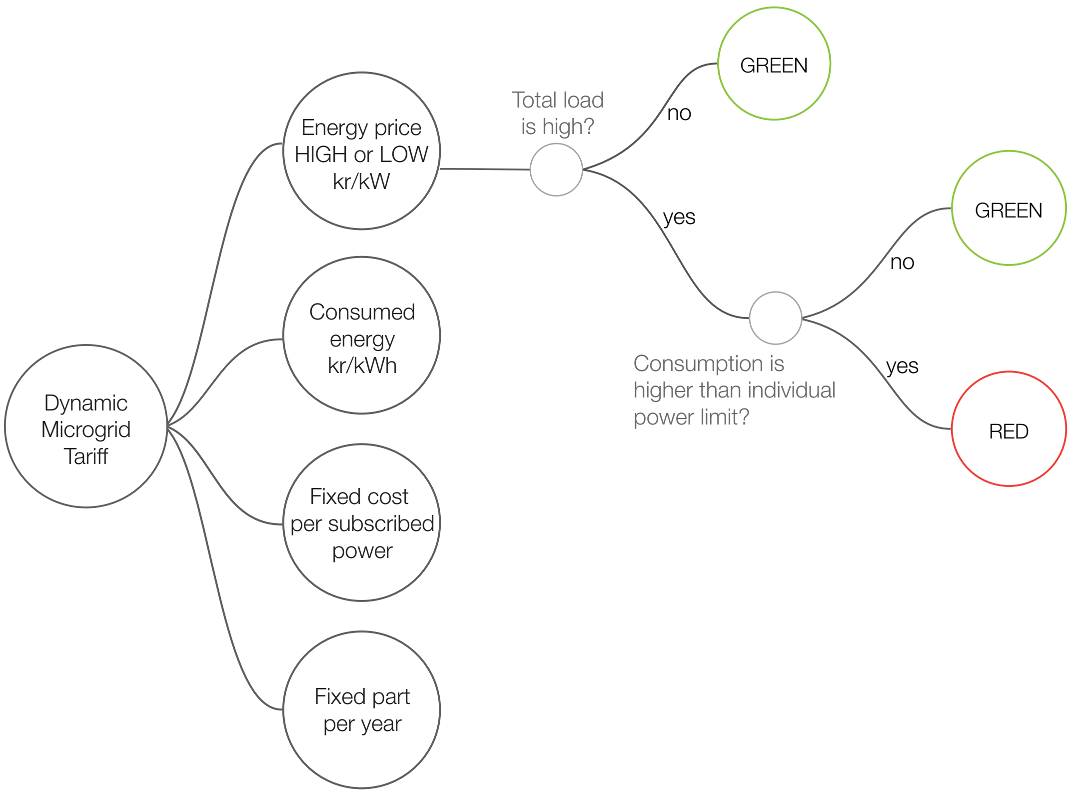
Figure 2.6: Connection between network load and price level [33].



The Microgrid Tariff tariff consists of 5 parts:

- **Fixed part**, which is a specified cost per year.
- **Power part**, which is a fixed cost per subscribed kW. The subscribed kW is an individual power limit that defines the threshold between high and low price.
- **High electricity price (red)** occurs when there is high load on the network station.
- **Low electricity price (green)** is the price level when there is low load on the network station.
- **Energy part**, consisting of consumption taxes to the state and taxes to the Energy Fund.

Figure 2.7: The relationship between the different parts in the tariff.

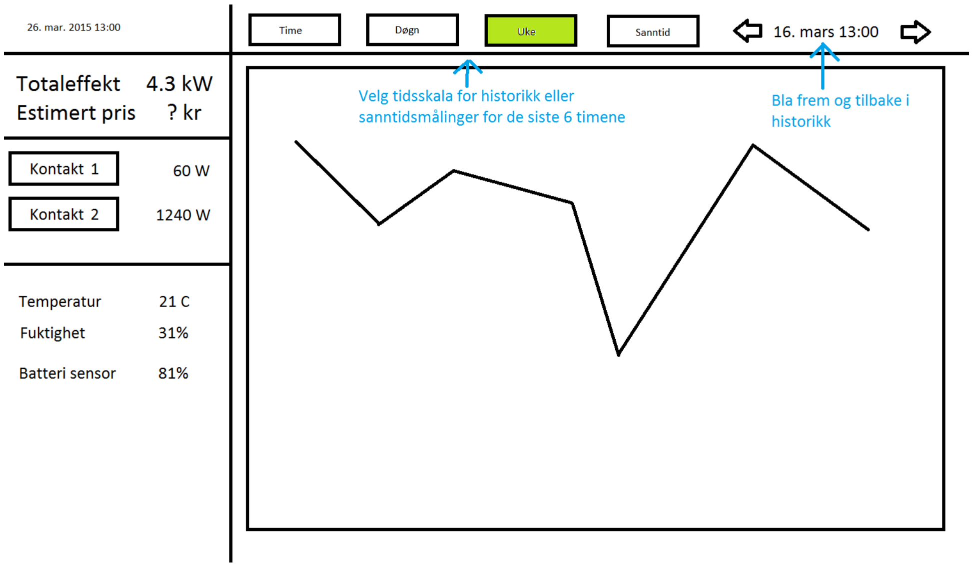


The occurrence of high and low electricity price depends on the total load on the network station in addition to the customer's individual consumption. The participants select an individual power limit based on recommendations from the power company. The high price occurs when the total load on the network station is high and the customer's consumption exceeds his or her individual power limit. The low price occurs when the load on the network station is low, or if the network station load is high but the customers consumption is below the individual power limit.

A complex tariff like the Microgrid Tariff leads to the need of a display visualizing how the tariff works, in order to make the system easier for customers to understand.

Figure 2.8 displays an early prototype of the display to be used in the project, which was made by SINTEF ICT. As shown in the figure, users will be able to turn on and off two electric appliances by using the two buttons on the left, *Kontakt 1* and *Kontakt 2*. This ability will allow users to take action in order to reduce their energy consumption during red hours. The sketch also allows users to view historic consumption data.

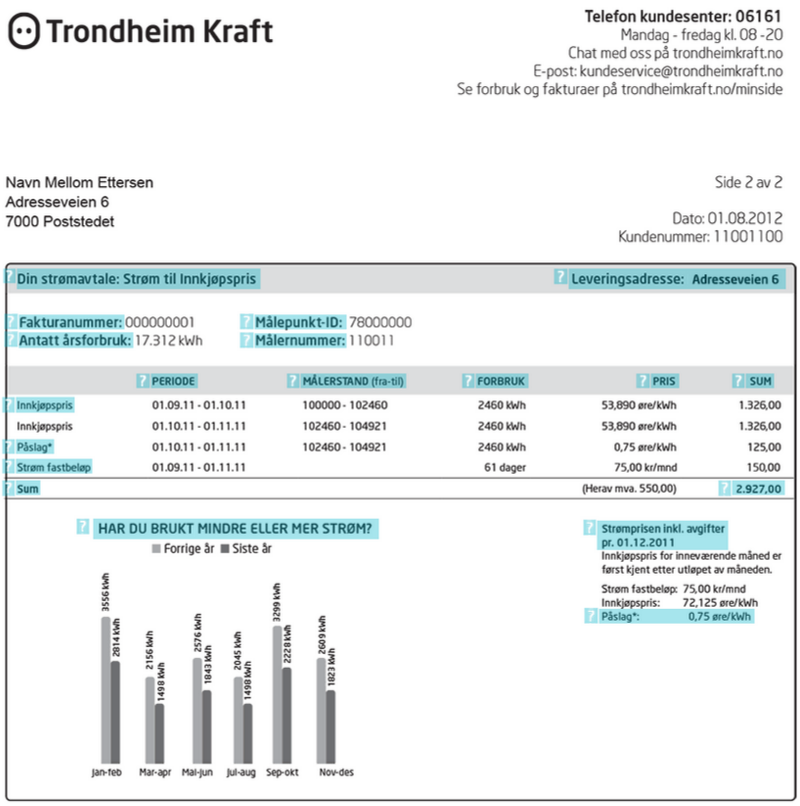
Figure 2.8: A sketch for the display done by SINTEF ICT.



2.3 Existing Solutions

This section presents a selection of existing solutions for communicating information about electricity consumption to users. Both commercial and research-based solutions are included.

Electricity Bill


Trondheim Kraft

Telefon kundesenter: 06161
Mandag - fredag kl. 08 -20
Chat med oss på trondheimkraft.no
E-post: kundeservice@trondheimkraft.no
Se forbruk og fakturaer på trondheimkraft.no/minside

Navn Mellom Ettersen
Adresseveien 6
7000 Poststedet

Side 2 av 2

Dato: 01.08.2012
Kundenummer: 11001100

Din strømavtale: Strøm til Innkjøpspris
Leveringsadresse: Adresseveien 6

Fakturanummer: 000000001
Antatt årsforbruk: 17.312 kWh
Målepunkt-ID: 78000000
Målernummer: 110011

	PERIODE	MÅLERSTAND (fra-til)	FORBRUK	PRIS	SUM
Innkjøpspris	01.09.11 - 01.10.11	100000 - 102460	2460 kWh	53,890 øre/kWh	1.326,00
Innkjøpspris	01.10.11 - 01.11.11	102460 - 104921	2460 kWh	53,890 øre/kWh	1.326,00
Påslag*	01.10.11 - 01.11.11	102460 - 104921	2460 kWh	0,75 øre/kWh	125,00
Strøm fastbeløp	01.09.11 - 01.11.11		61 dager	75,00 kr/mnd	150,00
Sum				(Herav mva. 550,00)	2.927,00

Strømprisen inkl. avgifter pr. 01.12.2011
Innkjøpspris for inneværende måned er først kjent etter utløpet av måneden.
Strøm fastbeløp: 75,00 kr/mnd
Innkjøpspris: 72,125 øre/kWh
Påslag*: 0,75 øre/kWh

Figure 2.9: Electricity bill from Trondheim Kraft [81].

The standard electricity bills of today are usually sent to Norwegian households quarterly or every month [53]. For most consumers a bill such as this is the main source of information about their electricity consumption. The bill displays the amount of electricity consumed during the last months, as well as the electricity price those months. The electricity bill displayed in Figure 2.9 also contains a bar chart comparing the monthly usage of the current year to the previous.

eWave

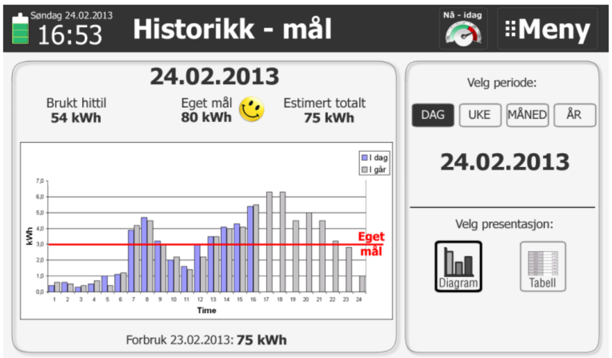


Figure 2.10: eWave [67].

eWave is an energy display tested at Demo Hvaler, a research facility similar to and working with Demo Steinkjer [67]. It was tested to find out how energy awareness was affected by offering information about consumption through a display. The display uses charts and visualizations to give information about daily and historic consumption, costs, and pricing-model. Testing of the eWave combined with a new pricing model at Demo Hvaler resulted in up to 20 percent reduction in both maximal power load and total energy usage [66]. However, it should be noted that participants volunteered, and that a reduction of 20 percent might not be achieved in other settings.

PowerCost Display

Figure 2.11: The PowerCost display.

The PowerCost Series system is a wireless energy monitoring solution allowing users to monitor and manage their usage remotely. Updated every 32 seconds, the in-home display provides information about watts and costs, and how much individual appliances use. In addition, the display offers an estimate of how much energy will be consumed in a 30 day period. [29]

Aware Clock

Figure 2.12: Aware Clock.

Created by Swedish designers at the Interactive Institute, the Energy Aware Clock uses a 24 hour circular pattern to visualize energy consumption during a selected time span [46]. It focuses on design and readability, and uses a circular graph to display the amount of energy consumed.

eSmart Systems

Figure 2.13: eSmart Systems Consumer App [41].

eSmart Systems is a Norwegian company developing Smart Grid software. Their line of products include the eSmart Consumer App, a smartphone application that lets users experience rich, real-time information and takes advantage of predictions and optimization in a way that add value to their day-to-day life. [41]

Google Power Meter

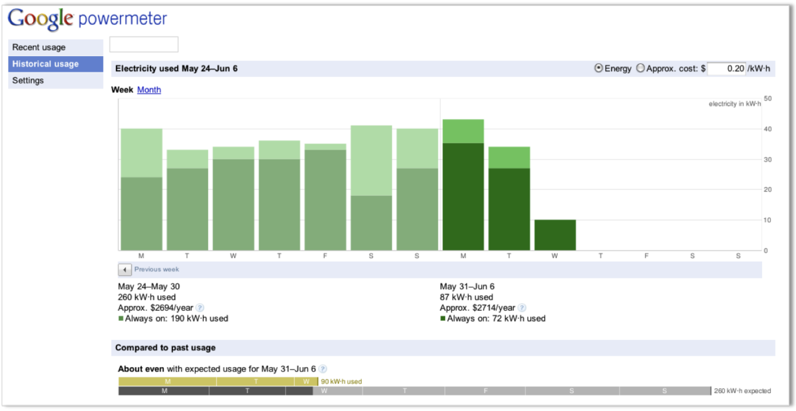


Figure 2.14: Google Power Meter.

The Google Power Meter was launched in 2009 as a means to raise home-owners' awareness of how much energy they use and make users more energy efficient. The project was ended in 2011 as a result of it failing to bring in enough users [44]. The web application enabled its users to monitor and manage their energy consumption online via an iGoogle widget.

3 Adopting Technology

This chapter provides insight into topics essential when exploring how a display tool can be designed for and adopted by users. Previous research in the fields of human-computer interaction, data visualization, and user behavior has crafted knowledge forming the foundation for this thesis work. The following sections present knowledge from each of these fields of study.

3.1 Human-Computer Interaction

The introduction of technology into our electrical grid can help streamline, simplify, and secure use of electricity. However, for this new technology to be helpful, it must be implemented, embraced, and used. Implementing new technology often leads to new encounters between technology and humans, and this encounter is what the field of human-computer interaction, hereby HCI, sets out to explore.

HCI is an area of research that incorporates theories and knowledge from several disciplines, as it recognizes the importance of design, ethnography, computer science, and human psychology and memory, when investigating how human interaction with computers occurs. An essential part of this investigation is understanding how users experience systems and technologies.

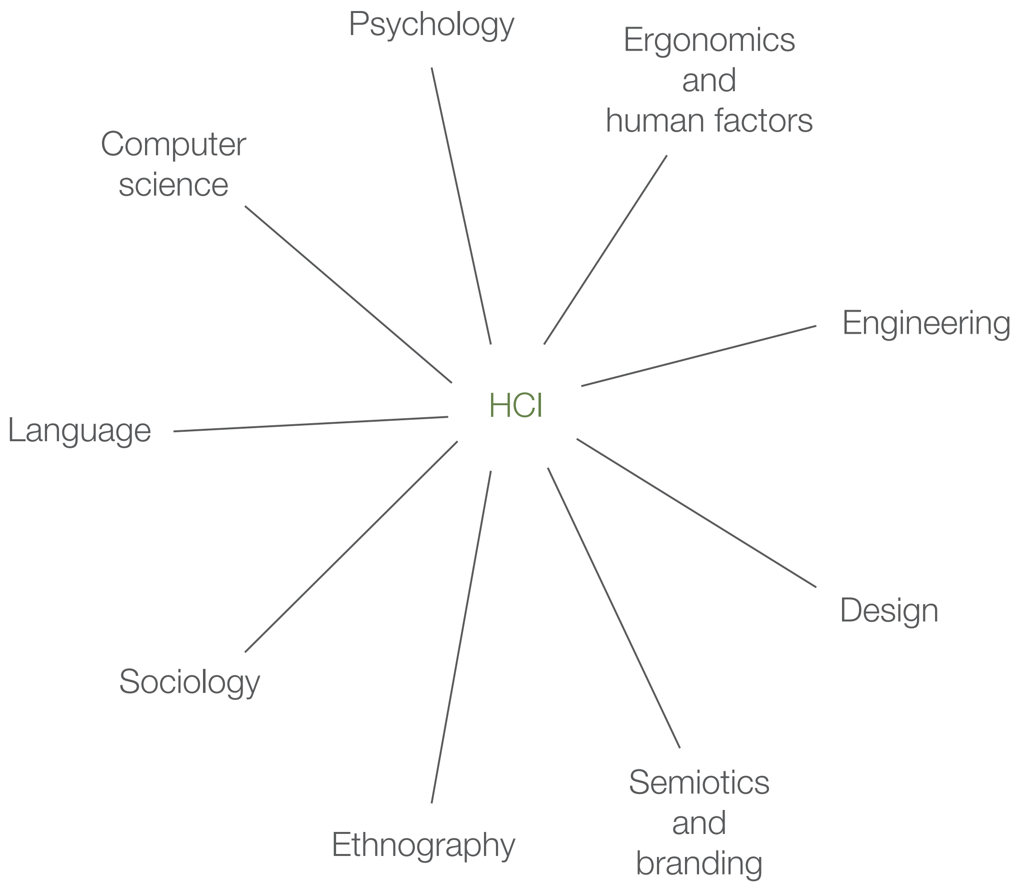


Figure 3.1: Fields constituting human-computer interaction.

3.1.1 The User Experience

Whether it is satisfaction, frustration or indifference, every product brings out a reaction in its user. This reaction is determined by several factors, spanning from its ease of use to the shape of a button. Every product that is used by someone has a user experience [61], and by uncovering what constitutes this experience, one can start designing for satisfaction.

Usability

Usability is a characteristic of a product affecting how users experience it, and is dependent on personal taste, goals, experience, and context of use. Improving the usability of a product involves optimizing the interactions people have with it to enable them to achieve their goals in a satisfying way [61].

Figure 3.2: Usability definition and attributes.

Stating that a system should have high usability is a very vague statement. However, by breaking down usability into testable subgoals, we can start assessing usability in a meaningful way. Usability can be broken down into the following goals [65]:

Easy to learn: Users have a finite amount of time and patience to learn how a system works, and a minimum time to learn can improve usability.

Efficient to use: When users have learned how to use the system, tasks should be carried out with a minimum of time and resources.

Easy to remember: It should be easy for users to maintain their knowledge about how the system works when returning after a day, a week, or a month.

Few errors: The possibility of making errors should be minimized, and if errors occur they should be easy to recover from.

Subjectively pleasing: The user should find the system pleasant and satisfying to use.

Although all of the five goals above help achieve usability, tradeoffs must often be made, and some goals might surpass others. These tradeoffs will depend on who the user is, what he or she is trying to achieve, and what the context is. The importance of error prevention in life critical systems may for instance limit short learning time and efficient use.

Don Norman presents in his book *Design of Everyday Things* six fundamental design principles. These principles determine to what degree a design is functional, easy to use, and intuitive.

Consistency
The degree to which a system uses similar operations for accomplishing similar goals. Helps users discover patterns, and eases learning and understanding.

Visibility
A property describing whether available user operations are apparent, in order to let users know what can be done.

Affordance
An attribute of an object that allows people to know how to use it. Lets users know what can be done with an object.

Mapping
Making a relation between controls and their effects in the world. Helps users make correct assumptions about the outcome of an action.

Feedback
Reactions to user actions. Let users know what the system is doing, and the results of their action.

Constraints
Restrictions on the kinds of user interaction that can take place at a given moment. Guides users away from making incorrect interactions, and towards doing what is intended.

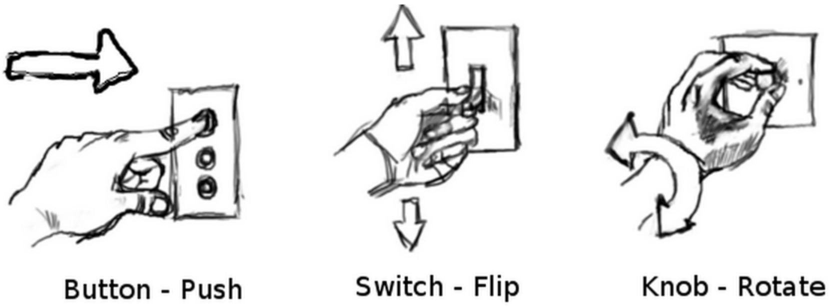


Figure 3.3: The affordance of an object.

Mental Models

A computer system, with all of its subtle details, analogies and metaphors, is neither created nor used in a vacuum. Every time we learn how to use a new system, we make connections, assumptions, and generalizations about how it works. Although unconsciously, we use our existing knowledge and cognitive abilities to put what our senses tell us into a conceptual framework in order to make sense of the system. We create a *mental model*.

When developing a system, developers have the opportunity to shape and affect the mental model that takes form in the minds of users. A successful mental model is one that makes sure that the user knows what should be done, and what goes on [61]. Mental models can be shaped by using well defined analogies, clarify system structure, utilize standards, and make clear connections between cause and effect.

Don Norman has defined the following seven guidelines for making complex tasks easy and ensuring a strong mental model:

Table 3.1: Don Norman's guidelines for making complex tasks easy [54].

1.	**Build on knowledge from both head and world** We base our models and perceptions on whatever knowledge we have. These models are essential in helping us understand our experiences, predict the outcome of our actions, and handle unexpected occurrences.
2.	**Simplify task structure** A clear structure eases memory load by reducing the knowledge required to perform actions.
3.	**Make things visible** Bridge the gap between action and evaluation by making things visible.
4.	**Make the right connections between cause and effect** We attribute causes to events, and as long as these cause-and-effect pairings make sense, we accept them and use them for understanding future events.
5.	**Utilize both natural and artificial constraints** Limit what can be done in order to guide the user towards the correct action.
6.	**Design for errors** Predict possible errors and help the user avoid and recover from them
7.	**Create standards if everything else fails** Take advantege of what has already been established as a standard way of doing things.

3.2 Data Visualization

The implementation of smart technology represents a great leap for our electric power system, both in terms of possibilities and complexity. Retrieving detailed data on household consumption can help consumers towards a safer, more economic, and more eco-friendly consumption [27].

However, achieving these goals requires better means for utilizing the data that is now on our hands. If residents are to make informed decisions about their electricity usage, they will have to receive information in a way they understand. The information should enable them to solve their problems and achieve their goals. This is where the benefits of data visualization enters.

This section explores the field of data visualization, and endeavors to explain its benefits, and how visualizations can be made effective.

3.2.1 Why We Visualize

Simply stated, a data visualization is a graphical representation of information. It is a tool that utilizes the capabilities of humans to perceive visual patterns in order to interpret information in a more intuitive manner. Edward Tufte is noted as a pioneer in the field, and his books [82], [83], and [84] will be used for reference throughout this section. In one of his books, Tufte states that "At best, graphics are instruments for reasoning about quantitative information [82, p. 10]". This statement illustrates the nature of data visualizations, and that they can serve as instruments for reasoning, exploring and getting insight into information.

Figure 3.4 is an example of how visualizations can reveal the information present in data. The tables at left show four series of x- and y-values, all having the same average and standard deviation. In fact, they appear to be very coinciding. However, when plotted into the simple graphs on the right, the stories of the datasets are revealed, and patterns emerge.

I		II		III		IV	
X	Y	X	Y	X	Y	X	Y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56

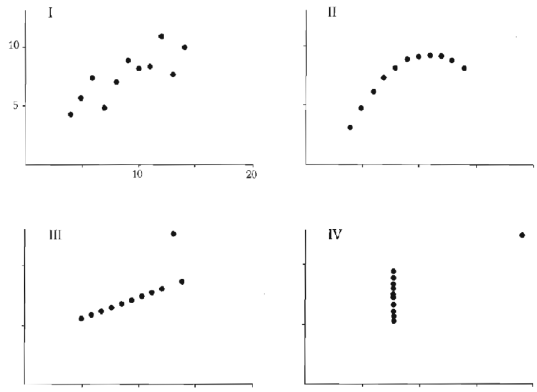


Figure 3.4: Anscombe's Quartet revealing connections between data [82].

Table 3.2 lists four principles described in Edward R. Tufte's books [82], [83], and [84]. Although not encompassing, the list states some of the ground principles for making data visualizations effective. The following sections address these principles one by one and explain why they are important, and how they can be pursued.

Table 3.2: Data visualization principles.

A	**Tell a story** Tell a story that is truthful to the data it represents, and do not manipulate or deceive users.
B	**Utilize human perception** Build on human abilities to perceive and interpret visual variables.
C	**Benefit from knowledge** Benefit from knowledge, references and ideas already present in the viewer.
D	**Simplify, do not just decorate** Simplify the information, do not just decorate it.

3.2.2 A - Tell a Story

When creating graphical representations of data, one has the potential to uncover stories hidden in overwhelming datasets. This section investigates how connections in data can be visualized, and how data visualizations always should be made in a context.

Visualizing Connections

Hans Rosling is a Swedish doctor and professor known for telling stories through visualizations. In his TEDx talk in April 2012 [62] Rosling presented the visualizations displayed in Figure 3.5, telling the story of children born per woman linked with income in both 1960 and 2010.

Each circle represents a country, and its size is determined by that country's population. When observing the graph, patterns and connections immediately emerge. It takes a small amount of effort to see that the two big red circles, namely India and China, have radically decreased in number of children born per woman since 1960. The graphs also suggest that there is a connection between high income and getting a low number of babies.

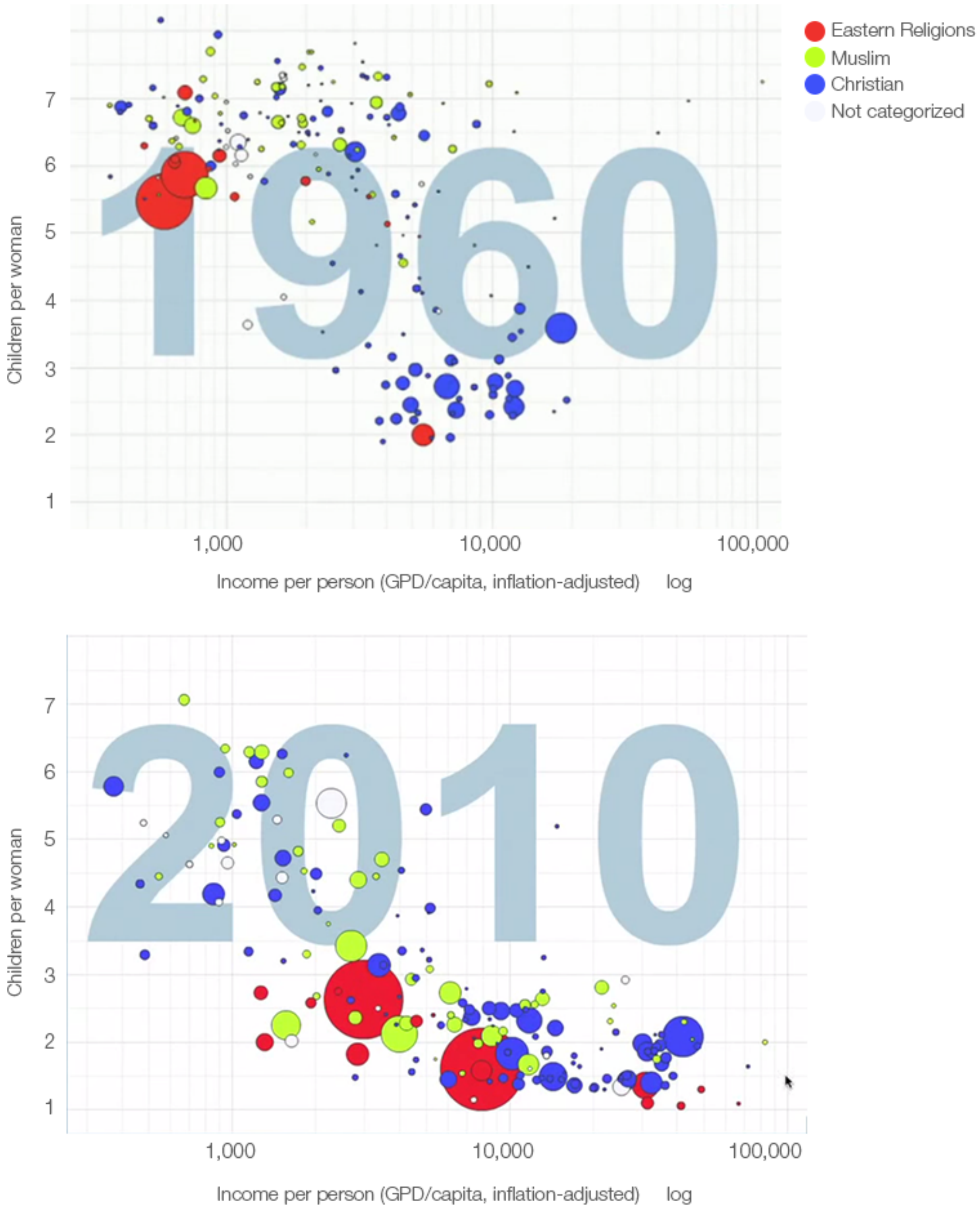


Figure 3.5: Hans Rosling's visualization of children born per woman in the world [62].

These graphs hold huge amounts of information, and by showing the data they rise questions about the connections between variables; their cause and effect. Some questions one might ask include *Do people have fewer babies when they are wealthy?*, *Does religion determine how many babies we get?*, and *How will the population grow if this evolution continues?*

Indeed Rosling succeeds in telling the story of children born per woman. However, there is one distinction to be made, and that is the one between seeing and reading. The fact that women gave birth to fewer babies in 2010 than in 1960 can easily be determined by looking at the graph. On the other hand, if one were to answer the question of which religion gave birth to fewer babies in 2010, Muslims or eastern religions, one would have to study the visualization closer, and start reading. This distinction between seeing and reading is further examined in a later section describing preattentive processing.

Context

Data visualizations are used within a context, and good design should take into account how, when and where the information is used [84]. Furthermore, whether they are made for description, exploration, tabulation, or decoration, visualizations should serve a purpose. Usually this purpose involves a viewer, and the goals and capabilities of this viewer should be taken into account during the design process [49]. The goals and capabilities of the viewers determine the level of precision needed, and also how visual variables can be used.

Figure 3.6 is an example of a visualization made in a context, clearly taking into account the goals of its viewers. The visualization is an abstraction of the London railway system. It benefits from the viewer's goal of either staying on or getting off the railway, and creates straight lines between stations, when in reality the railway has curves and bends [49].

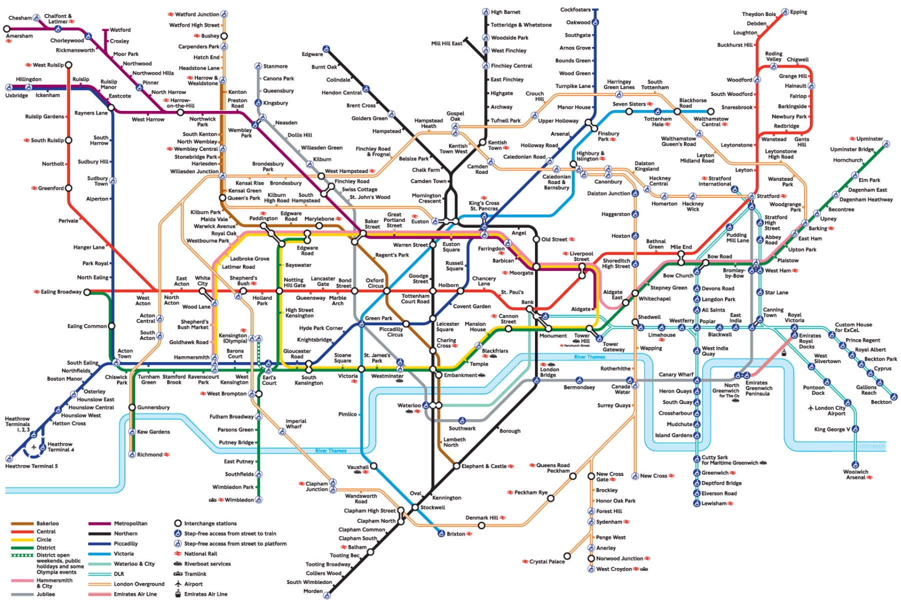


Figure 3.6: London's railway system [49].

3.2.3 B - Utilize Human Perception

This section investigates human perception and visual variables, which combined allows data visualization to be the powerful tool that it is. The investigation is carried out in terms of data visualization, and will not get into detail about human cognition. The section explains some principles for human perception, and how visual variables such as colors and shapes can be utilized in data visualizations.

Order and Deviations

"Placement is everything."

Moritz Stefaner,
Data visualization designer

It is in human's best interest to detect patterns, deviations, and abnormalities. This ability helps us create order, detect dangers, and interpret visualizations. Fortunately the human brain is a pattern-detecting machine, being very good at detecting patterns and deviations in visual variables such as color, size and shape. The ability to almost immediately detect patterns and deviations in such variables is called preattentive processing, and usually takes about 200-250 milliseconds [14].

The knowledge of preattentive processing can be applied when creating data visualizations. By taking into account visual properties, the designer can draw attention to areas of interest in a display, and in turn help viewers interpret the display very quickly.

Figure 3.7 is an example of preattentive processing-principles in practice. By glimpsing at the figure we instantly create order in the display, and see a line of Xs going from top left to bottom right. The viewer instantly identifies some deviations; the red cross, the cross out of line, the circle, the shaded cross, the tiny cross, and finally the tilted cross. The order in which viewers detect these deviations is not random, and as the figure suggests, color and placement are strong variables for preattentive processing.

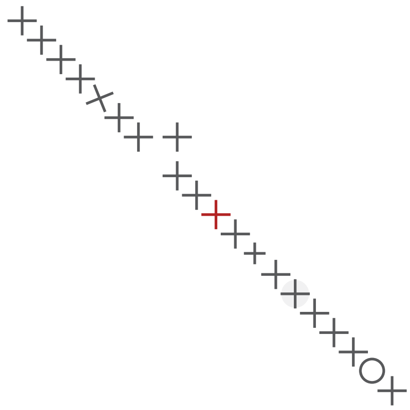


Figure 3.7: Example of perceived order and deviations [49].

A high number of varying variables will make it more difficult to locate deviations [14]. If the crosses in Figure 3.7 where to deviate from each other in a more extreme manner, two results could occur. The crosses could appear to no longer create a line, making the order cease to exist. Additionally, the individual deviations would take longer to discover. This phenomenon is called visual masking, and happens when large changes overshadow smaller ones [84]. When discussing visual masking, Tufte suggests that all visual distinction should be made as subtle as possible but still clear and effective.

Color

"Color is difficult."

Moritz Stefaner,
Data visualization designer

Color is one of the most versatile and effective tools in data visualizations. It can be used to label, measure, represent reality, and to decorate [83, p. 81]. Being the primary visual variable enabling preattentive processing, color helps viewers organize and categorize visual displays very rapidly and intuitively. However, for color to be an effective tool some of its properties should be noted.

Although the human brain is very good at detecting differences in color, and many humans are able to distinguish about 20,000 colors, color is not easily quantifiable. Humans have no embedded ability to perceive a color as twice the value of another, a fact making it difficult to use different colors for representing different values. Color intensity, or saturation, such as a color scale ranging from grey to very green, can be utilized to convey intensity in values. Dark colors convey intensity and more of something, and can thus help viewers understand which is more than the other. [82, 83]

Colors affect each other when used together. Bright colors are effective when used sparingly, but can be loud and disturbing when used next to each other. Also, cognition gives considerable weight to contour, meaning that areas of hard and bright color contrasted with light and white colors will draw attention and construct a visual contour. [83]

Figure 3.8 illustrates these color properties, as it uses differences in colors placed in a grid to depict US unemployment rates between 1948 and 2010. The color scale spans from solid green, representing a 2 percent unemployment rate, to a solid red representing an unemployment rate of 11 percent. The bulks of red immediately stand out and reveal which years had the highest unemployment rate, but it is more difficult to tell how much higher the rate was in January 2010 than in December 1950. For that to be determined we have to refer to the actual scale.

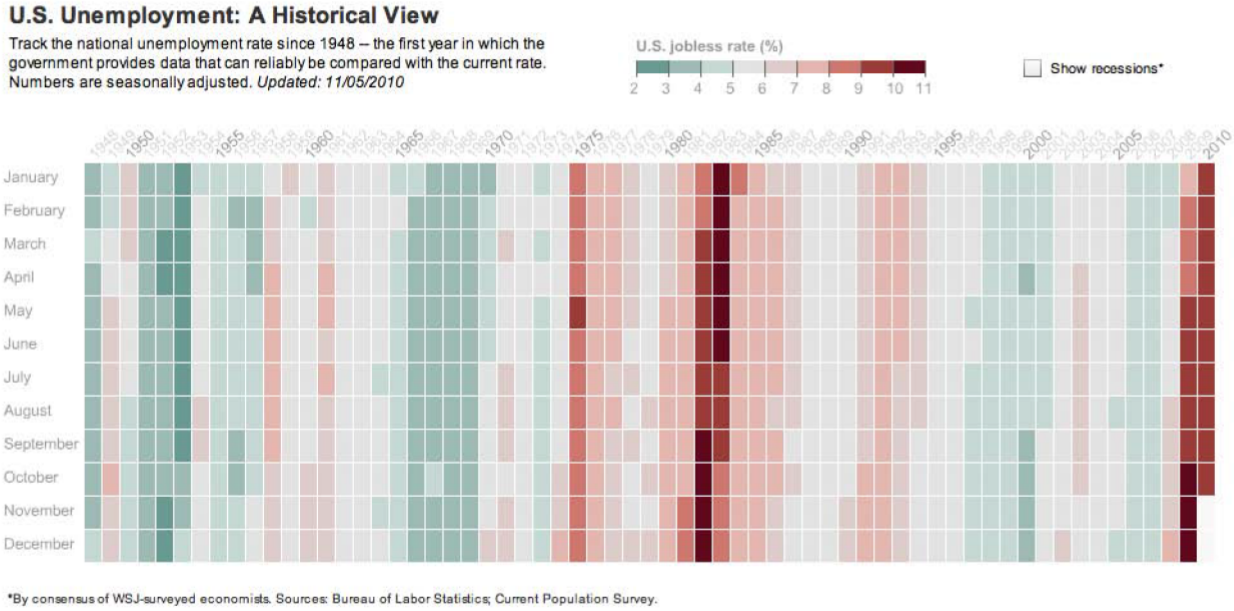


Figure 3.8: US unemployment rate, 1948-2010 [30].

Not only are the colors in this figure used to represent values, they also convey an abstract idea. Based on knowledge about the meaning of red and green, Figure 3.8 conveys the idea of an unemployment rate of 2 percent being positive, whereas an unemployment rate of 11 percent is considered negative. Also, describing the abstract phenomenon of unemployment rates, this graphic is non-figurative. This means that there is no correspondence between what is being represented, namely unemployment rates, and its representation, color-intensity. The relationship is in this context only conventional and not natural [30, p. 19]. A figurative use of color would on the other hand be using blue to represent water in a map.

