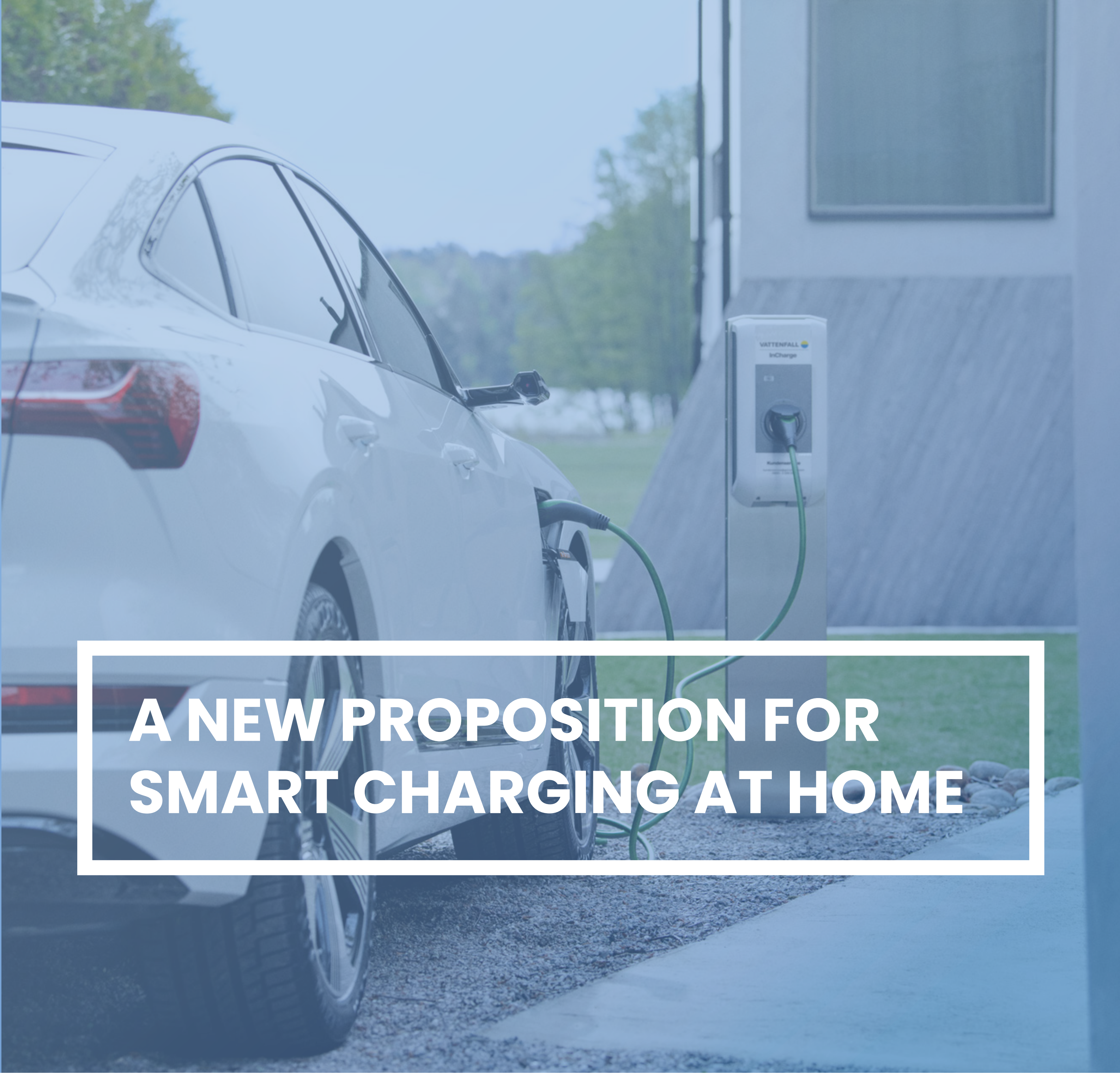

A NEW PROPOSITION FOR SMART CHARGING AT HOME

MASTER THESIS

MARE DE KONING

STRATEGIC PRODUCT DESIGN

TU Delft

VATTENFALL

MASTER THESIS
Mare de Koning 1

IN COLLABORATION WITH
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PREFACE

This thesis is my final project of my master Strategic Product Design at the Delft University of Technology. During this master, I have been taught by and worked with great people, collaborating to explore the world of strategic design. For this thesis, I have had the opportunity to work on a project in the energy domain in a time when the energy market was subject to volatile developments that had never been seen before. Doing the project therefore felt even more relevant. I want to thank Vattenfall for the opportunity to work on the topic of smart charging, and for giving me the freedom to pursue the direction that emerged during the project. Furthermore, I want to acknowledge and thank some of the people that have helped me during this project.

First and foremost, I want to thank my three supervisors. Harald, thank you for this interesting assignment, and your support during the project. Especially your enthusiasm and business oriented perspective supported me throughout this project. Evert, thank you for our weekly chats, in which your support varied from helping me discover a new way of looking at things to providing me detailed feedback on my approach or report contents. Thank you Sylvia for providing a solid foundation and guidelines for the entire project, to keep everything aligned while at the same time providing critical feedback on research methods or process. I have enjoyed the meetings that we have had together, in which we have not only discussed my project but also had a good laugh together.

I also want to thank the people that were willing to participate in my interviews and experiment, who were kind enough to dedicate time and effort to help me. I have spoken to many strangers and have enjoyed learning from them.

Lastly, thanks to everyone from the team of Vattenfall, that have made me feel part of the team and helped me in many ways.

For anyone taking the effort to read this report, good luck and enjoy. It has taken me some time to get acquainted with the subject, and hopefully I am able to introduce you or further inform you on the topic of electricity and smart charging. And hopefully you will become more aware of the future challenges of electrification and remember some take-aways that might be useful at some time in your own future.

Enjoy reading!

Mare de Koning

EXECUTIVE SUMMARY

Electric vehicles, electric cooking, heating installations running on electricity; the future is electric. This electrification creates a continuously growing demand of electricity. In addition, the growth of renewable energy resources are more weather dependent and therefore more volatile in electricity production. However, the electricity grid network is not able to transport these amounts of electricity. The grid network is facing problems already and even more so in the future.

Part of the problem is created by charging electric vehicles. As peak energy demand of a charging session of an EV's is approximately 10 times higher compared to a regular household demand (Geerts et al., 2020), this creates high peak demand on the local grid network. The challenge is to find better ways to charge these vehicles, especially in the future. This is what smart charging needs to do. Smart charging is adapting the time and or velocity of a charging session. The four goals of smart charging are: 1) reduce congestion problems, 2) support the increase of sustainable energy resources such as wind and solar, 3) minimize costs by charging during low demand and therefore low prices, and 4) make optimal use of at home sustainable energy resources such as solar panels.

An analysis of the context of smart charging uncovers various scenarios to achieve smart charging, three of which are simple scheduled charging using time-of-use (TOU) tariffs, charging to maximize local solar power, or charging using DLC, in which the supplier of the solution can steer the charging session according to real-time data.

In comparison to other competitors in smart charging solutions, Vattenfall has the ability to influence energy tariffs, which was also something recognized by consumers during interviews. Also, in the Netherlands, there are currently no relevant TOU tariffs available. Therefore, the development of a smart charging proposition primarily focused on the design of new TOU tariffs.

Based on analyses of available TOU tariffs abroad, energy market prices, literature and consumer input, two interesting TOU tariffs were developed. Tariff Short Peak is a tariff which applies a low price during night hours, a normal price during the day, and a peak price between 19h to 21h. The peak price should discourage people from using electricity during that time period - e.g. avoid to charge the car. The other tariff - called Daytime Plunge - offers a low price during the night and during the day from 11h - 17h, when solar power usually peaks and wholesale energy prices are usually low. Interviews to investigate desirability of both tariffs reveal that interest in these tariffs vary among consumers, and is partly determined by the financial advantage that results from such a new tariff, but also by the type of consumer and their personal needs and routines.

A behavioral experiment in which participants adopted one of the two tariffs was set up to investigate experience of - and behavior according to these new TOU tariffs. Participants were generally positive and expressed willingness to adopt such tariffs, if there is a financial advantage to it.

Next to the development of new TOU tariffs, it was found that giving a financial incentive for the other two scenarios of smart charging, namely charging using DLC and using your own solar power, interests EV drivers. In addition, DLC can serve as supporting technology that integrates TOU tariffs and maximization of solar consumption in the future.

Consequently, an implementation roadmap is suggested for Vattenfall on how to introduce these smart charging propositions. Three horizons are formulated in accordance with existing ambitions and Vattenfall's fossilfree mission. The horizons are formulated as follows:

1. Encourage improved electricity consumption
2. Support maximization of solar power consumption
3. Enable a self-sufficient home energy system and make EV's part of the decentralized grid

GLOSSARY & ABBREVIATIONS

This glossary defines some commonly used terms and abbreviations in this report. Although other definitions or meanings for the same term might exist, the definitions provided below are the definition that this report adheres to.

BPR = Balancing Responsible Party	A market player in the energy domain that is responsible for the balance of energy supply and demand in its portfolio
CTR = Click Through Rate	The percentage of people that click on an advertisment relative to the total number of views the ad received
DLC = direct load control	Remotely adjusting the electricity demand of a device (such as an EV) by ramping up, ramping down, (temporarily) pauzing or continuing the energy demand, controlled by an energy supplier or other organizaiton
DSO = Distribution System Operator	Organisation responsible for the physical transport of electricity on regional level (medium to low voltage)
EV = Electric Vehicle	A vehicle that runs on an electric motor. In this project, EV refers to passenger cars in particular
Network congestion	When the amount of electricity transported on the grid exceeds the maximum transport capacity.
RTP = Real time pricing	Highly dynamic electricity prices that fluctuate according to time frames of 1 hour, reflecting actual market prices
TSO = Transmission system operator	Organisation responsbile for the physical transport of electricity on national level (high voltage)
TOU = Time-of-use (tariff)	A tariff for electricity that fluctuates according to time blocks distributed over the day
UMC = User Managed Charging	Charging of EV controlled by the user of the system
VPP = Virtual Power Plant	An aggregation of energy producing- and consuming resources that are digitally connected so they can be centrally controlled and steered

TABLE OF CONTENTS

PART 1. INTRODUCTION

This part introduces the company Vattenfall, the scope of smart charging of electric vehicles and elaborates on the design assignment of this thesis. Furthermore, it introduces the reader to the structure of the report, which relies on the principle of 'design thinking'.

1.1 PROJECT SCOPE

1.1.1 VATTENFALL

Vattenfall is a Swedish owned international energy company operating in several countries in Europe, including the Netherlands. It supplies energy to around 2 million people in the Netherlands (Vattenfall, n.d.). Its ambition is to create fossil free living within one generation. To achieve this, they invest in and offer green energy (solutions) such as solar and wind energy, and partner up with businesses in other industries to contribute to lowering CO2 emissions in several domains (Vattenfall partnerships, n.d.).

Within Vattenfall, the business area of Customer & Solutions is responsible, amongst other things, to support customers in the energy transition (Group Vattenfall, n.d.). It is responsible to uphold and create (new) sustainable energy solutions and propositions. Valuable propositions are created “by accelerating digitalization and offering bundled and integrated solutions” (Group Vattenfall, n.d.). Within this business area, E-mobility plays a(n increasingly) big role. Vattenfall is aiming to support the electrification of mobility, by offering charging points amongst other things, both in the public and private context. The scope of this project will focus on electric vehicle (EV) charging in the private context, or in other words **electric vehicle (EV) drivers who charge their vehicles at home.** Research from ELaad has shown that more than 50% of EV drivers charge their EV at home (Duurkoop, et al. 2021), making this an interesting scope.

1.1.2 ELECTRIC CARS AND THE ELECTRICITY NETWORK

The number of electric vehicles will continue to increase in the coming years (Refa et al., 2021), and consequently the charging of EV’s will increase as well. This will pose a challenge to the electricity network (Ecar, n.d.). Charging EV’s on a large scale creates increased peak energy demand, which in turn leads to congestion problems in the distribution grid network. In addition, sustainable energy supply - on both national and local level - will increase in the future, which is less flexible in energy supply compared to the conventional (coal based) energy supply as it depends on weather conditions. The increase of EV energy demand and sustainable energy resources lead to a greater imbalance of energy demand and supply. Therefore, increased flexibility of the electricity network is required. To increase flexibility, smart charging of EV’s can pose as a solution. Simply said, smart charging is to adapt the speed and time of a charging session of an EV (ELaad, n.d.).

There are several goals of smart charging. By increasing flexibility in energy demand, the 4 main goals of smart charging are to 1) reduce congestion problems, 2) support the increase of sustainable energy resources such as wind and solar, 3) minimize costs by charging during low demand and therefore low prices, and 4) make optimal use of at home sustainable energy resources such as solar panels.

Figure 1: (left) solar panels on roof (jhorrocks/iStock) and (right)windmills (Vattenfall)

1.1.3 STAKEHOLDERS IN CHARGING EV’S

In the domain of charging EV’s, many stakeholders are involved, ranging from stakeholders in the electricity network, to the automotive industry and end consumers. Some stakeholders are energy producers, energy suppliers, transmission system operators (TSO), distribution system operators (DSO), aggregators, governmental institutions and regulators, car manufacturers, charging point operators, and diverse groups of end consumers. An additional interesting stakeholder that can be identified is called ELaad; an joint initiative from the seven Dutch DSO’s. Their ambition is to make smart charging a standard practice, and supports this by doing research and testing. Furthermore, the ‘nationale agenda laadinfrastuctuur’ (Agendalaadinfrastructuur.nl) is an joint initiative from the government and network operators that provides a roadmap to achieve smart charging infrastructure. In a recently published report on market consultation for smart charging, they urge organizations to become a provider of smart charging and offer guidelines and information, for example of the different goals of smart charging, to facilitate the process. Looking at the domain of smart charging in particular, there are some organizations that offer smart charging already. For example a provider of a smart charging application called Jedlix (Jedlix, n.d.), or an energy supplier such as Eneco (Eneco-Emobility, n.d).

1.2 PROBLEM DEFINITION

Smart charging can contribute to the energy transition on multiple levels. Firstly, on a national level with regards to sustainable energy sources, on a regional level to congestion challenges and on a local level to sustainable home energy supply. Furthermore, it provides a financial opportunity to various stakeholders in the system. However, these various levels and goals pose a complex system in which suppliers, users and other businesses must collaborate to create a system that is valuable to all. Vattenfall wants to offer smart charging to its current and future customers, but is not sure how to design the most valuable proposition. Therefore, the question is: ‘How can Vattenfall offer a valuable proposition to enable EV drivers to make use of smart charging at home?’
A number of areas can be distinguished and should be considered in order to come to a valuable proposition.

1) EV’s drivers’ preferences and barriers in a smart charging solution, for example regarding the control of users and main goals of the system, and the potential integration of smart charging into the home energy management system.
2) Internal organisation and external partnerships to be able to offer a smart charging proposition.
3) Opportunities and threats of Vattenfall to pursue a smart charging proposition.

RESEARCH ASSIGNMENT
Design a valuable proposition and accompanying implementation plan to enable EV drivers to use smart charging from Vattenfall.

A valuable new proposition should enable EV drivers on the short term to make use of smart charging, while the implementation plan elaborates on how Vattenfall should introduce and develop the proposition over time. The implementation plan should be based on the new proposition, combined with recommendations on preferred user interaction with the system.

1.3 PROJECT APPROACH AND REPORT

1.3.1 STRUCTURE OF THE PROJECT AND REPORT

The report is structured according to the design methodology that was applied in the project called 'the Double Diamond' (Design Council, 2019). The double diamond is a methodology that divides the design process into four parts, also called phases, as illustrated by figure 3.

The first diamond starts with a diverging phase, which is explorative and seeks for opportunities. Then, a converging phase aims to synthesize these findings and discover a new focus point. The second diamond starts with a diverging phase again, to explore solutions for the new focus. Then in the last converging phase, everything is brought together and a final design is made.

In all phases, the project is analyzed using three points of view; that of technology, business and customers. These three can also be associated with the three elements for innovation; feasibility desirability and viability.

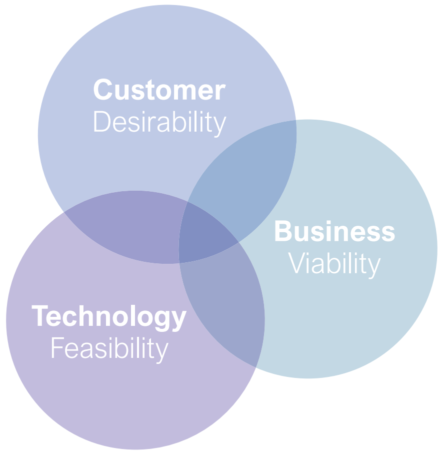


Figure 2: Trifecta for innovation

1.3.2 DISCOVER, DEFINE, DEVELOP, DELIVER

The first diverging stage, known as '**discover**', dives into the broad domain of the subject of smart charging. It ensures exploration in the depth and breadth of the problem and associated constructs. Therefore, it includes a technology analysis, competitor analysis, internal analysis, as well as a literature review, and insights from user interviews that were conducted.

Secondly, the **define** phase aims to synthesize the most important insights from the previous phase. Thereafter, a new focus is defined that narrates the design challenge for the remaining of the project.

During the **develop** phase, the design challenge which was formulated in the define phase is explored. New solutions are drawn up and users are involved in the process to ensure desirability of the solutions.