When using colors in a non-figurative manner, the potential for different interpretations appears, as colors bear different meanings for different people. Although not universal and absolute, the following figure is an attempt by Smashing Magazine [31] to describe meanings different colors convey in the western world:

Figure 3.9: Different colors and how they are perceived [31].

Shapes

"Compared to what?"

Edward Tufte,
Data visualization pioneer

A better means for representing and comparing values, is the use of shapes and sizes. The brain is very good at comparing sizes and heights [49], and this is the reason why bar charts are so effective when visualizing relationships between values.

Rosling's visualization in Figure 3.5 used the area of circles for representing values. The perceived area of a circle, however, grows somewhat more slowly than its actual area, and we have no absolute capabilities of telling when a circle is twice the size of another [82, p. 55]. This makes circles unsuited for representing accurate values. Figure 3.10 shows three pairs of shapes, each containing one shape twice the size of the other. It is considered more difficult to notice the relationship between the circles than that of the bars.

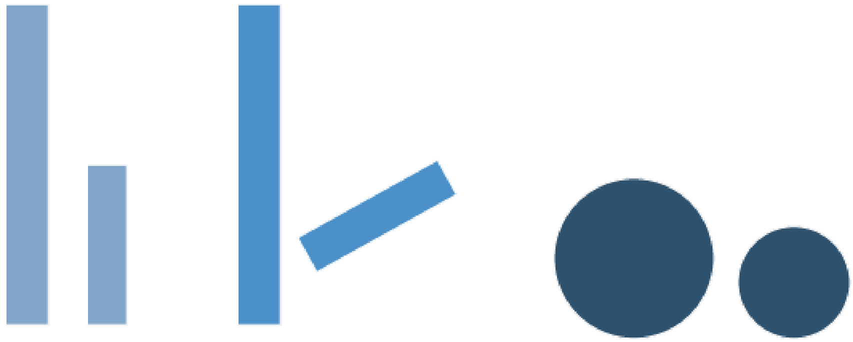


Figure 3.10: Comparing sizes of bars and circles.

The comparability of shapes and sizes are also determined by their placing. When the distance between objects increases, it is harder to compare them [23]. Also, alignment plays an important role in determining the ease of which we can compare sizes. Notice in Figure 3.10 that it is harder to compare the bars that have different angles than those that are aligned. Notice also how grouping is perceived, and whether it is by color or by shape.

3.2.4 C - Benefit From Knowledge

Using visualizations as a tool for conveying information, designers can build on experiences, knowledge, and references already present in the minds of the viewer. Time moves from left to right, red means danger, and big shapes portray big values. This section briefly describes how visualizations can benefit from building on the viewer's knowledge.

Build on What We Know

"The conclusion you jump to may be your own."

James Thurber,
American author, cartoonist, and humorist

Human beings have extensive knowledge about the world and its laws and properties. This knowledge can either be explicitly learned or intuitively built into our minds. Either way, what the viewer perceives when looking at a visualization is very much dependent on that viewer's knowledge. Perceptions also change with experience, and they are context dependent [82, p. 56]. Nonetheless, there are benefits to be drawn from building on what the viewer already knows. This way the designer can use defaults, and avoid having to teach the viewer a new language.

Icons and Symbols

Icons and symbols can be used in visualizations to label and describe certain aspects of the representation. The thumbs up-icon in Figure 3.11 can for instance be used in a scale, conveying which side of the scale is the desirable. In addition to representing good and bad, the thumb can hold a moral message and even judge the viewer. Furthermore, the use of the icon in Figure 3.11 assumes that the thumbs up icon is a universal symbol for something being positive, when actually it can be used as an insult in some parts of the world.

Figure 3.11: Thumbs up icon.

3.2.5 D - Simplify, Do Not Just Decorate

This section looks at how visualizations can avoid being complicated decorations, and provides some guidelines for efficient use of grids.

Keep it Simple

> *"Graphical elegance is often found in simplicity in design and complexity in data."*
>
> Edward Tufte,
> Data visualization pioneer

Creativity is an important aspect of data visualizations. Designers can be creative in the use of presentation methods, visual variables, and when forming a story with data. Along with this opportunity for creativity follows a potential for abandoning functionality and instead create art. The use of data in the creation of art contradicts the definition of data visualizations presented in Section 3.2.1, which is that of letting the viewer reason about and explore data. A good visualization brings absolute attention to data, and gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space [82, p. 51].

Tufte defines Data-ink ratio as the ink displaying data divided by the total ink used for the visualization. A high Data-ink ratio indicates high attention to data and minimal use of redundant ink, so called *chart junk*. Figure 3.12 is an example of how chart junk can be reduced when creating a bar chart. The figure lists principles applied when transforming the grid from the upper to the lower in Figure 3.12.

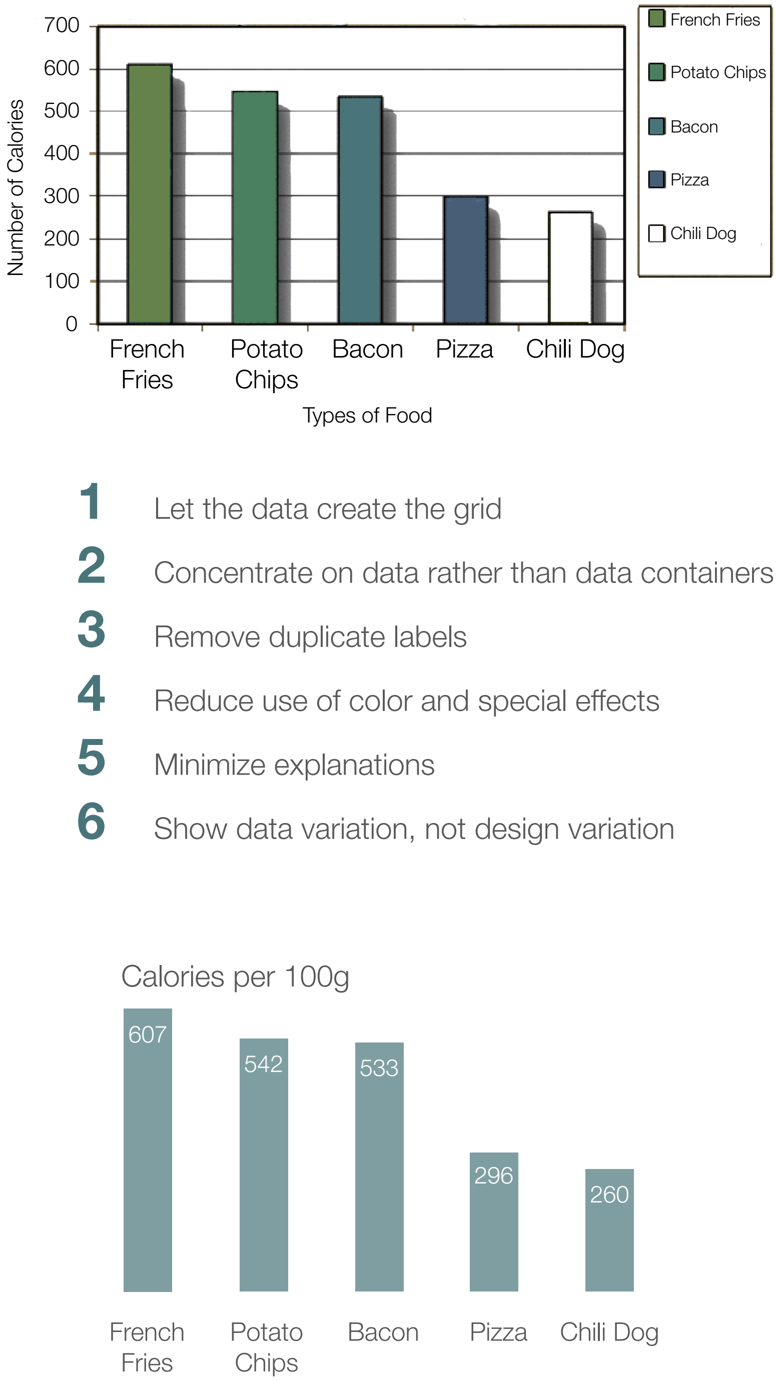


Figure 3.12: Principles for maximizing Data-ink ratio [82].

3.3 Motivation and Adoptation

The mechanisms behind bringing new technology into the everyday lives of users are not only concerned with usability and design. Behind the adoption of every new technology lies a series of motivational considerations, needs, values, and expectations. The goal of evening out electricity consumption depends on users' willingness to adopt the tools they are given in order to shift their consumption away from peaks. Hence, this section looks at how changes in user behavior can occur when adopting new technology, and especially when adopting tools for changing electricity consumption.

3.3.1 Motivation

Whenever driving a car over a long distance, driving can be affected by seeing how much fuel is being consumed. The driver can feel tempted to always try to keep consumption to a minimum, which in turn increases awareness of traffic ahead in order to avoid having to make unnecessary stops. This behavior is driven by motivation, and that motivation is dictated by feelings and values. Not only is economic driving cost effective, it is also environmental. At the same time, trying to always keep below average provides a game-like experience. Minimizing fuel consumption thereby conforms to values of saving money, saving the environment, and having fun. Human behavior in general is based on feelings and values, and to change behavior, we need to build on or alter the very feelings and values that the behavior is built upon [25].

A common distinction is made between intrinsic and extrinsic motivation. When individuals are intrinsically motivated, they engage in an activity because they are interested in it and enjoy the activity. Extrinsic motivations are, on the other hand, external from the activity, and can be manifested as a reward or fear of punishment [48]. Watching the fuel consumption of a car thus offers both intrinsic and extrinsic motivation, as it enables both having fun and saving money.

3.3.2 Needs

Motivation is the tool that helps explain behavior, and a motive is nothing more than a reason for a certain action, desire, or need. Needs and desires are fundamental drivers for human action, and Figure 3.13 illustrates how needs lead to behaviors that cause satisfaction. The figure shows how the motivation process emerges in a continuous manner, with the achievement of satisfaction having the potential of crafting new needs.

Figure 3.13: Motivation process.

The motivation process is initiated by needs, and human needs have been studied and classified in depth in psychological research. Maslow's pyramid of needs is an acknowledged way of organizing needs, and Alderfer's theory of existence, relatedness, and growth (ERG) from 1969 builds on Maslow's work and arranges motivations into three categories [48]. The model does not assume lower-level satisfaction as a prerequisite for the emergence of higher-order needs, and Alderfer believed that as you start satisfying higher needs, they become more intense.

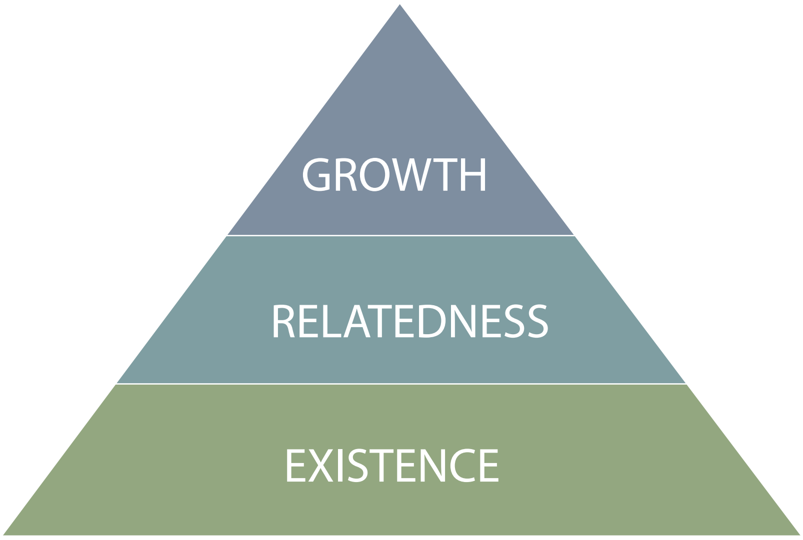


Figure 3.14: Alderfer's ERG pyramid.

Existence needs
Needs for existence include physiological and safety needs. These are the basic needs for human existence comprising hunger, sleep and prevention from fear and danger.

Relatedness needs
Relatedness needs include senses of security, belonging, and respect.

Growth needs
The highest level of needs constitutes the ones providing human growth, and involves needs for self esteem and self actualization.

Intrinsic motivations are often related to needs for personal growth, such as the enjoyment of doing an activity can be caused by a feeling of self actualization.

3.3.3 Facilitating Motivation

Throughout history humans have created and adopted technologies in order to satisfy needs. Whether it is saving money or having fun, needs motivate us to use technology in our everyday lives. Therefore, if new technology is to be accepted by users and motivate change in their behavior, it will have to satisfy needs in some way or another.

There exists several strategies and techniques for trying to motivate users into behavioral change. Linda Steg promotes in her article [16] two main strategies for motivation. *Psychological strategies* aim at changing an individual's knowledge, perceptions, cognitions, motivations, and norms. This can be done through information and education. *Structural strategies*, on the other hand, aim at changing the context in which decisions are made, e.g. imposing fees or legal changes.

Steg also recognizes three barriers for changing behavior related to energy consumption. First, the individual must be *aware of the need*. They must know that reducing energy consumption is environmental friendly, economic, or improves self esteem. It is difficult to get people to adopt a technology if they do not know its purpose. Second, the individual must be *motivated* to change behavior in order to satisfy the identified need. Finally, the individual must *be able to change behavior*. The ability to take action must be available and convenient, and conform to the individual's feelings and the resources that he or she has available.

Motivation is based on feelings, and lasting change is rarely achieved only by appealing to a user's morality [25]. Furthermore, environmental friendliness and knowledge of the Smart Grid has been shown to have little impact on the interest of services [22]. This implies that the rational knowledge about the moral responsibility of changing behavior is not sufficient to actually do so.

3.3.4 Adopting New Technology

Studies have shown that technology has a tendency to become invisible as it is given meaning and a position in everyday life [20]. After having used something for a sufficient amount of time, it drifts into being an everyday activity. These everyday activities become automated routines that are rarely reflected upon, and they become invisible [18]. Thus, they become very hard to permanently change.

Turning on a light switch is for most people indeed such an everyday activity, and is not necessarily associated with consuming energy, costing money, or affecting the environment. Instead of consuming energy, consumers use appliances and the convenience and comfort they provide [27]; the path from action to consequence is not visible. This also applies to both car driving and food wasting, two activities known to have considerable downsides. Still, consumers tend to choose comfort and convenience over money and what could be considered a morally better behavior.

Recent history has shown, however, that consumers have a willingness to change, and one might state that when behavioral change fails to take place, it lies in the failure to fulfill user needs, rather than shortcomings on users' behalf. The fact that 450,000 energy supplier changes took place in Norway in the year of 2003 [22] proves consumers' willingness to act when given the adequate motivation. Waste sorting is another example where environmental consciousness and a change in structural context has translated into actual behavior [20].

Technology Acceptance Model

Fred Davis has defined the Technology Acceptance Model (TAM) displayed in Figure 3.15 [32]. The model identifies factors influencing users' acceptance of a technology, and illustrates how these factors influence one another. A key purpose of TAM is to provide a basis for tracing the impact of external variables on internal beliefs, attitudes, and intentions. The model suggests that perceived ease of use and perceived usefulness are the two most important factors in explaining system use.

Although recent models, such as the Unified Theory of Acceptance and Use of Technology, have been proposed as extensions of this model, the Technology Acceptance Model suffices to illustrate how the actual use of a system is affected by perceived usefulness and ease of use.

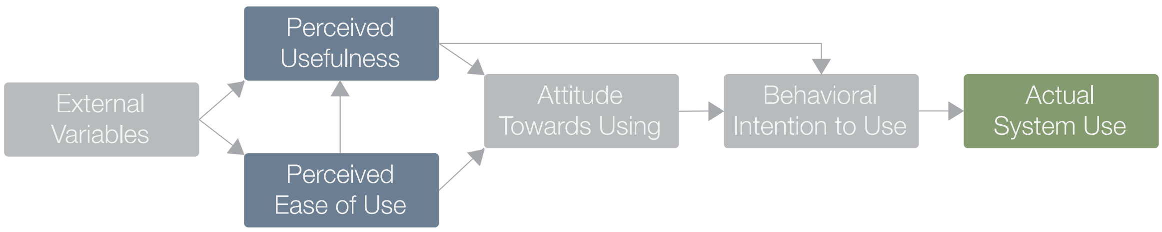


Figure 3.15: Technology Acceptance Model [32].

Perceived Usefulness
The degree to which a user perceives the technology as useful for satisfying needs.

Perceived Ease of Use
The degree of effort the user perceives the technology to require in order to achieve goals.

3.3.5 Scripts and Imaginary Users

The *script* of an artifact includes structural features that encourage specific user actions. A strong script encourages a specific form of use, whereas a weak script allows for interpretations and various forms of use. Building on norms, knowledge, and values embedded in both society and individuals, an artifact, or a system, has the opportunity to encourage a specific use to its users. [6]

The same way designers influence mental models, they can build certain scripts into the artifacts they design by embedding inscriptions into the artifact. Doing this involves an idea in the minds of the designers of how users react, and what norms, knowledge, and values they hold. Designers make predictions about the interests, skills, motivations, and behaviors of future users, and these predictions have a great impact on the design, and the scripts the technology hold. Hence, users' actual behavior does not affect design decisions alone. Designers' idea about users, so called imaginary users, also determine the way new technology is designed. [6]

Part III

Methodology and Research Design

4 Methodology

This chapter provides a description of the methodologies applied in order to explore, analyze, test, and answer the research questions proposed in the introduction. First, the Design and Creation strategy and Human-centered design for interactive systems are presented. Second, the methodology of literature reviews is explained. Finally, this chapter outlines the methodologies used to understand context, elicitate requirements, create artifacts, and evaluate these artifacts. These methodologies include conducting a survey and a focus group, prototyping, and evaluating prototypes by means of usability testing.

4.1 Design and Creation

The Design and Creation research strategy is a framework for information system research. The strategy defines an iterative sequence of activities that produces an innovative product, also known as an artifact. These activities comprise *awareness*, *suggestion*, *development*, *evaluation* and *conclusion*. As opposed to traditional software development, the Design and Creation strategy demonstrates academic qualities such as analysis, explanation, argument, justification, and critical evaluation. The strategy implies that the resulting artifact should contribute to knowledge in some way. [58]

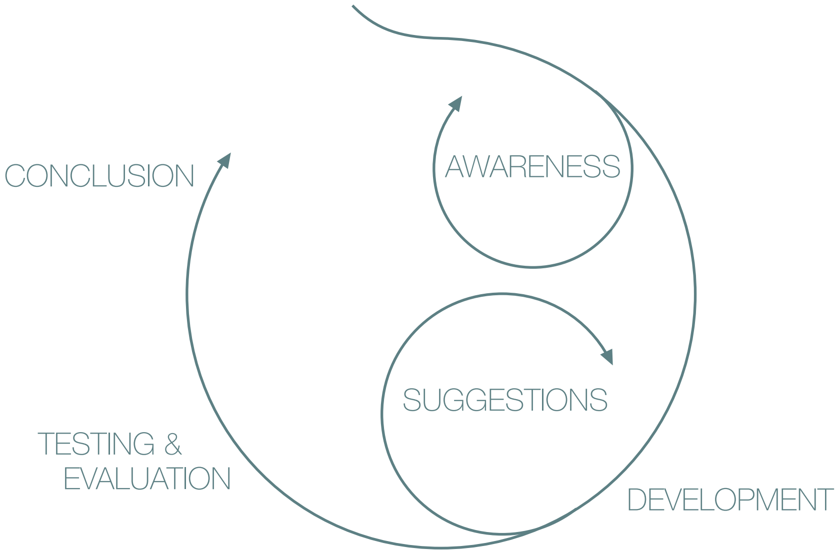


Figure 4.1: The Design and Research Strategy process.

Table 4.1: The five steps of the Design and Research Strategy.

1.	**Awareness** The recognition and articulation of a problem.
2.	**Suggestion** An idea of how the problem can be addressed.
3.	**Development** Creation and exploration of tentative ideas.
4.	**Evaluation** Assessing the value of the artifact that has been developed.
5.	**Conclusion** Identifying the outcome of the design process.

4.2 Human-Centered Design

In order for an artifact to be usable it must meet a set of requirements. The artifact will have to be 1) created in the right *context*, 2) with explicit *requirements* appropriate for its users, their goals and their context, 3) *designed* in a way that meets these requirements, and finally 4) tested and *evaluated* in order to check whether the artifact can be adopted by users in the actual context [4]. ISO 9241-210:2010 specifies these four requirements as a set of four process steps that can be repeated in an iterative manner.

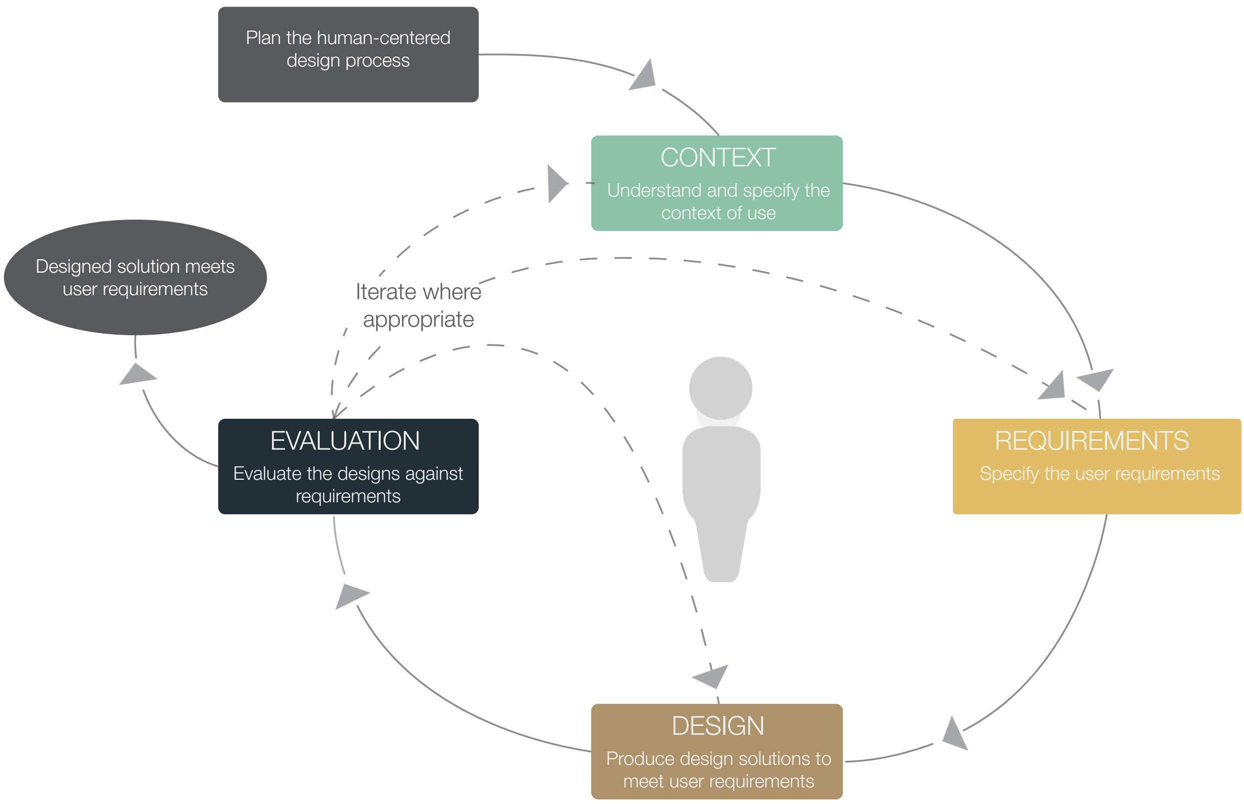


Figure 4.2: ISO 9241-210:2010 design process.

Context

Understanding and specifying context of use is the foundation of the design process, as it guides early design decisions and specifies environment, users, and tasks for the artifact to be designed [4]. This process step involves understanding the characteristics of the users, tasks and environment in which the system is to be used.

Requirements

A thorough understanding of context of use forms the foundation for explicitly stated user requirements. These requirements define what a user requires from the artifact in terms of functionality, ease of use, performance, and design [4].

Design

This process step involves producing solutions based on state of the art, results from the context of use analysis, and most importantly the user requirements [4]. Design solutions can be created as simulations, models, mock-ups, or as implemented prototypes.

Evaluation

When a solution based on both context and requirements has been designed it should be validated by users. Evaluating a solution involves presenting it to users and allowing them to perform tasks on it [4]. This process step is crucial for assuring that the solution is usable not only in theory, but in real life, by actual users, achieving their goals in the appropriate context. Depending on process progression, evaluation can emphasis concept, design, or usability. Several activities can support evaluation, including usability testing and focus groups.

4.3 Literature Review

A literature review is an account of what has been published on a topic by accredited scholars and researchers. The purpose of conducting a literature review is to form a conceptual framework for the fields of study in which the research takes place, as well as to provide insight into current state-of-the-art research and knowledge. A literature review enables researchers to put their work in a context, identify key issues and gaps in the research community, and show that the researcher is aware of existing work in the chosen topic area. [58]

4.4 Questionnaire

Conducting a survey by means of a questionnaire is a data gathering methodology aiming at collecting quantitative data from multiple participants. There are several advantages with performing a questionnaire. It produces data based on empirical data, and it has the possibility of reaching many people and get a representative selection. A questionnaire also produces a lot of data in short time. However, there are also some disadvantages to be aware of. The questions asked can be to broad, giving a result that does not say anything. The data produced by a questionnaire lacks the depth and detail which can be obtained through an interview. It can also be difficult to ensure a high response rate, which would reduce the validity of the survey [5]. The following section elucidates how to write a good questionnaire and what to be aware of.

4.4.1 Constructing a Questionnaire

There are several things to consider when making a good questionnaire. First, and maybe most important, one should define the purpose of the survey. What questions is the survey supposed to answer? Second, one should specify a target group, and how large the sample size should be. This is in order to have a strong basis when analyzing the results. Further, when constructing questions, the formulation and presentation of questions should be carefully thought through.

A well designed questionnaire should [63]:

(a) Meet the objectives of the research.
(b) Obtain the most complete and accurate information possible.
(c) Do this within the limits of available time and resources.

Rossi et.al [63] have listed the following steps for writing a good questionnaire:

1. Decide what information is required.
2. Draft some questions to elicit that information.
3. Put them into a meaningful order and format.
4. Pretest the result.
5. Go back to 1.

Selecting Target Group and Sample Size

Before making decisions about the construction of the survey, a target population should be chosen. Population is, in this context, the people who are relevant for investigation. The sample, or selection, is the subgroup of people from the population who actually are participating in the survey. It is common to use a selection whenever the population size exceeds 200. Having a representative selection, which means that every relevant characteristic in the population is represented in the corresponding distribution, is important for the credibility of the survey. [70]

The number of participants in the survey, its sample size, also affects the credibility of the survey. The required sample size for the survey to be reliable depends on the population size. The ratio between population size and sample size in turn affects the margin of error and confidence level, as shown in Figure 4.3.

A confidence level is the likelihood that the chosen sample mattered in the results. If the survey was repeated, the confidence level indicates the probability of obtaining the same results. The margin of error asserts a likelihood that the result from a sample is close to the number one would get if the whole population had been queried. A confidence level of 95 percent is the most commonly used.

Population	Margin of Error			Confidence Level		
	10%	5%	1%	90%	95%	99%
100	50	80	99	74	80	88
500	81	218	476	176	218	286
1,000	88	278	906	215	278	400
10,000	96	370	4,900	264	370	623
100,000	96	383	8,763	270	383	660
1,000,000+	97	384	9,513	271	384	664

Figure 4.3: Table showing the relationship between population, sample size and confidence level [77].

Writing Questions

When writing questions for a questionnaire, the researcher should first identify which factors are relevant to the problem and what information is required to solve it. Asking questions that do not relate to the objective of the research is irrelevant, and may also impact the response rate if the questionnaire is perceived to be too long. [8]

The layout and structure of the questionnaire is important. The questions should be presented in an orderly manner, numbered and grouped by subject. Clear instructions should be given to make the questionnaire easy to follow [5].

When formulating questions the target audience should be taken into account. The questionnaire should be written in such a manner that it encourages respondents to provide the most accurate and complete information possible. It should hence be adapted to the participants through the language and terms used based on their background. Abbreviations that are not commonly used should be avoided, and easy language and precise words should be used. If the question is far above the participants' understanding and experience they may answer at random rather than admitting their ignorance about the topic. [63]

In a questionnaire there are advantages of using closed questions with answer options. This applies to questions where the possible responses are known. Answer options can make the question easier for the participant to understand, and the results are easier to analyze than when open answers are provided [5]. However, there are some weaknesses to be aware of when writing such questions. Closed questions require a sufficient list of options that cover all possible answers. In cases where only one answer is allowed, the options should also be mutually exclusive, so that only one option fits the participant. In case of a likert-scale it is important that the scale is balanced, which means that there is an equal number of positive and negative loaded options.

Things to consider when formulating questions are summed up below:

- Questions should be neutral. Avoid loaded or leading words.
- Use short sentences, avoid difficult words and use well known terms. Use language that is appropriate for the audience.
- Do not ask two questions simultaneously.
- Avoid ambiguity and the need for analyzing the question.
- Offer adequate and mutually exclusive answer options.

Before Sending Out the Survey

To increase the response rate the invitation should give respondents the sense that their answers and opinions are valued and respected. It is also important to have an instruction at the start of the questionnaire that explains the purpose of the survey, who the information is for, and how it will be used. Another proven initiative for increasing response rate is to use vouchers or lotteries to award participation. [8]

Before sending it out, the survey should be tested on a few people. The survey should be tested with regards to the length of the questionnaire, if the questions are understood, and in general how participants perceive the survey.

What day and time the survey is sent out may affect the response rate. The best suited day depends on the target group. If the survey is to be answered by employees, then Friday after lunch and weekends are not the best time. Similarly holidays and summer vacation are not suited days for sending out surveys. [71]

4.4.2 Analyzing Questionnaire Data

When analyzing results from a survey the response rate and to what extent the respondents were representative for the population must be considered, as described in Section 4.4.1.

When evaluating results from closed questions with interval scale options it is important to look at the standard deviation. The standard deviation reveals how big the variations hidden behind an average are, and says something about how unified the answers are. A standard deviation of 0 implies that everyone has answered the same [72]. In addition, the confidence level and margin of error must be taken into consideration, as a large margin of error can be an indication of erroneous results.

4.5 Focus Group

Focus groups are a form of group interview with the purpose of gaining insight into a subject. It does so by exploring opinions through communication in order to generate data. The methodology benefits from individuals forming ideas and opinions in a social context by exchanging anecdotes and commenting on each others' experiences and points of view. Compared to the traditional interview, the focus group has the advantage of helping people explore and clarify their views in ways that would be less easily accessible in the traditional one to one interview. [50]

Another benefit is that group interviews gather data from several individuals in short time, and can hence be an effective way of collecting data. However, focus groups differs from regular group interviews in that they focus more on interaction among participants. Consequently, a regular group interview can be more effective when the goal is to collect the same kind of factual data from several participants. The social context that focus groups benefit from brings forth the possibility of natural interaction, including humor, anecdotes, and colloquial speech. These everyday forms of communication may tell us more than what is encapsulated entirely in reasoned responses to direct questions [50].

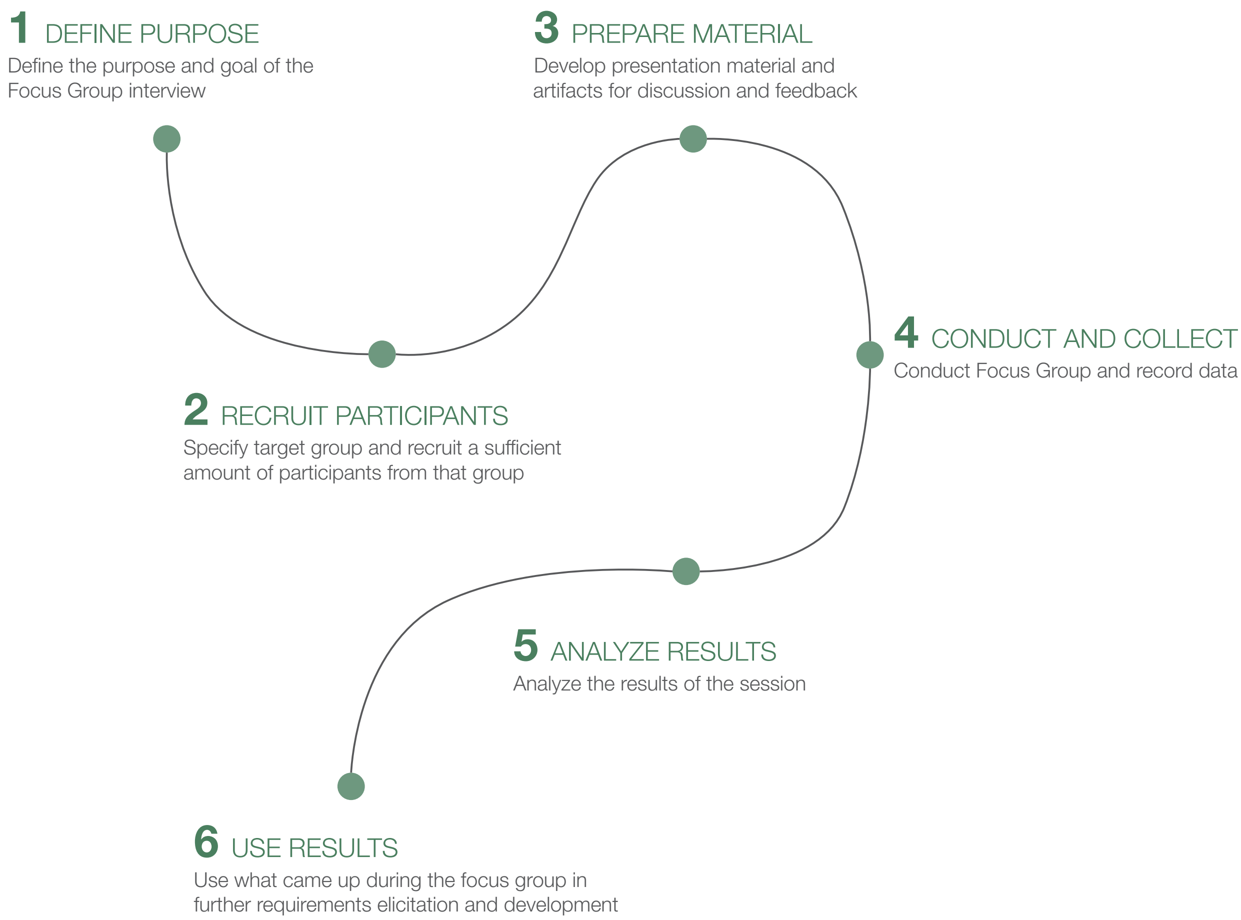


Figure 4.4: Steps of activities involved in conducting a focus group.

Although focus groups can be a suitable tool for collecting qualitative data, a few potential downsides should be noted. First, the methodology gets insight into opinions and ideas more than actual behavior. People have a tendency to portray themselves in a favorable way, and may convey their ideal self more than their actual self. Second, focus groups depend on a certain degree of group dynamic and willingness to share and comment on each other's thoughts and opinions. The articulation of group and society norms may on some occasions silence individual voices of dissent [50].

4.5.1 Running the Group

The ideal group size is between four and eight people, and sessions may last one to two hours. Refreshments and a comfortable setting may help provide a relaxing atmosphere, making participants feel more comfortable. The moderator should explain the purpose of the session, and encourage participants to talk to each other and explore ideas and opinions as they appear. The discussion should be tape recorded and transcribed in order to ease analysis of the data afterwards. [50]

4.5.2 Analyzing Focus Group Data

The data resulting from focus groups are qualitative, and should be analyzed the same way other qualitative data is analyzed. Percentages and averages may not be the outcome, but instead individual ideas may be valuable on their own. While methodologies such as questionnaires are appropriate for determining how many people hold a certain opinion, focus groups are better for exploring exactly how those opinions are constructed. Table 4.2 enumerates five steps associated with analyzing data from focus groups.

Table 4.2: Steps for analyzing focus group results.

1.	**Data Grouping** Group answers from all interviews to each question. For each question, what did the participants say?
2.	**Information Labels** What does each group of answers describe? Organize and classify answers into categories. Label each group of answers.
3.	**Knowledge (Findings)** How does the information answer the research objectives?
4.	**Theory** What theories develop?
5.	**Implications** What does it mean? What major themes emerge?

When analyzing data the researcher should be aware of the impact of group dynamics, and how group consensus has the possibility of influencing the opinions of individuals. The researcher will have to look for recurrent views and statements, and try to separate genuine opinions from the ones that are politically correct. Finally, when analyzing focus group data it is important not to present data out of context. The objective of facilitating a natural discussion leads to complex interactions including humor, sarcasm and fragmented sentences, and hence it may be necessary to present an opinion in its original context. [50]

Figure 4.5 shows how situational factors can affect the course of a focus group. Table 4.3 explains each factor.

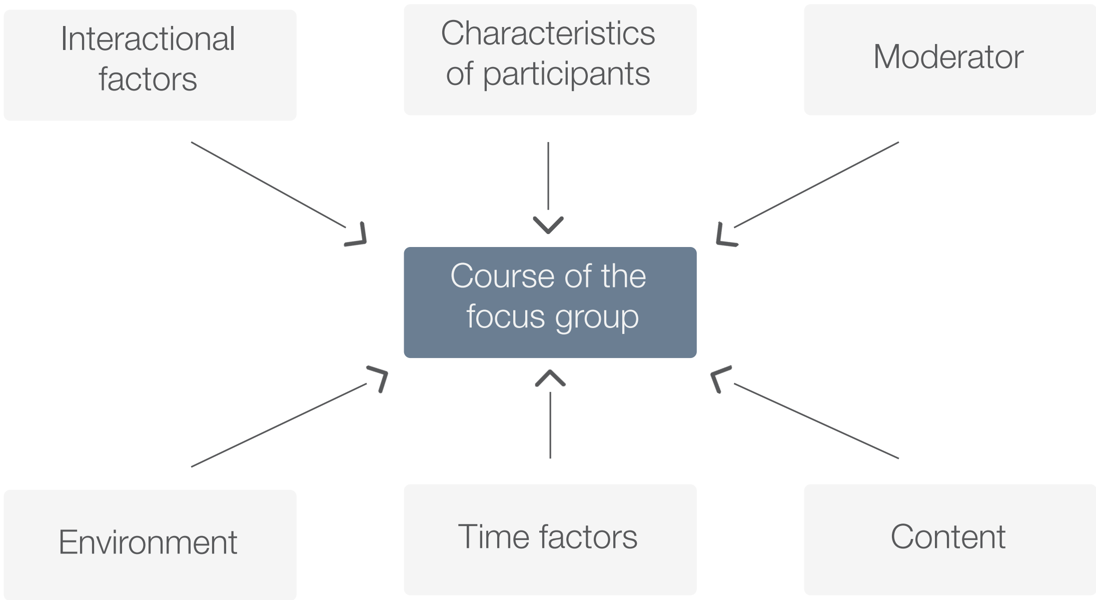


Figure 4.5: Situational factors in focus groups [12].

Table 4.3: Explanation of situational factors in focus groups.

Interactional factors
Includes social and psychological mechanisms that appear when several persons enter into interaction with each other. Social interaction takes place both between researcher and participants and among participants. As a result both individual and group influences may occur.

Characteristics of participants
Personal characteristics include age, gender, education, knowledge of the theme discussed, experience, group behavior, and what role participants assumed. These characteristics influence what the participant says and how he or she says it.

Moderator
Characteristics of the moderator influence the outcome of the discussions. The degree of control, level of knowledge, communication skills, and personal characteristics compared to the participants' affect the way the moderator is perceived by participants, and in turn how they interact with the moderator, and among each other.

Environment
The environment in which the discussion takes place can influence the degree of formality, and affect group atmosphere and easiness.

Time factors
Time of day and duration may influence participants concentration level and willingness to interact.

Content
Group discussion is lead by content, and how it is presented. How personal or intimate the matters discussed are, and whether there are strong social expectations on the subject, can affect what participants say.

4.6 Prototyping

The Design step of the Human-centered design process involves producing design solutions based on established requirements for the problem at hand. A prototype is such a design solution, being limited in functionality, design, or both [61]. Prototypes serve as a communication medium between designers and users in order to test ideas, concepts, usability, and acceptability [13]. Therefore, prototyping is an essential tool when entering the evaluation step later in the design process.

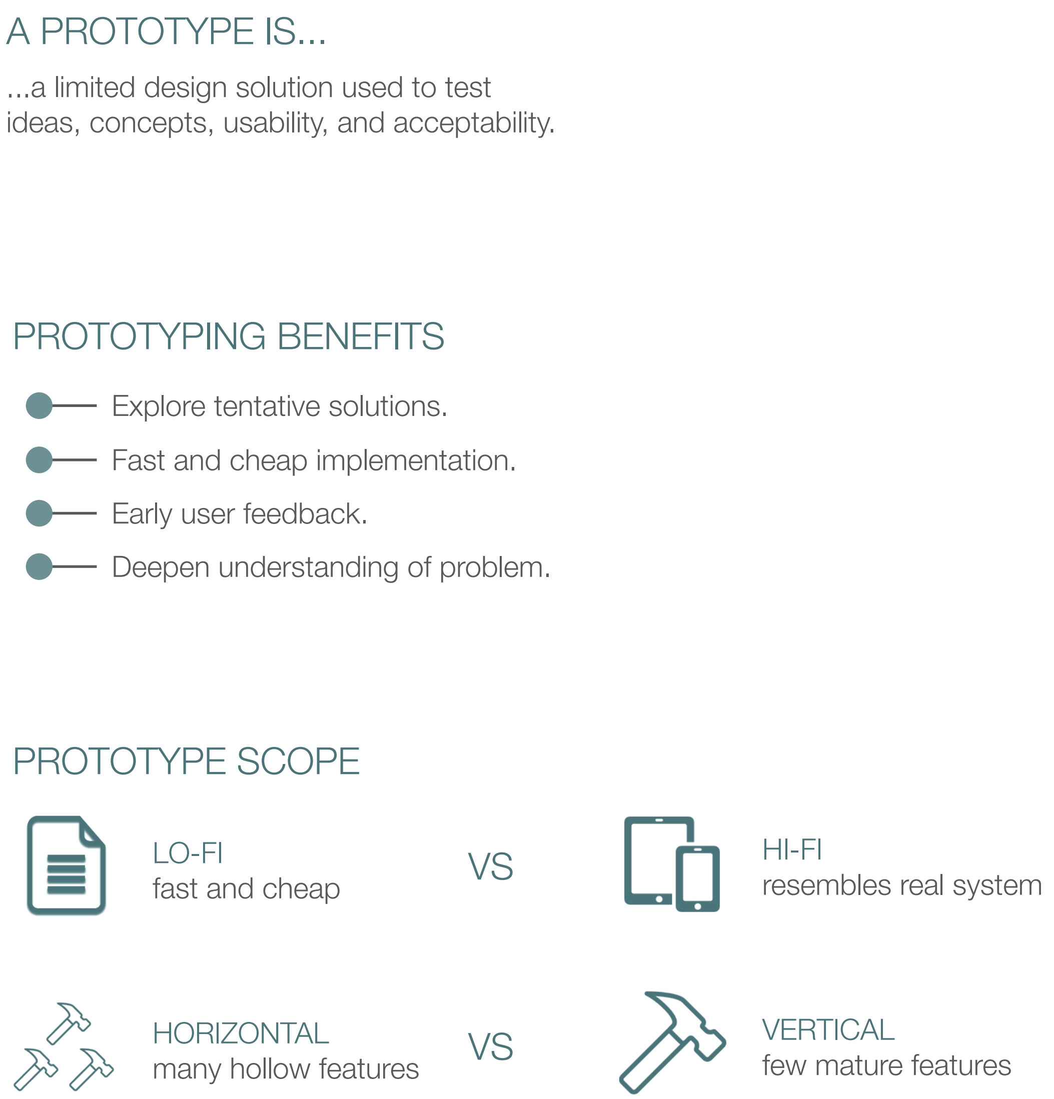


Figure 4.6: Prototype summary.

4.6.1 Prototyping Benefits

An advantage of prototyping is that it is not necessary to fully understand a problem before exploring tentative solutions, as prototypes are less resource-demanding than fully implemented systems [58]. Furthermore, the process of sketching and developing prototypes supports creativity during design, as changes are easily made and impulses can be acted upon. Thus, prototyping not only becomes a tool for testing design solutions, it also aids creativity as well as deepening ones understanding of a problem, its context, and the requirements for its solution.

Another benefit with this methodology is that prototypes are tangible objects rather than abstract ideas. This enables testing of explicit artifacts and incorporating user feedback into the design early in the development process [4]. Thus, evaluating a prototype on actual users can be more concrete and specific than having users evaluate an abstract idea or a concept.

4.6.2 Prototype Scope

Prototypes can have high or low fidelity, and they can be horizontal or vertical [61]. A hi-fi prototype resembles a working system more than a low-fi prototype, and a horizontal prototype incorporates a wide range of not-fully-implemented features, whereas a vertical prototype contains a low number of nearly-complete features.

4.6.3 Elements for Consideration

There are some aspects to be aware of when developing prototypes. First, the purpose of the prototype will have to be stated ahead of development. By not doing so, one runs the risk of developing a prototype not being able to test what is intended.

If the goal of the prototype evaluation is to get feedback on a concept, a high fidelity prototype may be too time consuming. Also, prototypes interpreted as real systems might draw attention to implementation details during tests [61], rather than drawing attention to the concept. On the other hand, low fidelity sketches may be too far from an actual system, and thereby inadequate for evaluating actual usability and design.

Another aspect to be aware of when developing prototypes is that users may ascribe meaning to elements meant to be meaningless, such as a date, a name or a placeholder-image. Therefore, it is important to consider every visual element, and assess how it should and will be interpreted by users during evaluation.

4.7 Usability Testing

Usability testing is a methodology encompassing several activities, such as experiments, observation, interviews, and questionnaire [61]. The goal of usability testing is to measure in a controlled setting how usable a product is in terms of effectiveness, efficiency and satisfaction in a specific context of use [4].

The *effectiveness* of the product to be tested is determined by the accuracy and completeness with which users achieve specified goals. Its *efficiency* is a measure of the effort and resources users have to invest in order to achieve these goals. Finally, a user's *satisfaction* with the product is affected by freedom from discomfort, and positive attitudes to the use of the product. All three factors can be tested during the course of a usability test; number of completed tasks can be a measure of effectiveness, time to complete tasks a measure of efficiency, and satisfaction can be measured by having users express their opinion in a SUS-form, explained in Section 4.7.3, or in an interview.

4.7.1 Guidelines for Usability Tests

When conducting a usability test, several factors will affect the outcome, and whether it is successful or not. In the context of usability testing, successful does not mean that the usability is proven to be good. A successful usability test is one that succeeds in finding usability problems, if there are any. Tognazzini provides ten guidelines for developers on how to facilitate a usability test [80]:

1.	Introduce yourself and the other facilitators of the usability test.
2.	Explain the purpose of the test, and that it is the product being tested, not the participant.
3.	Inform the participant that he/she can cancel the test at any time.
4.	Describe the technical equipment and limitations of the prototype.
5.	Teach the participant how to think aloud.
6.	Explain that you will not be able to provide help during the test.
7.	Describe the tasks and introduce the product being tested.
8.	Ask if the participant has any questions before conducting the actual test.
9.	Wrap up the test by letting the user comment on the product.
10.	Use the results.

The *test leader* manages communication with test subjects, and notes should be taken by an *observer*. An observation form can be a useful addition to recordings in order to capture unspoken occurrences. Jakob Nielsen recommends that five test subjects are sufficient when testing usability [52]. The reason for this, he states, is that five users on average will find 85 percent of the usability problems, and that these should be corrected before pursuing further usability testing.

Concurrent Think Aloud (CTA) and *Retrospective Probing* (RP) are two key elements when executing a usability test. When performing a task, users should be encouraged to think aloud (CTA) to clarify their thought process and understanding of the test object. After the test, a debrief should be performed to gather loose ends and elaborate on unanswered questions that might have occurred during the test (RP). [28]

4.7.2 Evaluating Data Visualizations

The evaluation of data visualizations involves evaluating their readability and comprehension. This can be done by means of usability testing, but an additional specification of which tasks users perform when studying a visualization of data can help assess readability and comprehension.

Weherend and Lewis [3] have classified a set of such user tasks that can be used when evaluating information visualizations. By evaluating to what extent the user is able to perform these tasks, researchers will be able to assess the readability and comprehension of the visualization. These user tasks are summed up by Winckler and Freitas [9]:

Table 4.4: Classified user tasks for evaluating data visualizations.

Locate	The user knows a dataset entry and indicates it by pointing or describing it.
Identify	Similar to locate but the user describes the dataset entry without knowing it previously.
Distinguish	Different objects should be presented as distinct visual items.
Categorize	Objects may be different because they belong to different categories, which should be described by the user.
Cluster	The user may find categories and that objects belonging to them are shown linked or grouped together.
Distribution	The user specifies categories and that objects belonging to them are distributed among them.
Rank	The user is asked to indicate the order of the objects displayed.
Compare	The user is asked to compare entities based on their attributes.
Compare within and between relations	The user is asked to compare similar entities or different sets of objects.
Associate	The user is asked to establish relations between objects displayed.
Correlate	The user may observe shared attributes between objects.

4.7.3 System Usability Scale

A System Usability Scale is the most used questionnaire for measuring perceptions of usability [64]. It includes ten statements used to help assess users' satisfaction with a product. After performing a usability test, users are asked to take a position on these statements with a 5-point likert scale, ranging from Strongly agree to Strongly disagree. The noted benefits of using the System Usability Scale include [28]:

- It is a very easy scale to administer to participants.
- It can be used on small sample sizes with reliable results.
- It is valid – it can effectively differentiate between usable and unusable systems.

Table 4.5: The ten statements constituting a SUS.

1.	I think that I would like to use this system frequently.
2.	I found the system unnecessarily complex.
3.	I thought the system was easy to use.
4.	I think that I would need the support of a technical person to be able to use this system.
5.	I found the various functions in this system were well integrated.
6.	I thought there was too much inconsistency in this system.
7.	I would imagine that most people would learn to use this system very quickly.
8.	I found the system very cumbersome to use.
9.	I felt very confident using the system.
10.	I needed to learn a lot of things before I could get going with this system.

In order to prevent users from checking *Strongly agree* on every statement, statements alternate between being positive and negative. Hence, the scores for the negative statements must be inverted before calculation; a score of five would be turned into a one. Then, one is subtracted from each score, so that scores span from zero to four. Finally, these numbers are added together and then multiplied by 2.5 to convert the scores of 0-40 to 0-100.

The SUS results in a score between 0 and 100, and scores above 68 are considered to be an indication of satisfactory usability. Scores below 68 are, however, an indication of usability issues and should be further developed. [64]

4.8 Validity of Research Strategy

When applying the methodologies described in the previous sections, the resulting data can be evaluated in light of four criteria that help assess the validity, or truthfulness, of the research. As part of a positivist research philosophy these criteria include triangulation, objectivity, and internal and external validity.

4.8.1 Triangulation

Triangulation in research refers to the use of various techniques for gathering information and results, performed with the purpose of confirming probable findings and to ensure a more complete, holistic and contextual portrait of the units under study [10]. It validates the findings and research by cross verifying the same information provided from more than two sources. There are four basic types of triangulation, comprising *data triangulation*, *investigator triangulation*, *theory triangulation*, and *methodology triangulation*.

Data triangulation refers to using evidence from different types of data sources such as documents, public records and photographs. Investigator triangulation involves using several different investigators in the analysis process. Using several theoretical approaches to analyze the data is called theory triangulation, whereas methodological triangulation combines multiple methods to obtain data, such as interviews, observations and questionnaires. [36]

4.8.2 Objectivity

When performing qualitative research methods such as focus groups and usability testing, objectivity should be considered. The researchers should remain distanced from what they study so that the findings are not influenced by the personality or beliefs of the researcher. The findings should not depend on who did the research, but on what was there to be found. [7]

Objectivity can be partitioned into two components, *reliability* and *validity*. Reliability is the extent to which a research activity yields the same results regardless of who performs the activity, and when or how it is carried out. Validity is the extent to which the findings are interpreted in a correct way. [2]

To increase objectivity, influence that the moderator may have on the participants should be avoided. This can be achieved by considering the choice of words and formulation, and by being aware of ones behavior, in order to avoid affecting what the participants say or do.

4.8.3 Internal Validity

Internal validity refers to the extent of which the right data has been collected from the right sources, and whether no other variables except the one being studied have caused the result. Threats to internal validity include elements such as faulty instruments or selected participants who are not representative for the target group. To ensure validity the purpose of the tests or surveys should be stated at the beginning of the session to ensure that it is understood by the participants. In terms of usability tests, internal validity concerns the moderator's responsibility of assuring that he or she knows what the participant really is talking about. [58]

4.8.4 External Validity

External Validity refers to the extent of which the results of qualitative research can be generalized or transferred to other contexts or settings. The qualitative researcher can enhance external validity by doing a thorough job of describing the research context and the assumptions that were central to the research. [58]

5 Research Design

This chapter presents the research design applied in this thesis work, including strategy, research process, and activities performed. First, the overall research strategy is presented, before an explanation of how this research conforms to the Human centered design process follows. Finally, this chapter presents a literature review.

5.1 Research Strategy

This thesis work follows the Design and Creation research strategy, as it follows an iterative process revolving the creation of artifacts for evaluation. Through designing tentative solutions and evaluating these, the ultimate goal is to contribute to the state of knowledge about how display tools related to energy consumption should be designed. The following list identifies each step of the Design and Creation strategy, and states how they are manifested in this thesis work.

1. Awareness
Recognizing the problem of peak loads in the electrical grid, and the possibilities that new technology brings.

2. Suggestion
The idea that display tools have the ability to address the problem of peak loads, as well as helping users.

3. Development
Developing design solutions for such display tools.

4. Evaluation
Testing the design solutions on users.

5. Conclusion
Identifying what knowledge results from the evaluation.

This research tries to identify, explore and explain factors affecting how a visual tool supporting energy usage should be designed. The research explores the motivations and opinions of users, achieving their goals in an everyday context. The research is therefore not purely positivist, as it recognizes that there might not be a single external reality when discussing a group of individuals, having individual motivations, goals, and preferences. Nevertheless, in order to evaluate the implications of what is found, the research applies four positivist evaluation criteria. These criteria evaluate the implications of the research in terms of how it achieves triangulation, objectivity, and internal- and external validity, as described in Section 4.8.

5.2 Research Process

The overall goal of a display tool concerning electricity consumption is to be adopted and used by users, and must consequently be usable. ISO 9241-210 defines the process of Human-centered design for interactive systems, and explains the process of developing usable artifacts. Hence, the Human-centered design process is applied in this thesis work in order to answer the research questions. Figure 5.1 shows how each research question corresponds to a specific process step in the Human-centered design process, and illustrates how the design process has been applied during the thesis work.

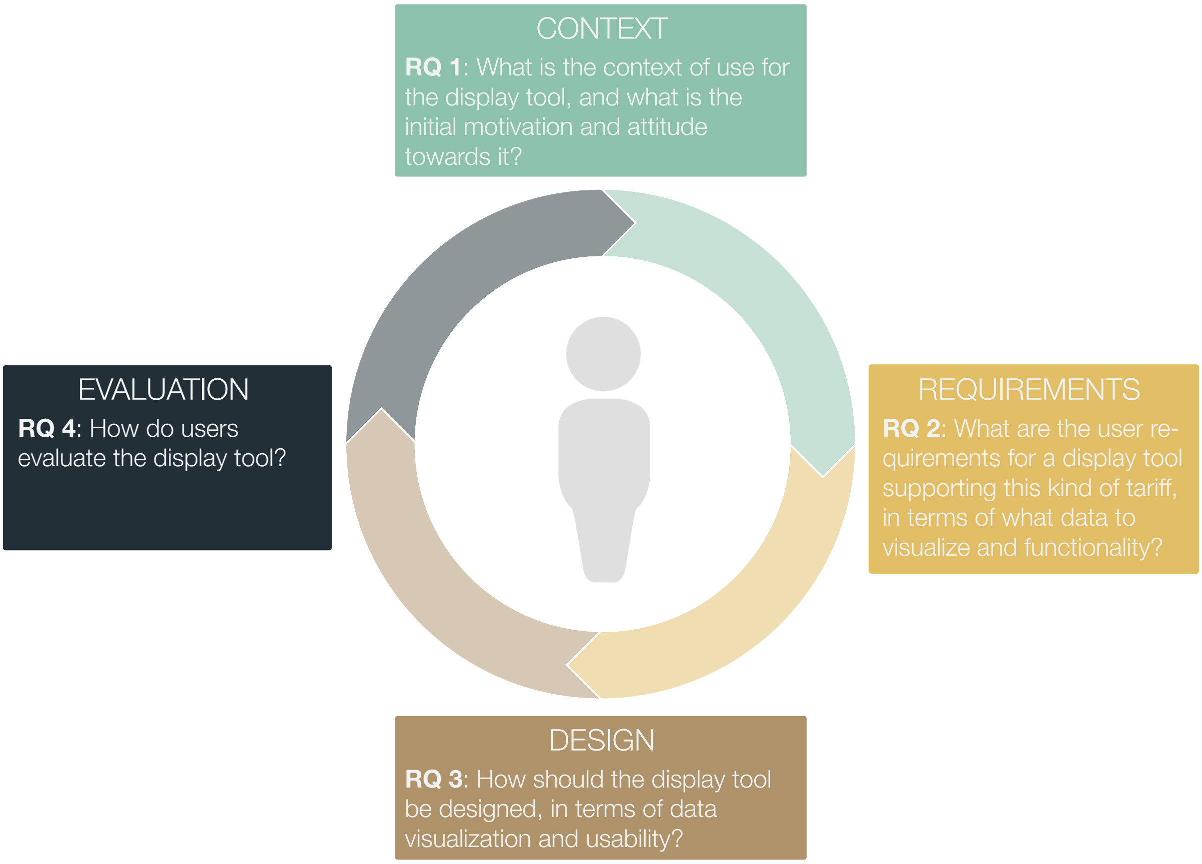


Figure 5.1: Research questions as a ISO 9241-210:2010 design process.

5.2.1 Research Timeline

Figure 5.2 displays a timeline comprising ten activities performed during the course of this work. Each activity can be associated with one of the four process steps - and thus also one of the four research questions. This association is far from absolute, a focus group can for instance be conducted for both requirement and evaluation purposes, but still the associations help clarify the rationale behind performing the activity. The association is done by means of color mapping, with each activity having the same color as the process step they have been associated with. As shown in Figure 4.2, displaying the Human-centered design process, the steps are not necessarily followed in a rigid manner. Rather, the evaluation of a design solution may be followed by e.g. changing user requirements. This property becomes apparent in the timeline below, as evaluations are not always followed by analyzing context of use. The activities have been grouped by parts, resembling iterations, as they are presented in this thesis.

Figure 5.2: Chronological timeline associating activities with process steps, and grouping activities by parts as they are presented in this thesis.

Context

CONTEXT

RQ 1: What is the context of use for the display tool, and what is the initial motivation and attitude towards it?

The following activities have been associated with understanding context of use:

01 Project Scope includes the first meeting with Demo Steinkjer, defining project scope and context of use for an application concerning electricity consumption, including who the users are and what Smart Grid and Smart Meters imply and offer users. Further clarifications were settled during **04 Tariff Project Context**, a session of meetings examining the context for the Microgrid Tariff. In order to assure that the application would be created within a real life context, **08 Expert Knowledge** was gathered from a Smart Grid seminar and a meeting with the developers of the Microgrid Tariff.

Requirements

REQUIREMENTS

RQ 2: What are the user requirements for a display tool supporting this kind of tariff, in terms of what data to visualize and functionality?

The essential activity for eliciting user requirements has been creating and getting potential users to respond to a **05 Questionnaire**. However, both the focus group, interviews, and meetings have been advantageous when establishing user requirements.

Design

DESIGN

RQ 3: How should the display tool be designed, in terms of data visualization and usability?

Design solutions have been developed on several occasions throughout the design process. Early charts visualizing energy consumption, **02 Prestudy Charts**, were made as a result of an early meeting with Demo Steinkjer and a literature review. Later, **06 Focus Group Sketching** produced sketches related to the Microgrid Tariff for use during the focus group interview. Finally, during the **09 Prototype Implementation**-activity, a working prototype was implemented for usability testing.

Evaluation

EVALUATION

RQ 4: How do users evaluate the display tool?

For every artifact that has been crafted, an evaluation has followed. The earliest charts were evaluated through **03 Prestudy Testing**, evaluating readability. The Microgrid Tariff sketches were evaluated during a **07 Focus Group**, giving explicit feedback on the sketches and the ideas behind them. The final activity conducted in this process was **10 Usability Testing**, where the implemented prototype was tested on project participants from Demo Steinkjer, participants from the focus group, and potential users uninformed about the tariff.

The first charts and sketches were designed and tested in terms of readability and conceptual ideas. The implemented prototype was based on the initial sketches and their test results, and was developed in order to test usability and acceptability. Only the results from the final usability tests provide answers to research question 4, as the early evaluations have been used in order to establish user requirements.

5.3 Literature Review

Literature on both Smart Grid, data visualization, and motivation has been studied in order to provide a conceptual framework for the research, as well as getting an insight into current state-of-the-art research and knowledge.

Smart Grid technology is a relatively new field of research, in which entails a constant shifting paradigm with considerable opportunities for innovation. Literature on the subject has been studied in order to develop an understanding of the context in which the technology emerges, and which challenges and opportunities lies ahead.

Communicating information is an essential part of an application related to energy consumption, and hence the field of data visualization becomes relevant. Literature has been studied in order to make good design decisions and visualize data the most effective way possible. Edward R. Tufte is noted as a pioneer in the field of data visualization, and his books [82], [83], and [84] have been studied closely as they are considered important works in the field.

An important aspect of this work is understanding how users adopt technology related to energy consumption. A considerable amount of research has already been carried out on the subject, and literature has been studied to understand how usability, mental models, and understanding of user motivation can help when trying to implement display solutions.

Part IV

Visualizing Energy Consumption Data

6 Prestudy Charts

02 PRESTUDY CHARTS

This chapter presents data visualizations that have been developed during a prestudy conducted in the early stages of this research. The goal of this prestudy was to develop practices for visualizing household consumption data. Hence, the prestudy work is carried out as a contribution to research question 3, addressing the design of a display tool related to electricity consumption.

Section 3.3 established that information and education are fundamental elements for changing user behavior. An important part of this prestudy was thus to explore thoughts and concepts revolving information through visualizations. As a result, this prestudy also contributes to answering research question 2, addressing user requirements.

6.1 Visualizing Energy Consumption

To answer the question of how energy consumption can be visualized to make it understandable for users, we have to apply the principles presented in Section 3.2 about data visualization.

6.1.1 A - Tell a Story

The purpose of visualizing consumption data is in this regard to give viewers an understanding of how their electricity use varies over time. When presented with a visualization, viewers should be able to tell when usage was high, as well as develop an understanding of patterns in their consumption. In order to enable comparison of data, the visualizations should allow users to compare their usage to a neighborhood average.

6.1.2 B - Visual Variables

To understand ones own usage and compare it to others, representing values is key. To see how usage changes from day to day, hour to hour, comparisons will have to be made. The goal of comparison is not to provide exact values for each hour. Instead it is to intuitively display which hours have higher usage than others. Simplicity precedes accuracy. Therefore, both color and size for representing consumption values over time should be tested.

Another key aspect is visualizing changes over time, and both daily and weekly representations are of relevance. Time can be represented as either circular or horizontal, where a circular representation better conveys days and weeks as repetitive cycles, whereas a horizontal representation might allow for better readability.

6.1.3 C - Knowledge and Understanding

A visualization of electricity consumption has to be based on the viewer's understanding of the subject. Knowledge about electricity usage varies, but most people know that heating, lighting, and cooking consume electricity. The visualization should build on this knowledge in order to allow viewers to visually discover changes in their usage, and in turn conceive an idea of what could have caused these changes to occur.

6.1.4 D - Simplifying Consumption Data

Consumption data can be both complex and overwhelming, and visualizations are made to simplify readability of this data. Approaches for increasing readability include reducing the number of readings, reduce accuracy in readings, suppress insignificant variations, and maximizing Data-ink ratio, described in Section 3.2.5. Visual variables, such as colors, shapes and sizes should benefit from preattentive properties and allow for rapid interpretation and pattern detection.

6.2 Prestudy Charts

This section addresses design choices and data used for the prestudy charts, and explains each chart.

6.2.1 Design Choices

As described in Section 3.2.3 about color, humans have no ability to perceive one color as having higher value than another. However, color intensity can be utilized to convey intensity in values. Tints, mixing a color with white, of only one color was thus chosen rather than applying a color scale between two colors. The color scale moves from light to dark blue, which indicates low and high consumption respectively.

Tints of blue were chosen since, in this context, blue is a more neutral color than red and green. Red and green may have stronger negative and positive associations, of which red is negative and green is positive when it comes to energy consumption. The scale in Figure 6.1 has been applied in most of the visualizations to indicate amount of energy usage.

Figure 6.1: Color scale.

In addition to using colors to indicate value, some charts have size as their main value indicator. Bar charts are effective for visualizing relationships between values, as discussed in Section 3.2.3 about shapes, and are hence used in several charts. All charts were created using *Adobe Illustrator*.

6.2.2 The Data

A visualization of consumption data will communicate various data to its users, and it is important that the visualizations strive to achieve realism. This is the reason why actual data from the Demo Steinkjer-API has been used when making these charts. The data consist of meter readings done every hour from 800 households. A client was made to retrieve data sets from the API, which were stored in a database. The relevant and desired data was selected through queries to this database.

Datasets from two different Smart Meters have been used in these charts. One dataset had an evident usage pattern, while the other had a more irregular usage. This was done to test the readability of the charts, and whether they were able to convey information without evident patterns. The neighborhood average was calculated from the 800 meter readings.

6.2.3 The Charts

Chart 1a and 1b: Daily, 12 Hour Circles

These visualizations present hourly energy consumption from a specific day. The layout is circular with 12 intervals, inspired by the layout of a clock dial. As mentioned in Section 3.2.4 there are benefits of building designs on what the viewer already knows. Associations with a clock dial might thus help navigation, and help finding the desired meter reading.

Since the day consists of 24 hours the day is split into two circles, one outside the other. To differentiate these two circles from each other, and decrease the desire of comparing them, a broader line is placed in between. To make the size of each cell approximately even, hence giving each cell equal degree of importance, the radius of the circles were expanded. This resulted in having a space in the middle which can contain additional information, in this case the date. Two versions were made where the first one had time labels placed outside the circles, whereas the other had time labels placed inside each measure.

Challenges regarding the first two visualizations concern possible difficulties in navigating due to the split of the day into two circles. The starting point of the day may be difficult to perceive, and the point where the day switches from inner to outer circle may also be problematic. Through this layout we aimed at investigating if associations with clock dials would help navigation or not.

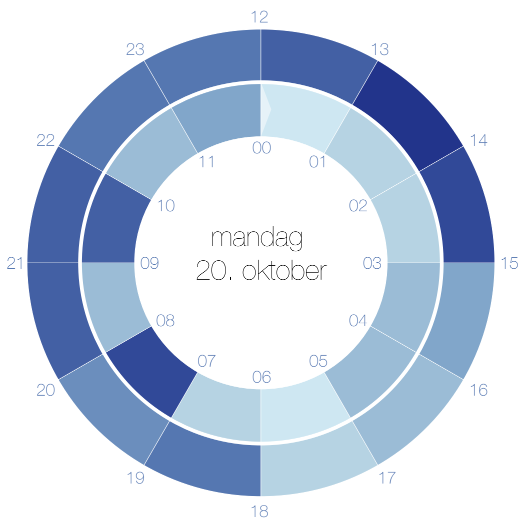


Chart 1a: Time labels placed outside.

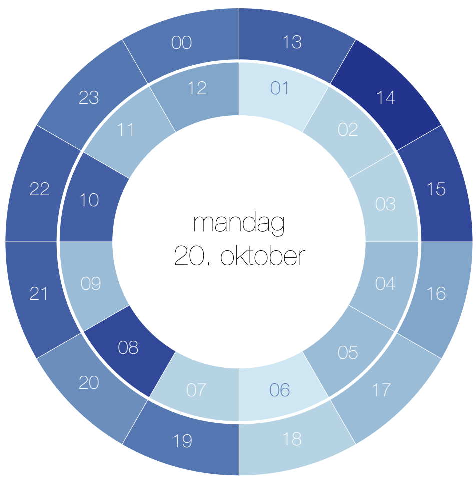


Chart 1b: Time labels placed inside.

Figure 6.2: Daily consumption visualized in a 12 hour circle. Value indicated by color.

Chart 1c: Daily, 12 Hour Spiral

Due to the possible challenges found in Chart 1a and 1b presented in Figure 6.2, another version was created where the two circles were replaced by a continuous spiral. This version represents time in a continuous manner, and eliminates the problem with the circle-swap at noon. The readings begin at the inner of the spiral and continues clockwise outwards. A discreet arrow is placed at the first reading to indicate the beginning of the spiral.

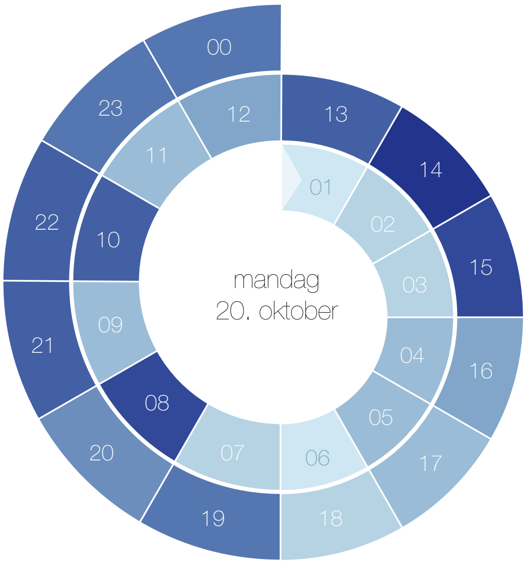


Figure 6.3: Chart 1c: Daily consumption visualized in a spiral. Value indicated by color.

Chart 2: Daily, 24 Hour Circle

This visualization also shows hourly consumption during one specific day, however, this layout contains 24 intervals instead of 12. The association with clock dials are hence reduced. In addition this chart contains both household consumption and neighborhood average for each hour during that day. The intention of this chart is to be able to compare the household consumption with the average of the neighborhood.

The household consumption is placed in the inner circle, and the neighborhood average is placed in the outer. The two circles are thus placed close to each other to facilitate comparison.

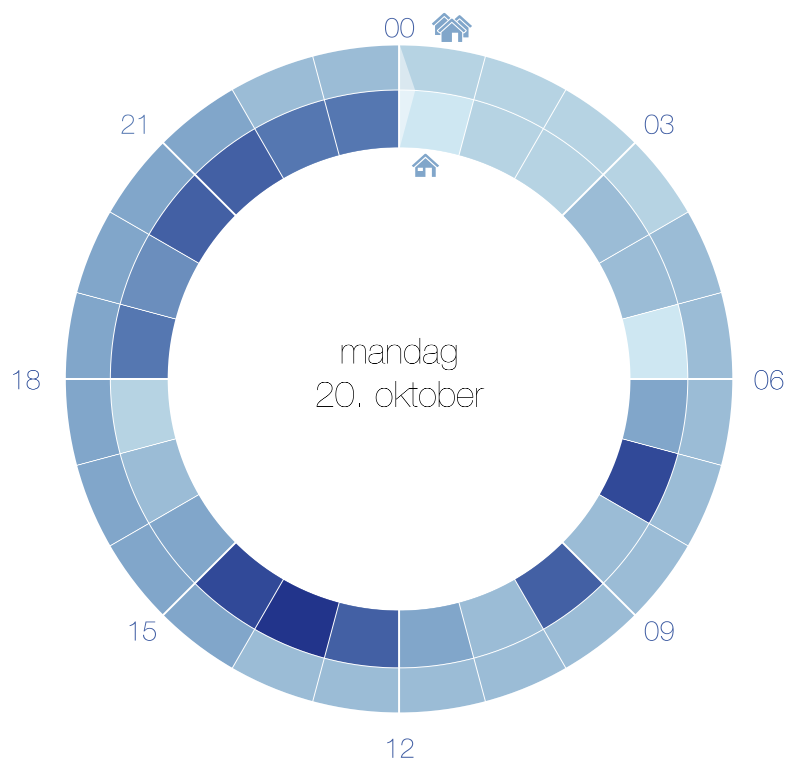


Figure 6.4: Chart 2: Daily consumption visualized in a 24 hour circle. Value indicated by color.

Chart 3: Daily Consumption - 24 Hour Circle

To explore other value indicators than color intensity, another version showing daily consumption was made. This chart displays consumption from one day in a 24 hour circle, and is labeled similarly as the previous chart, as shown in Figure 6.4. Each meter reading is represented by a bar, where both size and color indicate the amount of consumption. The use of bars may be more common and thus more familiar among consumers, and as already mentioned in Section 3.2.3, the brain is very good at comparing sizes, especially height.

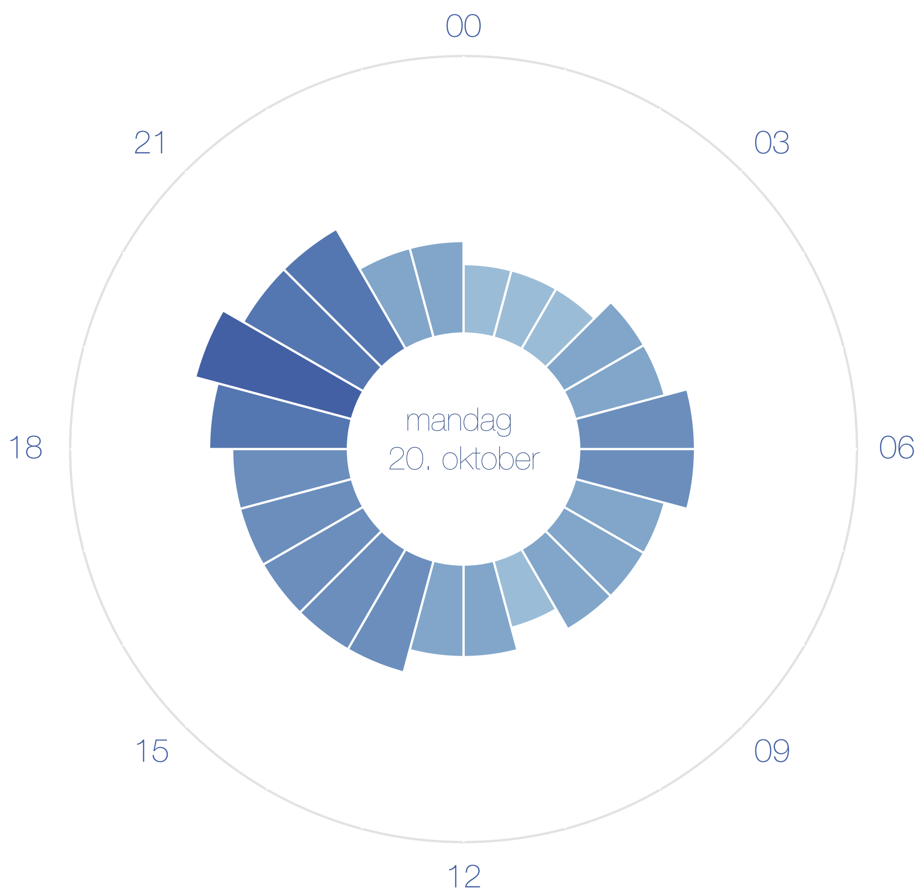


Figure 6.5: Chart 3: Daily consumption visualized in a 24 hour circle. Value indicated by size and color.

Chart 4: Weekly Consumption - Grid Layout

This visualization, containing meter readings from one week, illustrates energy consumption each hour, every day, during the course of a week. Each square represents a meter reading, each row represents a day, and each column represents an hour. Similarly the average consumption each hour during the week is shown at the bottom. The intention is to illustrate the household's usage patterns, and through this give an indication to the consumer which hours of the day the consumption is high throughout the week.

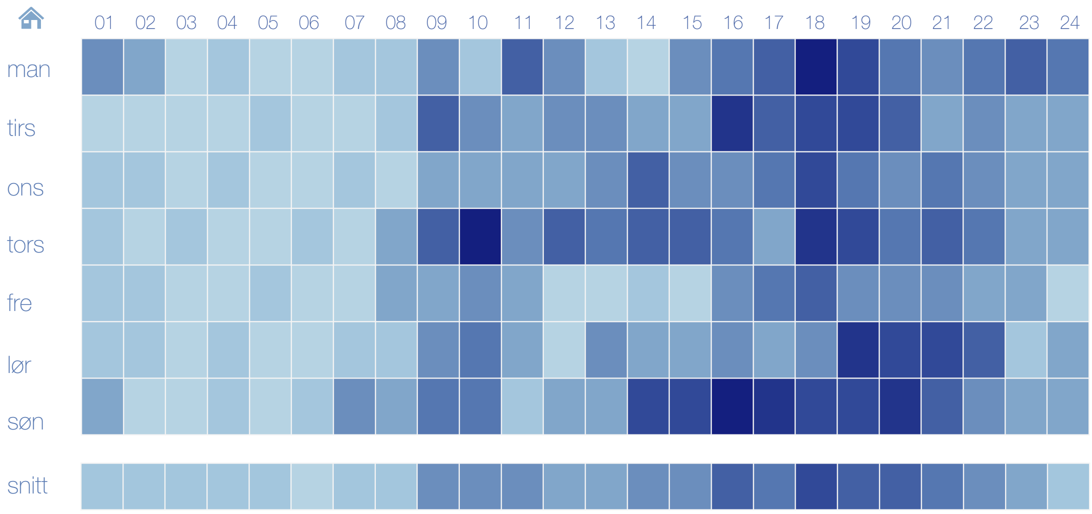


Figure 6.6: Chart 4: Weekly consumption visualized in a grid. Value indicated by color.