Deliver is where everything comes together. The design is put into place within broader context. It adresses the question of how Vattenfall should deliver the proposed design and what strategy should be pursued.

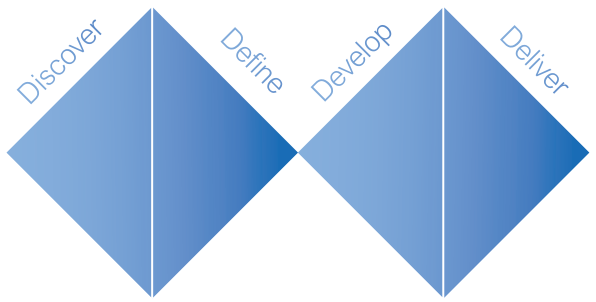


Figure 3: the double diamond and its four parts

1.3.3 INFORMATION FOR THE READER

A number of things need to be established in order to comprehend this report and its content.

CONTEXT

- Everything in this report is related to or based on the Dutch energy or electricity market, unless stated otherwise.

DEFINITIONS

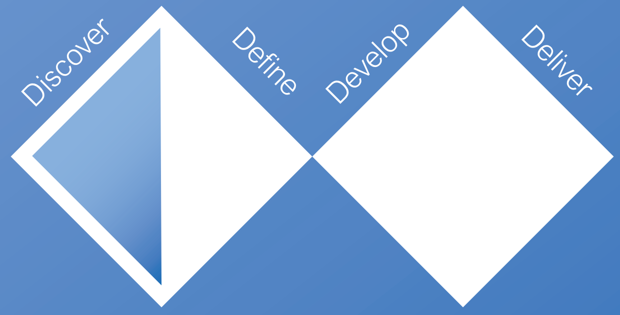
- According to some definitions, smart charging is only considered *smart* if it includes real-time data and steers charging sessions automatically. However, this project and report adheres to a 'simpler' definition of smart charging: charging is considered smart if *either it's timing or velocity is changed.*

- Although they are not the same thing, *energy* and *electricity* are sometimes used interchangeably in this report. Energy can be delivered in many forms, of which electricity is one. Because this report focusses on electricity, and not on other energy resources, the word energy is sometimes used instead of 'electricity' in particular.

- When solar power is mentioned, it often refers to the solar energy generated by solar panels on an individuals' roof.

PART 2. DISCOVER

To explore the domain of smart charging, this part elaborates on numerous subjects related to smart charging. It dives into the context of electricity, methods for smart charging, and current smart charging solutions. A literature review provides insights into user preferences and behaviors in (smart) charging EV´s. In addition, an internal analysis provides the context and abilities of Vattenfall related to emobility. Finally, to better understand the Dutch EV driver, user interviews are conducted and analyzed.



2.1 TECHNOLOGY ANALYSIS

Simply said, smart charging is to adapt the speed and / or time of a charging session of an EV. There are various ways to do this, some 'smarter' than others. However, before going into the concept of smart charging, it is important to describe some associated topics that enable or influence smart charging. Therefore, this chapter first gives a brief introduction to associated topics such as the Dutch electricity network, and then explains smart charging in more detail.

2.1.1. TECHNOLOGY CONTEXT OF ELECTRICITY AND THE ENERGY SYSTEM

The topics that will be discussed to get an understanding of the context are the Dutch energy system, network congestion, the energy imbalance market, energy tariffs, and local solar power.

THE DUTCH ENERGY SYSTEM

As explained before, the energy system consists of many stakeholders. As the scope of this project focusses on the energy system in the Netherlands, it's important to establish the general situation of the main stakeholders and how they interact. In the Netherlands, the energy market is liberalized (since 2004 (ACM, 2007)) and consumers are free to choose their own energy supplier. *Energy suppliers* are responsible for trading energy between producers and consumers; they buy energy from energy producers or other energy traders and sell it on to consumers through energy contracts. Some energy suppliers, including Vattenfall, also produce energy themselves. However, this production role is of little importance for the scope of this project. Therefore, Vattenfall's role in this report will be focused on its energy supplier (and trading) capabilities rather than production facilities. Whereas the energy suppliers and producers are responsible for trading energy, the *grid operators* are responsible for the physical transport of energy. There is one national operator for the transmission network (TenneT) and there are seven grid operators for distribution networks, each operating in their own region (Minder.nl, n.d.). Consumers are required to pay fees for their grid connection, which are paid to energy suppliers and who passes them on to the grid operators (Enexis, n.d.). The simplified visualization below (figure 4) shows the most important stakeholders and their role, including Vattenfall to represent the role of an energy supplier.

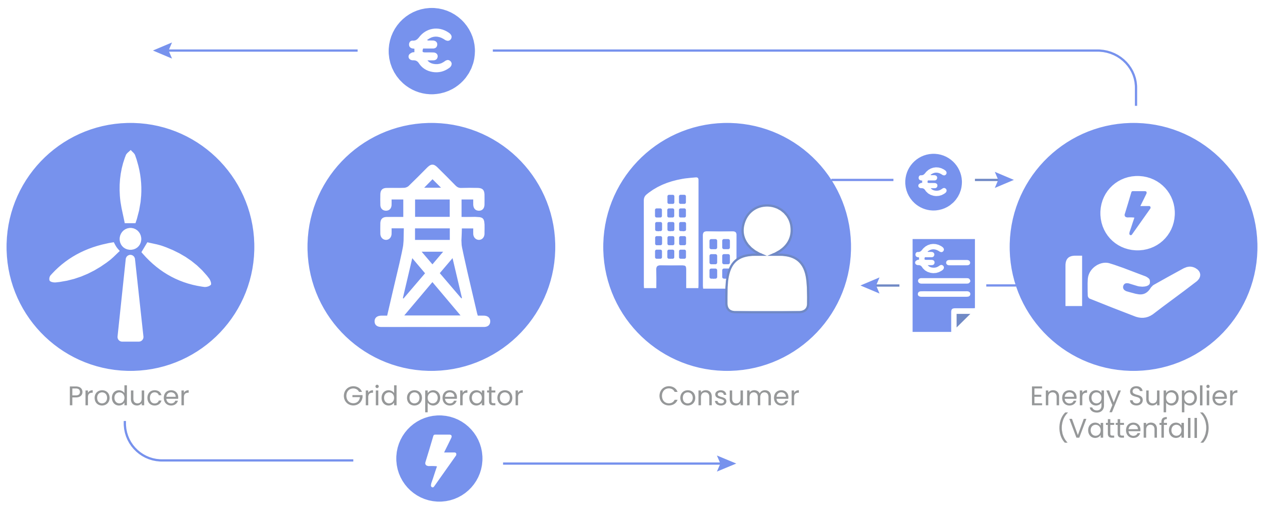


Figure 4: visual respresentation of the Dutch energy system and the most important stakeholders

NETWORK CONGESTION

The electricity network has a limited transportation capacity, which determines the maximum amount of electricity that can flow through the network. When the total amount of transported electricity exceeds the maximum capacity, network congestion occurs (Liander, n.d.) (as illustrated by figure 5). To avoid network congestions, grid operators apply two main strategies. For the long term, grid operators are increasing the capacity of critical parts of the network by physically enlarging network cables. For the short term, grid operators apply congestion management, which is the trading of buy- and sell-orders on the short term energy market to ramp down energy production or consumption in places where congestion is about to take place (Mastenbroek, 2022). Every energy trading company, thus including energy suppliers, can voluntarily participate in these orders.

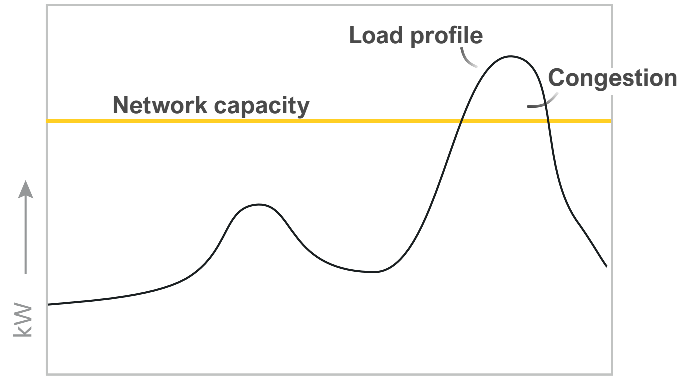


Figure 5: illustration of network congestion

IMBALANCE MARKET

All electricity in the grid network should remain in balance at all times (Tennet, n.d.). This means that the amount of energy produced should always be equal to the amount of energy consumed. All energy trading companies in the Netherlands, including energy suppliers, are responsible for its own (portfolio) balance, and are a so called Balancing Responsible Party (BRP) themselves, or are represented by one. BRP's are required to balance their energy consumption and production at all times. However, due to irregularities, imbalances can arise. To deal with these imbalances, electricity is traded on the imbalance market, the aFRR (NextKraftwerke, n.d.). This market is regulated by the TSO, who is responsible for keeping the electricity network balanced. The TSO determines how much energy needs to be added to or subtracted from the network and places orders accordingly. Those BRP's who were responsible for creating the imbalances, are fined. Those who help solve the imbalances by trading energy on the imbalance market, are rewarded (Tennet, n.d.).

The concept of imbalance and the imbalance market is relevant to the topic of smart charging because it explains how organisations can use the (flexible) energy demand of EV's to act upon energy imbalances, and save or earn money doing so.

ENERGY TARIFFS

Consumers pay a price for their electricity consumption, which is determined by the energy tariffs (price / kWh) and *structure* of tariff. The price itself will not be discussed in further detail, as this simply varies from time to time. The structure of the tariff, on the other hand, is more interesting. In general, the most important distinction in energy tariff structures is that between a flat tariff, also called single tariff, and a time-of-use (TOU) tariff, which includes a wide variety of possible tariff structures (see figure 6). In contrast to flat rates, in a TOU tariff the energy prices vary during the day (or season) and customer pays the price that applies during the time period the electricity is consumed. Within TOU tariffs, there is a distinction between static and dynamic tariffs. In static time-of-use tariffs the prices are set in advance, and vary according to 2 or more time periods during the day (and / or season), often referred to as 'peak' and 'off-peak' hours. In the most dynamic variant of dynamic time-of-use tariffs - called 'real time pricing' (RTP) - prices are not set in advance and vary each hour and each day, reflecting actual market prices. To make smart charging financially attractive for customers, energy contracts with static time-of-use rates or dynamic rates are interesting, which will be discussed later on.

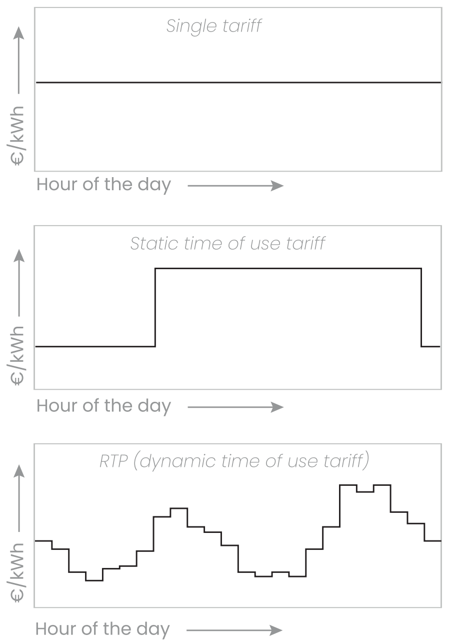


Figure 6: visual representation of most important different energy tariff structures

In the Netherlands, energy suppliers offer flat tariffs, a static time-of-use tariff and only a few suppliers offer RTP (Woldring, 2022). Currently, the static time-of-use tariff available in the Netherlands is divided into two time blocks (see figure 7), its hours determined by grid operators (Pricewise, n.d.). Off-peak hours during weekdays start at 21 p.m. in the two most southern provinces, at 23 p.m. in the other provinces, end at 7 a.m. everywhere, and apply all day long during weekends and public holidays. This is called the 'dubbeltarief' in Dutch.

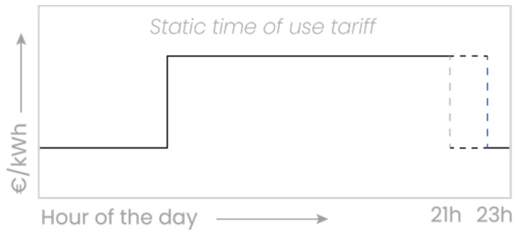


Figure 7: the time-of-use tariff in the Netherlands ('dubbeltarief')

Over the last several years, Vattenfall has experienced a decline in users with contracts for static time-of-use rates (De Boer, A., 2022, personal communication, October). This decline can be explained by two main reasons. The first one is the decrease of the price difference between off-peak and peak hours, and thus the financial advantage that this tariff structure offers. The second is the practical reason that the communication signal of the time-of-use tariff to old energy meters has been discontinued since 2021 (Enexis, 2021). Therefore old energy meters, which still occur in some households, can no longer comply with this TOU tariff structure.

LOCAL SOLAR POWER

Solar power generated by panels on people's home is important for the scope of smart charging for two reasons. Firstly because one of the four goals of smart charging is to make more use of renewable energy resources, including local solar panels. Secondly, around 79% of all EV drivers who charge their vehicles at home also owns solar panels (Wolterman et al., 2022), which therefore makes it inherently a part of the system.

An important characteristic of solar power is the concept of '*behind-the-meter*'. Normally, electricity flows through the grid network, through the meter and into your home. However, *behind-the-meter* means the power generated by ones solar panels will flow through the home energy system and will be 'consumed' by appliances directly, without interference of the electrical meter. Only when there is an excess of solar electricity that is not used in the home directly, the electricity flows 'through the meter' and is 'fed' back into the grid (figure 8). Currently, under Dutch legislation, all electricity that you feed back into the grid, is subtracted for 100% from the energy that you have consumed on a yearly basis ('salderen' in Dutch) (Van der Wilt, 2022). For example, if your solar panels feed back 10kWh on a sunny day, and you use 10kWh electricity (from the grid) the next day, the net consumed energy will balance out to 0, and no costs apply; this is also called *net metering*. However, new regulation is put into place that will gradually decrease the compensation, starting from 2025, by lowering the percentage of the solar energy that can be subtracted from your total energy consumption each year (see table 1 for the decrease over the years) (Zwaan, 2022). This means that currently, it makes no (financial) difference whether you use your solar power directly or feed it back into the grid. However, the decrease in compensation in the future means people will be incentivized to directly use or store their solar energy.

Furthermore, if a household produces more solar power than it consumes on a yearly basis, they receive a financial compensation for every kWh production surplus (Van der Wilt, 2022). This compensation varies among energy suppliers, but is often only a fraction of the price you pay for energy.

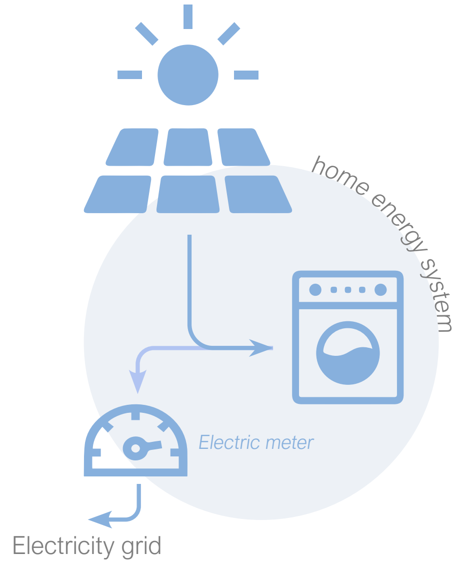


Figure 8: illustration of 'behind-the-meter' concept

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Percentage	100%	100%	100%	64%	64%	55%	46%	37%	28%	0%

Table 1: decrease of deductable solar energy from total energy consumption over the years (data from Zwaan, 2022)

2.1.2 CURRENT SMART CHARGING METHODS

Now that some associated concepts relevant to smart charging are established, this section will introduce some methods of how smart charging can be applied. As stated before, smart charging is to optimize the speed and/or time of a charging session of an EV. Smart charging methods can range in 'smartness', from rather simple implementations, such as manually plugging in your vehicle at more optimal times, to more sophisticated solutions that digitally connect EV's to the grid and automatically optimize charging sessions according to real time data. In this section, the most prevalent smart charging methods will be described. In general, smart charging can use three main input variables; energy tariffs, solar power, and real-time data from network congestion or energy imbalances.

(Examples of solutions that are offered as integrated propositions to consumers will not be discussed here, but in *2.2 Competitor analysis*.)

SIMPLE SCHEDULED CHARGING (ACCORDING TO STATIC TOU TARIFFS)

Scheduled charging is a commonly used approach to adopt 'smart' charging. Although not truly smart due to the lack of any real-time data integration, scheduled charging is a way to postpone charging sessions to a specific point in time, and therefore it optimizes the time of a charging session. Users can decide to physically plug in the charger at a later point in time, or control the charging session through the interface of the car or a charging application to postpone the start of a session. Often, scheduled charging is adopted to make use of cheaper energy tariffs (concluded from chapter *2.5 User interviews*) (illustrated by figure 9). Cheaper tariffs are offered in off-peak hours of the time-of-use tariffs. Insights from user interviews, see section 2.5 *User interviews*, reveal EV drivers are aware of this option and research from Duurkoop et al. (2021) shows around 25% of all EV drivers in the Netherlands use this simple way of 'smart charging'.