Chart 5: Weekly Consumption - Spiral

This version also illustrates meter readings from one week, just like Figure 6.6. However, this chart illustrates time as a continuous spiral. In the previous visualization of weekly consumption the week was divided into seven rows, separating days at midnight. Such a subdivision might disrupt the flow of the reading and lead to misinterpretations of the daily rhythm. This becomes evident when a day spawns into another, especially during the weekend when consumers might go to bed later than midnight, and hence use energy into the early hours the next day.

A potential drawback with this chart is that the outer circle's radius is significantly larger than the radius of the inner circle. The area of the squares in the outer circle are thus greater and may be given more weighting and focus than the inner circles. This gives room for misinterpretations of the data.

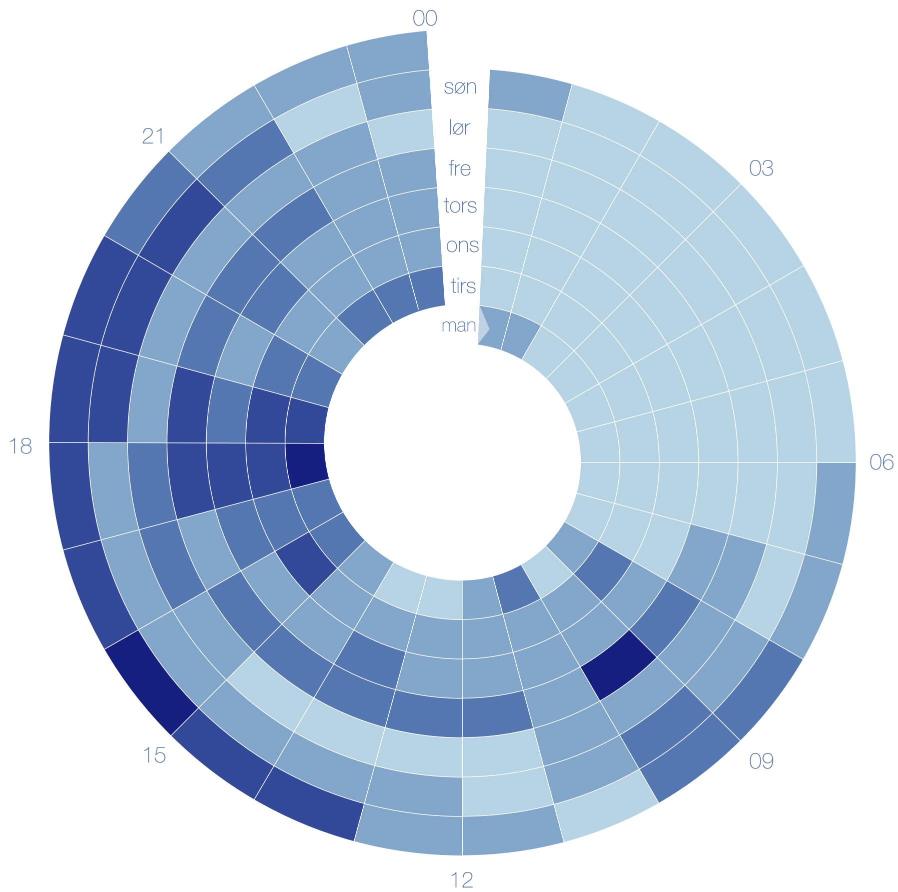


Figure 6.7: Chart 5: Weekly energy consumption visualized in a spiral. Value indicated by color.

Chart 6: Weekly Consumption, Comparison - Grid Layout

The next visualization contains a considerable amount of data. The concept is the same as in the chart shown in Figure 6.6. However, this chart contains both household consumption and neighborhood average. Here, the consumer has the possibility of comparing his or her own energy usage against the average, and thereby obtain an indication of potential saving spots. The days are separated by a small space for a slight enhancement in readability. Both household and neighborhood average for each hour is shown at the bottom.

This chart does not enable preattentive processing very well. Users may not see information and patterns right away, and might need to read the chart to find wanted information. Since household consumption-squares are separated by neighborhood average-squares, readings from different days can be difficult to compare, and hence a consumption pattern might be hard to discover.

This visualization investigates the degree of complexity and the amount of information that a user is able to perceive.

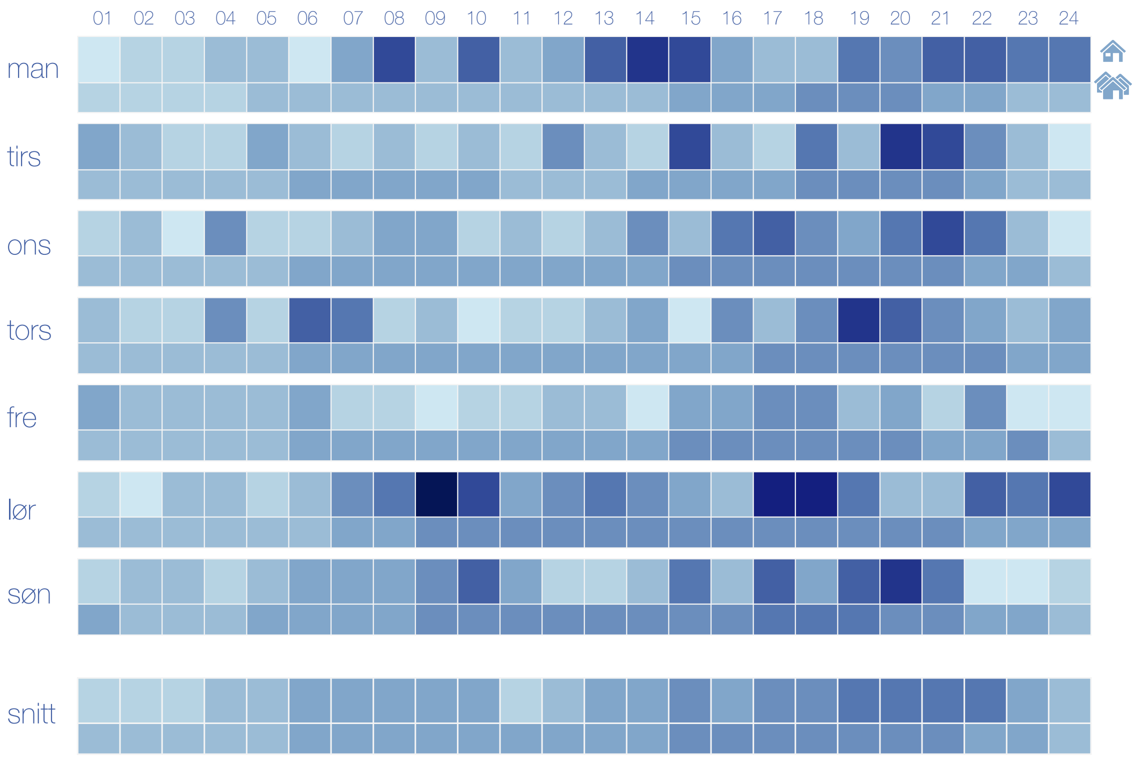


Figure 6.8: Chart 6: Weekly and average consumption visualized in a grid. Value indicated by color.

Chart 7: Weekly Consumption, Comparison - Bar Chart

In most of the previous visualizations color has been the main value indicator. This chart, however, presents each meter reading as a bar, where both size and color indicate the amount of consumption. In addition, the average consumption is indicated by orange lines positioned in front of their respective bars. On the right side, average consumption each day for both household and neighborhood are displayed.

Although the layout is the same here as in chart 4 in Figure 6.6, the visual expression is significantly different. Having bars representing household consumption makes this the most prominent data displayed. Although neighborhood average is displayed by a thin orange line, which makes it a more subtle representation, the variation in color makes it stand out from the bars. The difference between household and average can thus be seen immediately through the concept of preattentive processing, described in Section 3.2.3 regarding order and deviations, and the need of searching and reading is thus reduced.

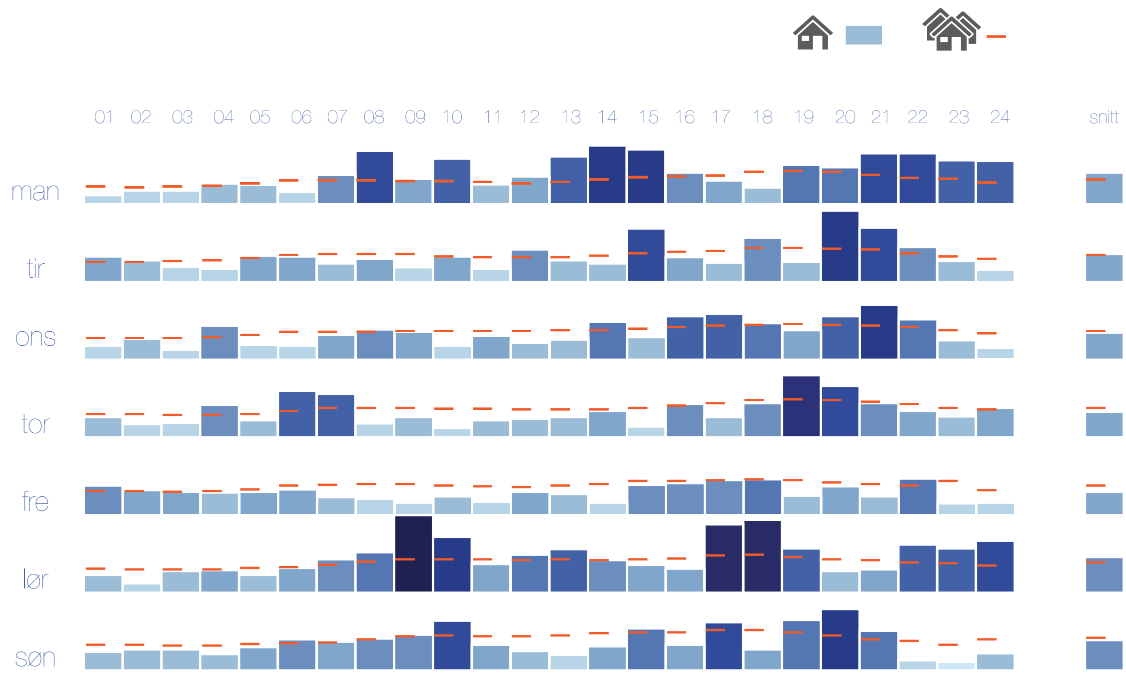


Figure 6.9: Chart 7: Weekly consumption visualized in a grid. Value is indicated by size and color.

Icons: Indicators of High or Low Consumption

Alternative versions of icons defining the color scale were made. Icons entail various associations, as described in Section 3.2.4, and these alternatives were thus made to investigate consumers preferences regarding indication of high and low energy consumption. The alternative icons entail various themes as well as differences in size.

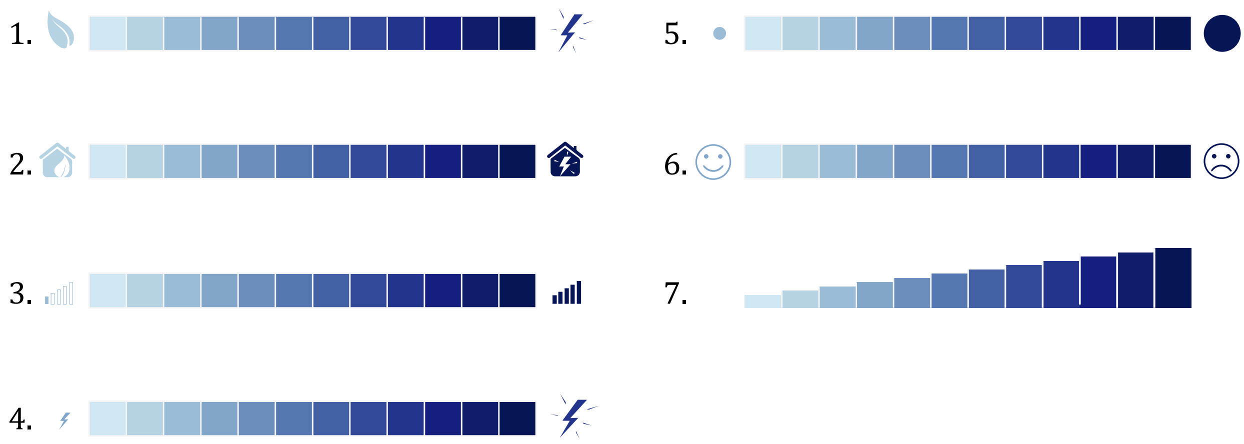


Figure 6.10: Different icons defining the color scale.

7 Prestudy Testing

03 PRESTUDY TESTING

This chapter presents the execution of six usability tests conducted in order to evaluate the charts described in Chapter 6. The tests were conducted to evaluate the readability and comprehension of the visualizations, and to get test subjects' thoughts on electricity consumption in general. Both test execution and results are presented.

7.1 Prestudy Test Execution

This section presents the conduction of the test and its participants.

7.1.1 Participants

Six participants having the following characteristics took part in the tests:

GENDER	
Women	2
Men	4

AGE	
18-25	4
40-45	2

MAIN PROFESSION	
Student	4
Employee	2

RESIDENTIAL SITUATION	
Apartment	5
House	1

RECEIVES ELECTRICITY BILLS	
Yes	3
No	3

Every participant reported using a smartphone and computer daily, and had relatively high computer skills. In addition to standard characteristics such as gender, age and profession, "Receives electricity bills" was included since this can affect both awareness and their relation to energy consumption in general.

7.1.2 The Test

Static visualizations were shown on a tablet, and the participants were given several tasks to perform and questions to answer by studying the visualizations. Techniques such as Concurrent Think Aloud (CTA) and Retrospective Probing (RP), described in Section 4.7, were encouraged. In terms of CTA the participants were asked to think aloud as they performed the test, which gave insight into participants' thoughts as they occurred and as they attempted to work through issues they encountered. Retrospective Probing was done as an open interview after the test, where questions about the test and thoughts in general were discussed.

Each test was conducted within approximately 30 minutes, and sessions were audio recorded with the consent of the participants. The charts were divided into four categories with respect to layout and data presented:

Table 7.1: Categories and associated charts

CATEGORY	DESCRIPTION	CHARTS
Category A	Grid layout containing consumption of both household and neighborhood.	Chart 6 and 7
Category B	Grid layout containing only household consumption.	Chart 4 and 5
Category C	12 hour circles containing only household consumption.	Chart 1a, 1b and 1c
Category D	24 hour circles.	Chart 2 and 3

The order in which the visualizations were presented differed in every test execution. This was done to minimize the effect of comprehension being influenced by the previous charts presented. Each category was presented in the same sequence, A, B, C and D, in every test, but the order of the charts in each category was varied in a systematically way, giving six different sequences in total:

Table 7.2: Chart sequences

	A	**B**	**C**	**D**
Test 1	6, 7	4, 5	1a, 1b, 1c	3, 2
Test 2	7, 6	5, 4	1c, 1b, 1a	2, 3
Test 3	6, 7	5, 4	1b, 1a, 1c	3, 2
Test 4	6, 7	4, 5	1b, 1c, 1a	3, 2
Test 5	7, 6	5, 4	1c, 1a, 1b	2, 3
Test 6	7, 6	4, 5	1a, 1c, 1b	2, 3

The tests were conducted in a semi-structured manner, having some questions prepared in addition to asking spontaneous follow-up questions in each session. Some questions were related to specific tasks to check if the test subjects could understand and read the data correctly, while others concerned the test subjects' perception and comprehension of the different charts.

7.1.3 Tasks and Questions

Test subjects were given tasks and questions made according to the classifications presented in Table 4.4. The most relevant operations in this test were *Locate* and *Identify* with regards to navigation, *Distinguish, Categorize* and *Compare* considering the household and average values, and *Associate* considering the layout and associations with other objects or charts. Examples of questions asked:

- When was the energy consumption low on Tuesday? *(Locate)*
- Is the consumption higher than the average at some point? *(Compare)*
- How does the consumption pattern of the household in the weekend differ from the usage during the rest of the week? *(Compare, Distinguish and Categorize)*
- What time of the day and week can a change in consumption make the biggest difference? *(Compare)*
- What else can you read from the visualizations about the energy consumption this week? *(Identify)*
- What is your first impression/thoughts regarding this chart?
- How is your perception of this visualization compared with the previous one? *(Compare within and between relations)*
- Are you able to read something else from this one compared to the previous? *(Compare within and between relations)*

7.2 Prestudy Test Results

In this section the findings obtained during the usability tests are presented. First, results regarding each visualization are presented in detail, before presenting findings regarding relations to energy consumption. Charts belonging in the same categories were subject for comparison, and results regarding these charts are thus presented together. The section ends with summarizing the key findings obtained from the tests.

7.2.1 Visualizations

Chart 1a, 1b and 1c (Category C)

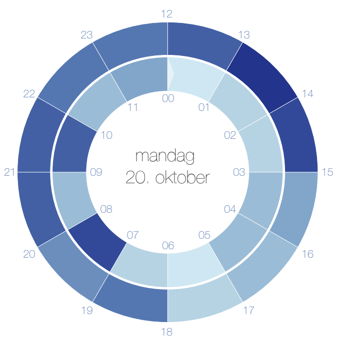


Chart 1a

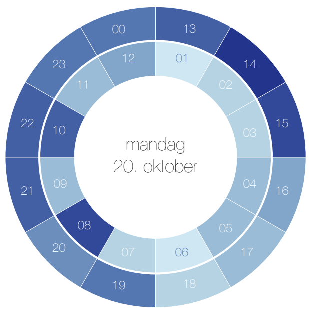


Chart 1b

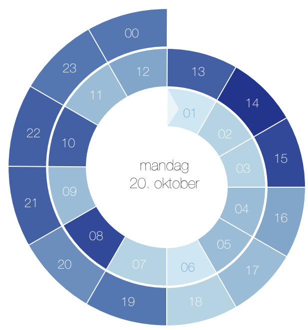


Chart 1c

When asked to point out the hour of highest or lowest consumption, each test subject was able to identify the correct hours. However, users experienced a recurring problem of navigating between the inner and outer circle in **Chart 1a** and **1b**. This concerned finding the starting point of the day, and perceiving the area where the day switches from inner to outer circle.

Regarding the positioning of time labels, the position did not affect the comprehension for most of the test subjects. However, some mentioned that having the labels outside of the circle, as in Chart 1a, gave stronger associations to a clock dial compared with the other ones having the labels inside each reading. Associations with clock dials helped reading efficiency for some of the test subjects due to familiar layout and positioning of hours. That being said, not everyone did associate any of these charts with a clock dial, and navigated after getting a quick overview of where the different time labels were positioned.

The majority considered the spiral in **Chart 1c** as easy to read, especially when reading the whole day from start to end. Due to a natural starting point, and a continuous line, 1c gave a more intuitive presentation of a day.

> *"Easier to read, see it like one time frame, and easier to see where it begins and ends. Okay to follow the day through a spiral."*

Comments regarding both Chart 1a, 1b, and 1c concerned the fact that night and day, e.g. 01 and 13, were placed close to each other and could easily be compared, something that was not of interest.

> *"What is scary is that you think they are related but then they aren't."*

Chart 2 and 3 (Category D)

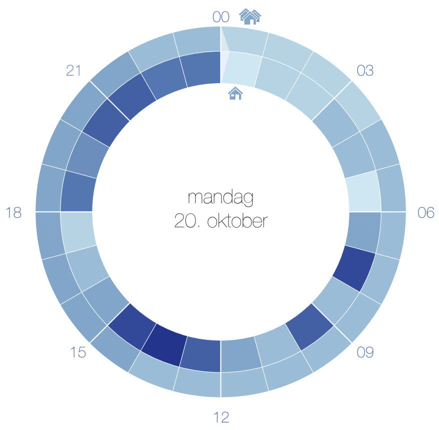


Chart 2

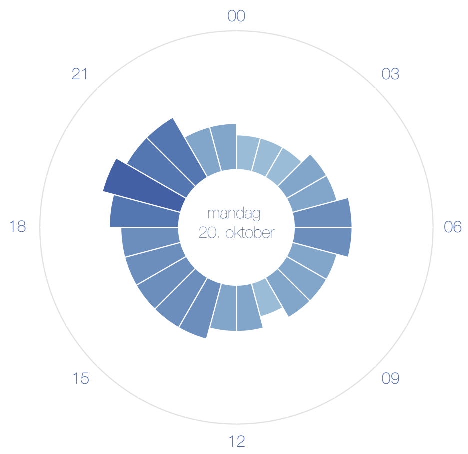


Chart 3

The feedback regarding **Chart 2** was divided. While four out of six participants immediately understood the concept of having the households' consumption in the inner, and the neighborhood average in the outer circle, two participants did not understand the illustration at all. Those who did not understand the illustration experienced trouble perceiving the difference between the two circles. When asked to compare the household consumption with the neighborhood average, one test subject tried to compare with the middle value presented in the color scale shown in Figure 6.1. Due to even neighborhood average values the outer ring was perceived as a blue ring surrounding the household consumption, making it unnoticeable, which might have contributed to misinterpretations of the visualization.

> *"Is there an average in this one as well? Okay.. (pause) Is it the inner or the outer one which is the average? Outer one? This one made me a bit confused."*

However, test subjects who understood the concept found it easy to compare household consumption with the neighborhood average, and see where their consumption differed from the average.

> *"Here you have the average in the outer circle. Easy to compare ones own usage with the average."*

The response regarding **Chart 3** was in general positive. Using size in addition to color was considered preferable. Test subjects found size easier to relate to consumption than color, and it was thus easier to designate hours of high or low consumption.

> *"This one was probably better than the previous one [Chart 2]. Here you see the ones that stand out, you see the peaks better."*

Having few numbers and units was also pointed out as positive, giving few objects to relate to. Due to the limited information presented, the chart gave a quick overview of the consumption.

The distance between the time labels and the bars was pointed out as a potential problem due to the need for visual estimates to get the exact value and the related time.

> *"I can see approximately the time of day I use the most, but if I want to find the value for a specific hour I almost need my ruler."*

The use of 24 hours instead of 12 did not cause great difference in test subjects' perception. Everyone was able to read the charts, although some found it unusual having the time label 12 at the bottom at first. For some test subjects the 24 hour circles were perceived as confusing at first, however, this confusion was, according to the test subjects, related to the mind being tuned in to the 12 hour circles previously presented. 24 hour circles were considered as giving a more clean and tidy presentation

Chart 4 and 5 (Category B)

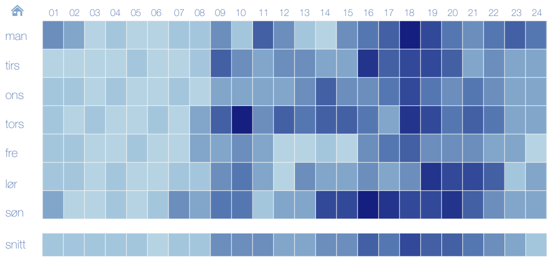


Chart 4

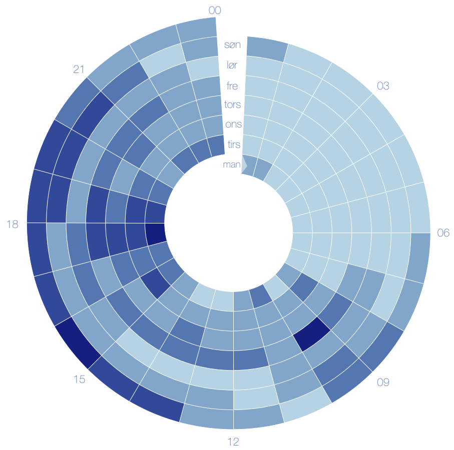


Chart 5

Due to a familiar layout the majority considered **Chart 4** as easy to navigate. As described in Section 3.2.4, perception is based on references and knowledge, and familiar layouts are thus easier to read. Everyone discovered usage patterns and was able to point out hours where the consumption was generally high throughout the week. The difference in night and day was quickly spotted.

Chart 5 was considered more difficult in terms of readability and navigation than Chart 4. Some test subjects found it challenging to locate which days the readings applied to, and the need of counting or scanning the day from start and to the desired reading made this chart more time consuming.

> *"It shows the consumption distribution of the day in an okay manner. A bit difficult to see which days they apply to. But that is probably something you get used to."*

However, some said that this chart gave a quick overview of the day and when the consumption was high and low. The chart was by some test subjects considered easy to navigate with regards to time, but difficult with regards to days.

One pointed out difficulties in navigating to the left due to the displacement of the circle, and thought it would be easier if the days were presented in continuous circles instead of a spiral. Another comment regarded the size of the different squares. The outer circles are bigger than the inner, making the size of the outer squares larger than the inner squares. The outer squares are thus given more attention and weighting.

It appears as if square charts are preferred above circular charts, particularly when the amount of data presented is high. One test subject considered circles as confusing to read in general, and explains this with the eyes struggling to find a focus point. The test subject expressed the following opinion:

> *"Charts should be square boxes with straight lines".*

Chart 6 and 7 (Category A)

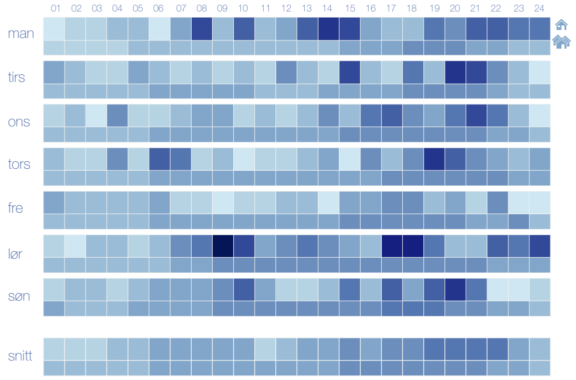


Chart 6

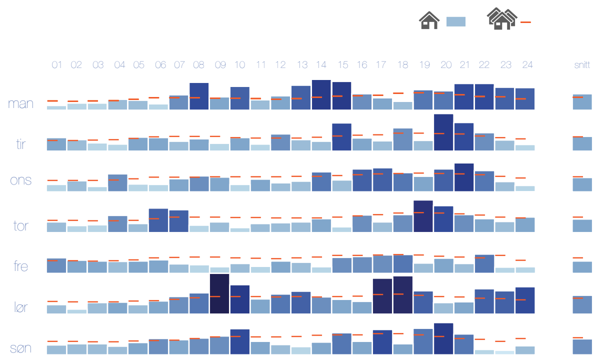


Chart 7

Chart 6 was considered challenging to read and was described as chaotic due to a lot of information given at once. Several commented on the need for spending time searching and scanning the chart before making sense of it. Everyone found it difficult to discover patterns in the consumption from day to day. One test subject could not read anything from the chart. Although the data presented in Chart 6 and 7 were exactly the same, the test subject did not see any connection between them.

The majority did not understand the difference between the higher and lower line of each day, which presented the household and the neighborhood average respectively.

> *"(...), but is it the average placed under? What are those two? I'm not quite sure about why there are many houses plus one house, that I don't get right away."*

Several tried to compare their consumption with the average placed at the very bottom when asked to find hours where consumption were higher than neighborhood average.

The participants also found it difficult to know what kind of average that was presented, and wondered if the average was calculated from the household, neighborhood, or if it was a national average.

The response regarding **Chart 7** was more positive. Although the amount of information presented in Chart 6 and 7 were the same, Chart 7 was considered easier and quicker to read.

The majority found it easy to point out when the consumption differed from the average.

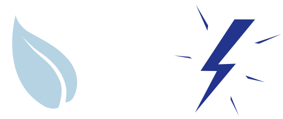
> *"Now it is much easier to see, in the morning, in the middle of the day, in the evening, everywhere the bar is higher than the red line, that is really easy to see".*

Differences in size and position were considered easier to compare than small differences in color tints. Due to the positioning of household and average data on top of each other, the need of making vague comparisons was eliminated. Hours where the consumption differed from the neighborhood average were thus quickly spotted. Several participants found it easier to see usage patterns in Chart 7 compared to Chart 6.

Icons Indicating High or Low Consumption

After completing all tasks of the test, test subjects were asked to give their opinion on which icons were most preferable for conveying high and low electricity use.

The leaves were associated with environmental friendliness, and were by some considered to have a more motivational factor concerning energy saving, due to the green profile, than the others. However, a recurring problem was, due to a similar shape and blue color, that the light blue leaf was mistaken of being a water drop.



The houses in icon 2, having the same profile as icon 1, were considered intuitive. Some pointed this icon out to be the best one, whereas others considered this one as "too much".

The bar icon was by several participants considered as confusing due to associations with battery level and level of cell phone signal. This icon was pointed out to be a symbol elderly people might not relate to.

The majority considered lightning as the best indicator of electricity, and an icon every generation could relate to. The combination of difference in both color and size was considered preferable. The two circles were regarded as understandable, however, having descriptive icons was preferred.

Some considered smileys as being an indicator of satisfaction and did not consider them suitable, while others pointed out the smileys as the preferable icon.

Feedback regarding the icons was hence quite divided. Icons preferred by one were disliked by another, however, the lightnings seemed to be the overall preferable choice.

7.2.2 General Feedback

The test subjects were also asked questions regarding level of detail, comparison of data, information of interest, and motivational factors related to energy consumption.

Levels of Detail

Regarding level of detail the feedback was divided. Some test subjects were not interested in detailed information containing hourly or daily consumption. Patterns were considered more interesting than accurate values and the same test subjects were more interested in longer time periods, like quarter overviews, than every hour. However, others valued the level of detail and wanted the actual values to be presented as well.

Comparison of Data

The majority found it irrelevant to compare consumption with other households, due to a perception of having a totally different energy consumption than others. A family of six living in a house would use a considerable amount of energy compared with a person living alone in a small apartment. Comparison with other equal households was of more interest, although some expressed skepticism regarding whether comparison would have any effect at all. Observation and comparison of ones own usage throughout the year were considered the most interesting and effective possibilities.

Information of Interest

Regarding additional information of interest, price was mentioned as a constant motivational factor. One test subject expressed an interest in getting an overview of the electricity bills given by the current power company compared with other power companies to get an indicator if one should change provider. With regards to price regulations, having higher prices during peak hours, some were not aware of this regulation, and wanted this to be communicated more evident. Others expressed interest in getting an overview of which appliances consume most energy, and hence become aware of potential saving spots.

Peak Issues as Motivational Factor for Behavioral Change

Considering peak issues, several test subjects were not aware of this problem, but regarded this as a motivational factor if the problem was communicated clearly to consumers. One mentioned the interest of knowing the hours of which the household consumption contributes to raising the average values, which is exactly the hours a lowering of consumption would be needed.

7.3 Prestudy Test Summary

Results from this prestudy testing have contributed to answering research question 3, regarding design. The following is a summary of the results obtained from the tests, and their implications for the research questions are stated.

Representing Values (RQ3)

- Differences in size was easier to designate than differences in color tints, especially when values were not located next to each other.

Organizing Data (RQ3)

- Square charts were preferred above circular charts when the amount of data presented was high.
- Navigating a 24 hour circle was found manageable, and the associations with 12 hour clock dials were not found as strong as expected.

Amount of Data (RQ3)

- Large amounts of data degrades readability, as in Chart 6.
- Users are divided in their needs for detailed data.

Comparison (RQ3)

- Comparison with other households was not found as interesting as expected.
- Potential comparisons should be made with other households having similar characteristics.

Information of Interest (RQ2)

- Price was mentioned as a constant motivational factor.
- Some test subjects were not aware of prices being higher during peak hours.

Part V

Requirements Elicitation

8 Questionnaire

05 QUESTIONNAIRE

In this chapter the construction of, and the results obtained from, a questionnaire are presented. The reason for making a questionnaire in this project was to gain insight into how people relate to energy consumption. *How is their interest in energy consumption? Do they have any motivation for saving energy? How is their understanding of electricity prices and electricity bills? Are they interested in information about their consumption and the ability to control their usage?* Answering these questions could help develop a service that is customized for the users' needs and interests. The first section describes the construction of the survey, whereas the second presents the results.

8.1 Constructing the Questionnaire

This section describes the selected target group and the process of constructing the questionnaire.

8.1.1 Target Group and Sample Size

The potential users of a display tool can be anyone who consume energy. The selected target group was thus people who somehow affect the energy usage at home, and were over 18 years of age.

To achieve a confidence level of 95 percent and a margin of error of 5 percent, a response level of about 350 was required, although this was somewhat ambitious when taking previous experiences with response levels into account.

8.1.2 The Questions

To increase the chance of people completing the survey, it was important that the questionnaire was not too long, and hence could be completed within five minutes.

When writing questions, focus was given on formulating the questions in an understandable and unequivocal manner. To get a representative result, questions that could be perceived differently among participants were avoided.

Most questions in the survey were closed in order to help clarify what the questions were asking, and to ease the analysis. The answer options were constructed in three different formats: Answer options with only one answer allowed, plural answers allowed, and likert scales where the participants were asked to grade statements according to how well it suited them. When making answer options it was important that they did not overlap, and were sufficient, as described in Section 4.4. In cases where there was a chance of participants wanting to answer something other than the given options, an "other"-field was provided.

The questionnaire focused on investigating people's understanding and habits regarding energy consumption rather than asking just which services the users were interested in. The questions addressed topics such as motivational factors, knowledge regarding electricity bills and electricity prices, current practices for saving energy, and willingness of moving consumption. A selection of questions is presented below, divided into five categories in which the corresponding results will be presented in Section 8.2. The related research question is stated for each category.

Interest in Energy Consumption and Energy Saving

In this category questions regarding people's interest in energy consumption and energy saving were given, contributing to answering RQ1.

- How often do you read the energy meter, or monitor your consumption on internet or display?
- How concerned are you with your own energy consumption?
- How concerned are you with saving energy?
- What is your biggest motivation for saving energy?

Knowledge Regarding Electricity Bills and Energy Services

The questions asked in this category were given to gain insight into people's knowledge and understanding regarding electricity bills and electricity services, and are related to RQ1. The participants were given a statement on which their answer reflected how well they agreed with it.

- I know the difference between the network tariff and electricity price.
- I find the electricity bill too complicated.

Current Practices

This question was given to reveal what people actually do to save energy, and contributes to RQ1.

- What actions are you performing in order to save energy?

Assessing Features

The questions asked in this category were included to reveal which services are considered useful and interesting, and contribute to answer RQ2. Various functions were suggested and answer options enabled participants to answer to what extent the function was found useful. Questions asked include:

- How interesting is it for you ...
  - ...to automatically control time of the day when appliances should turn on/off?
  - ...to get information about how much energy you are using right now?

Flexibility

These questions were given to reveal to what extent people are willing to move their energy usage for the purpose of saving money or reduce the risk of grid overload, and covers the heart of the tariff project.

- If you are home one evening and remember that you need to wash your clothes, would you postpone the wash one hour if you know that...
  - ...it reduces your electricity bill with 5 NOK?
  - ...it helps reduce the risk of overloading the electrical grid?

The web service "Online Undersøkelse" was used to create the web survey and receive responses. For the complete survey, see Appendix A.

8.1.3 Quality Check and Distribution

The survey was sent out to a few family members and friends for testing. The testers were asked to consider the structure of the form and the different questions. More particularly they were asked to point out if some questions or answer options were ambiguous or unclear, if the answer options where several answers could be given were adequate, and if more than one option was applicable in cases where only one option was allowed. They were also asked to note how long it took to complete the survey.

After receiving some suggestions for improvements, the survey was improved based on these comments, and sent out. The questionnaire was shared through Facebook, on internet forums and sent to participants in Demo Steinkjer by e-mail. In an attempt to increase the response rate, attendance was rewarded with participation in a prize draw of ten lottery tickets (Flaxlodd).

8.2 Questionnaire Results

In this section the results obtained from the questionnaire are presented. For the complete result set, see Appendix B.

8.2.1 Target Group and Sample Size

A total number of 226 participants responded to the questionnaire. With a confidence level of 95 percent this gives a margin of error of 6.5 percent.

The age distribution was fairly spread among the participants, except for the groups 20-29 years old, which had a larger percentage. In terms of education level, 61 percent of the sample had a college or university degree. When compared with statistics from SSB given in Table 8.1, this is higher than the population's percentage, where only 29 percent have a college or university degree.

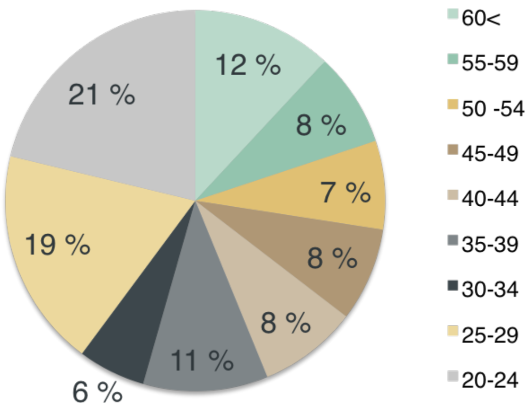


Figure 8.1: Age distribution.

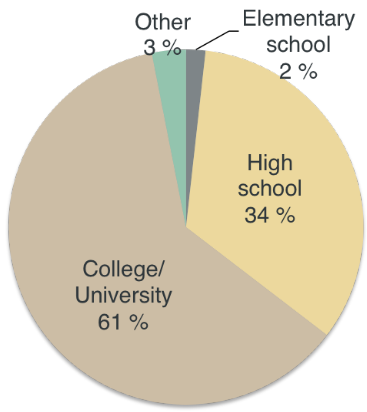


Figure 8.2: Education distribution.

Table 8.1: Level of education in Norway - population over 16 years of age [73].

	2013	
	ABSOLUTE NUMBERS	**%**
Elementary school	1 103 238	27 %
High school	1 650 483	40 %
College/University	1 203 824	29 %
Not given/have no education	160 264	4 %
Total	4 117 809	100%

8.2.2 Answers to the Questions

The following sections present the results, sorted by the categories presented in Section 8.1.2.

Interest in Energy Consumption and Energy Saving

Figure 8.3 shows the distribution of how often people read their energy meter. Despite the fact that periodically manual submission of meter readings to the power companies is still most common, 9 percent answered that they never read the electricity meter and 5 percent read it only one time per year. The ones who answered "other" have Smart Meters installed, and the readings are thus done automatically.

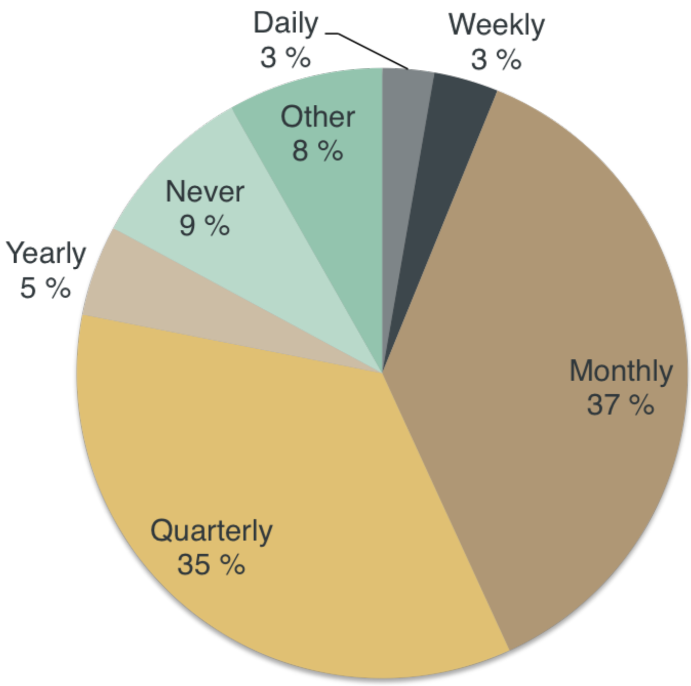


Figure 8.3: Distribution of how often people read their energy meter.

This figure shows the distribution of how concerned people are with their own energy consumption. 17 percent answered that they are not concerned with their consumption at all. 62 percent answered that they only look at the electricity bill.

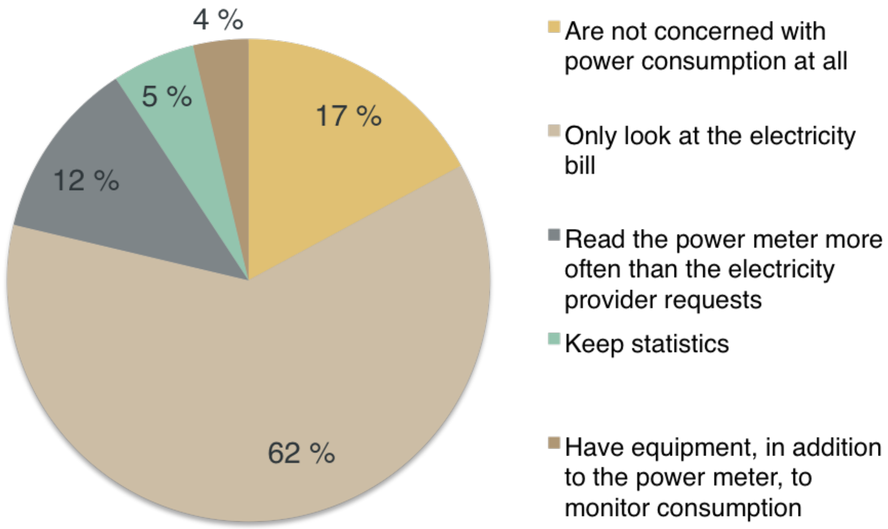


Figure 8.4: How concerned people are with their own energy consumption.

Figure 8.5 indicates how the participants see themselves compared to others when it comes to how concerned they are with saving energy. The result follows a normal distribution, where 19 percent considered themselves below average or not concerned at all, 60 percent were averagely interested, and 21 percent considered themselves above average or very concerned with energy consumption.

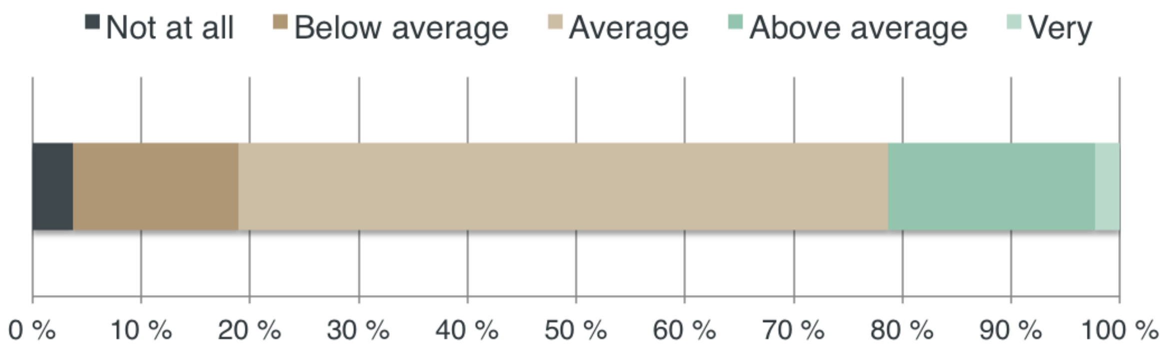


Figure 8.5: How people see their own interest in saving energy compared to others.

When combined with age, one finds that more young people than older found themselves below average or not concerned with energy saving at all. This applied particularly to the group between 20-24 years of age, of which 41 percent considered themselves below average or to have no concerns with energy saving at all. In comparison, only 10 percent of the participants in the age of 40 years or more considered themselves in the same group.

Table 8.2: Relation between age and how concerned they are with energy saving.

	NOT AT ALL	**BELOW AVERAGE**	**AVERAGE**	**ABOVE AVERAGE**	**VERY**
20-24	11,4	29, 6	50	9,1	0
40-60+	1,0	9,3	63,9	21,7	4,1

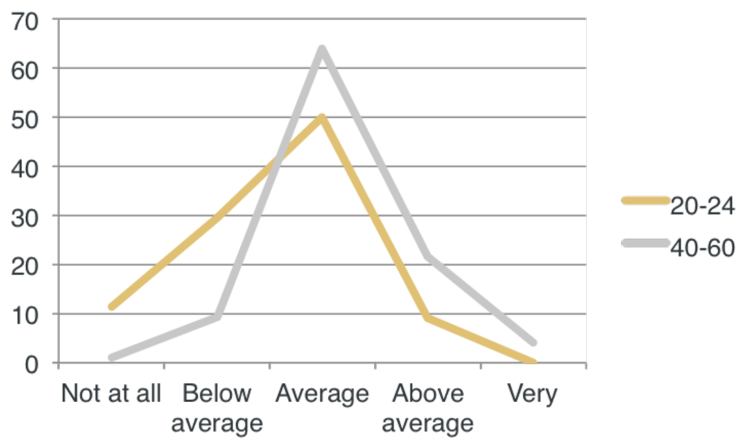


Figure 8.6: Relation between age and how concerned they are with energy saving.

Figure 8.7 shows what the participants considered their biggest motivation, if any, for saving energy. Saving money was by far considered the biggest motivation. Many also considered environment to be a motivational factor. It is interesting to observe that as many as 12 percent answered that "To contribute to a stable electricity line" was one of their biggest motivations.

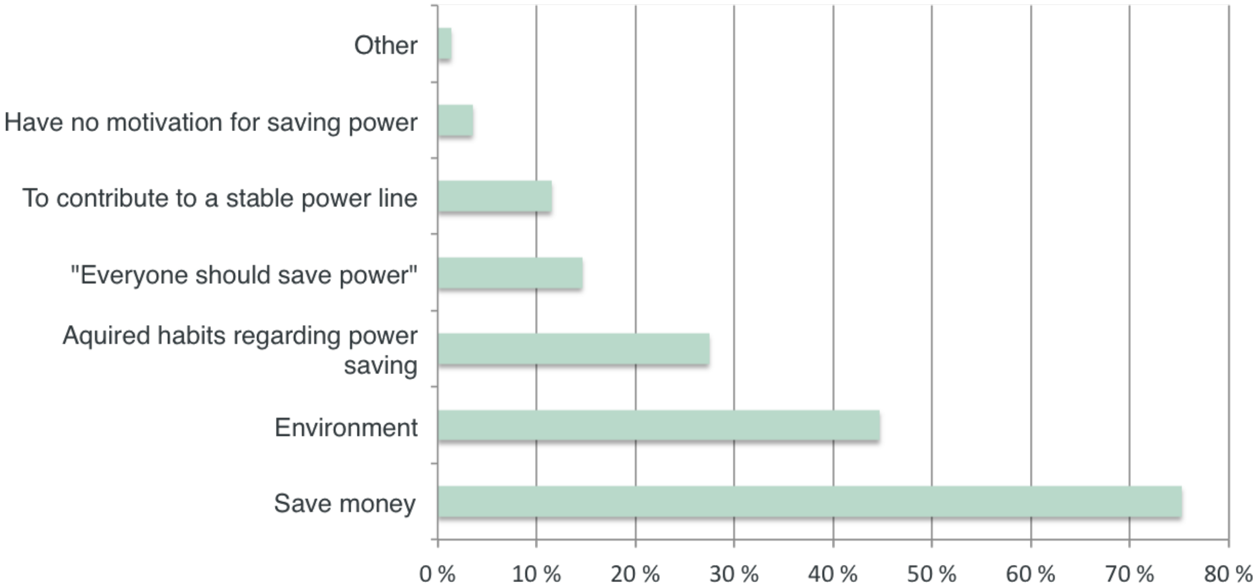


Figure 8.7: Motivational factors for saving energy.

More than 60 percent answered that they slightly or strongly agreed in being concerned with having the best electricity agreement. This can relate to saving money being the biggest motivational factor according to Figure 8.7.

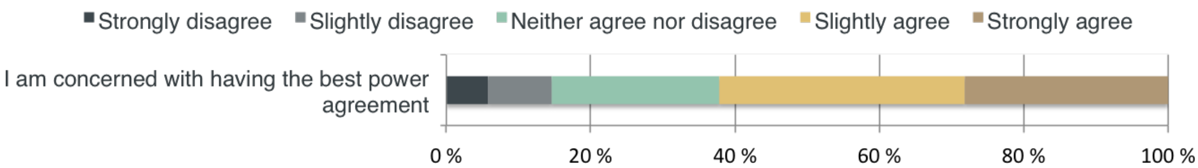


Figure 8.8: Peoples' interest in having the best electricity agreement.

Knowledge Regarding Electricity Bills and Energy Services

This chart shows to what extent people are familiar with the structure of the electricity bill, and which aspects underlie the calculation.

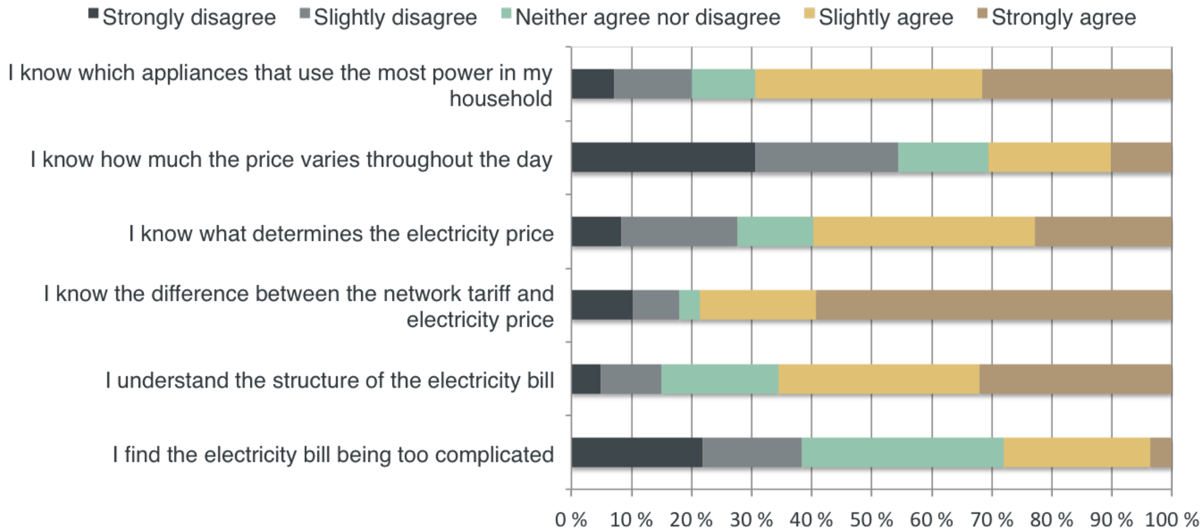


Figure 8.9: Peoples' knowledge regarding electricity bills and electricity services.

The assertion regarding varying electricity prices showed most insecurities among the participants. More than 50 percent answered that they somewhat or completely disagreed in knowing how much the electricity price varies throughout the day.

Almost 30 percent found the electricity bill to be too complicated. More than 30 percent said that they neither agreed nor disagreed. Analysis revealed that 30 percent of them were not concerned with energy consumption and did not read the electricity bill, which may indicate that they had no basis for answering.

Almost 80 percent answered that they know the difference between network tariff and electricity price, and 70 percent said that they know which appliances draw most power in their household.

Current Practices

Figure 8.10 shows that most participants do perform various initiatives in order to save energy. The most common action was to turn off lights in rooms that are not in use, which is the easiest and less demanding action to perform. When answering "other" people mentioned initiatives such as heating with firewood, hydronic heating, use of LED lights, and outdoor lights that turns on/off depending on how bright it is. One interesting initiative given was "to raise awareness among everyone in the household".

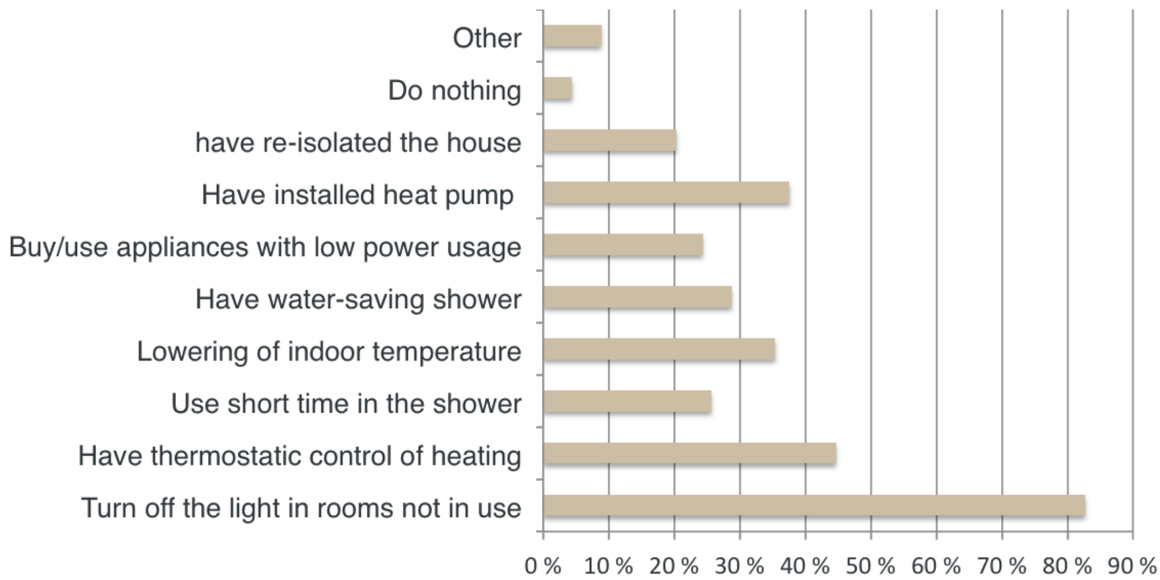


Figure 8.10: Actions being done to save energy.

Assessing Features

This chart shows to what extent people are interested in information about their energy consumption, and the ability to control usage remotely. The chart shows that there exists a general interest in having such possibilities. The ability to automatically control the time for when appliances should turn on or off was slightly more interesting than the rest. The feature appearing to be of slightly less interest than the others was the ability to turn appliances on/off with a smartphone or tablet.

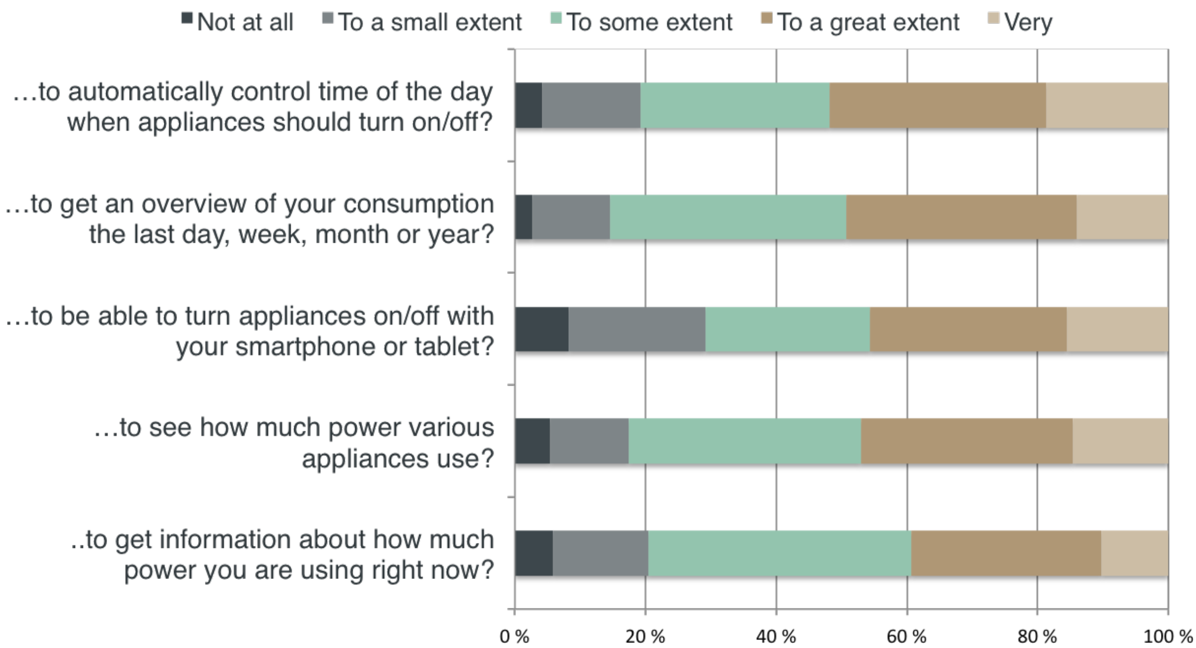


Figure 8.11: Peoples' interest in information about their energy consumption and the ability to control usage remotely.

Flexibility

Figure 8.12 reveals to what extent people are willing to move energy usage in order to save money or reduce risk of overload in the grid. As much as 80 percent showed willingness to move their energy usage away from peak hours, where 17-23 percent would do it rarely, 29-31 percent occasionally, 17-24 percent frequently, and 7-8 percent would do it every time, depending on the reason for postponing. Reducing risk of overloading the electrical grid gave slightly stronger incentives for moving energy usage than saving 5 NOK. This is a bit surprising taking the results in Figure 8.7 into account, where "save money" was by far the biggest motivation for saving energy. However, to save 5 NOK and reduce risk for overloading the grid are not well suited for comparison.

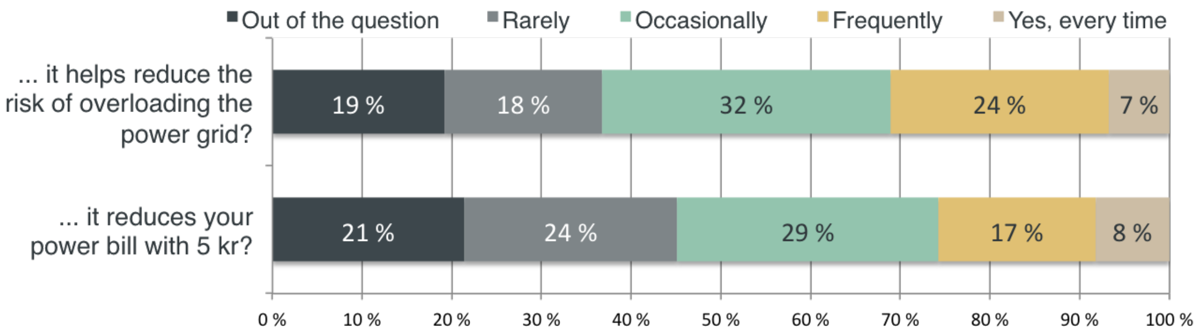


Figure 8.12: The willingness of moving energy usage.

When combined with age, there is a tendency where the youngest and the oldest age groups show a larger willingness to move consumption for the purpose of saving money. The participants between 40-49 were least flexible.

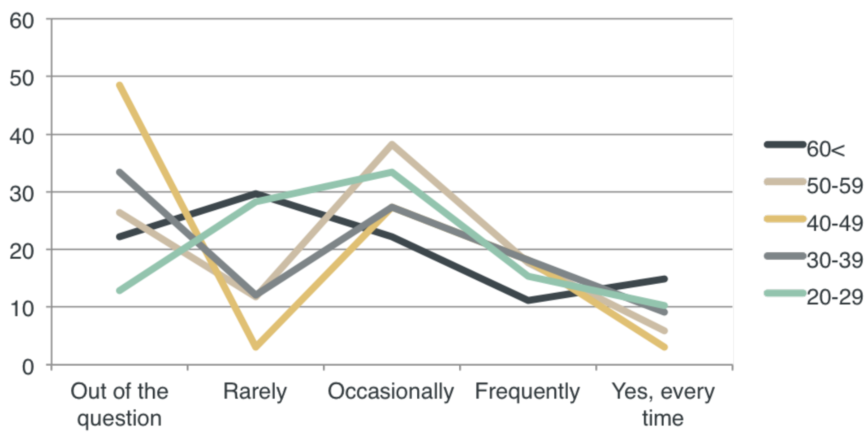


Figure 8.13: Correlation between age and the willingness to move consumption in order to save 5 NOK.

Table 8.3: The correlation between age and the willingness to move consumption in order to save money, numbers given in %.

	OUT OF THE QUESTION	RARELY	OCCASION-ALLY	FREQUENTLY	YES, EVERY TIME
20-29	12,8	28,2	33,3	15,4	10,3
30-39	33,3	12,1	27,3	18,2	9,1
40-49	48,5	3,0	27,3	18,2	3,0
50-59	26,5	11,8	38,2	17,6	5,9
60<	22,2	29,6	22,2	11,1	14,8
Average:	28,7	16,9	29,7	16,1	8,6

When combining age and the incentive of reducing risk of overload, the willingness to move consumption is quite even among the age groups. However, the participants between 40-49 also in this case stand out as the least flexible age group.

Table 8.4: The correlation between age and the willingness to move consumption in order to reduce the risk of overloading the electrical grid., numbers given in %

	OUT OF THE QUESTION	RARELY	OCCASION-ALLY	FREQUENTLY	YES, EVERY TIME
20-29	12,8	15,4	33,3	30,8	7,7
30-39	24,2	12,1	33,3	39,4	6,1
40-49	27,3	12,1	39,4	21,2	0
50-59	18,2	3,0	33,3	39,4	6,1
60<	16	20	32	16	16
Average:	19,7	12,5	34,3	29,4	7,2

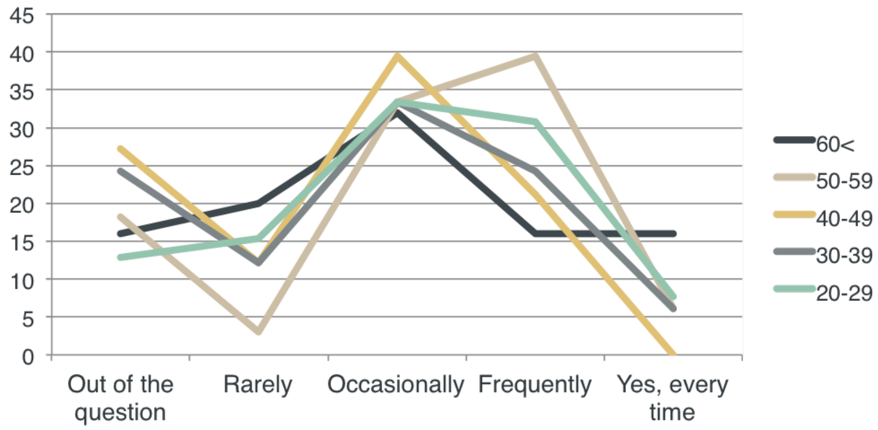


Figure 8.14: Chart showing correlation between age and the willingness to move consumption in order to reduce the risk of overloading the electrical grid.

8.2.3 Questionnaire Results Summary

The results obtained from the questionnaire have contributed to answer research question 1 and 2, regarding context of use and motivation, and requirements respectively. The following list summarizes the results obtained from the questionnaire, and their implications for the research questions are stated.

People's Attention Towards Energy Consumption (RQ1)

- 17 percent are not concerned with energy consumption at all, and 62 percent only look at the electricity bill.
- More young people (20-24 years old) than older ones(40-60 years old) find themselves below average or not concerned with energy saving at all.
- People consider saving money as the biggest motivation for saving energy.
- Most people do various initiatives in order to save energy, turning off light being the most common one, followed by having thermostatic control of heating.

Knowledge and Awareness (RQ1)

- The majority gave the impression of having a fairly good knowledge regarding appliances and the electricity bill. However, about 30 percent found the electricity bill too complicated.
- People have least knowledge regarding what goes on in the electrical grid, and how much prices varies throughout the day.

- **Functionality and Information of Interest (RQ2)**
  - There exists a general interest in getting information about energy consumption, and having the possibility of controlling appliances.
- **Flexibility (RQ1)**
  - 80 percent showed, in one degree or another, willingness to move energy usage away from peak hours. Reducing risk of overload gave slightly stronger incentives for adjusting the consumption than saving a small amount of money.

9 Focus Group

The following Chapter presents the execution of a focus group. The chapter starts with a presentation of the sketches used during the session. Then a description of the execution follows, before finally the results from the focus group are presented.

The purpose for conducting this focus group was to discuss electricity consumption and whether information through displays can be helpful when trying to reduce and even out consumption. Also, we wanted to receive feedback on several sketches designed to communicate the Microgrid Tariff. The results of these discussions have been used as a contribution to the requirements listed in Section 10.1.

9.1 Focus Group Sketching

06 FOCUS GROUP SKETCHING

Five sketches were developed for presentation during the focus group in order to get feedback on both concept of each sketch as well as their readability. Each sketch covered a specific function helping users benefit from the Microgrid Tariff. Applicable functionality was selected based on meetings with Demo Steinkjer, and results from the questionnaire. Sketches have been created to explore the functionality listed in Table 9.1.

Table 9.1: Functionality covered by focus group sketches.

Personal consumption forecast
Show forecasted consumption for every hour today based on history and weather data. This will help users identify the hours of which action may become necessary throughout the day.

Hourly consumption
Display actual energy consumed each hour today, in order to give users feedback on their behavior.

Green and red hours
Display information about which hours will be green and which hours will be red today. This will help users plan their usage, and be in control.

Appliance control
Ability to turn on and off two electrical appliances. This functionality will let users take action when consumption exceeds their limit.

Instantaneous consumption
Display instantaneous power used in order to let users see the effect of their actions in real time.

Consumption and cost history
Provide historic information about consumption and costs for previous days, months, and years. Both usability tests during prestudy and results from the questionnaire show that pricing and consumption information is valued by consumers.

Contribution to the electrical grid
Let users know whether they are affecting the electrical grid in a negative or positive way. This functionality is an experiment to test the motivation of contributing to a stable grid, as this was shown to be a motivational factor in the questionnaire.

9.1.1 Design Choices

The sketches developed for the focus group are based on meetings with Demo Steinkjer and results from the prestudy work, building on some of the sketches and principles that proved successful. An essential design choice was the non-figurative use of color, with the use of red drawing attention to something negative, whereas green conveys environmental-friendliness and something positive.

The sketches aimed at meeting users in their everyday context and help them avoid paying red prices. Focus was set on enabling rapid interpretations, with help from preattentive processing, using colors and shapes rather than details in data. To improve readability it has been important to minimize chart chunk, and let the data itself create the grids. Grids abide by the principles described in Figure 3.12, with the exception of labeling every bar. This exception was made in order to avoid mixing graphics with text.

9.1.2 The Sketches

Sketch 1 - Personal Day Forecast

Sketch 1 displays a 24 hour circle, and builds on the prestudy sketch presented in Section 6.2.3. The big circle is marked red on the hours of red prices for the day. 24 bars, one for every hour of the day, indicate forecasted consumption for each hour. This forecast tells which hours the users will have to watch their consumption in order to avoid exceeding their limit when prices are red. As an hour passes the bar shifts into displaying the actual consumption, and the color of the bar shifts to a darker shade of green. If the energy consumption exceeds the limit in hours of red price, the consumption which is above the limit turns red.

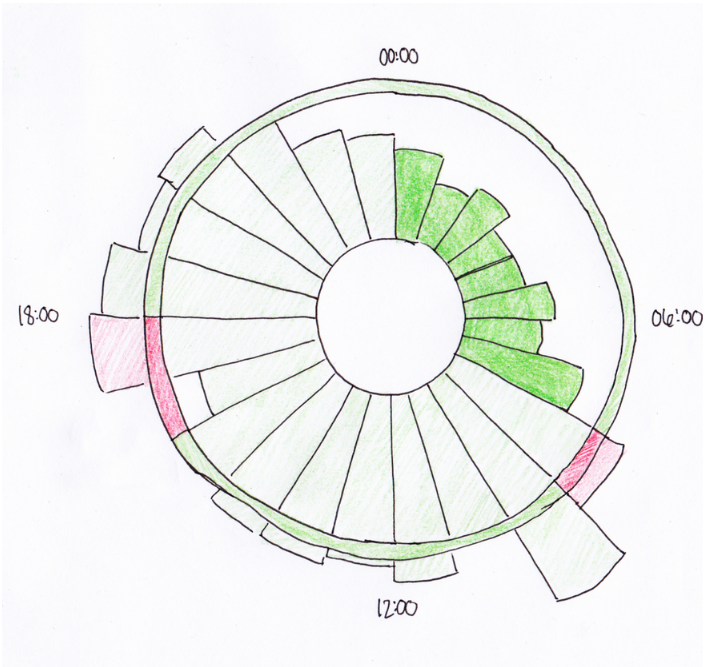


Figure 9.1: Which hours will have red prices today, and what is the consumption forecast for each hour?

Sketch 2 - Green or Red Price Right Now?

This sketch shows a section of a clock, zoomed in on a specific hour. The orange scale indicates the time right now, and moves just like a hand on a real clock. The green bar indicates the average kW used so far this hour, and whether it is below or over the red effect-limit.

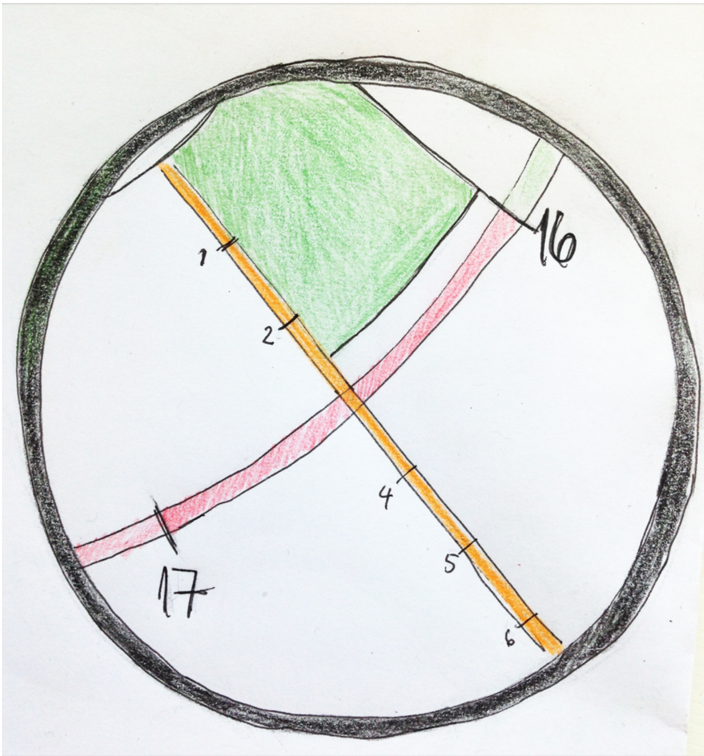


Figure 9.2: Is the user about to pay red price this hour?

Sketch 3 - Appliances' Energy Consumption

The third sketch lets users turn on and off two electrical appliances. A meter at the right displays the instantaneous power used in total for the household, and indicates if the total consumption is exceeding the power limit. Users can then turn off specific appliances to get below the red power limit.

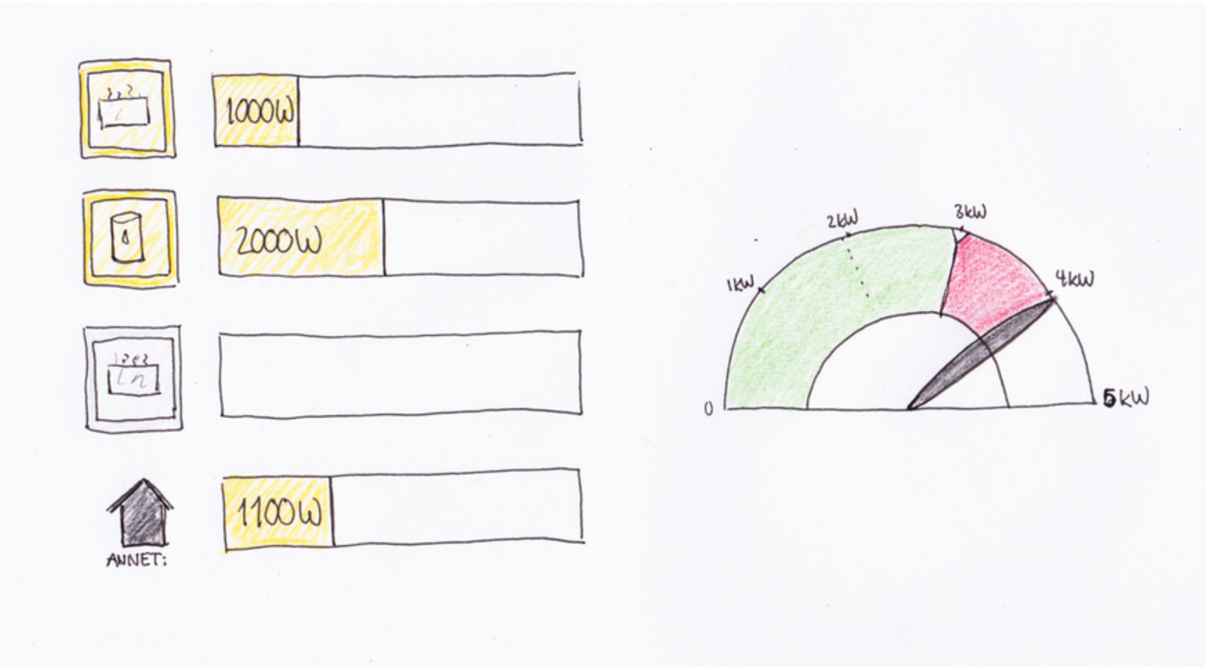


Figure 9.3: How much power do appliances draw, and which can be turned off to get below the effect-limit?

Sketch 4 - Billing and Consumption History

Sketch 4 consists of two bar charts. The first bar chart displays the costs for electricity the previous week, and its distribution on fixed, green, and red prices. The second bar chart illustrates the amount of electricity consumed the previous week, and how much has been consumed during green and red hours.

Figure 9.4: How much has been paid in red and green prices the previous week, and how much electricity has been consumed?

Sketch 5 - Contribution to the Electrical Grid

The big house represents the household of the user, and the smaller ones are houses in the neighborhood belonging to the same microgrid. The green user house and the red microgrid tells the user that the microgrid is overloaded and that he or she is not exceeding her effect limit, and thus having a positive impact on the grid.

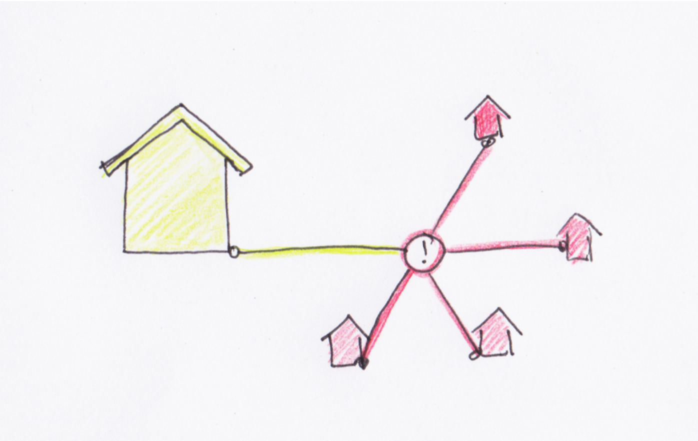


Figure 9.5: Is the user contributing positviely or negatively to the electrical grid right now?

9.2 Focus Group Execution

07 FOCUS GROUP EXECUTION

The focus group was conducted on March 24th at NTNU Gløshaugen, Trondheim. Six informants agreed to participate in the focus group, all six recruited through our questionnaire. Unfortunately only three were able to attend, all being in the age between 25 and 27 as well as being acquaintances of the interviewer. The focus group was lead by a moderator, and an observer took notes during the session. A presentation software called *Prezi* was used to present subjects for discussion as well as to guide the session.

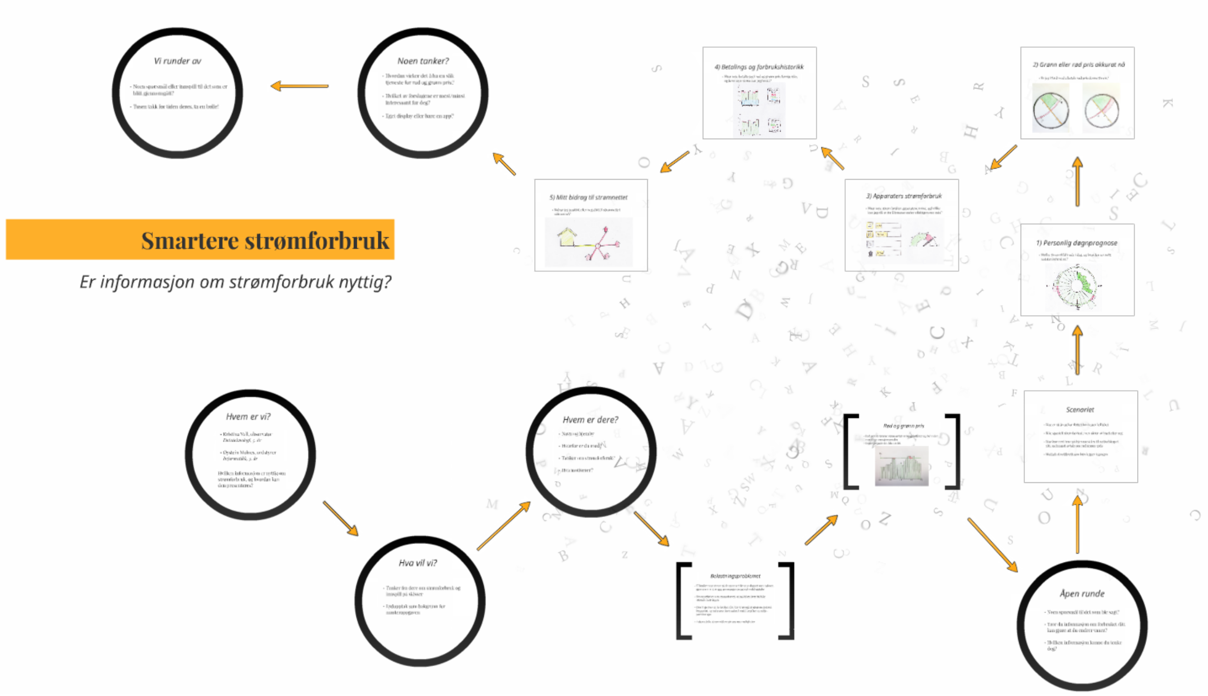


Figure 9.6: A map of the presentation used during the focus group, created with *Prezi* presentation software.