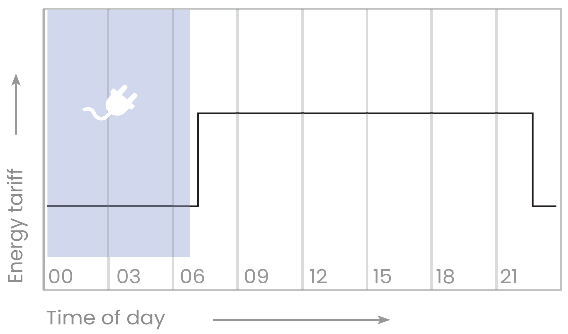


Figure 9: Simple scheduled charging

PRIZED OPTIMIZED CHARGING (USING DYNAMIC ENERGY TARIFFS)

Prized optimized charging is a solution similar to scheduled charging, however, with higher optimization possibilities due to shorter tariff time blocks. These shorter time blocks are enabled by dynamic energy prices, which are prices that vary by the hour. Using an app, the charging system adapts the time and speed of charging according to the cheapest tariffs during a specified – and plugged-in – period (see figure 10). Users can, for example, enter a departure time in order to specify the time period, and the system decides when to charge. Stekker is an example that offers this kind of smart charging (Stekker, n.d.).

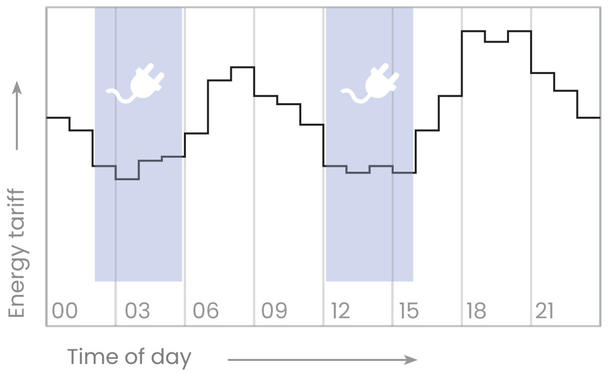


Figure 10: prized optimized charging using a dynamic tariff

2.1 TECHNOLOGY ANALYSIS

MAXIMIZATION OF LOCAL SOLAR POWER

Next to priced optimized possibilities, another smart charging possibility is to optimize for the use of solar power. Users can steer their sessions in such a way that (left-over) energy from their solar panels is used to charge their car. Again, this can be achieved either manually by plugging in their car when users notice an overload of solar power, or by using an application that automatically stops and starts charging accordingly (Jedlix, n.d.).

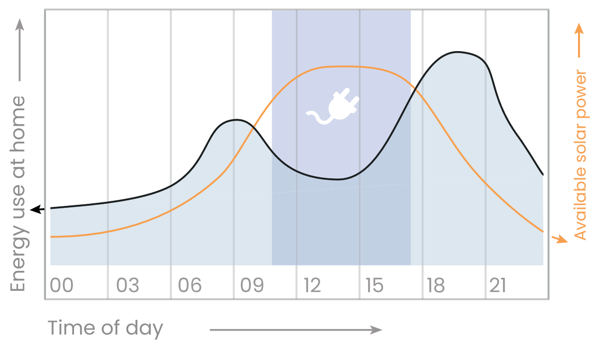


Figure 11: charging using excess solar power

A little side note to this method is discrepancy between the power generated by the solar panels and power consumption of the charging session. Solar panels at home usually do not generate enough power to charge the car at the desired speed (Tüzes & Van Barlingen, 2022). Therefore, charging an EV often requires additional electricity from the grid.

DIRECT LOAD CONTROL (DLC) ACCORDING TO GRID CONGESTION AND IMBALANCES

All charging methods described above operate on the electricity network on the home-level. However, smart charging is also applied at the electricity network on a neighborhood and even national level through something called *direct load control* (DLC) operated by a supplier and using real time data.

Individual EV's can be virtually connected to create a pool of EV's and be integrated into a Virtual Power Plant (VPP) (Zhang, 2022). A VPP is a collection of energy generators and consumers (e.g. energy storage systems), which is flexible in its energy production and -consumption. The pool of EV's within a VPP can act as a power consumer (in the future, if vehicle to grid possibilities are enabled, they can potentially also acts as producers). By ramping up or slowing down power consumption of a large pool of EV's through a VPP, the system operator can contribute to avoid energy imbalances and network congestion. For instance, if congestion is forecast, EV's charging sessions can be slowed down, thereby avoiding congestion problems. The charging sessions (and thereby load) are controlled directly by the supplier of the smart charging solution - which is why it is called direct load control. Due to the control of the supplier, this way of smart charging is also referred to as Supplier Managed Charging (SMC), because the supplier of the system steers the charging session according to real-time data from energy markets and prices.

Not only does this way of smart charging support the electricity grid, it also provides opportunities for financial gains. These financial gains are created in multiple ways. First of all, as described in section *2.1.1 Imbalance market*, imbalances of a BRP's portfolio are fined. If a BRP (the supplier) is able to minimize it's imbalances through DLC, the imbalance costs will be minimized as well. Secondly, because BRP's that help to solve imbalances are rewarded, BRP's can earn money to actively solve imbalances by ramping up or down energy demand. Thirdly, helping to solve local congestion can also be financially rewarded by grid operators (ACM, 2022).

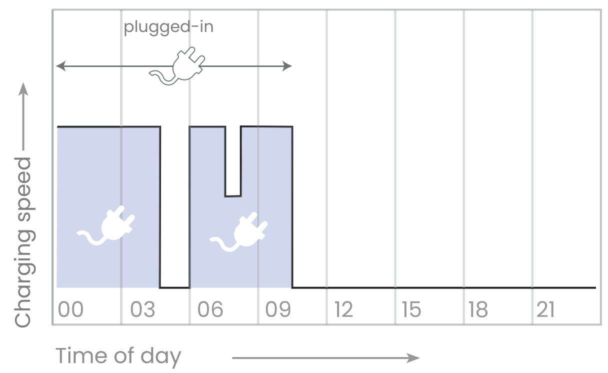


Figure 12: charging session using DLC

COMBINATIONS
The discussed methods in this chapter do not necessarily exclude one another. Some of these can be combined, for example scheduled charging that also uses direct load control. However, it should be considered that optimization for two of the above described methods might not always coincide and one method contradicts the desired charging times of the other.

2.1.3 CONCLUSION
Smart charging possibilities can operate on a number of levels, which have a different approach. On a home-level, smart charging is achieved by scheduled charging (either simple or dynamic) or optimizing for local solar energy. On a larger level, by integrating a large pool of EV's into a virtual power plant, smart charging can provide flexibility in energy consumption through direct load control. With the provided flexibility, smart charging can contribute to avoiding network congestion and electricity imbalances. Table 2 shows the summary of the method of smart charging, the level on which it operates and any requirements, if applicable.

Systemlevel	Method of charging	Requirement
Home	Scheduled charging	TOU tariffs
	Prize optimized charging	Dynamic tariffs
	Maximization of local solar power	Solar panels
Neighbourhood	Load control for grid congestion	Real-time data
National	Load control for imbalances	Real-time data

Table 2: overview of systemlevel, methods of charging, and requirements

2.2 COMPETITOR ANALYSIS

Even though smart charging is not widely adopted yet (NAL, 2022), there are several organizations that offer smart charging solutions or propositions related to it. The most well-known organizations will be discussed, as well as the type of solution they offer. The organizations are categorized according to three domains; the car industry, energy suppliers and smart charging platforms.

2.2.1 ORGANISATIONS THAT OFFER SMART CHARGING SOLUTIONS
Various parties enable EV drivers to make use of smart charging solutions. It's important to acknowledge a number of things related to these organisations and solutions. Firstly, not all provided solutions are equally smart, but if either the time or velocity of a charging session is adapted, it will be considered smart within the scope of this project. In addition, some of the solutions here are smart charging solutions which can stand on its own, while others require users to adopt additional products or services before they can charge smartly. Lastly, it should be noted that this competitor analysis is framed from Vattenfall's point of view; from that of an energy supplier involved in e-mobility.

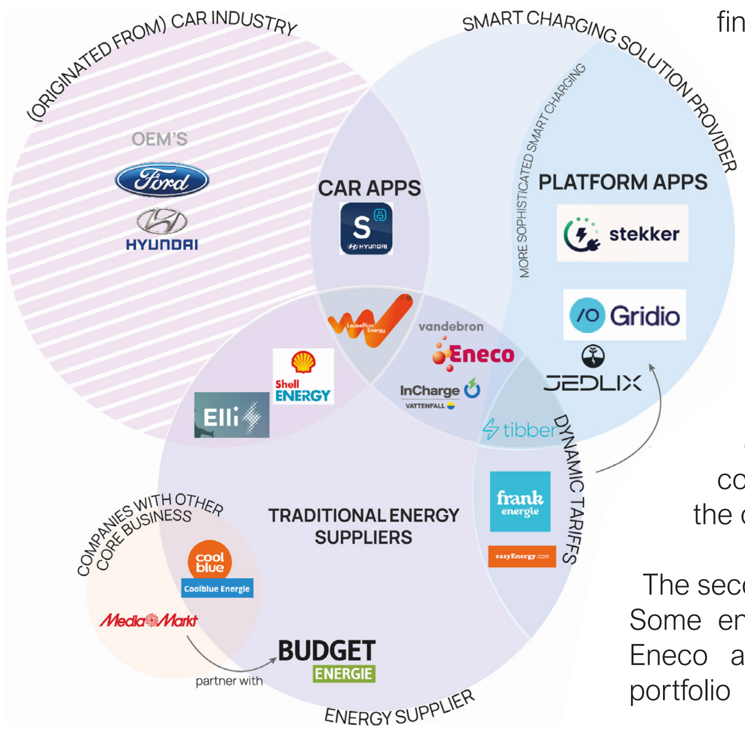


Figure 13: competitors organized according to three domains

Looking at the organizations that offer (part of) smart charging solutions in the Netherlands, three main domains of competitors can be identified: companies that originate from the car industry, smart charging solution providers and energy suppliers. In figure 13, the most relevant organizations for each of these three domains are identified. As can be seen from this figure, several organizations operate on the intersection of two or even three of these domains. The visualization may suggest a 'sweet spot', the area where all three domains intersect. However, this is not necessarily the 'best' position, rather it simply shows where the organization originated from and what it offers.

THE THREE DOMAINS
Organizations that only reside in the area of 'car industry' are not considered direct competitors but are simply shown for completeness and will therefore not be discussed any further. Many **car manufacturers** offer an app that enables users to specify time periods and schedules for charging, which thereby enables *simple scheduled charging*. Using this simple functionality, people can steer their car to charge, for example, during the night, with the aim to charge at lower costs or contribute to balancing the electricity grid. Looking at the intersection with energy suppliers, you can find car-related organizations that have recently become energy suppliers, such as Elli (energy supplier from Volkswagen) (https://www.elli.eco/en/volkswagen), Shell Energy (https://www.shellenergy.nl/) and LeasePlanEnergy (https://leaseplanenergy.com/). Leaseplan Energy offers an integrated proposition to lease drivers, including DLC functionality. And even though Elli does not provide significant smart charging solutions yet, it is a notable competitor due to its close connection to the car.

The second domain is that of **energy suppliers**. Some energy suppliers, for example Vattenfall, Eneco and Vandebron, have expanded their portfolio by moving into the emobility domain by offering charge points (Keuze.nl, n.d.). More recently, these energy suppliers offer simple smart charging applications, similar to those as offered by car manufacturers. Examples are apps from Eneco (Eneco SlimLaden, 2022) and Vattenfall Incharge (Vattenfall AB, 2022). These solutions enable scheduled charging, although Eneco also enables users to charge on their solar energy and using DLC (Eneco Emobility, n.d.). Another interesting proposition related to smart charging solutions is provided by a disruptor in the Dutch energy supplier domain. Recently, new-to-the-market energy suppliers are offering dynamic energy prices with real time pricing. Frank Energie (www.frankenergie.nl/) and EasyEnergy (www.easyenergy.com/) are examples of such suppliers. As discussed before, dynamic energy prices are highly interesting for smartly charging your car because of the large financial savings potential. Some of these suppliers are also in the domain of smart charging provider, as they focus on smart charging in particular and offer appropriate solutions, for example Tibber (Tibber slim opladen, n.d.).

Thirdly, a new domain has evolved in which **smart charging solutions** are provided **by third parties**, who have no relation to the car nor supply energy themselves. A notable provider here is Jedlix (Jedlix.com). Jedlix had initially started as a B2C platform that dynamically steers charging sessions by making use of a VPP and DLC (Jedlix, n.d.). However, over the last years, Jedlix has turned into a B2B organization, developing white label apps for other companies such as OEM's and energy suppliers. Other providers here are platforms that dynamically steer session according to dynamic tariffs, like Stekker and Gridio (Stekker, n.d.) (Gridio, n.d.).

TRENDS AND CONCLUSION

Within this spectrum of competitors, there are several relevant trends that should be noted. First of all, several companies which have previously only operated in a different domain have moved into the energy supplier domain, for example CoolBlue, Elli and LeasePlan. Probably induced by the prospects of electrification, as well as a possible future decline of the market they currently operate in as a consequence, companies have seen and see a growing market for electricity and want a share. Secondly, enabled by technological advancements such as the smart meter, new energy suppliers have entered the market offering dynamic energy prices (Breukelman, 2022). Although the exact number of customers is not clear, the number of providers has increased over the past few years (Koenraadt, 2022). Dynamic energy prices can be interesting for people who want to adopt prized optimized smart charging, as price variation is high and therefore high savings can be achieved. Furthermore, all three domains more or less provide the same solutions regarding smart charging, and users have the opportunity to adopt smart charging through a platform provided by either their car, energy supplier or third party.

2.2.2 SMART CHARGING SOLUTIONS

This section elaborates on the most interesting smart charging solutions provided by organisations in each of the three competitive domains.

SOLUTIONS FROM CAR-RELATED ORGANISATIONS

Car manufacturers

To analyze the current solutions of car manufacturers, the apps of the 10 most prevalent EV brands are considered (Duurkoop et al., 2022). In general, the main functionalities of the apps are very similar, and enable users to specify (a) time block(s) to charge their EV's, as well as a weekly schedule to adhere to. Some variety between the apps exist in the way to set the timing for charging. It requires users to indicate either a departure time (using backwards calculation to start a charging session), a 'start charging' time, or a time period (e.g. the off-peak period), or sometimes a combination of it. In the case of specifying an off-peak period, some apps provide the option to choose between sessions that charge *only* during off-peak hours, or that *prioritizes* charging during off-peak. In some cases, the app enables users to alter the amount of ampere that it uses to charge (for example Tesla). Lastly, in some car apps (for example Hyundai & Renault (Hyundai SmartCharging, 2022) (Mobilize smart charge, 2022)), users can indicate the percentage of the battery that they want to have charged immediately, before the charging session should switch to smart charging. In this case, smart charging applies direct load control, so the supplier dynamically steers the EV's charging session.