The focus group opened with a welcoming of the participants and an introduction of the moderator and the observer. The purpose of the session was explained, and permission to record audio was granted from the participants. Then, each participant was asked to give a short presentation of themselves, and include some comments on their thoughts on electricity consumption.

After an introduction of every participant, a short explanation of the electrical grid load problem and the Microgrid Tariff was given. The group was then asked some general questions regarding the ability of information to change behavior.

> **Question 1:** Do you think information about your energy consumption can make you change behavior?
> **Question 2:** What information would you find interesting?

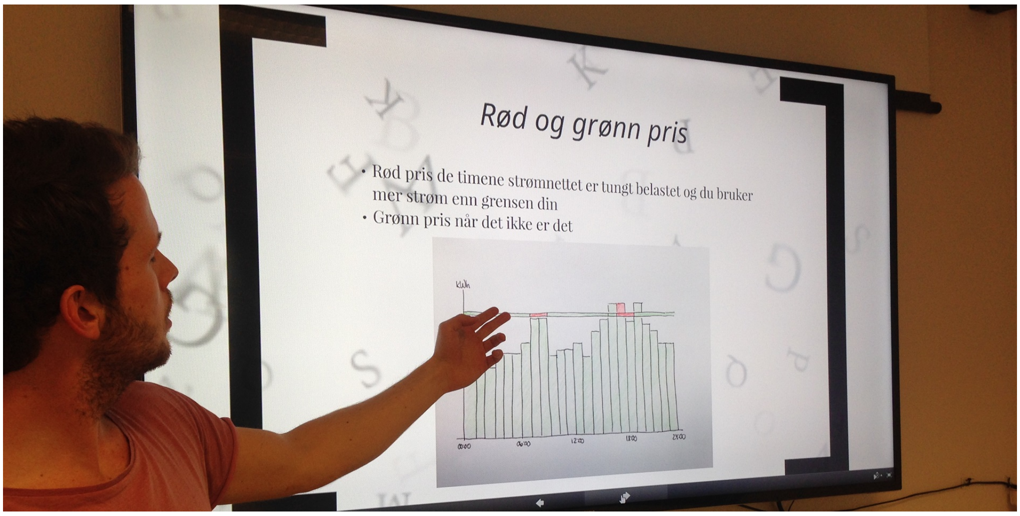


Figure 9.7: Focus group presentation.

Following a discussion of question 1 and question 2, a presentation of the five sketches was given. Each sketch was explained and discussed in terms of understandability and usefulness. The sketches were handed out to allow for a more tangible investigation and discussion revolving each sketch.

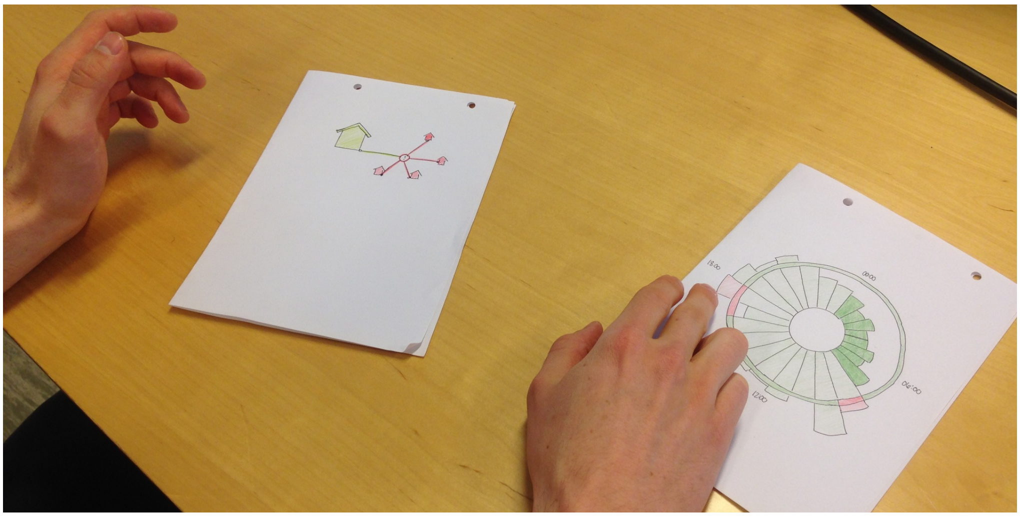


Figure 9.8: Focus group discussion - Sketch 1 and Sketch 5.

After discussing the sketches, participants where asked the following questions:

Question 3: What would you think of having the Microgrid Tariff as payment model?
Question 4: Which of the sketches do you prefer, and why? Which one is the least preferable?
Question 5: If you were to have such a display tool, would you have it in a dedicated tablet or as an appication on your smartphone?
Question 6: If you had such a display tool, would you use it regularly?

The session was concluded with letting the participants speak their minds about what had been discussed, and ask questions. Table 9.2 lists guidelines applied during the focus group.

Table 9.2: Guidelines applied during the focus group.

1.	Provide coffee and something to eat.
2.	One researcher governs conversation, another takes notes.
3.	Moderator should appear neutral, with authority and openness.
4.	Moderator should use probes in order to encourage discussion.
5.	Moderator should let everyone speak their minds.
6.	The discussion should be set in a real life context - use scenarios.
7.	Do not ask more then eight questions.

9.3 Focus Group Results

This section presents the results from the focus group, and uses the steps for analyzing focus groups, provided in Section 4.5, to analyze them.

Table 9.3: Focus group participants.

PARTICIPANT 1	
Age	27
Occupation	Architecture student.
Comments	Interested in reducing consumption in order to reduce the electricity bill.

PARTICIPANT 2	
Age	26
Occupation	Energy and Environmental Engineering student.
Comments	Interested in technology for streamlining energy processes.

PARTICIPANT 3	
Age	25
Occupation	Computer Science student.
Comments	Interested in reducing electricity bill, but enjoys comfort and dislikes effort.

The five steps for analyzing focus groups, presented in Table 4.2, have been applied to analyze the results. Statements, remarks, and questions have been transcribed and grouped by subject. Furthermore, the relevance these findings have for the research questions have been considered. Finally, theories emerge from this knowledge, and their implication is discussed.

The following sections first present knowledge emerging from the discussions. Then, a summary of the acquired knowledge is presented. The theories and implications emerging from this knowledge are discussed in Chapter 12.

9.3.1 Subjects Discussed and Findings

Energy Consumption

The first major subject for discussion was *thoughts regarding energy consumption in general.* Knowledge about electricity usage emerged as a centrel theme.

Participant 3: *I know how much I use in total, but not how much electicity specific appliances consume.*
Participant 1: *I think very few people know what appliances consume most electricity.*
Participant 1: *All I know is how much I consume compared to last year.*

Participants expressed a lack of detailed knowledge revolving electricity usage. It was also stated that people in general may have the same lack of knowledge.

The Grid Load Problem

When discussing the *grid load problem*, participants' understanding of the problem was discussed.

Participant 2: *Is it like a congestion chart?*

The comparison between the electrical grid and a highway was made by the moderator. Consequently, participant 2 made the comparison between critical peak pricing and congestion charts on roads.

Question 1 and 2 - Changing Behavior as a Result of Information

The first question asked whether information about consumption would have the ability to change behavior. The invisibility of energy consumption in daily routines, and peoples willingness to change behavior was discussed.

Participant 3: *Families have their routines.*
Participant 1: *If we are talking about 2 NOK extra for making dinner at 5 pm, I think a lot of people would pay those extra 2 NOK.*
Participant 3: *I don't think people are that interested in saving pennies. You want a bigger picture of what can be saved in the course of a year. Like ten percent in a year, and not just a lollipop a day.*

Participant 3 stated that families have daily routines that may impair their ability to make behavioral changes. Also, skepticism towards people's willingness to change behavior for pennies was expressed. Consumers would need to see a bigger picture.

Question 3: The Microgrid Tariff

Following an explanation of the Microgrid Tariff, introduced as a "Red-or-green price" payment system, a discussion of its principles and implications emerged.

Participant 2: *Does that mean that the red price only applies in those time slots?*
Participant 2: *I think the red price would have to sting for it to be effective.*
Participant 1: *Also, I think there is a limit. If the prices are too high I think people will get angry with the power company. Like if you get home at 5 pm and cannot make dinner because it is too expensive.* (laughter)

Participant 2 realized how the tariff only calls for user attention during red hours, which is correct. Furthermore, the participants explained how the red and green price would have to differ substantially in order for actions to be taken. On the other hand, if red prices are to high, participant 1 stated that customers would get angry with the power company.

Question 4: Preferred Sketches

After explaining each sketch, hand-drawn copies were handed out to allow participants to give their opinion on which they preferred the most, and which were least useful.

Participant 1: *I think the one where you see which appliances use most electricity would have been nice.*
Participant 3: *Yes, definitely.*
Participant 2: *It's the coolest and all.*
Participant 1: *It's most concrete. With all the others you can see that "Oh heck, I am getting close to a red zone", and run around and turn off everything in your house.*
Participant 3: *Something like that would have been very cool to have, because then you can see what you can actually do in order to save electricity.*
Participant 2: *It's fun when you get gadgets and get to see what goes on.*
Participant 1: *It becomes a sport, like when you're in your car and see the average consumption and get terrified of pressing the gas pedal.*

All participants agreed that **Sketch 3**, enabling appliance control, was the most desirable functionality. It was described as the most concrete of the five sketches, allowing users to easily take action instead of "...running around and turning off everything in the house" [Participant 1]. Participants saw the possibility of having fun using this function, and compared it to watching the fuel consumption of a car.

When looking at **Sketch 1**, displaying the consumption forecast for the day, participant 1 noted the benefit of getting an overview for the day.

Participant 1: *This one here as well, it creates an overview throughout the day.*

All participants found **Sketch 4**, displaying cost and usage information, to be useful.

Participant 3: *I find this one quite cool, actually.*
Participant 2: *It's a big difference from today's electricity bill, which actually is quite cryptic and general.*
Participant 1: *Yes, to see that it is actually more expensive when you are paying red prices, even though it is not that much, perhaps.*

Participant 2 remarked Sketch 4's big difference from today's electricity bill, and participant 1 noticed that this sketch visualized the impact of paying red prices.

The usefulness of **Sketch 5**, conveying positive or negative contribution to the electrical grid, was not obvious.

Participant 1: *But that green one, telling whether you are affecting the grid positively or negatively, what does it mattter?*
Participant 3: *Is it about awareness? So the neighbor is doing absolutely terrible right now?*
Participant 1: *And so you can go yell at your neighbor for using too much electricity the day before?* (laughter)
Participant 1: *I think the other ones are more interesting, because they have an actual impact on your electricity bill. And ultimately I think that is what people are most interested in.*

Remarks about the potential for neighbor conflicts where made, although humorously. Also, Sketch 5's lack of concise information and ecouragement for action made it the least favorable sketch among the participants.

Sketch 2 was perceived as quite complex, and required some explanation.

Participant 2: *That one is a bit more difficult, cause if suddenly you see that you are getting close to red then you're screwed.*

Participant 3: *Yes, you would have to get the information some time ahead. If you have to postpone dinner you cannot get the information fifteen minutes ahead.*

Participant 1: *So, when is the bar updated in sketch 2? You don't get to see the information until after the hour has passed?*

The need for getting information some time ahead, allowing users to plan their day, was expressed.

Question 5: Mounted Display or Application?

When asked whether they would have this service on a mounted display or as an application on a smartphone, the desire for availability emerged.

Participant 2: *If you where to look into the future, I think you will have to integrate it into something you already have, as an application.*

Participant 3: *At least easily available, so that you don't have to go to your energy meter in your basement in order to check.*

Participant 1: *And if you have a Smart House it would be fun to have it online so that you don't have to go home to check. If you're at work at 5 pm and you see a red hour coming up, you can turn something off.*

Integration with other Smart House technology was mentioned, as well as the ability to use the service outside your house.

Question 6: Would You Use it Regularly?

Participants expressed the difficulty of getting users to maintain interest in such services.

Participant 3: *Would have been cool to watch it for a week, but then you would get tired of it. It's exciting when it's new. It's all about getting people to save electricity without changing their lifestyle.*

Participant 1: *I think it would be smart in order to learn what can be done.*

Participant 3: *I think it has to be interesting from the start, and catch people's interest right away.*

Participant 2: *Using default settings could be helpful. Who changes their ringtone?*

Participant 3 imagined this service to be interesting the first week, but that the interest would ware off. Participant 1 saw it as a learning tool, educating users about what can be done in order to reduce and shift consumption.

Concluding Remarks

During the end of the focus group, a discussion about security emerged.

Participant 2: *Suddenly someone hacks your system and runs everything when it's most expensive. It creates some challenges.*

Participant 3: *But more and more things are getting online. You get washing machines that are online, don't you? That's extreme.*

Participant 2 expressed concerns for potential hackers, and that bringing technology online brings challenges in general.

9.3.2 Focus Group Results Summary

The results from the focus group session contributed to answer research question 1 and 2, addressing context of use and user requirements. The following is a summary of the results obtained during the session, and their implications for the research questions are stated.

Knowledge (RQ1)

- Knowledge about energy consumption was described as fundamental for behavioral change to occur.
- There exists a lack of knowledge regarding which electrical appliances consume most energy.

Motivation (RQ1)

- Cost reduction was expressed as the number one motivation when it comes to energy consumption.
- Participants expressed skepticism towards people willingness to changing their routines in order to save a small amount of money.
- Saving potentials over longer periods of time should be displayed.

The Microgrid Tariff (RQ2)

- The red price must be high to lead users towards action.
- There is a limit to how high the red price can be set before customers react negatively.

Preferred Functionality (RQ2)

- Sketch 3, enabling appliance control, and sketch 4, displaying cost and usage information, were the most desirable features among the participants.
- Sketch 5, conveying positive or negative contribution to the electrical grid, was not found useful.
- Participants expressed the need of getting information ahead in order to have time to plan and react.

Adoption (RQ2)

- Availability is essential, and integration with similar services, always-visible mounted displays, or having the service as an online application may improve availability.
- Technology may be interesting at first, but maintaining use over time requires usefulness and usability.
- The effort that goes into using the display should be minimized.

Part VI

Prototype Development

10 Prototype Implementation

09 PROTOTYPE IMPLEMENTATION

This chapter presents the process of implementing a prototype for the Microgrid Tariff display tool. First, a summary of all the requirements gathered from both the questionnaire, the focus group session and discussions with Demo Steinkjer is presented. Second, a description of the architecture and implementation is given, before presenting a user manual explaining the various functions and screens of the prototype.

10.1 Requirements

This section lists both functional and non-functional requirements elicitated when performing the activities presented in previous chapters, including prestudy work, meetings with Demo Steinkjer, a questionnaire, and a focus group session.

10.1.1 Functional Requirements

The functional requirements comprise requirements for what users should be able to do when using the Microgrid Tariff display tool. The priority of each requirement is graded from 1 to 3, where 1 has the highest priority.

Table 10.1: Functional Requirements.

ID	REQUIREMENT	DESCRIPTION	SOURCE	PRIORITY
FR 1	Run on tablet	The application should be run and used on a dedicated tablet.	Demo Steinkjer	1
FR 2	Appliance view	The application should allow users to manage individual electrical appliances.	Demo Steinkjer, Questionnaire & Focus Group	1
FR 2.1	Appliance management	Users should be able to turn on and off two electrical appliances and see how much electricity each of them use.	Demo Steinkjer	1
FR 2.2	Real time consumption	Display real time overall consumption.	Demo Steinkjer & Focus Group	2
FR 2.3	Manipulate overall consumption	The real time overall consumption (FR 2.2) should be updated when users turns on/off electrical appliances (FR 2.1).	Focus Group	2
FR 2.4	Indicate overuse	Users should be notified when the price is red and the current electricity consumption exceeds the limit.	Demo Steinkjer & Focus Group	2
FR 3	Today's view	The application should allow users to see the forecast for today, both in terms of prices and consumption.	Demo Steinkjer & Focus Group	1

FR 3.1	Green or red hours	Users should see which hours will have red prices and which hours will have green prices for the coming day.	Demo Steinkjer	1
FR 3.2	Consumption forecast	Users should see a forecast for his/her consumption today.	Focus Group	2
FR 3.3	Actual consumption	Users should see the actual amount of consumed electricity for the hours of today that have passed.	Focus Group	3
FR 3.4	Indicate red hour	Users should be notified when the price is red.	Demo Steinkjer	2
FR 3.5	Display prices	Users should see the price per kWh for both green and red hours for today.	Demo Steinkjer	1
FR 4	Historic view	The application should allow users to look into historic data.	Focus Group, Questionnaire	1
FR 4.1	Historic costs chart	Display daily, weekly, and annual expenses for electricity, and its distribution on green, red, and fixed prices.	Focus Group & Questionnaire	2
FR 4.2	Historic costs summary	Display total expenses for a day, week, and year.	Focus Group	1
FR 4.3	Potential savings	Tell what the cost would have been if all red costs had been shifted to green costs.	Focus Group	2

FR 4.4	Historic consumption chart	Display daily, weekly, and annual electricity consumption, and its distribution on green and red kWh.	Focus Group	3
FR 4.5	Historic consumption summary	Display total consumption for a day, week, and year.	Demo Steinkjer	2

10.1.2 Non-Functional Requirements

The following list includes soft sub-goals that are meant to influence design decisions, and function as overall guidelines for improving usability and the potential of users adopting the tool.

Table 10.2: Non-Functional Requirements.

ID	**REQUIREMENT**	**DESCRIPTION**	**SOURCE**	**PRIORITY**
NFR 1	Avoid red prices	The overall goal is to help users avoid exceeding his/her effect-limit during red hours.	Demo Steinkjer	1
NFR 2	Minimize user interaction	The application should call for a minimum of attention from users.	Focus Group	1
NFR 3	Minimize time to learn	Use explanatory instructions to help users understand what the application is for and how it is used.	Focus Group & 3.1.1-Usability	2
NFR 4	Help users achieve goals	Help users understand what can be done to achieve their goals, and communicate what will happen when its done.	3.1.1-Usability	1

NFR 5	See the big picture	Keep focus on the big picture when displaying costs and consumption, not on cents and kWh.	Focus Group	2
NFR 6	Allow user comfort	Allow the user to maintain comfort in terms of deciding for themselves when to use electric appliances.	Focus Group	1
NFR 7	Communicate network tariff	Communicate the Dynamic Microgrid Tariff, and that it is based on hour average(kWh) during an hour.	Demo Steinkjer	1
NFR 8	Offer rewards	Offer rewards for adapting energy consumption, and not punishment for refraining.	Demo Steinkjer & Focus Group	2
NFR 9	Clarify important info	At all times, it must be clear what information is most important.	3.2-Data Visualization & Prestudy	1
NFR 10	Design for target group	Design for energy consumers with smartphone competance and interest in costs/control/environment.		2
NFR 11	Data visualization principles	Use the least amount of ink to display the most amount of data.	3.2.5-Simplify	1
NFR 12	Preattentive Processing	Apply principles for preattentive processing in order to improve readability.	3.2.3-Order and Deviations	1

10.1.3 Change in the Microgrid Tariff

During an interview with the creators of the Dynamic Microgrid Tariff, *08 Expert knowledge*, it came to our knowledge that red prices not only applies for the actual overuse, but for every kWh consumed during a red hour of overuse. As a result, the consequences of exceeding ones effect-limit during a red hour is dramatically increased. The prototype that has been implemented is based on these new revealings about the Microgrid Tariff.

10.2 Implementation

A prototype based on the requirements from Section 10.1 has been implemented using HTML5 and JavaScript. This discussion will not get into detail about the implementation, as this does not help answering the research questions. Rather, the purpose of this section is to give an understanding of how the prototype came to be, as well as to provide suggestions for technologies, frameworks and libraries that can be applied when developing such prototypes.

The prototype was developed for an iPad tablet to be used during usability testing, and was thus designed to fit the dimension (1024x768) of an iPad screen. Hence, in order to get the right format it can only be tested using an iPad, or with tablets having similar characteristics. Also, several browsers such as Chrome and Mozilla, provide the possibility of setting preferred screen dimensions. Before testing, the prototype was uploaded to a web page hosted by one of the researchers, and can be found at
`www.intervallkollegiet.net/power-puff-project_v0.1/`.

10.2.1 Framework

HTML5 and Boilerplate
The template HTML5 Boilerplate formed the basic structure of the project, providing a folder structure with default HTML, CSS, and JavaScript files, and the Twitter Bootstrap and jQuery frameworks.

Twitter Bootstrap
Bootstrap is a HTML, CSS and JavaScript framework for developing responsive web applications. It offers a grid system for organizing the layout, reusable components such as buttons, navigation and carousel, and icons.

D3.js
D3 - Data-Driven Documents - is a JavaScript library for constructing visualizations based on data. D3 uses HTML, SVG and CSS, and combines powerful visualization components and a data-driven approach to DOM manipulation. D3 allows for binding arbitrary data to a Document Object Model(DOM) and apply data-driven transformations to the document. The D3 library reads data from arrays or external files, like CSV and JSON. In the prototype, the D3 library is used to create interactive SVG charts based on consumption data. This applies to both the chart presenting today's consumption, the chart presenting instantatnous power use, and the history charts. These charts are presented in Section 10.5.

JSON (JavaScript Object Notation)
Due to the use of JavaScript in this prototype, JSON data was the chosen and preferred file format, which allowed for easy manipulation and selection of the relevant data. Below is an example of an energy meter reading entry in JSON.

```
{"timeStamp":"2014-01-01T00:00:00.000Z", "value"
   :3200, "readingType":"7.12.3.1.0.12.0.0.0.0.72"}
```

Both hourly meter readings retrieved from Demo Steinkjer's API, and minute data retrieved from a private energy meter, formed the basis for the energy consumption presented in the charts. The data from Demo Steinkjer was retrieved as described in Section 6.2.2. A description of the components and implementation of the "home made" metering device is given in the next section.

10.2.2 Logging Consumption Data

In order to get data sets with minute resolution and be able to know the reason behind the consumption, equipment was set up on a energy meter at home.

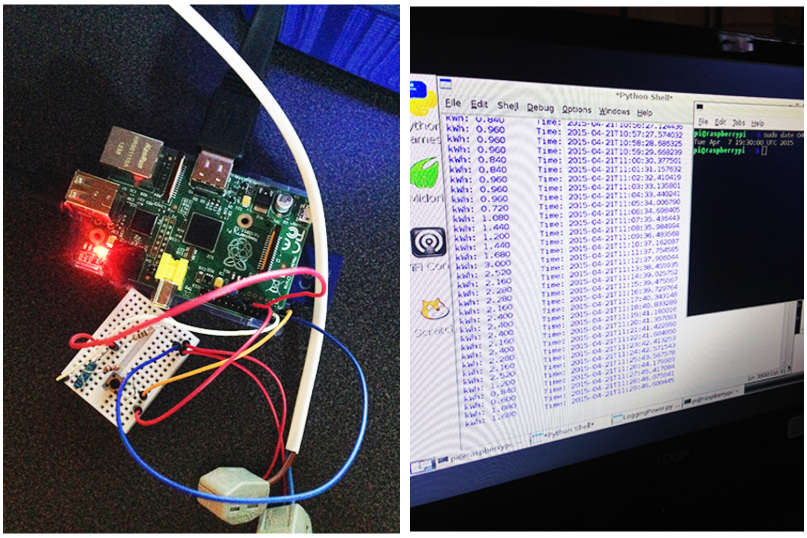


Figure 10.1: Images showing the metering equipment.

Most energy meters have a light that flashes with a rate proportional to the amount of power passing through the meter. The majority of meters are labeled either 500, 1000 or 10 000 Imp/kWh. With a imp value of 1000 the light will flash once for every Watt consumed. By registering this light, the instant energy consumption can thus be found.

With the use of a RaspberryPi, a breadboard, wires, resistors, a capacitor, and a photo resistor the equipment was assembled. A photo-resistor is a resistor whose resistance decreases when light intensity increases. The voltage in the circuit is held constant, and by detecting changes in the current caused by changes in the resistance, flashes of light can be observed and counted.

The GPIO (General Purpose Input/Output) pins are the physical interface between the RaspberryPi and other components, and can be thought of as switches that can be turned on or off from other components (input), or that the Pi can turn on or off (output), because the ports are digital [59]. A breadboard was used to connect the photo resistor to the RaspberryPi's GPIO, as shown in Figure 10.3.

In general it is sufficient to measure the current passing through the photo resistor, but this requires an analog I/O which the RaspberryPi does not have. Hence, a capacitor and an additional resistance were used to transform the analog signal into a digital signal (see Figure 10.3)

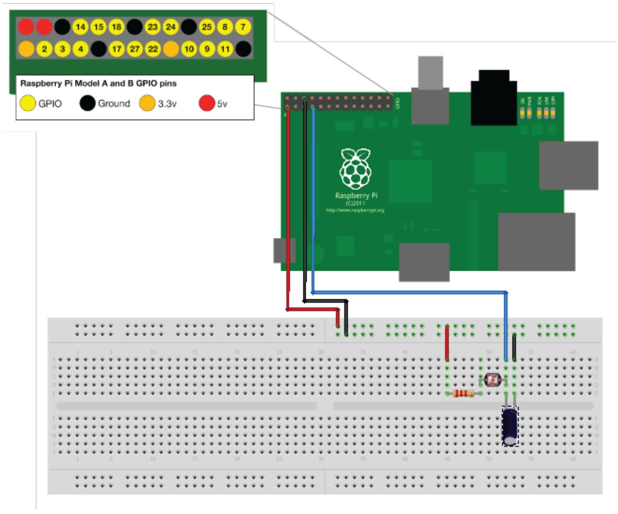


Figure 10.2: Breadboard and RaspberryPi [60].

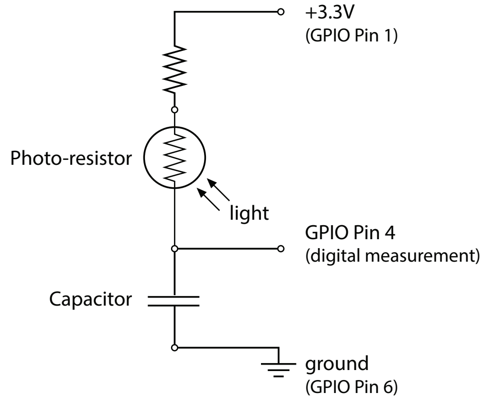


Figure 10.3: Circuit layout.

A script was made in Python, handling the input and output signals. The script counted every blink, and calculated the corresponding power value every minute,

$$E[\mathrm{kWh/min}] = n * \frac{60}{imp} \tag{10.1}$$

where E is the immediate energy consumption, n is the number of blinks per minute and imp is the imp value.

This value was then written to file in JSON format. A button was also added to start and stop the metering, and when stopped, the JSON file containing the data was uploaded to Dropbox by using a Dropbox-Uploader [43].

The script can be found in Appendix C.

10.3 Architecture

Figure 10.5 shows how the prototype is structured from a developer's point of view. The figure displays how frameworks and libraries described in Section 10.2 are connected. For simplicity, only relevant components are included. Components that do not affect functionality, design, or data have been omitted, including doc-files and insignificant js-files. Figure 10.4 illustrates the notation used in the development view.

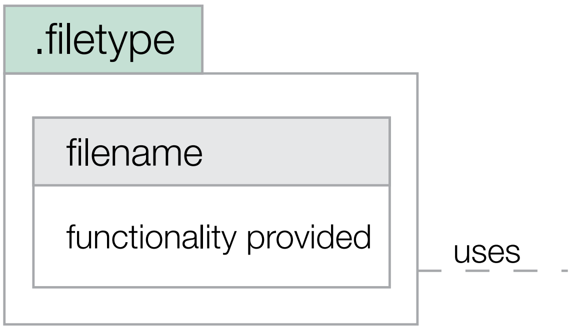


Figure 10.4: Notation used for the development view.

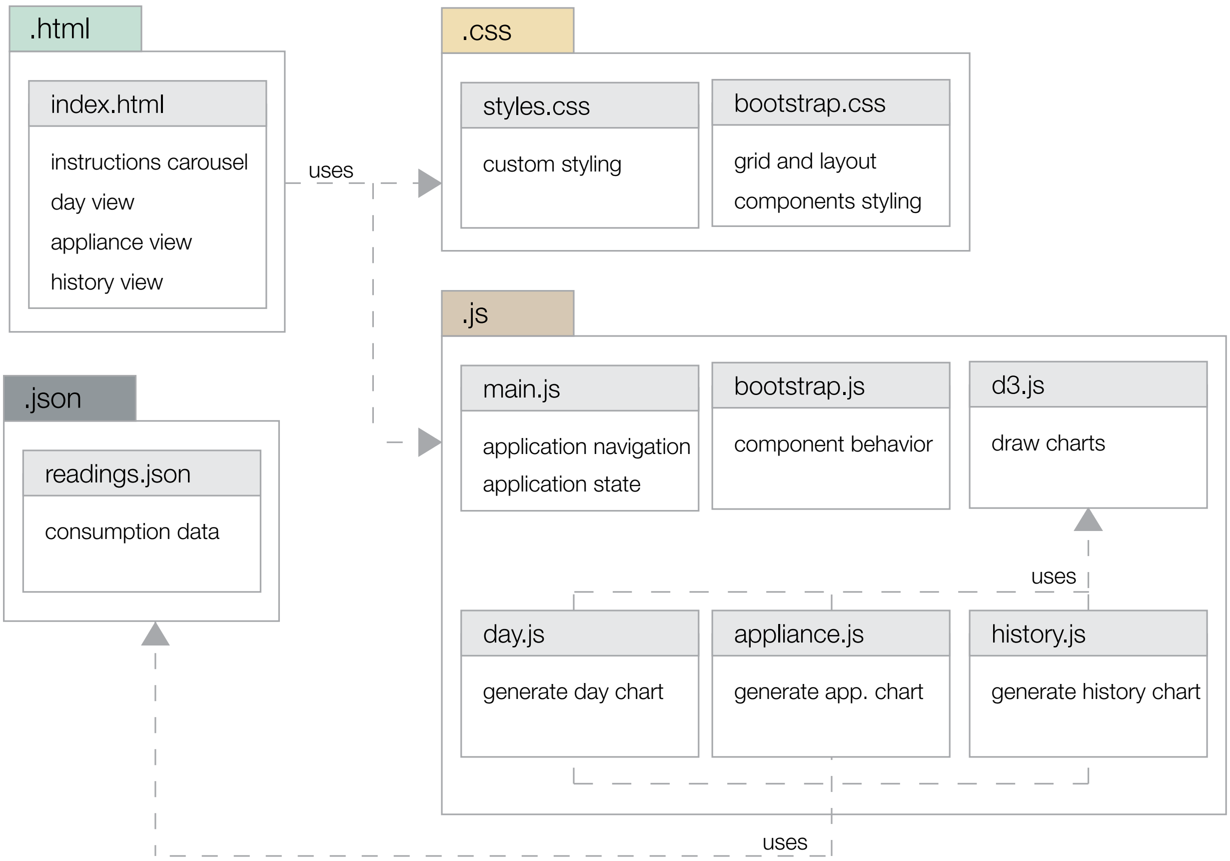


Figure 10.5: Development view for the Microgrid Tariff display tool prototype.

10.4 Design

This section outlines the design choices for the prototype, and explains the use of colors and interaction styles. The non-functional requirements of relevance are referred to by (NFR #).

Color Palette

The use of color is meant to reflect elegance, simplicity, and functionality. Dark shades of grey help achieve elegance and professionalism, and seem pleasing to the eyes through being neutral and calm. Also, the use of light text on a dark background eases readability, and allows for subtle use of colors to be effective and stand out.

However, colors with high brightness and saturation placed on a dark background causes the iris to open in order to allow more light in. This causes the lens to deform and may lead letters to blur, an effect known as halation. This explains why dark text on white backgrounds is most effective when reading large amounts of text. However, when the amount of text is limited, light text on a dark background may allow for more rapidly scanning and identifying of elements, as they stand out more (NFR 9). [85]

In addition to making the design more interesting and visually pleasing, colors have been used to convey functionality, and bear meaning as they allow users to rapidly interpret which areas call for attention (NFR 12). The use of three different colors may introduce challenges, as they might fight for attention. However, when faded down and used sparingly they give room to each other.

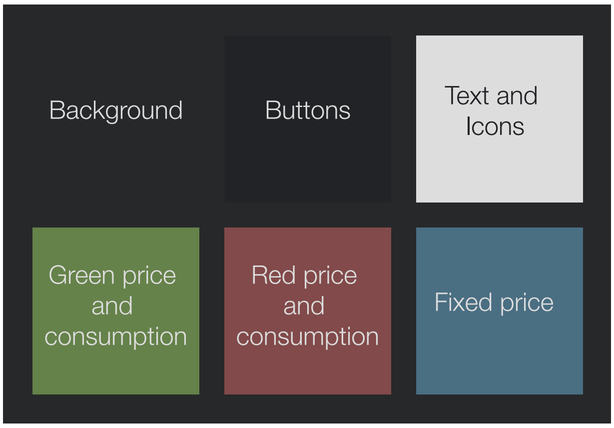


Figure 10.6: Color palette used in prototype.

Interaction

The prototype allows for user interaction, and provides three functions displayed in the menu, as well as buttons to turn on and off appliances and navigate history data. The use of complex navigation patterns with the use of levels has been avoided in order to allow users to always know where they are and where they can go (NFR 2). The menu displayed in Figure 10.7 is visible at all times, always allowing users to enter another view when desired.

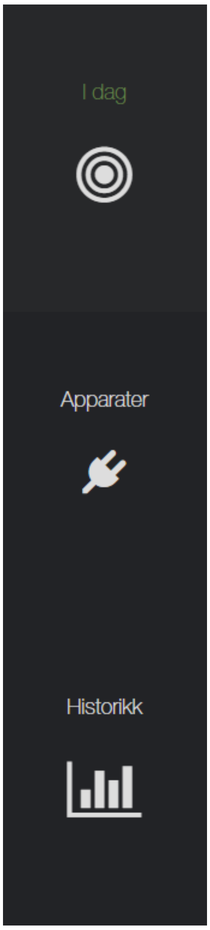


Figure 10.7: Prototype menu, allowing users to enter one of the three functionalities.

Buttons follow the principle of elegance and simplicity, as they are no more than subtle squares in a darker shade of grey, being allowed to stand out as a result of a low amount of visual elements. When selecting a button, its background color is lightened and the text turns green in order to communicate that the button has become active.

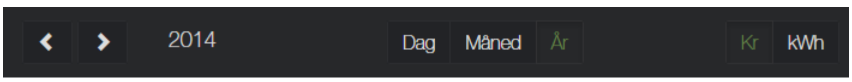


Figure 10.8: Buttons used for navigating through energy consumption and cost information.

10.5 User Manual

This section is a walkthrough of the implemented prototype, and presents the various screens and their functionality, and which functional requirements they cover.

10.5.1 Instructions

When a user enters the application for the first time he or she will be met with a set of instructions. These instructions are included to explain the electrical grid load problem, the Microgrid Tariff as well as the functionality of the prototype (NFR 3). To minimize the use of terms used to explain the network tariff, such as dynamic and microgrid, the Microgrid Tariff has been renamed *Green or Red Price* in the prototype. The screen shots of the instructions explaining the three functionalities of the prototype have been omitted in this report because these functionalities will be elaborated on later.

The Grid Load Problem

Firstly, the electrical grid load problem is briefly explained by comparing the grid to a highway, in that they both have limited capacity. The instruction also tells the user that using a high amount of electricity at the same time as their neighbor will lead to needs for new electrical grids. The instruction is based on the motivation for contributing to the community, and to a more secure and stable electrical grid. Also, building electrical grids will be associated with high costs.

Figure 10.9: Instruction 1: The Grid Load Problem.

The Microgrid Tariff

The main goal of the application is to help users avoid paying red prices. Therefore, two instruction screens have been included to explain how the Migrogrid Tariff works. Figure 10.10 states that with the Green or Red Price-tariff, users will get cheap electricity by not exceeding their individual consumption limit during red hours. Figure 10.11 labels the terms used in the tariff and connects them to a bar chart displaying the consumption during a day.

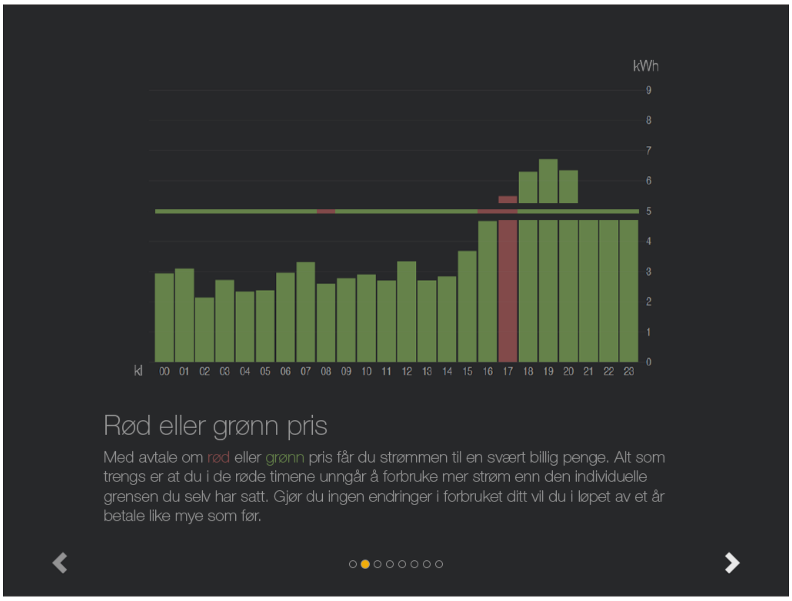


Figure 10.10: Instruction 2: The Microgrid Tariff.

Figure 10.11: Instruction 3: The Microgrid Tariff Terms.

10.5.2 The Day View

This view builds on the Personal day forecast-sketch used during the focus group, described in Section 9.1.2. The day view presents both metered energy consumption, colored with dark green or red, and estimated consumption for the remaining hours of that day, which are colored with a lighter green or red.

In addition, the individual power limit is represented by a colored ring, where normal hours are colored green, and peak hours are colored red. Consumption that exceeds the limit during red hours are colored red.

A white frame indicates the current hour. This framed bar shows the averaged energy consumption so far this hour, and indicates in real time whether the user is at risk of paying red price that hour. If the preliminary averaged energy consumption exceeds the individual power limit, the appliance icon in the menu turns red advising the user to go into the appliance view.

At the bottom right both the current red and green price per kWh is displayed.

FR 3.1 Users should see which hours will have red prices and which hours will have green prices for the coming day.
FR 3.2 Users should see a forecast for his/her consumption today.
FR 3.3 Users should see the actual amount of consumed electricity for the hours of today that have passed.
FR 3.4 Users should be notified when the price is red.
FR 3.5 Users should see the price per kWh for both green and red hours for today.

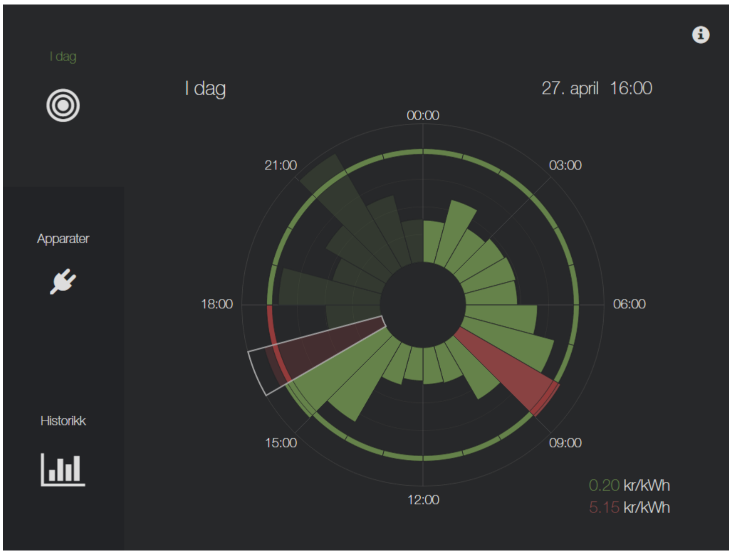


Figure 10.12: Prototype Function 1: Day View.

10.5.3 The Appliance View

The Appliance View is a further development of the Appliances' energy consumption-sketch used during the focus group. This view enables control over two appliances - in this case, a heater and a water heater.

The bar at the right reflects the instantaneous energy consumption. If the current hour has red price, a red line appears in the bar indicating the individual power limit. The color of the bar is normally green, however, if the consumption exceeds the power limit during a red hour, the bar turns red.

FR 2.1 Users should be able to turn on and off two electrical appliances and see how much electricity each of them use.
FR 2.2 Display real time overall consumption.
FR 2.3 The real time overall consumption (FR 2.2) should be updated when users turns on/off electrical appliances (FR 2.1).
FR 2.4 Users should be notified when the price is red and the instant electricity consumption exceeds the individual limit.

Figure 10.13: Prototype Function 2: Appliance View.

10.5.4 The History View

The History View presents historic data on both consumption and costs, and is based on the Billing and consumption history-sketch, also presented in Section 9.1.2. Users can toggle between cost and consumption data, and choose to see data for a specific day, a month, or for the whole year. A summary of the consumption or costs spent is presented on the right, above the chart. When displaying costs, potential savings for the period are also presented to let users know what can be achieved by shifting the red consumption.

FR 4.1 Display daily, weekly, and annual expenses for electricity, and its distribution on green, red, and fixed prices.
FR 4.2 Display total expenses for a day, week, and year.
FR 4.3 Tell what the cost would have been if all red costs had been shifted to green costs.
FR 4.4 Display daily, weekly, and annual energy consumption, and its distribution on green and red kWh.
FR 4.5 Display total consumption for a day, week, and year.

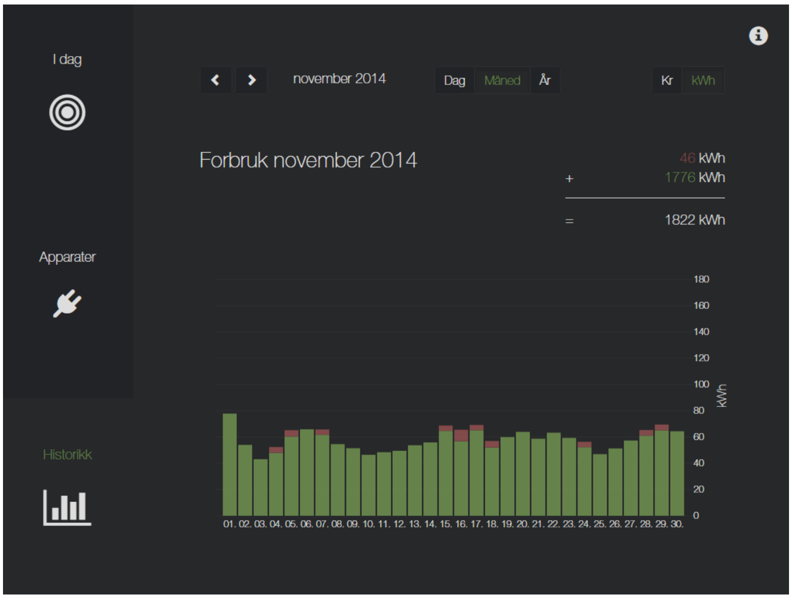


Figure 10.14: Prototype Function 3: History View (monthly consumption, kWh).

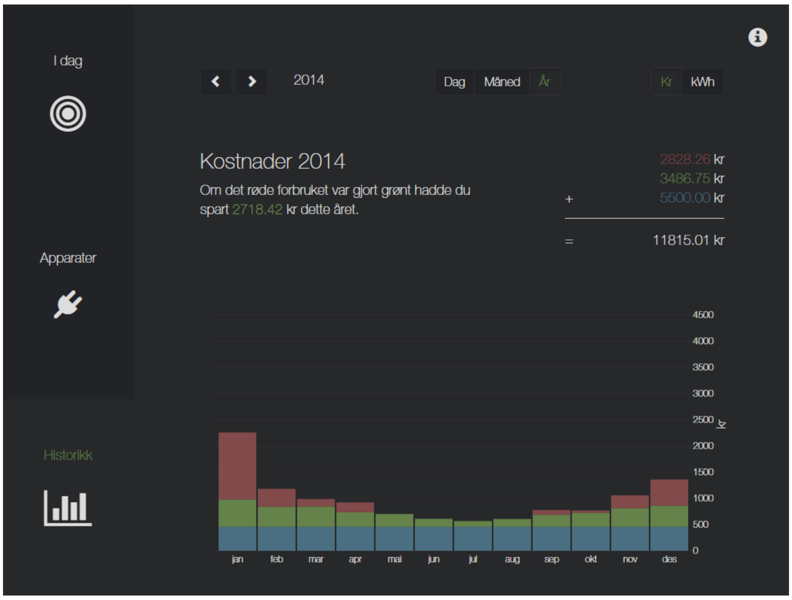


Figure 10.15: Prototype Function 3: History View (annual costs, NOK).

11 Usability Testing

10 USABILITY TESTING

This chapter describes the usability tests conducted in order to evaluate the prototype presented in Chapter 10. The objective of these tests was to reveal if the application was able to be a useful tool in conjunction with the Microgrid Tariff.

The tests were conducted according to the methodology presented in Section 4.7. First the participants are presented, before a description of the test execution follows. Finally, the results are presented.

11.1 Participants

The usability test was performed with seven participants having the characteristics presented below. Everyone was in the ownership of a smartphone, however, the extent to how much and what they used it for, varied among the participants.

Prior knowledge refers to how much the participants have been informed about the concept of the network tariff on beforehand.

AGE	
21-30	2
31-40	2
41-50	1
51-60	2

GENDER	
Male	6
Female	1

PRIOR KNOWLEDGE	
Attending network tariff project	3
Attending focus group	2
Uninformed about the network tariff	2

11.2 Usability Test Execution

The tests were attended by two facilitators: one test leader and one observer. Each usability test started with an introduction of both facilitators. The test leader then explained the upcoming activities as well as assuring the participant that the purpose of the test was to test the application, not how well they performed. The participants were encouraged to think aloud as they performed the tasks. The sessions were audio recorded, with the consent of the participants.

The tests were conducted in a semi-structured manner, having specific tasks and questions prepared, in addition to asking spontaneous follow-up questions at the end of each session. Some questions were related to the tasks, while others concerned thoughts regarding the tariff and the use of such applications in general.

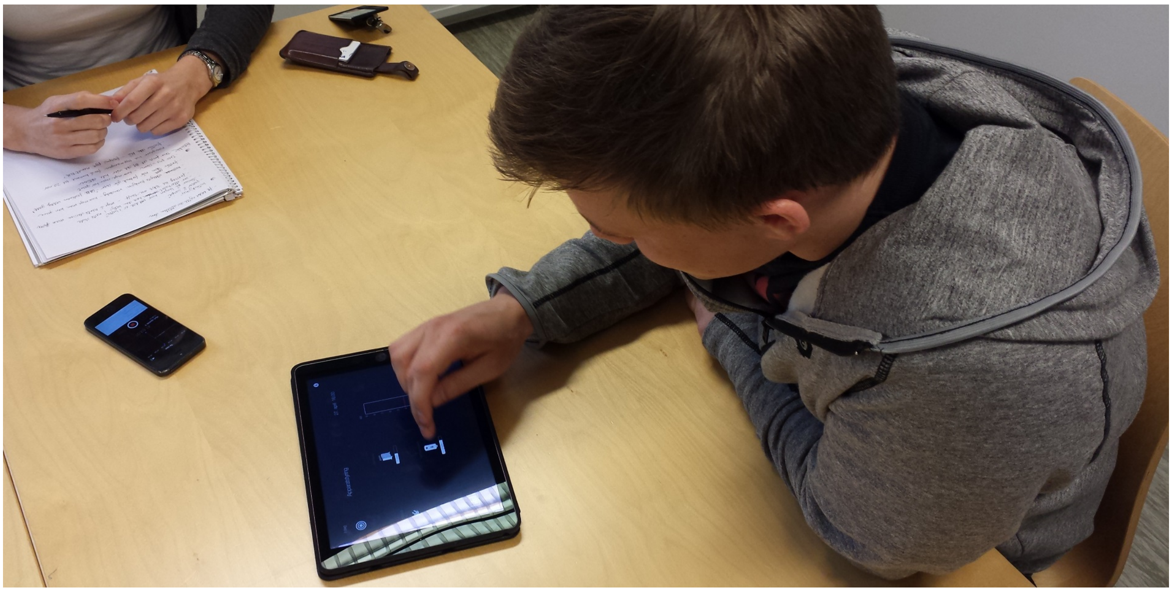


Figure 11.1: Usability testing: Appliance View.

Each test was conducted within approximately 30-40 minutes, and each participant was given the scenario and tasks presented below.

The Scenario

"You have recently renewed a new network tariff agreement, and have in this regard received a tablet with an application installed. This application has the purpose of giving you a greater benefit of your new agreement. You are now opening this application for the first time."

Tasks

Task 1 Explore which functions the application provides.

Task 2 How much did you pay for the network tariff in October 2014?

Task 3 How much energy did you consume throughout November 10th?

Task 4 If your entire consumption in 2014 was green, how much money would you have saved?

Task 5 You are home from work, and dinner is being made in your house. Avoid paying red price this hour.

When performing task 5, a simulation of the time passing was made in order for the test subject to test the functionality in a close to real setting, and see the energy consumption vary throughout the simulated hour. One second corresponded to one minute, enabling simulation of one hour to be done in one minute in the test.

Figure 11.2: Usability testing: The Day View.

Follow-Up Questions

Question a) Thoughts regarding the network tariff?
Question b) Okay to monitor red and green hours, or is it too much to relate to?
Question c) Do you think you would respond to such a tariff?
Question d) Which limit would you choose?
Question e) What is your biggest motivation for using an application like this?
Question f) What is the most important function in such an application, in your eyes?
Question g) General thoughts?

The participants were finally asked to fill out a SUS form (see Appendix D).

11.3 Usability Test Results

In this section the quantitative results from the SUS form will be presented, before the qualitative analysis from the transcribed interviews is described.

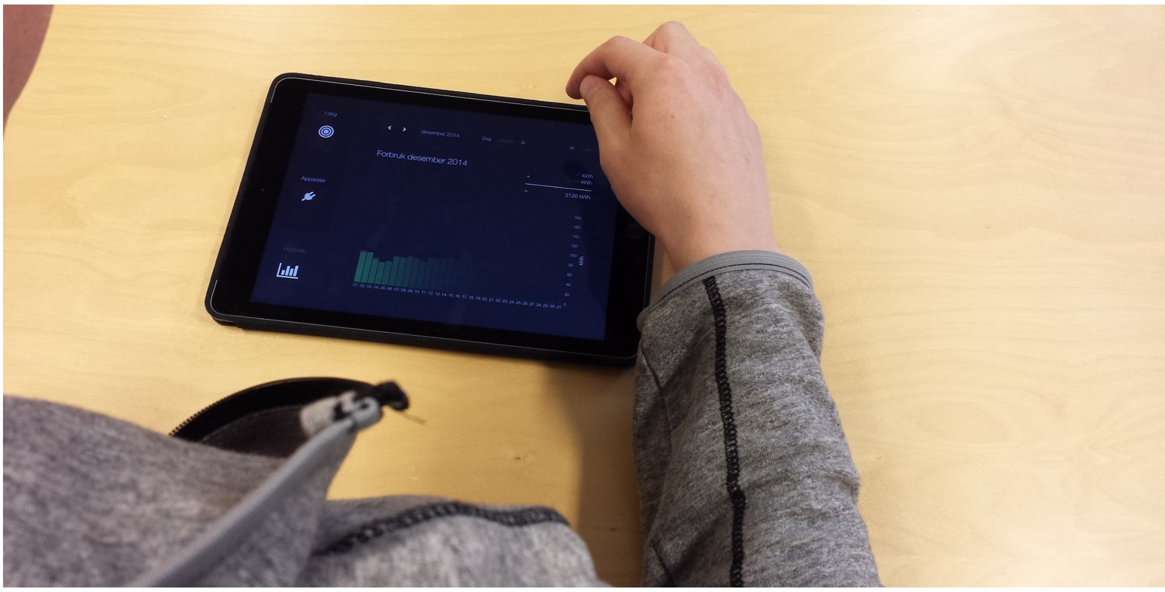


Figure 11.3: Usability testing: The History View.

11.3.1 User Preference: System Usability Scale

The primary function of the SUS questionnaire is to provide a measure of system satisfaction, as described in Section 4.7.3, and the scores were calculated according to the explanation given in the same section. The resulting SUS scores, as well as the average score, standard deviation, and confidence interval are given in Table 11.1.

Table 11.1: SUS-score results.

PARTICIPANT	SCORE
1	90.0
2	n/a
3	82.5
4	100.0
5	80.0
6	92.5
7	90.0
Average SUS-score	89.2
Standard deviation	7.2
95% confidence interval	5.8

As mentioned in Section 4.7.3, scores above 68 are considered to be an indication of satisfactory usability. An average score of 89.2 thus implies that the application had a high and satisfactory usability, and that it was well accepted among the participants. A standard deviation of 7.2 and confidence interval of 5.8 implies that the participants' perception of the application was quite consistent.

11.3.2 Evaluating the Main Views (RQ4)

Instructions

The majority of the test participants interpreted the instructions correctly, either right away, after some reading and thinking, or after seeing several instructions in the context of each other. Most participants understood the instructions explaining the tariff, which presented the basic background knowledge for using and understanding the concept of the application.

One problem that recurred when reading the instructions among most participants was that they tried to click on elements in the illustrations, due to a similar layout as the actual application.

A general impression was that the instructions gave a good introduction to the application, however it might have been too extensive. Some participants suggested that some of the instruction views could have been merged into one image, as they displayed a lot of the same information.

The Day View

Every participant understood the day view and saw the linkage between this chart and the tariff chart in the instruction. Hence, they understood that the ring represented the individual power limit, and that red and green color applied to red and green hours. They also pointed out the hours where the consumption had exceeded the limit during red hours, and where they were in danger of paying red price in the upcoming hours.

> Participant 6: *I think the graphical presentation is very logical considering the information it actually gives.*

The majority found the circular chart intuitive, and quickly understood that the chart presented a day with 24 hours. However, one found the linear chart explaining the tariff easier to read because it showed how much kWh that had been used. Some test subjects also found the "average usage for the current hour" a bit hard to understand, and wondered how often it would be updated, and whether it increased steadily or simply presented the average.

The Appliance View

When asked to perform tast 5, all participants managed to avoid paying red price by turning appliances on and off, and appreciated the ability to control the energy consumption by using the application.

> Participant 1: *Very cool to get an indication that you can do something here to reduce the energy consumption.*

> Participant 5: *And especially if you can see which appliances that are consuming, then it gets very easy to see what you can do.*

Some also enjoyed seeing the instant energy consumption.

> Participant 3: *But this is interesting, and likable that you can see the energy consumption happening right now, and an easy system which allows you to switch between this and the day view.*

Although the functionality of controlling appliances was well received, several wanted to be able to set a time for when the appliance should turn on again. Others also wanted the appliances to be controlled automatically.

> Participant 6: *Because, in worst case, if you are leaving the house right after you have turned something off, and then you are gone for several hours, then you can experience that there is pretty lukewarm water coming out of the tap.*

One challenge in this view was that some participants found it difficult to know when the appliances were turned on or off, as a result of the buttons having a subtle way of conveying their state.

The History View

Every test subject understood the concept of having the red fields in the bar representing overconsumption, and hence red costs. The majority found it very interesting to see the costs in addition to kWh in the history view, and believed it could be very effective.

> Participant 6: *..., and that, I believe, is very powerful in that it gets so specific in terms of what savings you have in dollars and cents.*

> Participant 3: *What is fine here is that you get out what I could have saved, and that I think is good. For many people I think this is a enticement that is worth seeing.*

Others also appreciated to see the relation between the energy used and how much that consumption resulted in costs.

> Participant 5: *..because I don't have any concept of one kWh and how much energy that really is. So it is nice to get it linked up with how much such a heater actually uses and how much it costs you.*

However, the amount of saving potential was perceived somewhat differently among the participants.

> Participant 1: *How much would I've saved? 2718.42 kr. Is that a lot? Yes, it is a bit, but over a year, that's quite a long time. It's not much per day.*

> Participant 5: *Then I could have saved 44 kr if I'd turned those 9 kWh green. That wasn't a lot of kWh, but it was quite a lot of money.*

Although the information given in the history was perceived as understandable, several wondered what the blue costs meant, and guessed it was the network costs. Many also wondered how the saving potential was calculated and why it was not simply the red costs.

Regarding navigation in the history view, everyone managed to find the desired dates and information, however, some experienced challenges along the way. Some misunderstood if the chart displayed one day or a whole month. Others did not see the year-button or the kr-button.

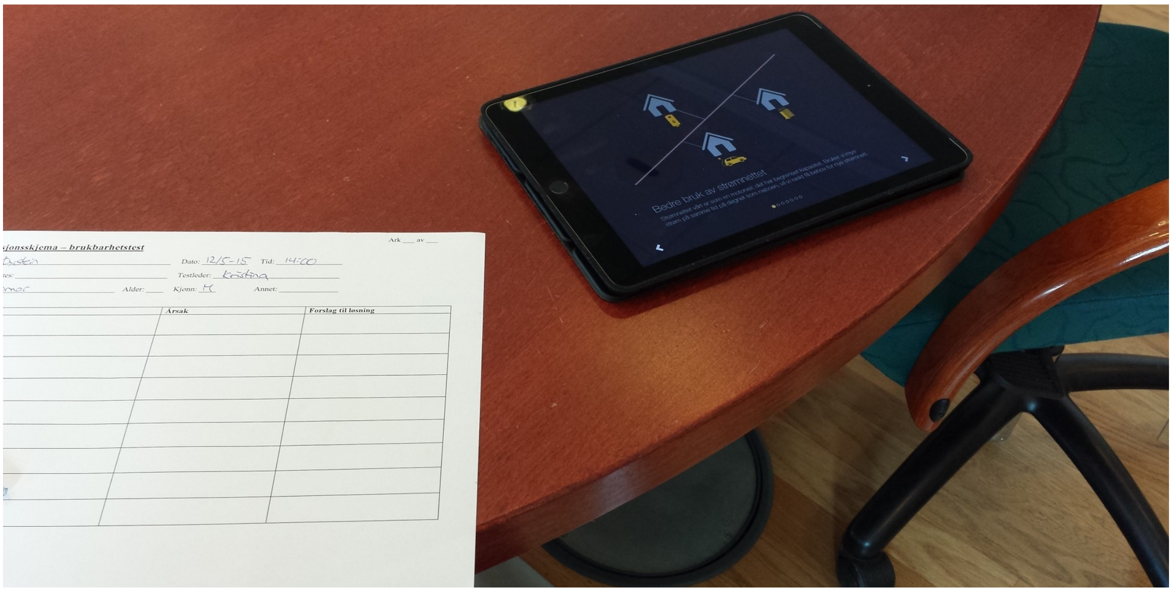


Figure 11.4: Usability testing: Peak problem instruction and observation form.

11.3.3 General Feedback

During and after completing the tasks the participants were given some of the questions presented in Section 11.2 regarding if they found such an application useful, and how and to what extent they would use it.

Flexibility - Respond to Price Signals

The application was by some participants regarded as a great tool for changing user behavior

> Participant 6: *The chart [history] or the circle with clock, and so on, is ingenious, because there you see which hours you are overconsuming, something that can give a good indication for changing daily routines to lower the energy consumption.*

The majority said that they would respond to price signals and adjust their user behavior to avoid high consumption in red hours.

Participant 7: *Because, I am already aware of.. If I'm baking a lot, then I don't turn on the washing machine.*

Participant 6: *Yes, I would try to avoid the red tops, and of course, with such an application it is super easy, right. Only two touches on the screen, and you have reduced the consumption a lot.*

Participant 3: *Even in the weekends we will be able to make actions if we know beforehand, we don't have to put on the washing machine, we can wait one hour.*

Participant 5: *Yes, I believe so. This application is worth gold when you can go in and see how much money we are talking about.*

Other said that they would respond to price signals, but found it hard to get the rest of the household on board, and that it was not a fight they would take.

Participant 2: *The others in my household are not interested in dealing with such things at all, because they use electricity when they need it.*

As already mentioned, several participants would like the appliances to be automatically controlled based on the green and red hours and the total consumption in the household.

Participant 2: *For heaters and the water heater I would like to have automatic control, so that they just switched off, because that no one would have noticed.*

Motivational Factors

When asked what their motivational factor for using such an application was, reducing the electricity bill was mentioned by most participants. Some participants additionally mentioned community aspects and taking care of the electrical grid as a reason for using an application like this.

Participant 6: *If many households take this seriously this could be a tool for reducing energy consumption, and could hence contribute in making constantly expansions of power lines less needed. And if you think in a personal financial perspective, it is beneficial for the economy to reduce the expenses related to energy consumption.*

Most Interesting Functionality

Some would primarily use such an application to plan their consumption based on when the red and green hours occur.

Participant 6: *It graphically and visually presents energy consumption in a very neat and orderly manner, and it can give a clear picture of when you are overconsuming and when you can use more. In addition, you get it out in "dollars and cents".*

Others found the ability to control appliances as the most important function.

Participant 4: *When it comes to useful features in such applications, it is probably time control I have missed the most, and to be able to control based on consumption and get it automated. (...) If red hour, then turn off the water heater, that there is a feature for that.*

Participant 4: *..it requires that there is some automation, so that you don't need to monitor it all the time. It is a bad hourly payment if you need to sit the whole year and look at the display to save 2000 NOK, so it needs to help us further.*

Several wanted some kind of warning when the consumption approaches the limit, either through a sound, or a message on the cell phone, to be able to make changes.

Participant 6: *Maybe the icon could turn orange if you started to approach the limit (...) and then it turned red when you exceeded. Because, if it went straight to red then you haven't got the chance to adjust something before you exceed.*

Participant 3: *I would like to get warnings realtime, not one hour afterwards. It was like that last year, and for me it seemed negative to get a warning one hour later. It became like a "neener-neener, you missed".*

General Thoughts

The general impression after conducting the test was that the participant saw the benefit of having such an application, and that they found it easy to use.

Participant 7: *Once you got started using it, then it was quite easy to understand. (...) Everything is a bit unfamiliar right away, but once you start learning how to use it, then it was fine to use.*

Some also stated that people's concern with energy consumption and saving money was fundamental for how such an application would be adopted in a household.

Participant 5: *If you receive the bill and it's fine, and you don't care, then this becomes useless. But I believe that most people will think that this is profitable and helps you a lot.*

During the tests the observer recorded problems that occurred in an observation form. All recorded problems that occurred during the conducted tests are summarized in a table to be found in Appendix E.

11.3.4 Usability Test Summary

The following list summarizes the findings from the usability test, and states which research questions they helped answer.

Information of Interest (RQ2 and RQ4)

- Information regarding the occurrence of red and green hours was found useful, as it enabled for planning the consumption.
- Information regarding cost related to consumption was found interesting.

Functionality (RQ2 and RQ4)

- Controlling appliances were by many considered as the most useful and interesting feature in the display prototype, preferably with automatic control.
- The participants wanted some kind of warning ahead of time if the consumption was approaching the limit during red hours, to be able to take action.

Design (RQ3 and RQ4)

- The graphical presentations of the charts were perceived as logical and intuitive.
- Red text on dark background was hard to read.
- The navigation in history could have been more evident, with larger headers and buttons

Motivation for Using the Display (RQ1 and RQ4)

- Reducing electricity bills was mentioned by most participants as the biggest motivation for using the display tool. Others also mentioned community and environmental aspects, considering reducing the peak load.

Flexibility (RQ1)

- Every participant said that they would respond to price signals connected to peak hours, but some found it challenging getting the others in the household to participate.

Part VII

Discussion and Conclusion

12 Discussion

This chapter addresses the results found when carrying out the activities presented in part IV, V and VI, and discusses these findings in light of the research questions proposed in Section 1.3. An evaluation of the research process is also included, identifying potential strengths and weaknesses in the work that has been done.

12.1 Implications for the Research Questions

This section addresses the research questions one by one, and discusses the results from the performed activities and considers their implications for each research question. The results will be discussed in light of existing research and theory presented in Chapter 2 and 3.

12.1.1 Research Question 1: Context of Use, Motivation and Attitude

> **Research question 1:** What is the context of use for the display tool, and what is the motivation and attitude towards it?

This research question considered the context of use for a display tool having the objectives of presenting information regarding energy consumption and encourage the reduction of power peaks. The research question also asked about people's motivation and attitude towards using a display tool related to energy consumption.

Knowledge and Awareness

Energy usage is something consumers in Norway in general to little extent reflect upon, as they do not consume energy itself, but instead they use appliances that consume energy, as mentioned in Section 2.1.5. The cost is relatively low, and the desire for comfort is increasingly high. According to the results from the questionnaire the majority only reflects on their energy consumption when receiving the electricity bill, and the majority see themselves as having an average interest in saving energy. Young people (20-24) show less interest than older people (40-60).

As described in Section 3.3.3, knowledge and awareness about energy consumption is fundamental in order to change behavior. Results from the questionnaire revealed that the knowledge regarding high consuming appliances and the electricity bill was fairly high. However, about 30 percent found the electricity bill to be too complicated, and about 50 percent responded that they do not know how much the electricity price varies throughout the day. This indicates that a lack of understanding may prohibit the first barrier of motivating change in behavior, namely being aware of the need.

Participants in the focus group expressed a lack of knowledge regarding varying electricity prices and how much electrical appliances draw, and suggested that this prevents them from taking conscious actions regarding their energy consumption. They thus recognized a lack of knowledge as a first barrier for changing user behavior. This strengthens the need for information as an enabler for behavioral change, supporting the physiological strategy described in Section 3.3.3.

Behavioral Change

The process of behavioral change can be seen in light of the motivation process described in Section 3.3.2, where needs lead to a certain behavior in order to achieve satisfaction. The process may be initiated by information, education, a change of context, or an existing need, and the achievement of satisfaction has the potential of altering the initial needs, and in turn cause a different behavior.

When made aware of the peak problem, many participants from all activities said that they would adjust the energy consumption according to information given to them. Results from the questionnaire showed that 80 percent show in one degree or another willingness to move energy usage away from peak hours. This corresponds with previous research done by Löfström [24], as described in Section 2.1.5, which found that households are able to understand the complexity of a smart grid, and may be willing to act in accordance to information in relation to it.

Motivation

As described in Section 3.3.1 and 3.3.2, human behavior is based on feelings, values, and needs. In order to change a behavior, the very feelings and values that the behavior is built upon have to be altered or built on. The technology will have to motivate by satisfying the user's needs.

Realizing why a shift in energy usage is beneficial depends on motivation and understanding of the electrical grid. Comparing the grid to a highway, having limited capacity, can help consumers understand, and in turn motivate. People know that overloading a highway have implications for cost, time, and environment, and congestion charts have become a reality, and something we accept to varying degrees.

Results from both the questionnaire, the focus group and the usability tests showed that reducing electricity bills was considered by most participant as the biggest motivation for saving or moving energy consumption. Others also mentioned community and environmental aspects. Section 3.3.5 claims that the script of a technology encourages specific user actions. The script of the display tool builds on society norms about reducing costs and saving environment when trying to motivate its users, and these norms were thus confirmed when carrying out the activities mentioned above.

During the focus group, the potential for having fun while using the display tool was mentioned as a motivational factor for using the appliance control functionality. Perceiving an activity as fun enables intrinsic motivation; finding the activity enjoyable in itself, as described in Section 3.3.2 about needs, which can be a highly motivational factor. The intrinsic motivation of having fun helps satisfying higher level needs related to personal growth, whereas saving money relates to needs on a more basic level, covering the needs for materialistic safety.

Attitude

Participants in the focus group stated that the red price must be high in order to lead users towards action. However, people should be allowed to make dinner when they want, implying that prices cannot be excessively high, revoking customers' freedom by punishing them. As found by the research presented in Section 2.1.5, consumers want to decide for themselves how much to consume and when to do it.

The Microgrid Tariff is in itself a structural strategy, described in Section 3.3.3 about facilitating motivation, as it changes the context in which choices are made in order to facilitate behavioral change. The potential of achieving behavioral change as a result of changing the structural context have been demonstrated in the international studies done on Critical Peak Pricing, presented in Section 2.1.5.

12.1.2 Research Question 2: User Requirements

> **Research question 2:** What are the user requirements for a display tool supporting this kind of tariff?

This research question addressed which requirements users have for a display tool in order to find it useful and usable.

Information of Interest

During the prestudy tests, test subjects stated varying interest and awareness of electricity consumption, and in most cases the awareness was limited to looking at the electricity bill and noticing whether usage had been high or low, as well as reducing the use of unnecessary lighting and heating. All test subjects conveyed an interest in some sort of consumption data, mainly for the purpose of reducing electricity costs. This also applies to the results from the questionnaire, where around 80 percent showed interest in getting information about their energy consumption. Historical consumption data, for the purpose of comparing with past months or years was found useful. The stated interest can however be overemphasized due to the context the test subjects were put in.

The introduction of the Microgrid Tariff induced a need for information regarding the occurrence of red hours, and if the immediate energy consumption is approaching the individual limit. Saving money being the greatest motivational factor for saving energy, brings the need of displaying costs and cost saving potential related to consumption. However, in order for cost savings to be motivational, users should be presented with information about what can be saved over time, showing a bigger picture rather than small amounts, as mentioned in the focus group session.

Although results from the questionnaire suggested environmental awareness to be a motivational factor for reducing energy consumption, the sketch showing the neighborhood and each household's contribution to the electrical grid load, was not found desirable by the participants in the focus group. This complies with the research findings presented in Section 2.1.5, stating that the connection between environmental awareness and practice is weak in Norway. Users should instead be provided with concise information that enables them to take action, and information that does not concern them directly may not be of interest.

This supports the requirement of personalized data. Tailored and personalized information is shown to be more effective than general information in changing behavior.

For behavioral change to occur, users should be provided with information about the consequences of their actions. Users benefit from seeing the immediate implications of their actions, which supports the need for displaying instantaneous consumption, which also was uttered in Löfström's research. The ability to take conscious actions enables user control, which was stated as a reason for preferring the sketch enabling appliance management in the focus group. To allow user control and day planning, information about red and green prices should be given some time ahead, at least a day, and in order for cost savings to be motivational, users should be presented with information about what can be saved over time.

Results from the prestudy tests also suggested that consumers are not very interested in comparing their own usage to others, unless the compared household have the same characteristics. The test subjects were skeptical as to whether it was possible to find another household suitable for comparison due to the fact that there are so many factors affecting energy consumption, such as number of residents and daily routines, as well as building structure, regarding how well the house is isolated, heating sources, square meters, and height under ceiling. Comparisons with one self was shown to be more interesting.

Functionality

The feature of controlling appliances combined with having an overview of instantaneous energy consumption was considered as most interesting by the participants in the focus group, as this enabled specific, easy actions to save energy and costs.

The results from the questionnaire also showed a general interest in having such possibilities. The participants showed slightly more interest in having the appliances controlled automatically, rather than manually controlling them with a smartphone or tablet. This difference might have been caused by participants perception of such technologies.

Having the data displayed real time, and getting information and warnings ahead was also uttered by the participants in the focus group as important in order to be able to take actions.

Adopting the Display Tool

Research show that consumers do not want too much to be required of them, and that they want a system that does not require too much focus and effort to use. The factors which influence users' acceptance of new technology, described in Section 3.3.4, becomes central when explaining why users would adopt such a display tool. The display tool must hence be perceived useful and user friendly in order to motivate use.

This tool will be adopted in everyday life, with everyday actions and routines. People have limited time and attention, and the demand for effort may prevent users from adopting the tool. The effort that goes into using the service must thus be minimized.

New technologies have a tendency to be exciting at first, but maintaining use over time requires usefulness and usability. The technology has to seamlessly fit into users' everyday lives, and satisfy a persistent need. Technology also has a tendency to become invisible when brought into daily routine. Availability plays an important role when adopting new technologies into daily routines. Actions that help increase availability include integration with similar services, always-visible mounted displays, and having the service as an online application on a smartphone.

Users needs to feel safe when using new technology. Bringing technology online bears the potential for misuse of data and unauthorized access. Users must hence be assured that the technology is safe to use, and that their data is kept safe from misuse.

12.1.3 Research Question 3: Design

> **Research question 3:** How should the display tool be designed, in terms of data visualization and usability?

This research question aimed at answering how a display tool communicating information and enabling control regarding energy consumption should be designed. It considers how data should be communicated and how the design may help assure user satisfaction.

Connections and Context

During prestudy testing, prototypes visualizing both daily and weekly electricity consumption were tested. In both cases test subjects were capable of detecting patterns, and see the connection between varying visual variables and causes for changes in electricity usage. However, a tradeoff between readability and detail had to be made, with readability triumphing detail both in terms of accuracy in values and number of readings. Some of the charts used during prestudy testing, especially Sketch 6, might have been too extensive. By trying to display a lot of information at the same time, the data disappeared instead.

Regarding the level of detail in the visualizations, test subjects' opinions were divided. Some were not interested in detail at all, while others valued a high level of detail and wanted even more precise information. A solution may be to enable users to choose level of detail through user settings in an application.

The need for reducing complexity in order to enhance readability, complies with the theory presented in Section 3.2.2, stating that data visualizations should be made for the context in which they will be used. The context of visualizing consumption data is to communicate patterns and draw attention to deviations, and hence complexity should be reduced. Instead, characteristics of preattentive processing, described in Section 3.2.3, should be utilized for enhancing readability and let users detect patterns and deviations in their consumption data.

Representing Values

The prestudy test results indicate that viewers prefer to compare sizes rather than shades of color, as already suggested in Section 3.2.3 about shapes. Differences in size were easier to designate than differences in color tints, especially where the values were not located next to each other. The ability of colors' to convey abstract ideas, described in Section 3.2.3, was manifested when test subjects recognized the red bars as something to avoid.

As one test subject pointed out, the use of only color scales may be problematic for people with impaired vision. Another drawback of using red and green to convey information and ideas is that it bears difficulties for color blind people.

Building on What the User Knows

The results from the prestudy tests showed that horizontal charts were preferred above circular charts, particularly when the amount of data presented was high. However, circular representations of data from one day were well received. Test subjects expressed that 24 hour circles were understandable, and that the complexity of having two 12 hour circles outweighs its associations with a familiar clock. Hence, the hypothesis that 12 hour circles would lead to associations with clock dials, and thus making navigation easier, was not fully confirmed.

The benefits of relying on the familiarity of a horizontal grid supports the theory presented in Section 3.2.4 and 3.2.5, describing the benefits of building on users' existing knowledge. However, their ability to understand a 24 hour clock somewhat contradicts this belief, and opens the potential for users being able to acquire and comprehend new ways of interpreting visualizations.

12.1.4 Research Question 4: Evaluation

Research question 4: How do users evaluate the display tool?

The test participants have the domain knowledge, they know the context of use, and they are the ones who will be using the display tool. Hence, the final research question addressed how the display tool is evaluated by users, and answering it includes discussing users' feedback after interacting with the implemented prototype in the usability tests.

Usability

The test participants found the tool easy to learn and use, and the tests resulted in few recurring errors, conforming with the definition of usability given in Section 3.1.1. Also the average SUS score of 89.2 implied a high perceived usability among the participants. Several said that the charts were intuitive and that they found them visually pleasing. This applied to the history bar charts due to a well known presentation, but also the day chart, which could have been perceived as unfamiliar, was found intuitive. This might have been due to the instructions given in the start up of the application. Perceived usability depends on personal taste, goals, experience, and context of use, and the response might have been somewhat different with other test participants.

Improving usability involves optimizing the interactions people have with the product in order to achieve their goal in a satisfying way. Some improvements that would increase the display tool's usability applies to having more evident navigation in the history view. The majority of faults that happened related to the buttons being too small, and the headers being too similar. In addition, red text on dark background was found hard to read, and the color and/or size of this text should be adjusted for better readability.

Usefulness

Information regarding occurrence of red and green hours, combined with information about immediate energy consumption in relation with the limit, was found useful, as it enabled planning the consumption. This relates to the findings discussed in Section 12.1.2. Also, seeing the relation between energy used and costs, in addition to potential cost savings were found interesting, and was considered as a motivating factor for shifting the energy consumption away from peak periods.