Car-related organisation x energy supplier

Shell Energy's offering is quite similar to a regular energy supplier. However, their unique

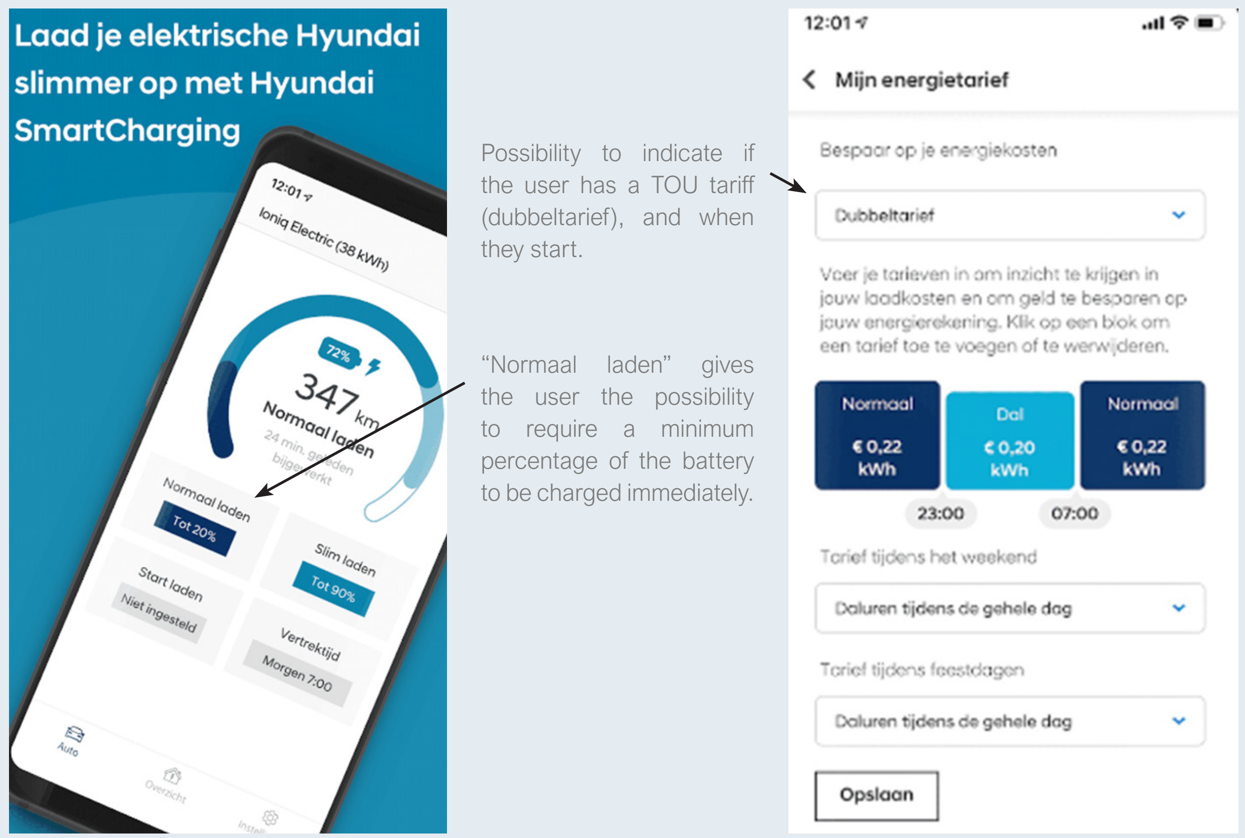


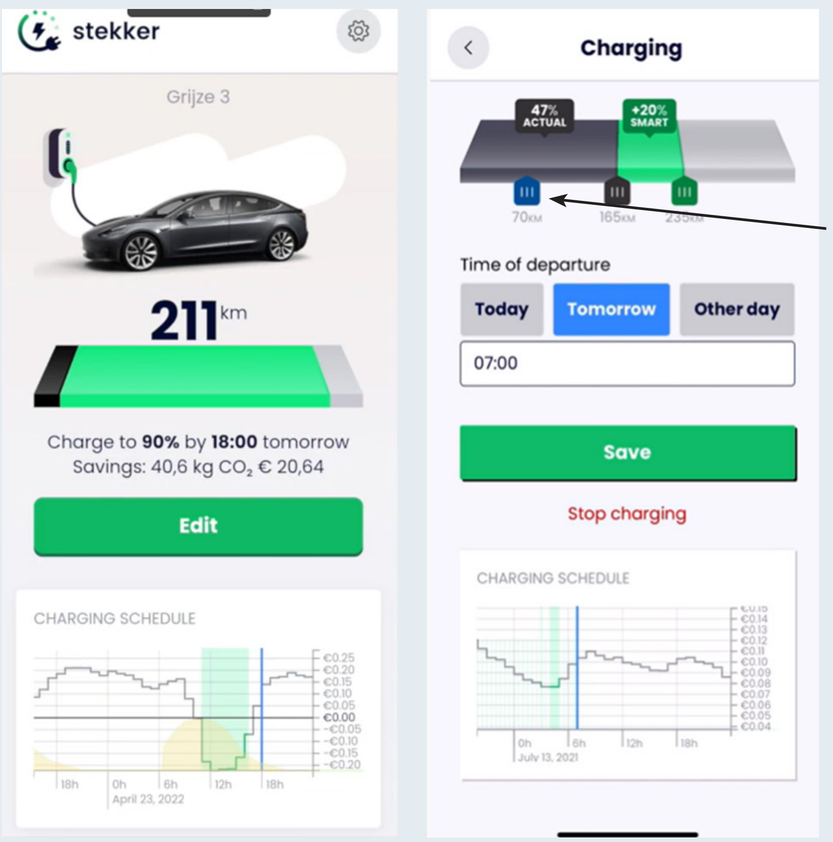
Figure 14: smart charging application by Hyundai (Hyundai SmartCharging, 2022)

proposition is the discount offered on public charging sessions at Shell Recharge locations. The Shell Recharge app also enables users to apply scheduled charging. LeasePlanEnergy is specifically developed for people who drive leased cars, as their proposition directly invoices the charging costs to the employer. Similar to Hyundai, LeasePlan also seems to offer smart charging functionality based on DLC, although it is not clear if this is fully functional yet.

SMART CHARGING SOLUTION PROVIDERS

Jedlix
Jedlix has developed apps for several OEM's and energy suppliers, which makes it an interesting player within the competitor analysis. Through Jedlix's integration with a virtual power plant, it can offer companies a smart charging solution with direct load control without the need for companies to integrate with a VPP themselves. By making use of a VPP, Jedlix dynamically steers charging session according to real time market data, thereby saving on electricity costs or earning money. Part of these savings or earning are then passed on to the end-consumer. More on Jedlix can be found in *2.4 Internal analysis*.

Stekker (similar to Gridio)
Stekker is an example of a 'third' party – with no connection to a car manufacturer nor an energy supplier – that offers prized optimized charging according to time frames of 1 hour (see figure 15). To be able to do that, it requires the user to have a contract with dynamic energy prices (which is not very prevalent at this time). Dynamic prices and consumer acceptance will be discussed in further detail in section *2.3.3 TOU and dynamic tariffs*. In short, dynamic prices are interesting for charging ones car, however, energy prices apply to the entire household which poses a large disadvantage.



Also Stekker enables a 'direct' charge battery requirement in addition to smart charging. Smart charging in this case is according to dynamic energy prices. Users need to indicate a time of departure, so the system knows when it should be fully charged.

Figure 15: smart charging application by Stekker (Stekker, n.d.)

ENERGY SUPPLIERS
Traditional energy suppliers
As previously discussed, some traditional energy suppliers offer smart charging solutions. Eneco offers a similar application like the one offered by Hyundai. This can be explained by the fact that these apps are developed by Jedlix and therefore have similar functionalities. Vattenfall offers simple scheduled charging through their Vattenfall InCharge app, and Vandebron seems to prepare to provide a smart charging application in the near future. Vandebron has not launched its application yet, but displays their future proposition on their website already. It offers monetary compensation for direct load control to balance the grid, and does not provide a scheduled charging functionality. Another possibility for energy suppliers that offer charge points, is to rely on the charge point supplier for smart charging functionalities, like Engie does with the EVBox charge point (Engie, n.d.).

Dynamic energy tariff providers
Dynamic energy tariffs are based on real-time prices of energy traded on the short term energy market. As a consequence, these energy prices vary each hour, and can get close to zero or even negative in times of high energy supply and low demand (Annemieke, 2022). Examples of energy suppliers that offer dynamic energy contracts are Frank Energy and EasyEnergy. They do not provide smart charging solutions themselves, but can be an important part of other smart charging solutions that make use of these dynamic energy prices, for example *Stekker*. Dynamic energy contracts are relatively new, and it is unclear how they will develop in the future. Therefore, more about user acceptance of dynamic energy tariffs can be found in *2.3.3 Time-of-use and dynamic tariffs*.

Tibber
Tibber is an example of a combination between a smart charging solution and an energy supplier. Tibber is a relatively new energy supplier, operating in several countries, who offers dynamic pricing and energy management solutions including smart charging (www.tibber.com). Once Tibber is connected to your car or charge point, it charges according to dynamic prices (similar to Stekker). It also offers additional smart services and devices that can be added to your home to give insight in electricity consumption and enable you to steer consumption even more (see figure 16 for an illustration). Tibber has already launched in the Nordic in 2016, and is now entering the Dutch market (Luimstra, 2022). It should be noted however, that in the Nordics (Sweden & Norway) electricity consumption is much higher compared to the Netherlands (Enerdata, 2020). Therefore, the potential for savings in the Nordics is much higher than in the Netherlands. Furthermore, a disadvantage is that it only offers electricity and no gas, which is uncommon practice in the Netherlands. Only time will tell how Tibber will develop in the Netherlands.

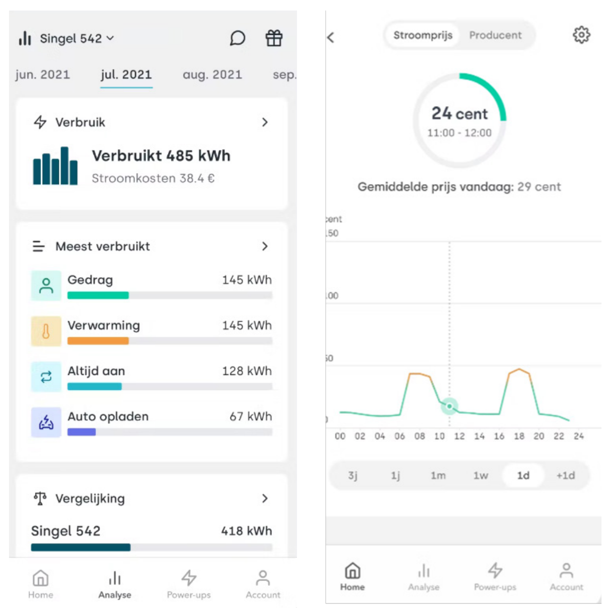


Figure 16: application screenshots of Tibber (Tibber, n.d.)

2.2.3 CONCLUSION

Some of the advantages and disadvantages related to the competitors are discussed in the table 3 below. The most important take-away is that it's an extremely dynamic domain, with an increasing number of competitors, not only in the energy supplier domain, but also in the smart charging domain. Looking at the diversity of solutions and electricity offers, it is difficult to say how these will develop in the future. It appears that many organisations are offering DLC, which in the future might no longer be a competitive advantage but rather a necessity. Adoption of the various solutions will depend on a number of things, including what solutions consumers are willing to adopt. Therefore, the next chapter will dive into researches and studies of EV drivers, and user preferences and behavior towards smart charging and energy tariffs.

Organisation	Advantages	Disadvantages
Traditional energy suppliers	Existing customer base, experienced energy supplier, brand associations	Currently not most prevelent platform for scheduled charging & disadvantage on point in customer journey
Energy suppliers with other core business	Large customer base from other core business	Trust from customer might not be optimal for new energy contracts
Energy suppliers with dynamic contract	High potential to save on charging sessions	Dynamic tariff applies to home consumption and acceptance of dynamic contract is uncertain
Dynamic energy supplier with focus on smart charging / HEM	Resonates with EV drivers (assumption) due to car focus	Due to novelty, lack of brand image. Same disadvantages as regular energy suppliers with dynamic tariffs
Car related energy contract (e.g. LeasePlan)	Lease companies have high advantage due to 'package' offers & point in customer journey	Business model is limited to lease drivers
Car related 'smart' charging app	Logical connection to start smart charging sessions	Requires manual input about off-peak periods / starting time etc. No influence on energy tariffs.
Platform that enables smart charging	Compatible with any energy provider	Necessity to have a dynamic contract

Table 3: overview of potential advantages and disadvantages of competitors

2.3 LITERATURE REVIEW

This chapter covers the literature review of various studies and researches related to the topic of EV drivers, smart charging and associated constructs. It covers studies about user preferences and behaviors related to smart charging and energy tariffs.

2.3.1 THE EV DRIVER

The number of full electric vehicles in the Netherlands is currently approximately 303.000 (in September 2022), representing just over 3,4% of total car fleet in the Netherlands (RVO, 2022). According to Roger's innovation curve (Rogers, 1962), this small percentage of adoption indicates that current EV drivers mainly represent the *innovators* and *early adopters*. The current EV driver can be well described by its characteristics; 91% is male, and over 50% is between 40 and 60 years old (Wolterman et al., 2022). Figure 18 displays a picture of a smart charging event, which shows people that indeed seem to have these characteristics.

Although the EV driver seems to be a clear cut target group, its characteristics are slowly changing. If we compare the results of research conducted in 2021 (Duurkoop et al.) to 2022 (Wolterman et al. 2022), the EV driver is getting slightly younger, the percentage with high income has decreased (income of >€70.000 was 59% in 2021, in 2022 this percentage is 51%), and the percentage of 2nd hand EV's (versus new) is going up. The number of EV drivers are expected to grow quite a bit, with a forecast growth to 1 million EV's in 2025 (Refa et al., 2021). For the near future, according to Roger's innovation curve, the next group to adopt EV's are what he calls the *early majority* and even *late majority*. Also, the EV itself has evolved over recent years; ranges have increased, offering has increased by 15% in a year (IEA, 2022), and with that the EV appeals to a larger number (and perhaps type) of people.

However, this project focuses on the EV driver that can charge at home. Those who can charge at home, need to have their own driveway of some sort. Therefore, the changes in characteristics of the driver might not apply to the same extent to this group, and this group might still be best represented by the current group of EV drivers.

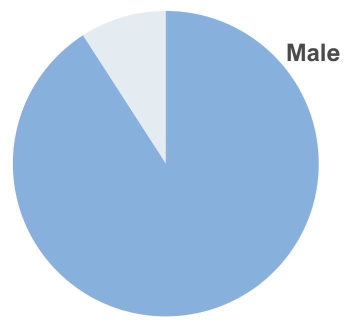


Figure 17: Distribution of male vs female in EV driver population (Wolterman et al., 2022)

Figure 18: People at a smart charging event

2.3.2 USER PREFERENCES AND BEHAVIOUR IN SMART CHARGING

ELECTRICITY COSTS

A study by Kubli (2022) found that *costs* are the most important attribute of (regular) charging. The researcher also briefly concludes that financial rewards can stimulate EV drivers to adopt smart charging solutions. Delmonte et al. (2019) studied user perceptions of smart charging propositions, and found that potential savings are indeed important to make these propositions appealing to consumers. In addition, propositions need to have *high* saving potential to make it appealing to a *large* group of consumers. Slightly in contrast to this, a study by Duurkoop et al. (2021) found that financial advantage is not the most important *argument* for adopting smart charging. In a more general context, Duurkoop et al. (2022) found that 'low costs' is one of the most important drivers for the early majority (and even more so for the late majority) to acquire an EV in general. The early majority is group of consumers to become the next segment of EV drivers in the near future, which is why (electricity) costs will be important, especially for the future EV driver.

CONTROL OF THE SOLUTION, UMC VS SMC

There are several smart charging possibilities and solutions, as we have seen in previous chapters. One important distinction of these solutions is the power of control over the solution. In some cases, the solution is controlled by the user(s), for example by adopting a simple scheduled charging solution in which users indicate the desired charge times. This is called user-managed charging (UMC), and can be incentivized by a tariff structure (Beard, et al., 2019). On the other hand, some of the solutions are controlled by the supplier of the system, also called supplier-managed charging (SMC). This is the case in direct load control (solutions). The supplier is in charge of managing the charging sessions and can guarantee costs savings or give financial rewards. A research by Beard et al. (2019) assessed and compared user preferences of these two approaches, using a trial in which EV drivers who charged at home used either system. Both UMC and SMC participants were positive about both systems after the trial, and overall there was a slight preference for UMC. In addition, there seemed to be an influence of experience; participants were slightly more likely to express a preference for the system they had personally experienced. Another study by Delmonte et al. (2020) had somewhat more dominant results, where two-third of the participants expressed the preference for a UMC solution. One of the reasons for this was the desire for control, which is supported by the finding that "users want to be in control of their sessions" (Brey et al., 2020). Another study (Fell et al., 2015) found somewhat contradicting results. In the study, the most attractive solution was one with direct load control, which is similar to a SMC solution. However, it should be noted that this study was about demand side response in general, and not EV charging specifically.

OVERVIEW

To give an overview of the types of smart charging, the provider who offers such a solution, as well as the type of control and whether it requires a specific tariff is illustrated in the table 4 below.

Smart charging method	Provider	Type of control	Required tariff
Simple scheduled charging	InCharge (Vattenfall)	UMC	Time of use*
Price optimized charging using dynamic tariffs	Stekker / Gridio	UMC with automation	Dynamic tariff
Smart charging using DLC	Eneco	SMC	-

Table 4: overview of some examples of smart charging solutions and associated characteristics
** time-of-use is not necessarily required, but is the only way that it brings financial advantages for the consumer*

2.3.3 TIME-OF-USE - AND DYNAMIC TARIFFS

Time-of-vuse tariffs and dynamic tariffs are relevant to smart charging as these tariffs can incentivize people to shift their charging sessions. They can serve as the foundation of smart charging solutions, as shown in table 4. Followed by the roll-out of smart meters, and combined with the electrification of households, TOU tariffs and dynamic tariffs are expected to become more wide spread (Nhede, 2019) (Cassidy, 2022) (Torriti, 2022). Due to these reasons, we will discuss these two tariffs in more detail.

TIME-OF-USE TARIFFS FOR UMC

For effective user managed charging, you need a TOU tariff that will influence consumers' behavior. Beard et al. (2019) have shown that users' behavior can indeed be changed by time-of-use tariffs, as participants in their study shifted charging sessions to off-peak hours when they are offered TOU tariffs. This is in accordance with results from a survey about real charging behavior in the Netherlands. In this report, there is a clear spike in charging sessions at times when the regional off-peak hours start, showing that more than 25% of EV drivers make use of scheduled charging according to off-peak hours (Duurkoop et al., 2021). From literature, it is unclear to what extent price elasticity plays a role in this behavior. On one hand, in one study, EV drivers in San Diego indicated a higher responsiveness to TOU tariffs for increased price ratio's between off-peak and peak hours (Jian et al, 2018), however, another research found consumption behavior to be inelastic to price ratios (Burns & Mountain, 2021).

INTEREST OF TOU TARIFFS

One study shows a little more than one third of the participants ("British energy bill payers") are interested to switch to a presented 3-tiered TOU tariff (Nicolson et al, 2017). In addition, prior experience with time-of-use tariffs as well as EV ownership both increase the average willingness of uptake of such a 3-tier TOU tariff. This shows the potential interest of EV owners for a (3-tiered) TOU tariff. Also Fell et al. (2015) found similar results; 30% of the participants, who were average British bill payers as well, showed interest in a time-of-use tariffs. Although these numbers sound promising, these results do not necessarily reflect actual market uptake, as stated interest in studies or surveys is much higher than actual uptake of such tariffs if offered commercially (Nicolson et al., 2018). This gap might be reflective of intention-behavior gap known from psychology.