The feature of controlling appliances was appreciated among the participants in the usability test, and were by many considered the most useful and interesting feature in the display prototype. It made taking actions based on the given information easier. Although being able to turn appliances on and off remotely were perceived as useful, several wanted the appliances to be controlled automatically, either by setting the time for when the appliance should be on, or preferably by the appliance responding to peak hours. Having the appliances to be controlled automatically was considered convenient, and required low effort. Automation was also preferred as this was considered something that the household would not notice, and could thus help those who felt alone in caring about adjusting their consumption in the household.

As already discussed, receiving indications of when the consumption exceeded the individual limit during red hours was found useful. This conforms with Löfström's[24] suggestion of direct intuitive feedback as an enabler for making informed decisions. However, several wanted some kind of warning, either through a sound or a change of color of icons in the display, or through a notification on the cell phone, when approaching the limit in red hours. This was to be able to take actions before the limit was exceeded.

The participants in the usability test saw the benefit of having such display tools, especially considering handling the network tariff, and gaining better control over their consumption. The display was regarded by some as a great tool for changing user behavior based on information.

12.2 Validity of Research Strategy

This research has followed the Design and Creation strategy, and has tried to form a complete and holistic picture of how to design a display tool helping users get information about and control their energy usage. In order to evaluate the implications of our findings, this section discusses the validity of the research methods in terms of triangulation, objectivity, and internal and external validity.

Triangulation

In order to ensure a more complete, holistic, and contextual portrait of how to design a display tool related to energy usage, various techniques have been applied. The research achieves methodological triangulation through the combination of conducting a survey, a focus group, and usability testing. The gathering of the same types of data from these various methodologies has allowed us to better understand the importance, relevance, and trustworthiness in our findings.

Objectivity

As described in Section 4.8.2 objectivity is important when performing qualitative research.

The selection of focus group participants might have limited the methodological strength of the focus group, as the selection was narrow and the familiarity between interviewer and interviewee had the potential of interfering with the objectiveness during the session. However, the discussions were held factual and on topic, and the familiarity might also have contributed in honest inputs to the topic at hand.

Regarding the conduction of usability tests, objectivity was pursued by considering choice of words and behavior during the test, and hence avoid guiding the participants when solving the tasks. During the focus group, the moderator pursued objectivity through being neutral and not express opinions.

Internal Validity

In terms of the questionnaire, internal validity was pursued by explaining the purpose of the survey at the beginning of the form, and through descriptive comments before every question. The reliability of the results can be discussed, as the number of participants was a bit low, and that there is no guarantee that the answers given by the participants were entirely true. However, a varied and representative sample set was pursued by getting respondents from both the Demo Steinkjer households, and other households, in various age groups.

With regards to the usability tests, the test leader explained the upcoming activities and the purpose of the test. During the test, the test leader tried to assure what the participants meant by asking follow-up questions.

External Validity

This research was conducted with a user centered approach, exploring the actual context and requirements from individual users. Hence, achieving total generalization has not been pursued as realistic. The complexity of an individual's everyday life, including motivations, attitudes and preferences, prevent the possibility of establishing an absolute truth for every user.

However, the external validity of this research was enhanced by gathering quantitative data through conducting a survey, as it took into consideration the opinions and characteristics of a larger group of people.

13 Conclusion

This chapter concludes our research, and extracts the key findings for each of the four research questions.

13.1 Answering the Research Questions

13.1.1 Research Question 1: Context of Use, Motivation and Attitude

Knowledge and Awareness

- The majority of our participants only reflect on their energy consumption when receiving the electricity bill. Further, a lack of knowledge and information makes behavioral change less probable, thus strengthening the need for information as an enabler for behavioral change.

Behavioral Change

- Participants expressed willingness to adapt energy consumption according to information given to them.

Motivation

- A reduced electricity bill was considered the biggest motivation for saving or moving energy consumption.
- Enabling intrinsic motivation, such as having fun, can be a highly motivational factor.

Attitude

- Comparing the grid to a highway, having limited capacity, is an effective way of increasing awareness. However, perceiving the Microgrid Tariff as an overpriced congestion chart might have negative impacts on people's attitude towards it.

13.1.2 Research Question 2: User Requirements

Information of Interest

- Consumers expressed a need for consumption and cost information.
- In order for cost savings to be motivational, users should be presented with what can be saved over time.
- Users should be provided with concise information that enables them to take immediate and conscious action. Inconcise information about environmental influence may not be effective.
- Accommodating the needs of all electricity consumers with a single solution can be difficult. It will be beneficial to allow tailored and personalized information or select a specific target group.
- Users should receive pricing information at least one day ahead to be able to plan their consumption.
- Users are not interested in comparing their consumption with other households unless they share characteristics.

Functionality

- Users want the ability to control appliances, but automation should be provided where applicable.

Adopting the Display Tool

- The display tool should demand for a minimum amount of effort in order to be adopted in an everyday setting.
- In order to assure use over time, the display tool has to seamlessly fit into the everyday lives of the users by being easily available, and satisfy a persistent need.

13.1.3 Research Question 3: Design

Connections and Context

- A visualization of energy consumption should focus on readability rather than detail in data in order to convey patterns and deviations in usage. However, some users appreciate detailed information.

Representing Values

- Using sizes, especially bar heights, for representing values is more preferable than using colors and circles.
- Colors have the possibility of conveying abstract ideas, but the use of red and green may cause difficulties for color blind people.

Building on What the User Knows

- Familiar horizontal charts are most effective when displaying large amounts of data.
- Users are able to read circular 24 hour charts, implying that users are able to acquire and comprehend new ways of interpreting data visualizations.

13.1.4 Research Question 4: Evaluation

Usability

- Test participants found the display tool usable, indicated by a SUS score of 89.2.

Usefulness

- Test participants found the display tool useful for handling the Microgrid Tariff and gain better control of their consumption.
- Test participants found information about red and green hours combined with instantaneous power useful as it allowed planning.
- Test participants found information about the relation between consumption, costs, and potential savings both useful and motivational.
- Test participants found appliance control useful, but automation was considered convenient.

- A notification, e.g. on their mobile phone, telling users when to act may allow a decrease in demanded effort.

13.2 Overall Conclusion

Concluding with the importance of a user centered perspective might, for a thesis taking a user centered approach, be considered a self-fulfilling prophecy. However, our findings suggest that listening to the motivations, preferences, and ideas of individuals, might allow designers to develop a display tool that is based on the premise of its potential users. A solution should cover the needs of these individuals, and not simply force them into solving the needs of the power companies.

Turning to the question proposed in the introduction, asking whether technology is capable of changing our behavior and routines, or if we start using technology that better fits our desires and needs, the answer is both. Users show willingness to change behavior and adopt new technology, but only if they are provided with the appropriate tools that help them achieve their goals in their everyday lives.

13.3 Future Research

This research only tested the display tool in a short-term usability test. A display tool related to energy consumption is something that will have to be integrated into the daily lives of users, and in order to determine the actual outcome of using such a tool, it will have to be tested over a longer period of time.

The structure of the Microgrid Tariff has not been evaluated in this research. Future research should determine how such a tariff should be structured, which parts it should consist of, and which parts are relevant for users.

The test participants contributing to this research live in a world were Smart Meters and effect-based tariffs are not part of their vocabulary, and still something to come some time in the future. Testing display tools in a context where households have Smart Meters installed, and network tariffs based on power rather than consumption have become a reality, might lead to new conclusions.

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Appendices

A Questionnaire

1. Hvor gammel er du? *

Alder: ______

2. Hva er din høyeste fullførte utdanning? *

- ○ Grunnskole
- ○ Videregående
- ○ Høyskole/Universitet

3. Hvilket av disse alternativene passer best med din nåværende bosituasjon? *

- ○ Leier leilighet
- ○ Eier leilighet
- ○ Leier hus
- ○ Eier hus

4. Hvor lenge har du bodd i din nåværende bolig? *

- ○ mindre enn 1 år
- ○ 1-2 år
- ○ 3-4 år
- ○ 5-6 år
- ○ mer enn 6 år

5. Er det du som leser av strømmåleren der du bor? *

- ○ ja
- ○ nei

6. Er det du som betaler strømregningen der du bor? *

- ○ ja
- ○ nei

Neste

Om interesse for strømforbruk og motivasjon for strømsparing

8. Hvor opptatt er du av ditt eget strømforbruk? *

	Følger ikke med i det hele tatt	Ser kun på fakturaen	Leser av strømmåleren oftere enn strømleverandøren min etterspør	Fører statistikk	Har utstyr, i tillegg til strømmåleren, for å overvåke forbruk
-	○	○	○	○	○

9. Hvor opptatt er du av å spare strøm? *

	Ikke i det hele tatt	Under gjennomsnittet	Gjennomsnittlig	Over gjennomsnittet	Veldig
-	○	○	○	○	○

10. Hvilke tiltak gjør du for å spare strøm? *

- ☐ Slår av lyset i rom jeg ikke bruker
- ☐ Har termostatstyring på oppvarming
- ☐ Bruker kort tid i dusjen
- ☐ Senker innetemperatur
- ☐ Har skaffet sparedusj
- ☐ Kjøper/bruker apparater med lavt energiforbruk
- ☐ Har fått installert varmepumpe
- ☐ Etterisolering
- ☐ Gjør ingenting
- ☐ Annet: ____________

11. Hva er din(e) største motivasjon(er) for å spare strøm? *

- ☐ Spare penger
- ☐ Miljø
- ☐ Tillærte vaner om strømsparing
- ☐ "Alle bør spare strøm"
- ☐ Å bidra til et stabilt strømnett
- ☐ Har ingen motivasjon for å spare strøm

[Forr.] [Neste]

Om strømregning og strømtjenester

12. **Hvor enig er du i følgende påstander? ***

	Helt uenig	Litt uenig	Hverken enig eller uenig	Litt enig	Helt enig
Jeg synes strømregningen er for komplisert	○	○	○	○	○
Jeg forstår oppbyggingen av strømregningen min	○	○	○	○	○
Jeg vet hva som er forskjellen på nettleie og kraftpris	○	○	○	○	○
Jeg vet hva som bestemmer strømprisen	○	○	○	○	○
Jeg vet hvor mye strømprisen varier i løpet av døgnet	○	○	○	○	○
Jeg er opptatt av å ha den beste strømavtalen	○	○	○	○	○
Jeg vet hvilke elektriske apparater som forbruker mest strøm der jeg bor.	○	○	○	○	○

13. **Hvor interessant er det for deg... ***

	Ikke i det hele tatt	I liten grad	Noe	I stor grad	Veldig
...å få informasjon om hvor mye strøm du bruker akkurat nå?	○	○	○	○	○
...å se hvor mye strøm ulike apparater (alt fra kaffetrakter til varmtvannstank) bruker?	○	○	○	○	○
...å kunne slå av og på apparater via smarttelefon/nettbrett?	○	○	○	○	○
...å få oversikt over forbruket ditt siste dag/uke/måned?	○	○	○	○	○
...å automatisk styre når på døgnet apparater skal slå seg av og på?	○	○	○	○	○

14. **Om du er hjemme en kveld og kommer på at du trenger å vaske klær, vil du utsette det en time om du vet at... ***

	Helt uaktuelt	En sjelden gang	Av og til	Ofte	Ja, hver gang
...det reduserer strømregning din med 5 kroner?	○	○	○	○	○
...det bidrar til å redusere risiko for overbelastning i strømnettet?	○	○	○	○	○

Forr. Neste

15. Helt til slutt ønsker vi å vite hvordan du ble oppfordret til å delta i undersøkelsen.

- ○ E-post
- ○ Facebook
- ○ Nettforum
- ○ Gjennom Demo Steinkjer
- ○ Annet: ______

Tusen takk for hjelpen!

Invitasjon til gruppediskusjon

Enten du ønsker å bidra i utviklingen av framtidens strømtjenester, eller bare er glad i gratis kaffe og hjemmebakst, inviterer vi deg med dette til å delta i en gruppediskusjon tirsdag 24. mars på NTNU Gløshaugen, hvor vi vil presentere forslag til løsninger og diskutere disse. Har du spørsmål til gruppediskusjonen eller om spørreundersøkelsen kan du sende mail til krisvol@stud.ntnu.no.

Dersom du kunne tenke deg å delta kan du skrive inn e-postadressen din i feltet under.

16. E-post:

______

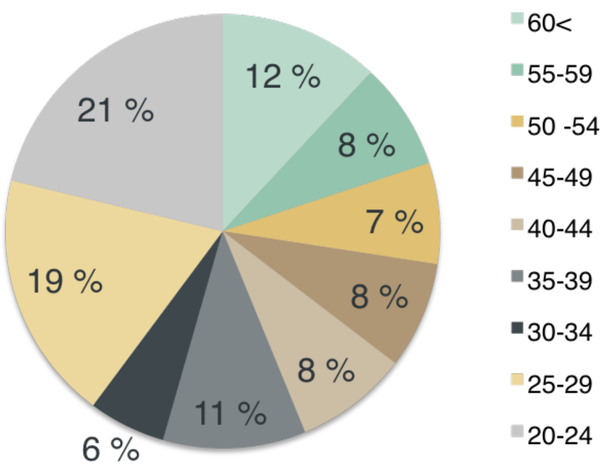
Forr. Ferdig

B Results from Questionnaire

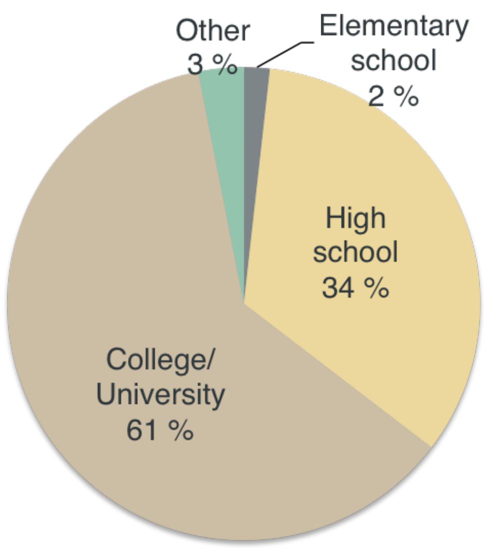
This appendix presents the complete result set from the questionnaire, conducted during March 2015.

Background information

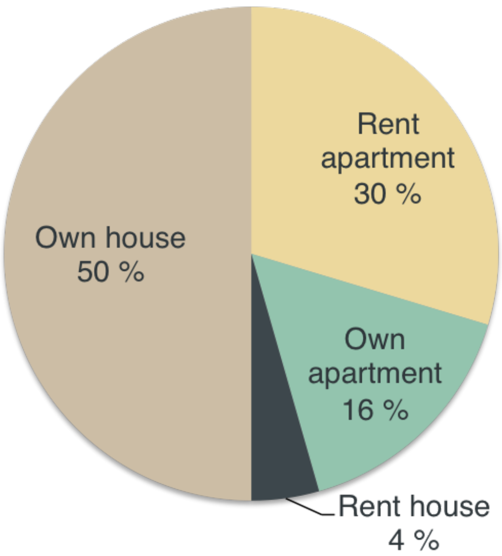
Question 1: How old are you?



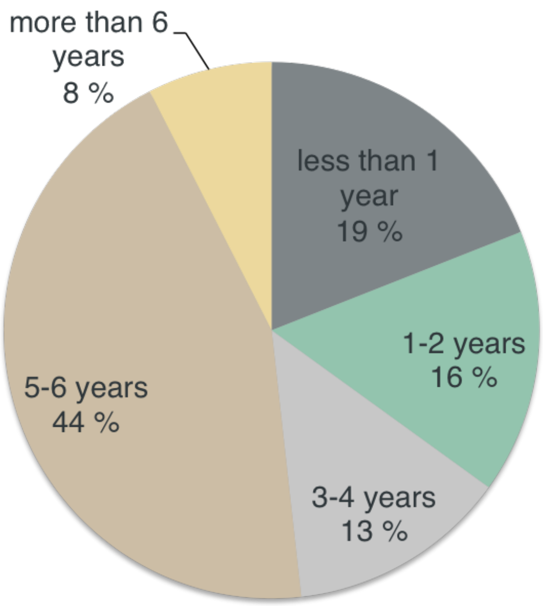
Question 2: What is your highest completed education?



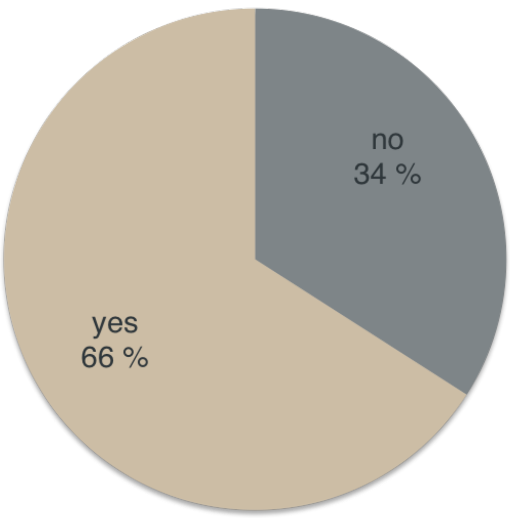
Question 3: How is your residential situation?



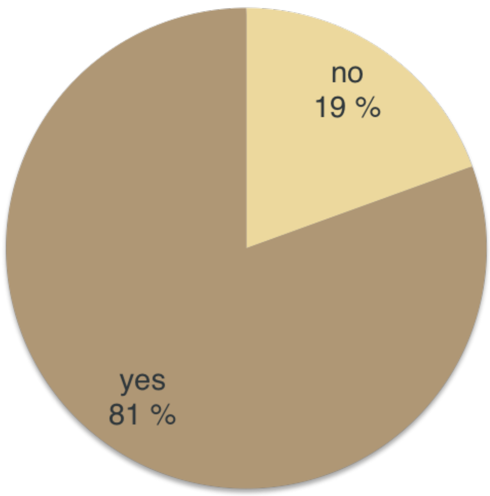
Question 4: How long have you lived in you current residence?



Question 5: Are you responsible for reading the power meter, or monitor your energy consumption on internet or display, in your household?

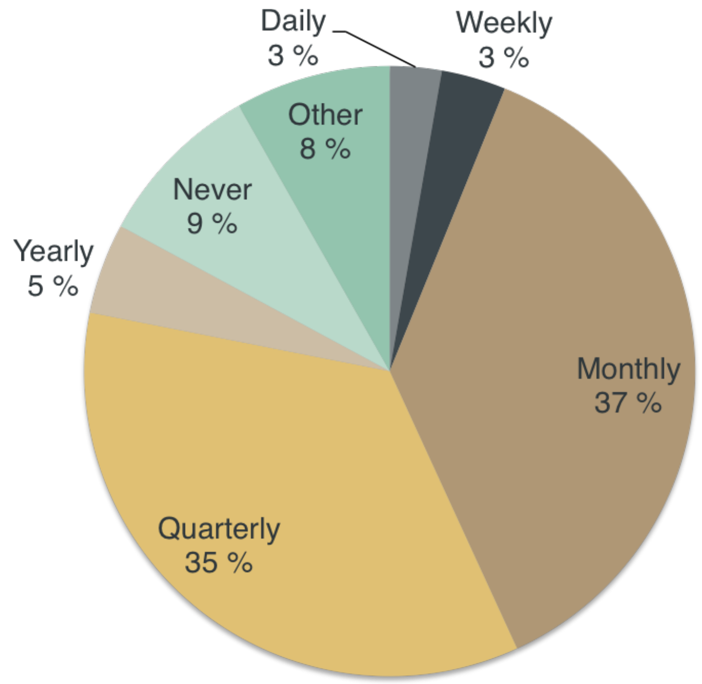


Question 6: Are you responsible for paying the electricity bill in your household?

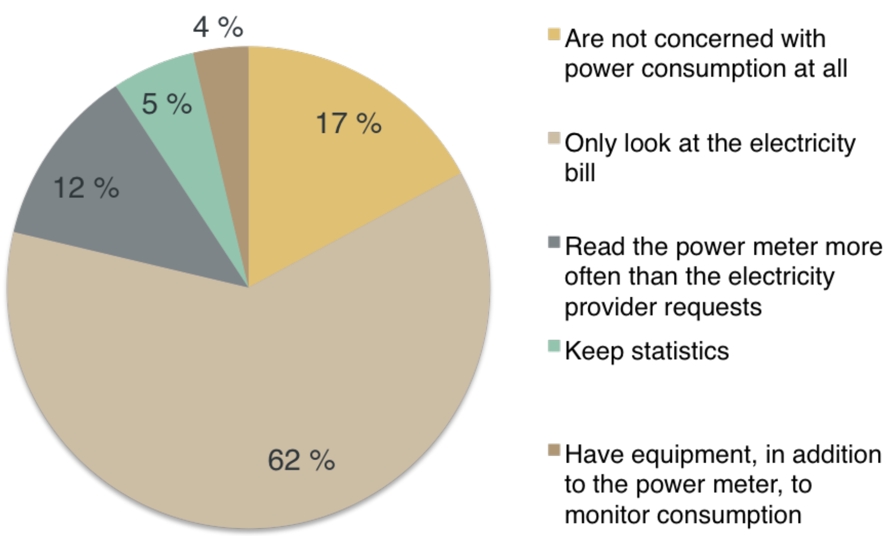


Interest in energy consumption and motivation for saving energy

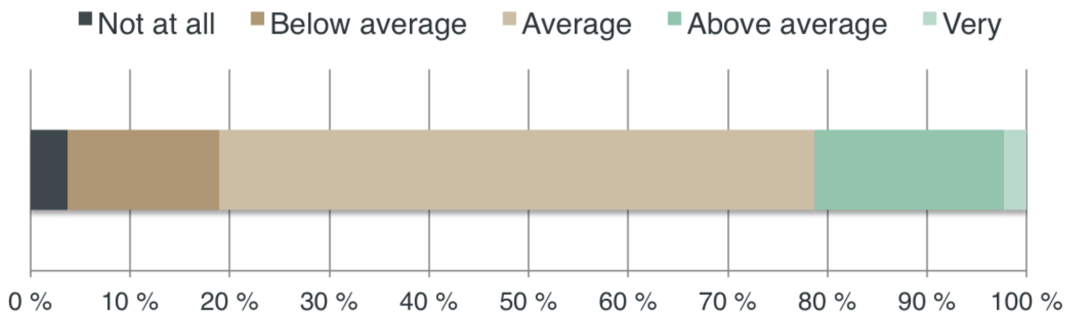
Question 7: How often do you read the power meter, or monitor your consumption on internet or display?



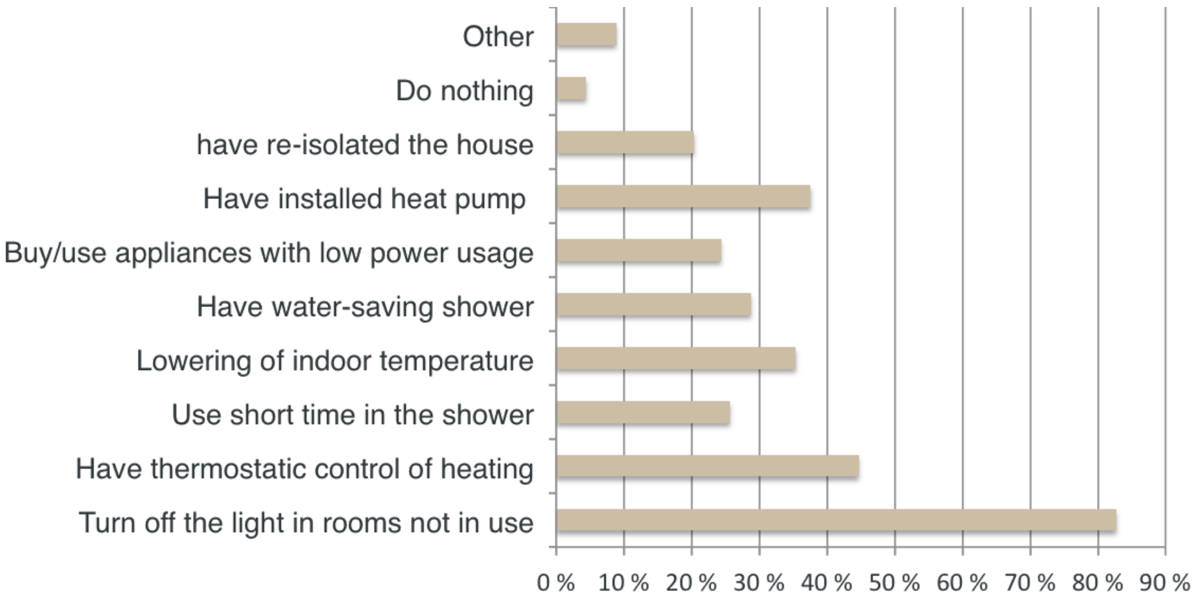
Question 8: How concerned are you with your own energy consumption?



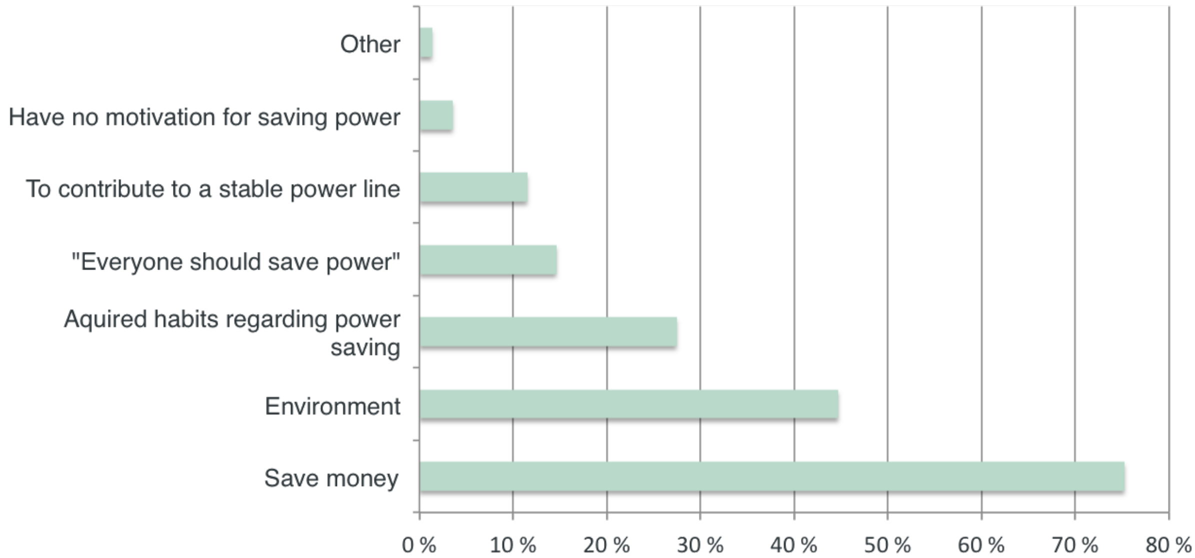
Question 9: How concerned are you with saving energy?



Question 10: What actions are you performing in order to save energy?

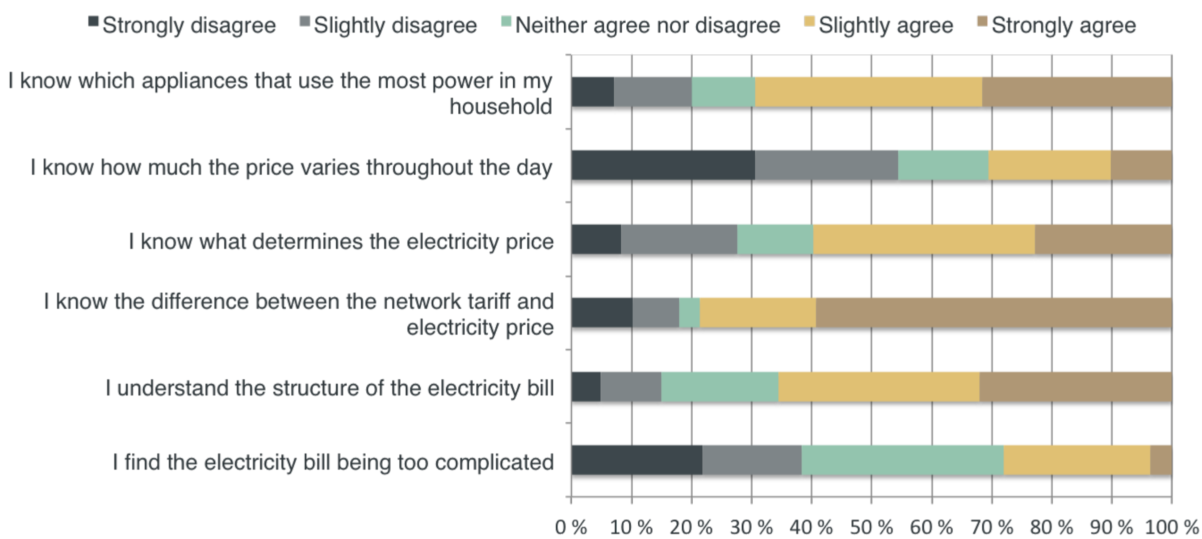


Question 11: What is your biggest motivation for saving energy?

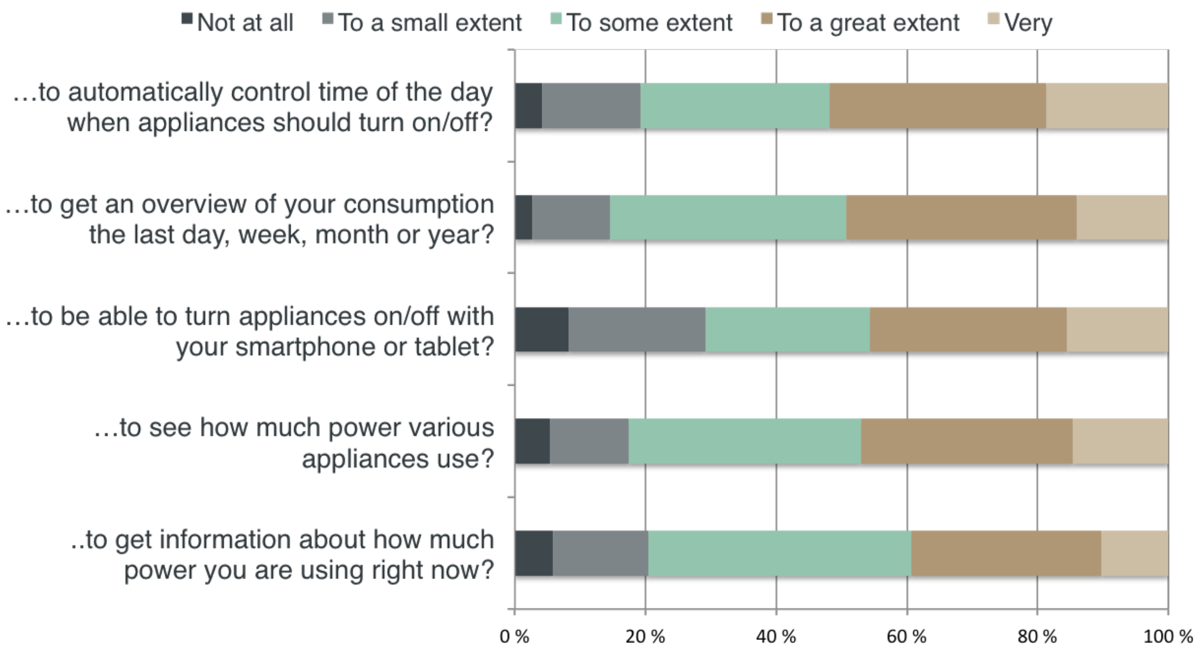


Electricity bills and electricity services

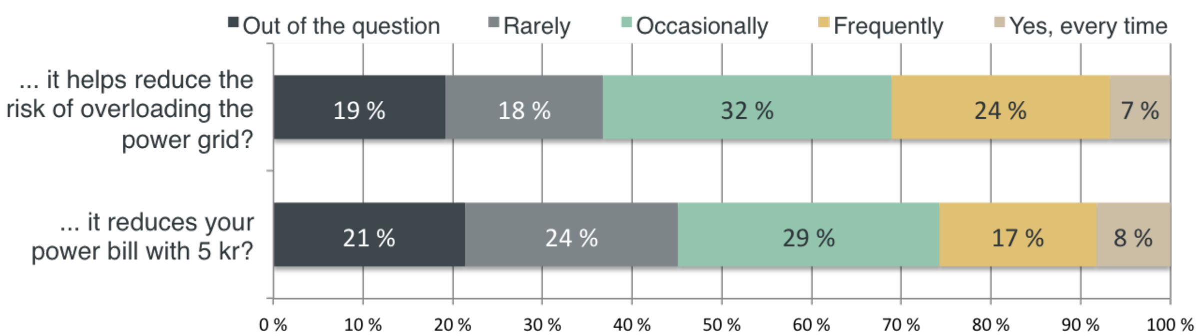
Question 12: To what extent do you agree with the following statements?



Question 13: How interesting is it for you to...



Question 14: If you are home one evening and remember that you need to wash your clothes, would you postpone the wash one hour if you know that...



C Home Made "Blink Counter", Minute Metering

In this appendix the code for implementing the blink counter is given.

```
import os
import RPi.GPIO as GPIO
import time
import datetime
import sys
from subprocess import call

GPIO.setmode(GPIO.BCM)
GPIO.setup(17,GPIO.IN)

kWh=0.00
x=1
yprev=0
xpre=0
y=0
s=1
t=0

def ReadButton(ButPin,prev):
    if GPIO.input(ButPin)==1:
        time.sleep(0.3)
        if prev==0:
            y=1
```

```
        else:
            y=0
    else:
        y=prev
    return y


def RCtime(RCpin):
    reading=0
    GPIO.setup(RCpin,GPIO.OUT)
    GPIO.output(RCpin,GPIO.LOW)
    time.sleep(0.1)
    GPIO.setup(RCpin,GPIO.IN)
    while (GPIO.input(RCpin)==GPIO.LOW):
        reading+=1
    return reading


while True:
    y=ReadButton(17,yprev)
    yprev=y
    n=0
    count=0
    timecount=0

    if t==0:
        print "Push button to start logging..."
        t=1

    while y==1:
        if n==0:
            timestamp = datetime.datetime.now().isoformat()
            filename="LogData"+str(timestamp)+".json"
            fid=open(filename,"w")

            print "Logging started..."
```

```
            fid.write("[")
            n=1
            s=0

        x=RCtime(4)
        y=ReadButton(17,yprev)
        yprev=y

        if (xpre-x)>0 and (x/xpre)<=0.7:#x<=13000:
            count+=1
            time.sleep(0.2)
        if time.time()-timecount>=60:
            timestamp = datetime.datetime.now().isoformat()
            kWh= float(count*60.0/500.0)
            print "kWh:␣%0.3f"% kWh +"\t"+"Time:␣"+str(timestamp)
            fid.write('{"timestamp":␣"'+str(timestamp)+'",␣"value":␣'+
                str(kWh)+'},␣\n')
            count=0
            timecount=time.time()
        xpre=x

    if s==0:
        fid.write("]")
        fid.close()
        print "Logging␣stopped..."
        t=0
        s=1
        logfile = "/home/pi/Dropbox-Uploader/dropbox_uploader.sh␣upload
            ␣/home/pi/"+filename+"␣"+filename
        call([logfile], shell=True)
        print "File␣uploaded␣to␣dropbox"
```

D SUS Form

Noen spørsmål om systemet du har brukt.

Vennligst sett kryss i kun en rute pr. spørsmål.

	Sterkt uenig				Sterkt enig
1. Jeg kunne tenke meg å bruke dette systemet ofte.	1	2	3	4	5
2. Jeg synes systemet var unødvendig komplisert.	1	2	3	4	5
3. Jeg synes systemet var lett å bruke.	1	2	3	4	5
4. Jeg tror jeg vil måtte trenge hjelp fra en person med teknisk kunnskap for å kunne bruke dette systemet.	1	2	3	4	5
5. Jeg syntes at de forskjellige delene av systemet hang godt sammen.	1	2	3	4	5
6. Jeg syntes det var for mye inkonsistens i systemet. (Det virket “ulogisk”)	1	2	3	4	5
7. Jeg vil anta at folk flest kan lære seg dette systemet veldig raskt.	1	2	3	4	5
8. Jeg synes systemet var veldig vanskelig å bruke	1	2	3	4	5
9. Jeg følte meg sikker da jeg brukte systemet.	1	2	3	4	5
10. Jeg trenger å lære meg mye før jeg kan komme i gang med å bruke dette systemet på egen hånd.	1	2	3	4	5

SUS
Norsk versjon ved Dag Svanæs
NTNU 2006

E Observation Form Summary

Task	Problem
Task 1 (illustr. 1)	• Participant 1: Tried to swipe to navigate to next image. • Participant 2, 3 and 4: Thought that the image was clickable. • Participant 3 and 5: Was not sure what the yellow appliance icons meant.
Task 1 (illustr. 2)	• Participant 1: Wondered what the red line that "flows in the air" meant. Found out in the next image. • Participant 2 and 4: Found it difficult to know what the prices meant.
Task 1 (illustr. 3)	• Participant 5: Found the circular graph harder to read than the horizontal graph. • Participant 6: Questioned the meaning of the dark red color indicating the consumption between 4 and 5 pm. • Participant 6: Perceived the dark green color as the yesterday's consumption. Understood the actual meaning in next instruction.
Task 1 (illustr. 5)	• Participant 5: Thought that the day-month-year buttons were clickable.

Task	Problem
Task 1 (illustr. 7)	• Participant 1, 5 and 6: Were unsure what the blue costs represented. • Participant 2 and 5: Did not understand why the potential saving was 237kr, and not the entire red cost at first.
Task 2	• Participant 1: Thought that October 1st showed all of October. • Participant 2: Missed the arrows from the illustrations, tried to swipe to navigate. • Participant 2 and 4: Found red text hard to read. • Participant 2: Struggled to find the cost for November 10. • Participant 3: Used time to click on year. Discovered after a while that the consumption was given in kWh, and clicked on kr. • Participant 4: Did not find the kr button at first. • Participant 5: Clicked on "Today" to find the correct month. • Participant 5: Thought that the hours on the x axis were days. • Participant 5: Browsed one day at a time to find the correct month.
Task 3	• Participant 1: Browsed forward to December before browsing backwards to find November 20. • Participant 5 and 6: Perceived the day view as month view, and tried to push on 10 am to get to November 10th. • Participant 2 and 7: Read the day value from the month view.
Task 4	• Participant 2: Browsed between months at first, thinking that the year information was before January. • Participant 2: Calculated the saving potential before the text was observed. • Participant 5: Was not sure what the bars in "today view" and bar in "appliance view" really showed. • Participant 4 and 6: Answered the red cost as the saving potential at first.

Task	Problem
Task 5	• Participant 1: Thought that the red costs were the savings potential. • Participant 2: Found it hard to know if the appliances were on or off. • Participant 2: Thought that the today's consumption was in history view. • Participant 4 and 6: Took care not to use power over the limit in green hours as well. • Participant 7: Tried to pull the bar in the appliance button to turn down the heater.