DYNAMIC TARIFFS

As briefly discussed in previous sections, dynamic energy tariffs are relevant within smart charging context. Households with high energy consumption, and especially with 'steerable' energy consumption such as the battery of an electric car, can profit from dynamic energy tariffs. However, there seem to be barriers to the adoption of dynamic energy tariffs. Uptake of a RTP tariff, as reported by surveys or by actual uptake commercially available tariffs, is lower compared to TOU tariffs (Nicolson et al., 2018). Furthermore, dynamic prices and RTP are perceived as complex and less appealing compared to other tariff structures (PWC, 2020)*. Also, these two are found harder to understand. Another study found similar results: willingness to switch to a dynamic tariff scored lowest among several tariff designs, and also scored lowest in perceived usefulness, ease of use, and general control (Fell et al., 2015). However, if automation is added to the dynamic tariff, e.g. when it automatically controls the electric heating in the home, willingness to switch increases and perceived usefulness increases, even beyond usefulness of a TOU tariff.

Not only the tariff itself has barriers, also the consequence it has for the monthly costs are negatively perceived. One study found that fluctuations in the monthly electricity bill was criticized by 84% of the respondents (Ruakomo et al 2019). This problem is mitigated by some energy suppliers by offering a standard monthly payment. However, a disadvantage that this brings, is the large potential difference in forecast payments and the actual bill at the end of the year.

Although the amount of suppliers that offer dynamic tariffs have increased recently, it remains unclear if the large public is ready to adopt such tariffs.

**the participant population of this research has a large share of EV owners*

2.4 INTERNAL ANALYSIS

Now that much of the external context has been discussed, it is time to analyze Vattenfall in context of smart charging. Therefore, this chapter describes Vattenfall's current product offering related to emobility services. Also, it elaborates on previously discussed topics like direct load control and imbalance costs. Lastly, the future vision in relation to e-mobility propositions is briefly discussed.

2.4.1 CURRENT (& FUTURE) PRODUCT OFFERING

INCHARGE AND PRODUCT MANAGEMENT

Within Vattenfall, the InCharge department (www.incharge.vattenfall.nl/) is responsible for all e-mobility services. InCharge offers hardware products such as private and public charge points, as well as charge cards and a charge application. For the development of propositions, there is close collaboration with the Product Management team. Product management is responsible to develop and maintain all products related to electricity and gas offered to consumers.

PRODUCT OFFERING

Vattenfall offers both single tariff and static time-of-use tariffs. Vattenfall does not offer and has no intention to adopt dynamic rates such as RTP in the near future (although they might be obliged to under new legislation in the future (Rijksoverheid, 2021)). As alternative to the nationally regulated off-peak hours, Vattenfall has developed the proposition – which has not yet been launched to the public - of VoordeelLaden, which offers an off-peak period between 12 p.m. and 6 a.m. (see figure 18). This is an example of a product developed for emoblity purposes. The off-peak time period is shorter compared to regular off-peak hours, but offers a greater price difference between on-peak and off-peak tariffs. The pilot has started with Vattenfall employees at the end of June 2022. The proposition is expected to be implemented in the near future. Vattenfall will be the first energy provider to deviate from regular off- and on peak hours in the Netherlands.

2.4.2 DIRECT LOAD CONTROL (IM)POSSIBILITIES

As previously discussed, direct load control enables a supplier (of a system) to steer energy demand (for instance through a charging session). This way, a supplier can regulate its (im)balance of energy.

Vattenfall is currently able to apply a form of DLC in a B2B situation; they can steer energy demand and production of large installations of business customers to help avoid imbalances in their portfolio. In these situations, Vattenfall and the business have agreed on this 'flexibility' service in which the business enables Vattenfall to steer their energy consumption or production (within certain constraints) for financial rewards. In a B2C situation, such as with EV's, Vattenfall is currently **not** able to apply DLC. However, as part of their

Figure 18: Image of VoordeelLaden proposition (Vattenfall, n.d.)

search for new values within the flexibility market, they are looking into the opportunity to offer DLC to consumers in the near future. If the pool of EV's is large enough and can be bundled into a VPP, DLC of EV's can financially benefit the company, which can on its turn pass on part of the financial benefit to the end consumer. The financial benefits exist of the following two aspects:

- As the government wants to stimulate smart charging, the RvO (Rijksoverheid voor Ondernemend Nederland = Netherlands Enterprise Agency) will financially reward organisations for each charging session that adheres to certain requirements (time & KWh)
- Financial benefit as a consequence by acting upon imbalances and congestion

OPPORTUNITY WITH JEDLIX

Jedlix, which has been discussed in chapter *2.2 Competitor analysis*, is an interesting party to collaborate with for Vattenfall. It offers a white label app for smart charging, including the possibility to make use of direct load control. By collaborating with Jedlix and making use of a VPP, Vattenfall 'unlocks' the possibility to steer charging session according to network congestion and energy imbalances. Currently, they are investigating a potential collaboration. This partnership is interesting because it offers a readily available solution and eliminates the need for enormous ICT requirements to set up a solution themselves.

IMBALANCE COSTS

Costs for energy imbalances continue to grow, in general and therefore also for Vattenfall. This growth is due to the increase of electricity prices but even more so due to the growth in sustainable energy resources (Zwang, 2022), which makes accurate prediction of energy production difficult. Indirectly, this increases the energy tariffs for end customers as the margins for risks are increasing. Related to this, in the proposition of VoordeelLaden, a time-of-use concept, it becomes vital that energy consumption matches the forecast consumption made by Vattenfall. VoordeelLaden only profits the company, and the consumer, if the consumer actually consumes energy during the night, and thereby follows the predictions of Vattenfall.

Also related to imbalances but slightly different are associated costs to solar power that is fed back into the grid. As weather forecast is unpredictable, sunny days can cause imbalances to increase. In addition, prices for which Vattenfall can sell 'returned' solar energy on a sunny day are much lower than prices for energy they need to deliver on other days, causing extra costs for Vattenfall due to the net metering regulation.

2.4.3 TOU AND DYNAMIC TARIFFS

Since 2016, Vattenfall has looked into different time-of-use tariffs, however, has only the found appropriate proposition of *VoordeelLaden* to offer distinct time-of-use tariff. However, due to these past developments, pricing and IT departments have begun to put a system into place that could potentially handle 9 different time blocks. This means IT is ready to implement static TOU tariffs (but not yet dynamic tariffs, as these require hourly time blocks).

2.4.4 FUTURE VISION

Vattenfall is exploring how they are going to play a part in the 'flex' market in the future. The flex market is referred to as the market(s) that revolves around flexibility of electricity. The topic of smart charging at home can become a part of this flex market. However, in order for Vattenfall to pursue a solutions within the flex market, it must be of significant value. Therefore, for smart charging, a new solution should be of significant value to the business. To achieve that, it's necessary to create a solution that is valuable to the user. Therefore, it is necessary to know who the customer is and their perception of smart charging. The next section will go into the topic of the user.

2.5 USER INTERVIEWS

To better understand the potential user of smart charging, the Dutch EV driver, qualitative interviews with 11 participants were conducted. The aim of these interviews was to get an initial understanding of what EV drivers think of smart charging, how they view the role of solar energy in charging EV's and their perception of energy contracts in relation to the acquisition of an EV. The interviews lasted approximately 45 minutes, were conducted through video- or telephone calls and consisted of open ended questions regarding various topics of the electric vehicle and charging at home. For the recruitment of participants, convenient sampling was used and participants were recruited through acquittances and through the 'VER' (Vereniging Elektrisch Rijden) Facebook group.

2.5.1 RESEARCH QUESTIONS

The aim of the qualitative interviews was to get an answer to the following research questions according to a number of themes.

Smart charging

- To what extent are people aware of smart charging, or use some form of smart charging?
- What are requirements for people to adopt smart charging?
- How do people think smart charging can be a part of the home energy system?
- What (kind of) organization do people think should offer them smart charging?

Energy contracts

- What do people think of an offer for an energy contract with the acquisition of an EV?
- How does trust play a part in the perception of additional services, e.g. an offered energy contract?

Solar energy

- In what way do people 'experience' their solar panels (as part of the energy system)?

Appendix B1 provides the full description of interview questions that were used for the interviews.

2.5.2 RESULTS

The following section discusses the main insights from the interviews, supported by several quotes that illustrate the insight. Appendix B2 provides all relevant quotes per theme.

(PERCEPION OF) SMART CHARGING

- **Familiarity with smart charging varied:** Some participants were more aware of smart charging than others, of whom some had never heard of the term before. The way that they viewed smart charging varied among the different methods as in 2.1.2; optimize charging to solar production, according to tariffs or according to real-time data from e.g. congestion.

- **Scheduled charging EV:** Many participants stated they use(d) scheduled charging. Often for financial incentives, by charging during the night tariff. Some are also aware that it brings advantages to the electricity grid. *"I always charge using cheap electicity, and it does not make a huge difference but it's more about the principle"*

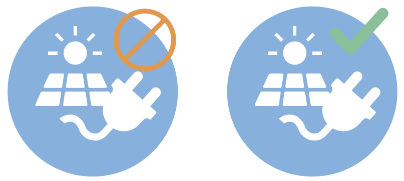
- **Financial incentive**: Some participants want or even assume financial gain in order to adopt smart charging. *Q: At this moment, what would be a reason for you to adopt smart charging? - "Costs. At this moment, costs only"*

- **Future vision with home battery**: Integration of smart charging into the home triggers the thought of home batteries. *"you have to have an additional battery to be able to bridge the entire 24 hours to supply energy to your household."*

- **The organisation to offer** smart charging is the **energy supplier**: The majority of the participants think the energy supplier is the organisation to offer smart charging, as they influence energy tariffs and (although this is a misperception in some cases) thrive if energy is better distributed. A few participants mentioned the grid operator as potential organisation. *"I can imagine that the energy supplier would be the one to do that, as they are also the orgnisation that calculates the costs and determines the tariff for the user."*

SOLAR ENERGY

- As current compensation for 'overproduction' of solar energy is high (net metering), and energy tariffs during night are low(er), people **currently don't see much value** in using their own solar energy for charging *"as long as the net metering is in place, it [charging the car at night] is fine ofcourse"*
- When people are no longer (fully) compensated for their generated solar energy, they see much **value** in using their own generated power to charge their EV **in the future**, and see this as part of smart charging. *"But if net metering is no longer in place, then the situation will change. Then I will try to get as much energy as possible directly from my solar panels into my car."*



Currently Future

- 2 participants mentioned the **disconnection** of the moment solar energy is generated and the timing of charging sessions *"I think I don't charge on solar energy 9/10 times, because once I get home at 18, it's already evening.. So I think the link [between moment of charging and solar energy] is close to 0.. "*
- **Monitoring** solar panels: Almost all participants monitor their solar panel energy production, charge session or energy usage. *"I have an app for my solar panels that I use regularly. I check at least once a day to see how things are going."*

ENERGY CONTRACTS

- Participants expressed a slightly negative opinions about energy contracts from new providers: People have experienced the offer of new energy contract from new (random) providers, and are not really positive about this *"Once in the Mediamarkt, I was there for shopping and suddenly I was offered an energy contract.. I have mixed feelings about that.."*
- Neutral / mixed opinions on energy contract from a car manufacturer: Some perceive it as acceptable and logical, others not so. Many express a clear intention to have a look at the offer being made. Trust in the energy supplier or car seems to play some role. *"I would like to know all about that. I would like to know if they came up with something that would benefit me a lot" "If I just make a request to a supplier for a charge station and they start stalking me for cheap electricity, I would find that annoying "*
- A few participants expressed an indifferent opinion due to low energy consumption (as a result of solar panels), and thus a low energy bill. *"So I pay zero each year, so it does not really matter which supplier and associated costs, because due to net metering, my balance is simply 0 until 2025.*

2.5.3. CONCLUSION

People's familiarity with smart charging varies a lot, but most are generally interested in smart charging if it provides a financial advantage. The energy supplier is seen as potential organisation to offer smart charging, as they are able to influence electricity tariffs, which seems to be the main thing people think about when talking about smart charging. Furthermore, solar energy is on top of mind for many EV drivers, especially with upcoming changes in legislation. EV drivers foresee a potential change in their attitude in this realm. Lastly, energy contracts from random providers are not perceived positive, but from a car manufacturer are more acceptable. In the end, people prefer to have the best deal, but need some level of trust to consider a new contract.

2.6 CONCLUSION

2.6.1 CONCLUSION PER CHAPTER

2.1 TECHNOLOGY ANALYSIS
The technology analysis has introduced the context of smart charging by elaborating on network congestion, imbalances and energy tariffs, which demonstrate the opportunity that smart charging offers. Furthermore, the analysis of smart charging methods has shown how smart charging can operator on different levels - from the home level to optimize generated solar energy production to the national (grid) level for balancing energy consumption and production. Also, the methods for smart charging can range in 'smartness', from simple scheduled charging using static TOU tariffs, to more dynamic prized optimized charging and to DLC based on real-time data of energy imbalances.

2.2 COMPETITOR ANALYSIS
Although smart charging is not adopted by many people yet, there are many competitors already. The organisations can be classified according to three domains; the car domain, the energy supplier domain and smart charging providers. When analyzing these organisations and the solutions they offer, it becomes clear that scheduled charging is the most provided solution to offer smart charging, but also DLC is adopted by an increasing number of organisations.

2.3 LITERATURE REVIEW
An investigation of available literature has provided numerous insights about the EV driver and their behavior towards smart charging. Firstly, it appears the current EV driver is most often a male of between 40 - 60 years old and higher income. However, these characteristics might slightly change in the future. From studies about consumers behavior in relation to smart charging, it appears both user managed charging and supplier managed charging solutions are considered valuable solutions, although there is a slight preference for UMC. At the same time, it became clear that participants slightly preferred the system they had experienced. This is important to take into consideration when designing new smart charging proposition.

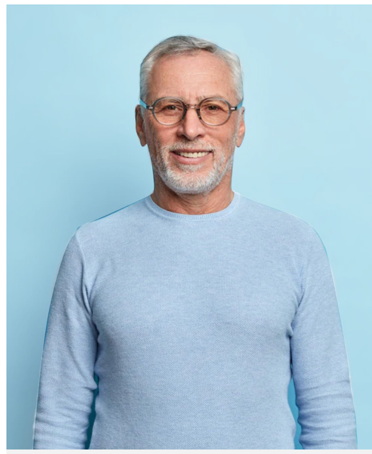
2.4 INTERNAL ANALYSIS
An internal analysis of Vattenfall discussed the current product offering related to emobility products and services. Vattenfall is probably the first energy supplier to offer a differentiated TOU tariff structure, which is especially interesting for EV drivers. On the other hand, Vattenfall is not able yet to offer DLC to their EV drivers, although they are looking into a collaboration with Jedlix to do so in the future.

2.5 USER INTERVIEWS
Interviews with several Dutch EV drivers reveal they are well aware of the upcoming changes in legislation of solar net metering which might influence their behavior in the future. Furthermore, when asked about smart charging, they tend to think of electricity tariffs as most important input, as well as their own solar power.

Combined with data from literature reviews, a persona of the typical EV driver was created based on these user interviews. This persona, as displayed in figure 19, serves to get a better feeling of who the EV driver is, in order to be able to design for them.

2.6.2 NEXT STEPS
How these insights influence each other, and how this leads to a new design focus will be discussed in the next chapter.

PERSONA



EV driver since 2018

Solar panels, since 2019

Lives semi detached house

Pieter

Age	55
Occupation	Software developer
Status	Married
Location	Hillegom

Goals
- Wants to retire early
- Prefers high quality food and products
- Save up money for holiday home

Personality
- Strong minded
- Has his things in order
- Likes to optimize his life

Needs
- Luxury
- Ease
- Comfort

Bio
Pieter is married and has 3 kids who moved out a few years ago. He and his wife both work 4 to 5 days a week. In general, they live a normal to luxurious life, and do not have to worry about money. In their free time, they like to go to museums.

In daily life, they pay little attention to the environment. However, as they are a wealthy couple, they have invested in solar panels and drive an electric vehicle.

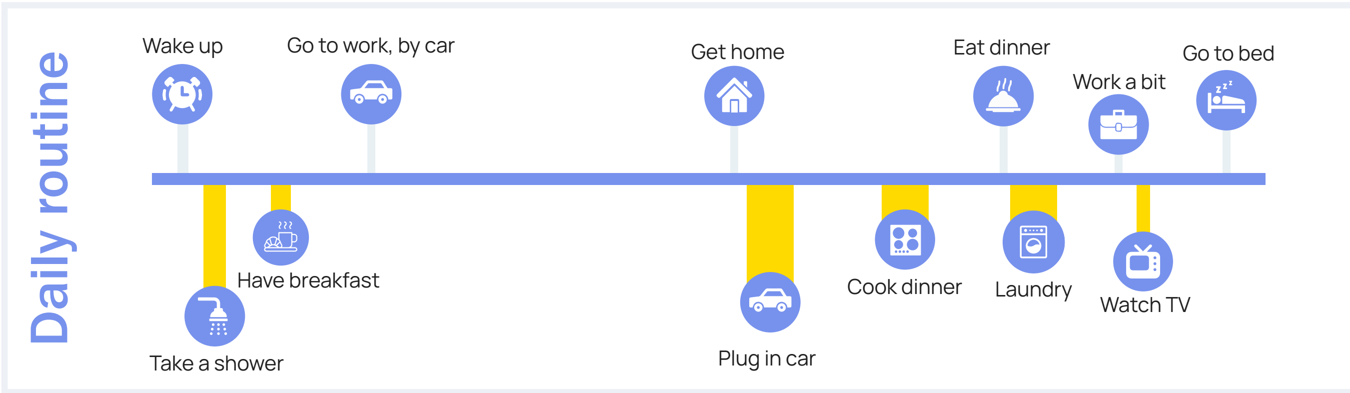
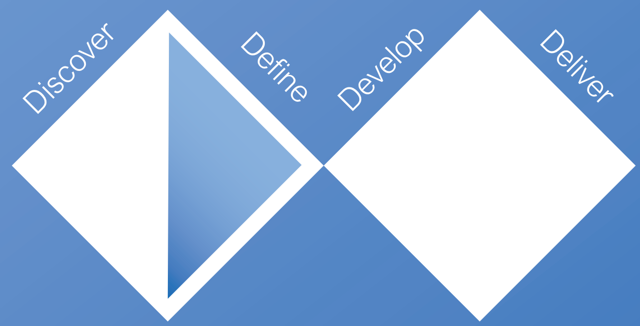


Figure 19: persona of Pieter, the typical EV driver

PART 3. DEFINE

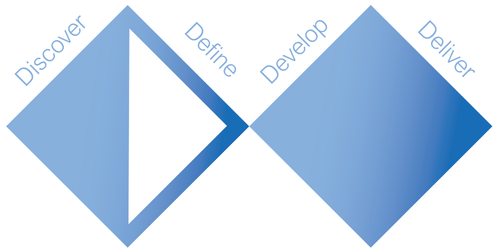
3.1 MOST IMPORTANT INSIGHTS
3.2 DESIGN CHALLENGE

After the wide exploration of the context of smart charging, it is time to synthesize the findings. This part summarizes the most important insights from 'discover', and will propose a new design challenge.



3. DEFINE

The previous phase, the *discover* phase, has explored the scope of smart charging in various ways. It discusses various methods for smart charging, the competitors in relevant domains, literature on user preferences and behavior in relation to smart charging, and gives insights of the user perspective. The question is; what can we learn from these insights, and what is the challenge for Vattenfall in a new smart charging proposition? This chapter first highlights the most important insights from the discover phase, followed by a conclusion with a new design challenge.



3.1 MOST IMPORTANT INSIGHTS

SOLAR ENERGY; AN IMPORTANT ASPECT
Solar energy is relevant in smart charging because many EV drivers that charge at home possess solar panels (Wolterman et al, 2022). In addition, in the Netherlands, solar energy is subject to changes in legislation in the coming years, changing the rules of net metering of solar power. User interviews reveal EV drivers currently see little value in charging their car using solar power, as current net metering makes it financially uninteresting or even unattractive. However, EV drivers are aware of the upcoming changes in legislation, and foresee a change in financial value and possibly their own attitude.

SMART CHARGING ADOPTION AND SOLUTIONS
Available smart charging solutions are abundant, but only limited variations exist. Also, in some cases a limited number of car models are supported. Adoption rates of smart charging solutions are not known, but *simple scheduled charging* is one solution that about 25% of the EV drivers seem to have adopted (Duurkoop et al., 2021). The current 'dubbeltarief' (static TOU tariff with night off-peak hours) incentivizes such a smart charging method. On the other hand, also solutions with direct load control (DLC) are perceived as valuable according to research and real-life trials. Jedlix is an organisation that provides companies the opportunity to adopt and offer DLC.

NEW ENTRANTS & DYNAMIC ENERGY TARIFFS
The energy supplier domain has seen many new entrants over the past years, including those offering dynamic tariffs. Also traditionally automotive focused organizations are moving into the energy domain. More entrants are expected to come, including organizations providing VPP or DLC functionalities. Even though the offering of dynamic tariffs has increased over recent years, from literature it appears there are barriers to the adoption of dynamic tariffs, and often TOU tariffs are perceived as more appealing.

TIME-OF-USE TARIFFS AS PART OF SMART CHARGING
From user interviews and literature, it appears people are incentivized by time-of-use tariffs to change their charging behavior. Also, UMC, which relies on TOU tariffs, is perceived as valuable (Nicolson, 2018). In the Netherlands, diversity in TOU tariffs is lacking, and therefore people have limited opportunities to steer their charging sessions according to TOU tariffs.

VATTENFALL AS FIRST MOVER
Vattenfall is the first to offer a new time-of-use tariff to consumers in the Netherlands. The proposition is especially interesting for people who charge their EV at home.

3.2 DESIGN CHALLENGE

CONSIDERATIONS TO FORMULATE THE CHALLENGE
The previously discussed insights summarize the context of smart charging, and contain various interesting areas for further investigation. To come to a design challenge, we need to apply a focus. From all the insights, three relevant 'scenarios' to achieve smart charging can be distinguished, which will form the foundation to formulate a new design challenge;

1) Static TOU tariffs
2) Charging using (home-generated) solar power
3) Charging using DLC

The design challenge must be relevant to Vattenfall, and seek to find an answer to previously unanswered questions. Therefore, each scenario is briefly discussed, and some unanswered questions are highlighted.

1. Static TOU tariffs
Even though TOU tariffs seem to be an effective method for smart charging, currently there are limited choices of tariff structures. For Vattenfall, new TOU tariffs might be interesting for smart charging solutions, also to better compete with increasingly popular dynamic tariffs. An unanswered question is; what tariff structure is desirable from a business and consumer perspective?

2. & 3. Charging using solar power and using DLC
Charging EV's using solar power and using DLC will be considered in context in which a financial compensation is given as reward. The reason for this is because these two scenarios in itself will require only little further research, and should be focused on the question if consumers are interested to adopt these 'methods' if they are financially incentivized to do so. From a business perspective, giving financial compensation for DLC has been discussed before, and for solar power can be achievable due to imbalance costs that solar energy might generate (see *chapter 2.4 Internal analysis*). The question for these subjects is to what extent are consumers interested in either or both? And how are these two scenarios relevant in the future, in which the context has changed?

FORMULATING THE CHALLENGE
From these three smart charging scenarios and relating questions, two sub-challenges and one main design challenge are composed.

1. Design a new time-of-use tariff structure that can serve as a smart charging proposition

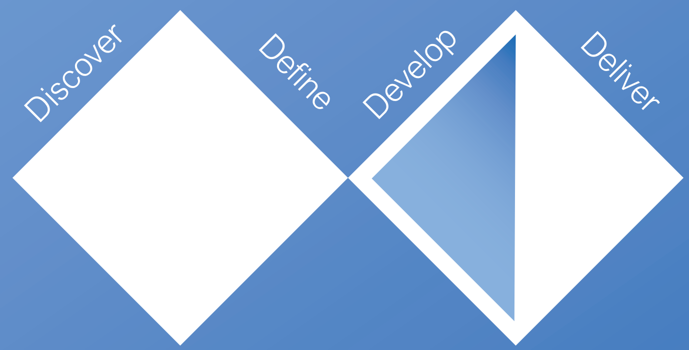
2. Investigate consumer preference related to (financial compensation for) charging using their own solar power or DLC

Main challenge
Design a smart charging proposition roadmap that incorporates new TOU tariffs and financial compensation for charging using solar power or DLC, to support and guide consumers to charge their EV conveniently and economically

RELEVANCE OF THE DESIGN CHALLENGE TO VATTENFALL
A new time-of-use tariff structure can be an interesting alternative tariff to better compete with dynamic tariffs. As we have seen in literature, dynamic tariffs have some disadvantages, which might withhold people from adopting such a tariff, whereas TOU tariffs seem to be more appealing. Also related to competition, a clear advantage that energy suppliers have compared to smart charging providers is the ability to influence energy tariffs. By providing TOU tariffs, Vattenfall can leverage this competitive advantage. Lastly, it can strengthen Vattenfall's position as a first mover in the Dutch time-of-use domain.

PART 4. DEVELOP

Now that three main scenarios for smart charging (TOU tariffs, charging using solar energy and charging using DLC) are defined, it is time to explore these and develop meaningful solutions. The first two, and most substantial, chapters of this part focusses on TOU tariffs and aims to develop interesting new TOU tariffs for the Dutch EV driver. Therefore, these TOU tariffs are tested through user interviews and a behavioral experiment. Then, in chapter *4.3 Desirability of smart charging scenarios* all three scenarios are considered and tested in a quantitative set-up to investigate consumer preference and thereby get an understanding of the most appropriate smart charging proposition.



4.1 DESIGN OF A NEW TIME-OF-USE TARIFF

What are the most (financially) attractive tariff structures that benefit the end consumer and the energy supplier, as well as the entire system? This chapter will explore the following four topics for the design of a new time-of-use tariff; 1) previous research on user preferences of TOU tariffs 2) static TOU tariffs as applied in other countries, 3) prices of the Dutch energy market that influence the time bands and prices for tariff blocks and 4) input from Dutch EV drivers. It concludes by suggesting the most promising tariffs according to the analyzed topics.

4.1.1 LITERATURE ON TOU TARIFFS

From previously discussed research it appears TOU tariffs can be appealing to consumers, especially those with an EV (or other battery system). To design the most appealing TOU tariff, more insights into user preferences are needed. Therefore, this section will elaborate on more detailed findings of research into TOU tariffs. It should be noted that, although some findings might be universally applicable, research that has taken place in other countries means other cultures and social norms might apply and results might not be applicable to the Dutch context.

TOU tariffs have three characteristic that influence its effectiveness, which are the price differences between off-peak and peak tariffs, the length of the peak period and the amount of tariff blocks (Nhede, 2019). Not so surprisingly, consumers are more responsive and their behavior is easier to be influenced if the peak is shorter (Trabish, 2018). Furthermore, consumers are more willing to accept a high peak price, if the price difference to the low tariff is relatively large.

Belton & Lunn (2020) compared three TOU tariffs and a flat tariff. From their research, a 4-period TOU was chosen most often, followed by the flat tariff, then the 2-period TOU tariff and last the 3-period TOU tariff. Those results show the preferred number of pricing periods is difficult to predict, and it might depend on the tariff design which TOU is preferred, also when comparing it to a flat tariff.

To make it even more complex, the same research found users do not always choose the option that would in fact turn out to be most financially beneficial to them. In the study, researchers asked participants for a preferred tariff among the 4 types of tariffs. Then participants were asked to fill in their estimated consumption during the day, so the most (financially) beneficial tariff could be calculated. It appeared that the tariff that was most financially beneficial did not always lead to a choice for that tariff.

To conclude, preference for a specific type of TOU tariff is difficult to predict, as people do not seem to be able to choose the most beneficial tariff. Also, there seems to be no conclusion if people prefer simpler tariffs (e.g. 2 time blocks) or more complex ones (e.g. 4 time blocks.)

4.1.2 TARIFF STRUCTURES IN OTHER COUNTRIES

Compared to other countries, the Netherlands applies a very basic form of static time-of-use tariff structure. Structures that are applied elsewhere in the EU consist of more than two time blocks or tariff rates, differ during the seasons or vary among different energy suppliers (Justwe, n.d.) (Endesa, 2022) (EDP, n.d.). In addition, other countries apply a combination of static and dynamic time-of-use rates, for example a structure in which the time blocks and prices are established, but the days on which lower or higher prices apply are announced a day ahead. France is an example that applies such a tariff structure, called Tempo tariff (Rte, n.d.). Other interesting tariff structures are found in the UK, Spain, and Portugal and will be explained in further detail. These structures will serve as inspiration for the design of time-of-use tariffs.

FRANCE

EDF, a French energy supplier, offers a time-of-use tariff called the Tempo Tariff (Rte, n.d.). The Tempo tariff consist of two tariff periods a day. The off-peak hours depend on the distribution operator but usually runs from 10 p.m. to 6 a.m.. The prices for these two tariff periods vary according to the 'type' of the day that applies, classified according to colors. The days are classified into three colors, blue, white and red, and correspond to increasing prices levels. Three hundred days a year are classified as blue days, for which the prices are lowest. White days, of which there are 43 each year, correspond with slightly higher tariffs. Lastly, the highest prices apply for 22 'red' days a year (mainly in the winter), in which especially the peak rates are really high (as illustrated in figure 20). The 'color' of the day is announced a day ahead. To illustrate, the colors of the days during the month of December might look like the calendar shown in figure 21.

Figure 21: color-assigned days in december for the France TEMPO tariff (Rte, n.d.)

Figure 20: illustration of TEMPO tariff (as offered in France) for each type of day

UNITED KINGDOM

The most interesting time-of-use tariff in the UK is provided by Green Energy UK, called 'TIDE' (GEUK, n.d.). The tariff varies between three tariffs levels, provided over four time blocks. The highest tariffs is between 16 and 20 o' clock, and lowest from 00 to 07 o' clock, as illustrated by figure 22.

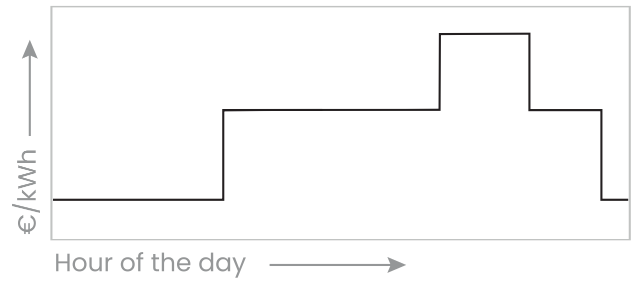


Figure 22: Vizualiation of the TIDE tariff

SPAIN

In Spain the energy market is divided into the free market and the regulated market. Last year, in 2021, the standards for the regulated market have changed and automatically put every consumer into a three-level tariff structure (Endesa, 2022). In the free market, consumers can choose between flat-tariffs or various time of use tariffs. The 'One Luz 3 periods' offered by Endesa (Endesa, n.d.), is a tariff structure with 3 tariffs and 6 time blocks. Another option of a time-of-use tariff is one in which you get free electricity for the day in the week that you use most of your electricity.

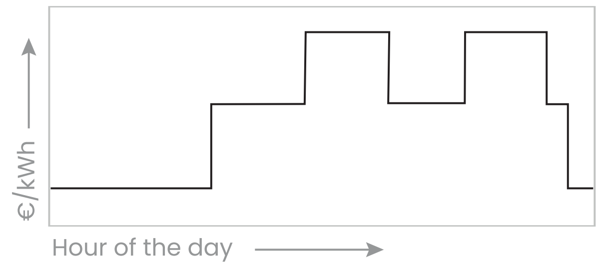


Figure 23: visualization of One Luz 3 Periods in Spain (Endesa, 2022)

PORTUGAL

Portugal has similar time-of-use tariffs to Spain in means of number of tariff level and number of time blocks. However, the peak periods are shorter in Portuguese TOU tariffs, as illustrated by figure 24. Also, in Portugal energy suppliers offer the option to differentiate on seasonal basis only (called 'ciclo diario'), in which all days apply the same tariff structure, or on a weekly basis, in which the structure varies according to the type of day (EDP, n.d.). Figure 25 illustrates this differentiation.

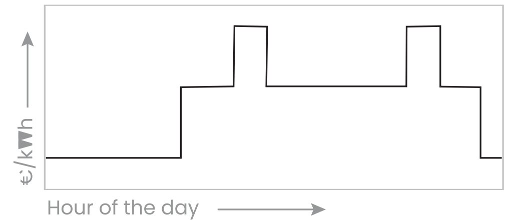


Figure 24: visualization of TOU tariff in Portugal

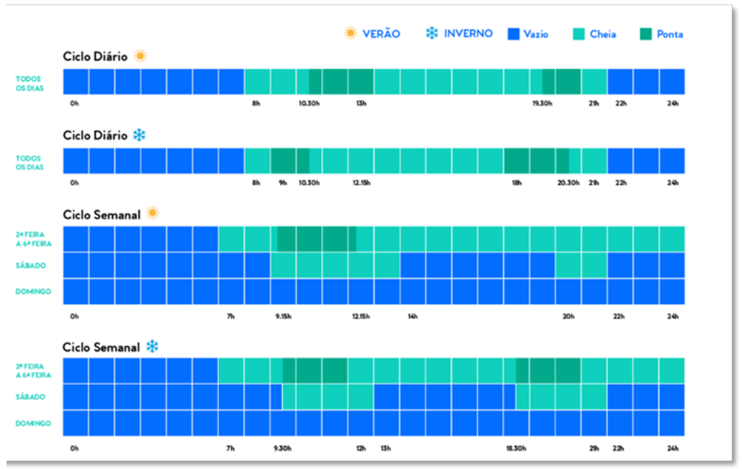


Figure 25: diffences in time periods as applied in a daily cycle or weekly cycle in TOU tariffs in Portugal

CONCLUSION

Time-of-use tariffs in other countries are more diverse and more 'sophisticated' – with more tariff levels and time blocks. Although these tariffs can serve as inspiration, it is also important to consider plausible reasons why these tariffs have been available in certain countries, but not in the Netherlands. Firstly, the share of renewable energy among countries varies greatly, and all mentioned countries have a greater share of renewables in electricity compared to the Netherlands (see figure 26) (Eurostat, 2020). Renewable energies are not flexible in energy supply, which is why it requires appropriate energy consumption and why these countries might have put these TOU tariffs in place. Another reasons could be that grid congestion is a larger problem, and requires these TOU tariffs as a measure to solve it. Despite these plausible reasons, these different tariff structure can definitely serve as inspiration, as long as these country specific conditions are considered.

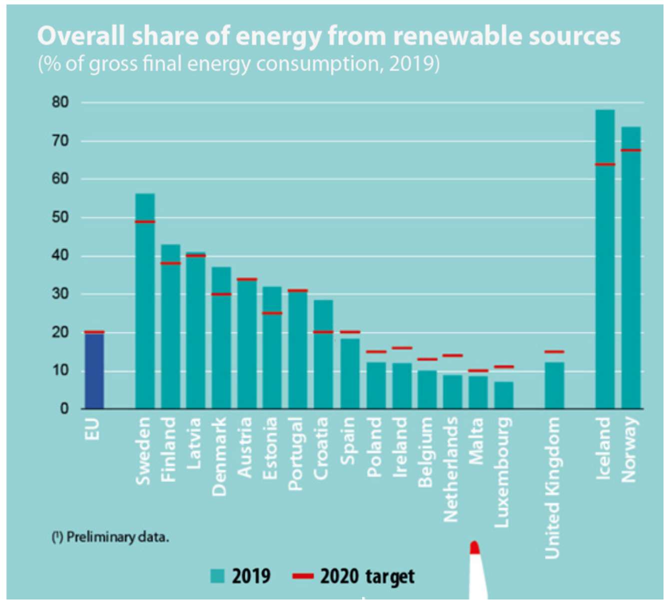
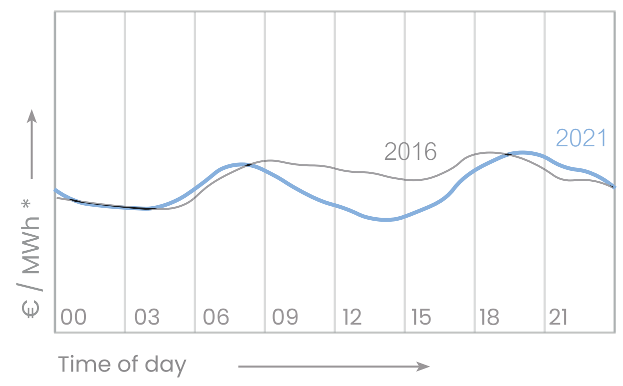


Figure 26: overall share of energy from renewable sources (Eurostat, 2020)

4.1.3 ENERGY PRICES

DAY-AHEAD MARKET PRICES

In order to be able to offer differentiated prices during the day, the tariff levels need to reflect actual wholesale market prices to some extent. Energy is traded on several markets, ranging from markets that trade energy 5 years ahead, to markets that deal with intraday trading (om nieuwe energie, n.d.). For time-of-use tariffs, it is important to look at the market that is most influential for the hourly prices during the day, which is the day-ahead market. The day-ahead market prices fluctuate over the day, following a certain pattern. The blue line in graph 1 shows the average hourly price per MWh for the most recent 1-year time frame (sept 2021 to august 2022). As can be seen from this graph, prices during the night are low, then increase during the morning with a peak around 8 o'clock, then decrease during the day (when a lot of renewable energy is produced, but not a lot of energy is consumed) and increases during the evening hours again, peaking around 19 o' clock. Also, the graph of 2016 is added in grey, to show the development of this hourly price curve over the years. The main difference between the two graphs of 2016 and 2021/2022, is the price level during the day, which is significantly lower in the 2021/2022 graph. The decreased price during the day can most probably be attributed to the increase in renewable sources, and this development will therefore continue in the future due to the continuous increase of renewable energy resources. This phenomenon can be explained by the 'duck curve', which shows the development of net energy demand over the years. The curves in figure 27 show that the daily net (dispatchable) energy demand will decrease over the years due to an increase of solar energy. This development will on its turn influence energy prices (Oosterveer, 2022).



Graph 1: day-ahead prices in the Netherlands in 2016 and 2020. Based on data from Entsoe (n.d.)

** scale of the graph is different for 2016 and 2021 due to recent market developments which have caused prices to increase by 5 - 10 folds*

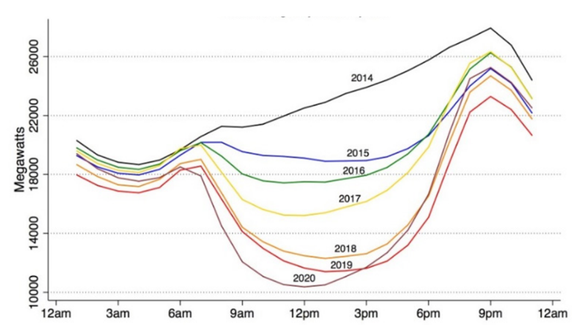


Figure 27: the development of net energy demand from dispatchable energy sources over the years, called the Duck Curve (Oosterveer, 2022)

POTENTIAL OF A LOW TARIFF

As can be seen from the graph, prices during the night are – still - low. However, prices during the middle of the day are also low. Due to the valley between approximately 10h and 17h, as seen in the graph of day ahead prices, it could be interesting to offer a low tariff somewhere in that time frame. Especially if you consider that this trend will continue and prices during the day drop even further. These results will be a guidance for the tariff levels and time blocks for the time-of-use tariff to be designed.

4.1.4 CONSUMER PREFERENCES: A CODESIGN ASSIGNEMNT

Besides the potential for tariffs based on market prices, it is important to consider a human factor as well; preferences of the consumer. In order to include consumers in the design of new tariffs, a codesign assignment was set up. The assignment enables consumers to design their own tariff structure, within certain constraints. It enables participants to apply a low, medium, or high tariff to time blocks of 2 hours. The interactive part of the assignment is displayed in figure 28, the entire assignment is included in Appendix C1. The available tariff levels in each time block are loosely based on the market prices of electricity (see previous section *4.1.3 Energy prices*), to keep it within financially realistic constraints. Also, a number of rules were set, so participants were restricted in the number of low and high tariffs they could apply.

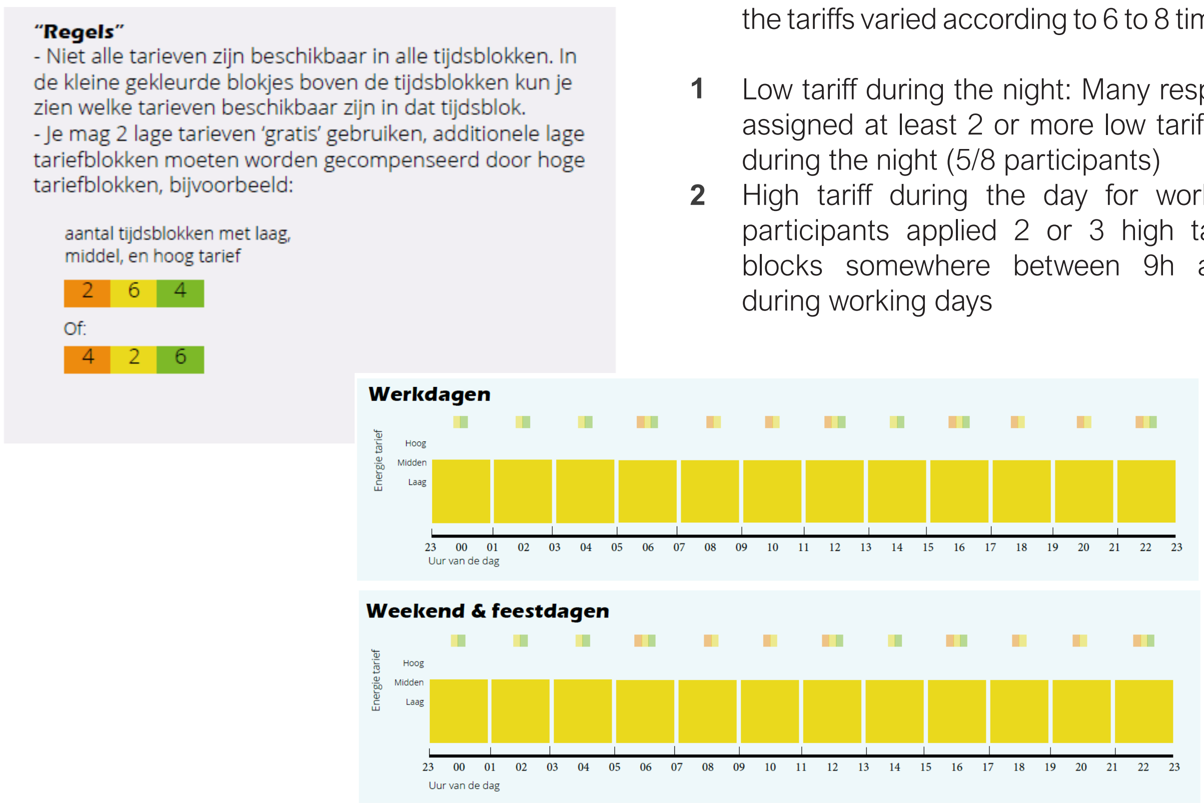


Figure 28: interactive part of the co-design assignment. Every individual time 'block' can be assigned a high, medium or low tariff. Some blocks do not allow a high or low tariff, depending on the time.

SET UP & RECRUITMENT

The assignment was composed as a self-explanatory PDF file with visual and textual elements. The assignment was sent by email to around 15 people, kindly asking them to participate. Participants were recruited from previous interview participants (from chapter *2.5 User interviews*) and newly selected participants from the VER Facebook group.

RESULTS

The assignment was completed by 8 participants. The result of 3 participants are displayed as illustration in figure 29, the results of all participants are included in Appendix C2.

The results of the codesign assignment are very diverse and do not show 1 coherent tariff structure. However, insights that came from the results are the following:

- The task was to design the *most valuable* tariff, without further explanation. All respondents created a rather complex structure, in which the tariffs varied according to 6 to 8 time blocks

1. Low tariff during the night: Many respondents assigned at least 2 or more low tariff 'blocks' during the night (5/8 participants)
2. High tariff during the day for workdays: 6 participants applied 2 or 3 high tariff time blocks somewhere between 9h and 17h during working days

3 Low tariff during the day in the weekend: 3 participants assigned a low tariff between 11 and 17 during weekends, 2 assigned a low tariff between 13 and 17
4 Low tariff in the late afternoon during workdays: 4 participants applied a low tariff from 15 – 17 during workdays
5 Not everyone diversified among workdays and weekends
6 Five who did diversify workdays and weekends, applied a high tariff between 5h and 9h during the weekend (and not during weekdays)

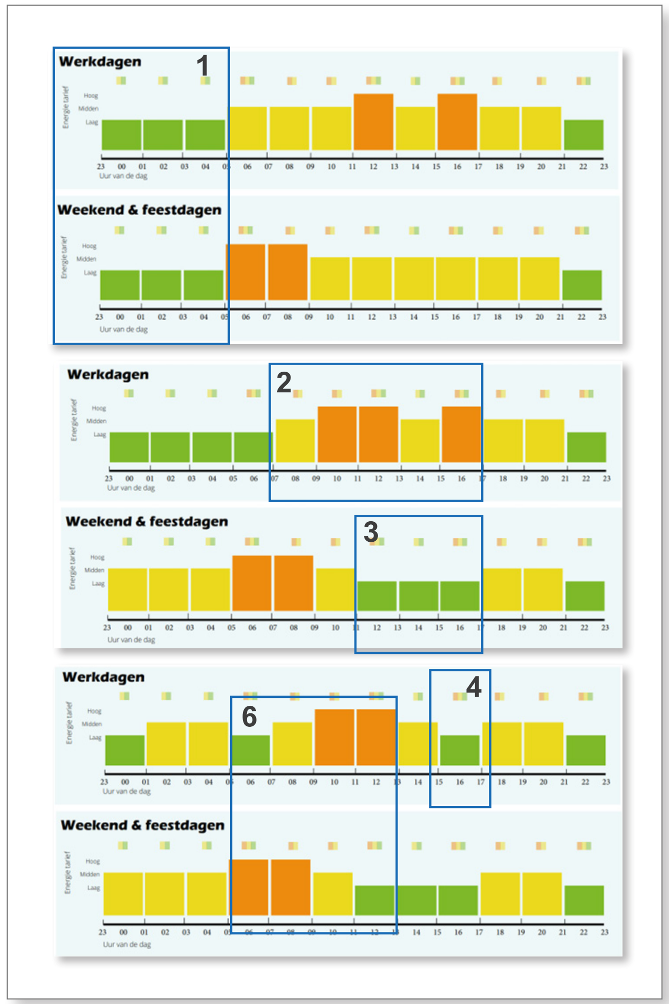


Figure 29: results of three participants to illustrate some of the findings

CONCLUSION

Weekday

All participants had a job at the time of participating. Looking at the results, we can perhaps conclude some participants applied high tariffs during the day because it would not affect them as they are not at home during that time. Furthermore, those who applied a low tariff between 15 – 17 during weekdays might want to profit from a low tariff once they get home from work during that time. Therefore preferred tariffs during weekdays seem to be influenced by the working routine.

Weekends

Those who diversified between weekdays and weekends, of which there were 5, applied a high tariff from 5 till 9 a.m. during weekends, suggesting their routine is significantly different and typical energy consumption starts at a later time in the weekends. Also, the low tariff applied during the day in the weekend suggest people see opportunity to make use of that.

These findings are synthesized in this figure 30.

Consumption pattern vs potential consumption

Due to the low tariffs applied in weekends, we can perhaps conclude that people are aware of the opportunity of low prices and do not only think about their actual usage pattern, thereby anticipating on a potential consumption. On the other hand, apparently these participants do not see any opportunity during workdays, even though from statistics it seems like more than 40% of Dutch employees sometimes work from home every week (Kennisinstituut voor Mobiliteitsbeleid, n.d.).

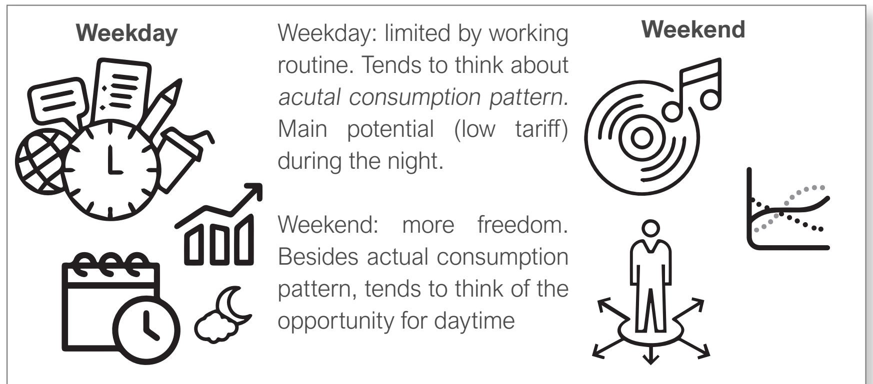


Figure 30: results of three participants to illustrate some of the findings

4.1.5 CONCLUSION: MOST PROMISING TARIFF STRUCTURES

According to all gathered information, three interesting tariffs have been designed. Based on results of the codesign assignment, and low day-ahead prices during the night, all tariffs have a low tariff applied during night hours. To make comparison easier, as this might be quite important in consumer preferences, timing of these night tariffs are similar across the three tariff options. The tariffs have been given a number and name (T1 Evening Peak, T2 Two Peaks, T3 Daytime Plunge) to make further referencing easier. The tariff structure and reasoning for each individual tariff is discussed in more detail.

Tariff 1: T1 Evening Peak - applies a peak tariff during the evening hours, inspired by the TIDE tariff from the UK. Even though from the co-design assignment an evening peak does not seem desirable, according to day-ahead prices, an evening peak is the best representation of actual day-ahead prices. The peak starts at 18h, giving people some room to make use of normal tariffs until 18h once they get home from work, as inspired by the co-design assignment. Compared to the other tariffs, this tariff applies 4 time blocks, which might be more desirable compared to 5 (as in T2 and T3).

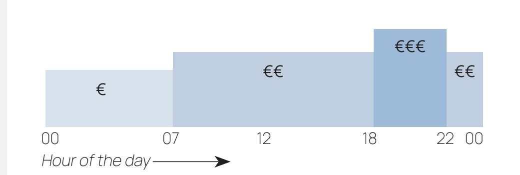
Tariff 2: T2 Two peaks - applies a morning and evening peak, inspired by the tariffs of Portugal. As results from the co-design assignment seem to suggest, people's working routines influences the preferred tariff, and along with the data from the day-ahead prices, it was decided to start the evening peak the 'latest as possible', at 19h. To make the tariff easy to understand, both peaks run from 7 to 9, morning and evening. Furthermore, the peak in the evening is even more expensive because of its shorter time length (relative to T1).

Tariff 3: T3 Daytime Plunge - applies a (second) low tariff period during the cheapest, according to day-ahead prices, hours of the day; from 11 till 17h. These hours also coincide with the preferred low tariff that some in the co-design had applied during the weekend. An evening peak is applied from 17 till 21h. This tariff might be interesting for people who see opportunities to make use of the low tariff during workdays (like how some participants saw this opportunity during weekends).

T1: Evening Peak

Tariff	Hours	Price
Low tariff	00:00 to 07:00	€
Normal tariff	07:00 to 18:00 22:00 to 00:00	€€
Peak tariff	18:00 to 22:00	€€€

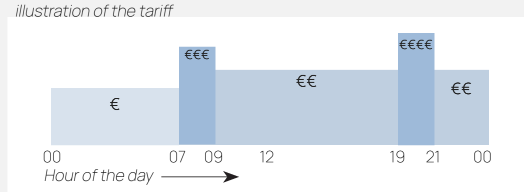
illustration of the tariff



T2: Two Peaks

Tariff	Hours	Price
Low tariff	00:00 to 07:00	€
Normal tariff	09:00 to 19:00 21:00 to 00:00	€€
Peak tariff	7:00 to 9:00 19:00 to 21:00	€€€(€)

illustration of the tariff



T3: Daytime Plunge

Tariff	Hours	Price
Low tariff	00:00 to 07:00 11:00 to 17:00	€
Normal tariff	07:00 to 11:00 21:00 to 00:00	€€
Peak tariff	17:00 to 21:00	€€€

illustration of the tariff

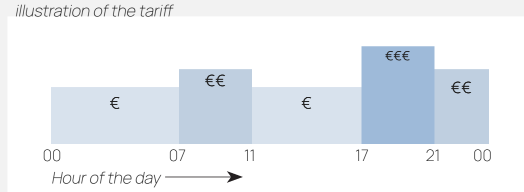


Figure 31: most promosing new tariff structures

NEXT STEPS

The most promising tariffs are drawn up, however, they were designed using several inputs, of which consumer preferences was only one. Therefore, it is important to investigate the opinion and preference of EV drivers on these specific tariffs.

4.2 DESIRABILITY OF THE NEW TARIFFS

Now that the tariffs are designed, they should be tested for desirability. This chapter describes the set-up and results of qualitative interviews that were conducted about the newly designed tariffs. In addition, it elaborates on a behavioral experiment that was executed with three participants, in which they tested the new tariffs in a simulation setting. A qualitative set up has been chosen because it is essential to investigate *why* people prefer certain tariffs, and how they would adapt their behavior accordingly. Qualitative research enables to uncover underlying needs and reasons of people's preferences (Creswell, 2014).

4.2.1 QUALITATIVE INTERVIEWS ON DESIRABILITY OF TARIFFS

Using the designed tariff structures, qualitative interviews were conducted to test the desirability of the tariff structures and investigate for potential iterations.

RESEARCH QUESTIONS

The interviews served to gain an understanding to the following questions:

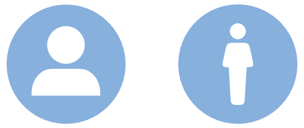
- What (type of) tariff structure do people prefer, and why?
- What type of peak (tariffs) do people prefer?
- What aspects of the tariff are most important to people?
- To what extent are people interested in such energy tariffs?
- Are the tariffs easy to understand?
- How will people remember the tariff structure to make use of it?
- In what ways can / will the tariff influence their behavior?

INTERVIEW SET UP

A total of 14 participants was interviewed. The interviews followed a semi-structured interview guide and lasted approximately 30 minutes. The interviews were preferably conducted through videocalls, however, some were conducted through telephone calls due to technical limitations of some of the participants. To stimulate and reward for participation, a Bol.com gift card of €50 was awarded to one out of each ten participants.

ACQUISITION OF PARTICIPANTS

The participants were recruited through Vattenfall's customer base of people who had acquired a charging station in the past year. Ownership of a charging station on one hand guaranteed (or, at least, guaranteed to a high degree) that people have an electric car, and most probably charge their car at home. As the interviews indirectly aimed to elicit opinions and preferences of people about the costs of electricity, it was essential that participants bear the costs of electricity themselves. Therefore, this was listed as a specific requirement in the recruitment email that was sent out. In addition, it was made sure that the majority (12 / 14) of the participants had a part-time or full-time job, in order to avoid too many retired participants as they are not representative for the EV driver population (Wolterman et al., 2022).



14 participants 14/14 male

INTERVIEW QUESTIONS

For the interviews, a semi-structured guide with open-ended questions was used. The entire interview guide can be found in appendix D1. Semi-structured interviews secure that covered topics are similar, but allows for personalization and follow up questions for each individual participant. It also allows the conversation to flow more naturally, and react to the things participants say during the interview (George, 2022).

The interviewees were asked for personal opinions and preference concerning the three proposed new energy tariffs. The new energy tariffs were shown one after the other, after which they were shown together on one page for comparison. In case of a telephone call, the visuals were sent to the participant, who opened en looked at them at the appropriate times during the interview.

RESULTS

Participant characteristics

The participants had the following characteristics:

- 3/14 have kids who live at home
- 2/14 are retired
- 7/14 charge as soon as they come home / don't think too much about timing
- 5/14 try to charge on solar energy as much as possible
- 2/14 try to charge during the night (as much as possible)

General insights

- Participants were aware of the high energy consumption in the evening hours – in general or regarding themselves. *"Peak rate is probably because at that time a lot of people cook, and put the car on the charger, those are elements that play a role" [1] "in the peak between 17h and 21h, and I'm no expert, but I expect that we consume a lot of power"[13]*
- Some participants don't know when they use most energy. *"I never really realized, but I don't really know when I use the most electricity.. "[5]*
- Some don't immediately see the potential financial benefit. They do not seem to understand the potential if you shift energy consumption from peak tariffs to low tariff, that it can be profitable. *"In fact, they are going to charge you more..."*
- Some have explicitly said the difference between peak and low tariff must be large to make such tariffs interesting.
- 2 suggested such tariffs would be (more) appealing to them if the tariff only applied to car energy; *"If you could somehow apply it [the tariffs] to the charge point [only], then I would say 'Yes I like the idea'.*

Preferred tariff design

Preference for each tariff was quite evenly distributed. The stated preference of each participant was as follows;
T1 Evening Peak: P1, P4*, P10*, P12, P13*
T2 Two Peaks: P5, P6, P11, P14
T3 Daytime Plunge: P2r, P3r, P7c, P8, P9

- * is for participants who choose the first option only because they dislike the morning peak in the second option.
- 'r' is for participants who were retired
- 'c' is for people who leave their car at home during workdays.

Summary of reasons for preference of a tariff

T1 Evening Peak: Participants preferred this tariff because there was only 1 peak (in contrast to T2 Two Peaks): *"A morning peak is a step too far.." [10].* Also, some saw this option as having the least impact, and easiest to understand, while it still aimed at behaviour change. *"If I think from a consumer perspective, than option 1 (T1 evening peak) impacts the consumer the least." "Because that one [T1 evening peak], has the greatest potential to change your behavior [..] and you don't have to be aware of the time the entire time" [4]*

T2 - Two peaks: Participants preferred this one due to a short peak and a start time of 19h, which is after cooking for most people. The peak in the morning did not bother the participants that choose this option, as they do not have much energy consumption in the morning. *"I find this one [T2 Two peaks] more interesting because the peak is shorter."[3]*

T3 - Daytime Plunge: Participants value the low tariff during the day, and see big potential because of long timeframe. *"Then the opportunity for us to choose low tariff is significantly large." [2]*

What type of peak tariff do people prefer?

Peak duration and timing

- Timing of a peak that is long, may not be very important. *"17 until 21.. 18 until 22, yes that is basically the same for me." [5]*
- Shorter peak is preferred, also because of later timing (as in T2 Two Peaks). *"I like that the peak tariff, with those high prices, is shortened" [5], "I think it is easier for us to steer [electricity consumption], so we can have some things done before 19h in the low tariff and stay away from the peak tariff in the evening."[13].* Only 1 participant thought a peak tariff of 18 – 20 h was more preferable than from 19 – 21

- Cooking is often mentioned as activity that takes place in the evening hours, and is the reason why people prefer the tariff to start once they have finished cooking. *"Because we usually cook between 6 and 7, and then you avoid the peak so this [T2 Two Peaks] will be more interesting" [11].*
- People are more willing to accept a long peak, if the opportunity to make use of low tariffs is relatively large - as is the case in T3 Daytime Plunge.

Insignificance of the price of peak
Participants seemed to pay attention to the duration and timing of the peak, but not so much to the price. Only one participant mentioned the very expensive peak tariff in T2 Two Peaks. *"Those 4 euro-signs worry me.. if it [the peak tariff in T2 Two Peak] is indeed significantly higher, then I would go for T3 I think."[5]*

Opinion of the two peaks / the morning peak
The morning peak in the T2 Two Peaks evoked different reactions. In general, two main groups of opinions can be identified.

- People who don't use, or think that they don't use, that much energy in the morning. Therefore, they don't care if there is a peak tariff in the morning. (P5, P6, P7, P11) "I don't have any problems with that morning peak. I don't know what people usually do in the morning, but I don't think that I use a lot of electricity [in the morning]."[5]
- People who use, or think that they use, a lot of energy in the morning. They have a negative opinion about the morning peak. (P1, P4, P7, P10, P12) *"This would be so disadvantageous, because the majority of our electricity consumption is during times of a high price; both in the morning and evening!"[4]*
- In general, whether or not people use a lot of energy in the morning, participants did not see a lot of opportunities for changes in consumption in the morning. *"I am going to have breakfast ready before 7 all of a sudden, so I can go to work at 7h, just because of a high price.."[13]*

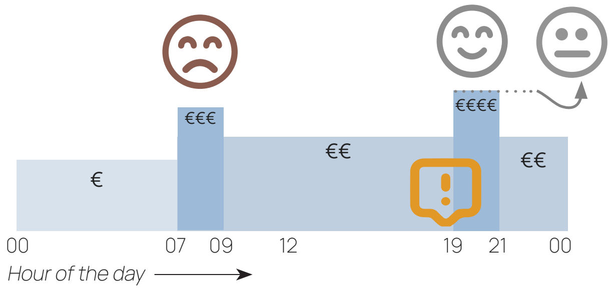


Figure 33: summary of insights: dislike of a morning peak, preference for a short peak, importance of the starting time of the peak, and the seemingly indifference of the price level of the peak

To what extent are people interested in such tariffs?
The level of interest was very diverse.

- *"No, not in the way it is designed right now, unless it applies to the car only, then I would reconsider."[1]*
- *"It gives me a lot more freedom to choose and make use of a low tariff!"[2]*
- *For both the Dutch citizen as well as for the EV driver, this [T3 Daytime Plunge] is a nice alternative."[3]*
- *"No, it will not tempt me to choose another tariff option."[4]*
- *"Yes.. Does it benefit me in comparison to 'dubbeltarief'? Probably, yes."[8]*
- *"Practically, my entire yearly electricity consumption is produced by my solar panels, so it would not tempt me really.." [8]*
- *"If it is advantageous compared to what we have now, it might be an option to consider."[9]*
- *"So yes, I would definitely consider this"[10]*
- *"Yes, this is certainly interesting, although I am not aware of the differences yet..."[11]*

How well do people understand the tariffs?
All participants were able to understand the proposed tariffs easily and without further explanation. The three tariff levels, as well as several time blocks during the day did not seem to pose any difficulty to understand the tariff design. Moreover, some participants (P4, P10, P12) even called the tariffs 'logical', which can indicate they understand the tariffs are applied in such a way to support the network: *"The most expensive tariff is during evening hours, and that is logical because then consumption is at its peak."[4]*
The ease of understanding might due to the fact that people - and therefore participants - are well aware of the current time-of-use system that is available, regardless whether they are on the tariff or not.

4.2 DESIRABILITY OF THE NEW TARIFFS

How will people remember the tariff?
Both low and high tariffs are mentioned as main thing to remember. However, the peak period is mentioned more often as main period to remember.

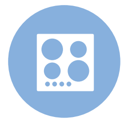
"So, what are the times of day when the tariff is low. To steer consumption I am able to steer by using timing. "[8]

"Well for T2 Two Peak I would remember 7h - 9h and 19h - 21h and avoid those."[3]

T3 Daytime Plunge: "That I can use everything I want until 7h in the morning, starting at midnight. And also from 11h until 17h. Well, that's easy to remember. ."[3]

In what ways can / will the tariff influence people's behavior?
Participants were generally willing to adapt their behaviour according to the tariff. Participants mentioned very similar things about possible behavior changes:

- Cooking usually takes place around 17:00 or 18:00 (and most participants expect to be finished before 19:00). **The new tariffs will not change their routine of cooking.** *"Cooking or using the oven is inevitable, it's something that has to happen around dinner time."(P10).* Also, participants view it as a bad thing to apply peak tariff during cooking *"to pay large amounts of money for cooking is something I don't think is right, than you are being punished for something you cannot avoid"(P1)*



- **Household appliances** that consume much electricity will be adapted to the tariff; the washing machine, dryer, and dishwasher are mentioned by participants 1,6,7,8,9,10, and 11 regarding energy consumption that they can and will steer to avoid peak tariffs. *"By turning on and using the dryer, washing machine, dishwasher more during periods of low prices."(P8)* However, some also see some difficulties to do so; *"Yes, the dishwasher is fine to use during the night, however, the washing machine and dryer is a difficult to judge because they are next to the bedroom and therefore not desirable to be used between midnight and 7 a.m."(P13)*

- **The car** is also mentioned as something people can and will steer, by participants 3, 7, 11, 13, 14, 1. *"maybe the car doesn't need to charge immediately, and you can program it for later."(P13).* On the other hand, some participants are not sure how they would charge their car, as their solar panels also play a part in their charging behaviour *"[about T1 Evening Peak] And I am in doubt about the car, I might charge it during the day if necessary, but it depends on the weather conditions."(P7)*

CONCLUSION
From the results, we can conclude preferences among the tariff structures is evenly distributed. However, looking at the reasons for choosing T1 Evening Peak, it appears this one was often chosen because people disliked having 2 peaks as in T2 Two Peaks. In addition, due to the insights that many participants saw no opportunity to shift energy consumption in the morning, combined with the limited electricity consumption in the morning, a peak in the morning (as in T2 Two Peak) does not seem effective nor critical. Therefore, a combination of the advantageous characteristics of T1 Evening Peak and T2 Two Peaks might be the most desirable tariff for all participants that chose either of them. In that case, the tariff would have an evening peak only, for a time period of 19h - 21h. Presumably, such a tariff would probably be preferred by all that choose T1 or T2 in the interviews. The newly found tariff will be referred to as Tariff Short Peak (see figure 34). With the introduction of this new tariff, the old *T2 Two Peaks* and *T1 Evening Peak* will from this point onwards no longer be part of the study. Also, from here onwards, T3 Daytime Plunge will be simply referred to as Tariff Daytime Plunge.

Furthermore, it should come as no surprise that preference for the Tariff Daytime Plunge relies on the opportunity people see to make use of the low tariff during the day. This is illustrated by the types of people that showed preference for this tariff; some can leave the car at home during workdays or did not have a working routine because they are retired. On the other hand, the participants that preferred either T1 Evening Peak or T2 Two Peaks need their car for commuting, and therefore do not see any benefit in T3 Daytime Plunge.

Another interesting insight is the fact that people tend to pay far more attention to the timing of the periods for the tariffs, rather than the exact price levels of each period.

Furthermore, cooking is an important behavior to consider in the context of TOU tariffs; the routine of cooking will not be influenced by TOU tariffs, and it influences the perception of peak tariffs a lot.

T1 Evening Peak + T2 Two Peaks

Tariff Short Peak

Tariff type	Hours	Price
Low tariff	00:00 to 07:00	€
Normal tariff	07:00 to 19:00 21:00 to 00:00	€€
Peak tariff	19:00 to 21:00	€€€€

illustration of the tariff

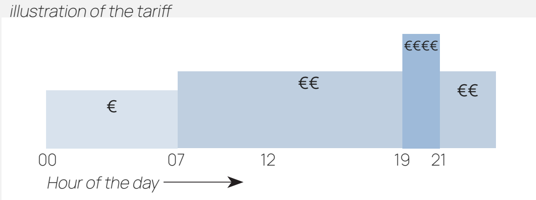


Figure 34: the new tariff: Tariff Short Peak

Lastly, although interest is diverse, a number of participants expressed interest in such TOU tariffs if it would be financially beneficial. This is a promising finding.

NEXT STEPS
What people say is not always the same as what people do. So in addition to the results of these interviews in which participants have *said* what they would do, it is interesting to understand how people would actually *behave*. How do people experience a TOU tariff, and how will their behavior actually change? Are people able to make use of a low tariff during the day as in Tariff Daytime Plunge, especially if they also have solar panels? These questions require additional research, and are the reasons for a behavioral experiment in which participants adopt the tariff. For Vattenfall, these insights are important because it is essential to make the right estimates of an energy consumption pattern, influenced by people's behavior.

4.2.2 BEHAVIOURAL EXPERIMENT

To investigate actual behavior according to the new tariff design(s), a follow up research was set up. In this experiment, 3 participants (P1, P2, P3) are recruited from the interview participants (from section 4.2.1). Below is a short description of each participant and the type of tariff they are going to experience during the experiment.

P1: retired lives with his wife	Tariff Daytime Plunge
P2: working full time 2 kids at home	Tariff Short Peak
P3: irregular workdays 1 adult child at home	Tariff Daytime Plunge

GOAL
The goal of the behavioral experiment is to get an answer to the following questions:

- To what extent do people change their behavior according to time-of-use tariff?
- In what ways / situations do people not adopt their behavior according to the time-of-use tariff?
- What are unexpected experiences of people that are on a time-of-use tariff?
- To what extent is there an intention – behavior gap? Do people behave according to what they expected / declared beforehand?
- How do people experience time-of-use tariffs?
- How do people perceive the usefulness and ease of use of a time-of-use tariff?
- How do people perceive the financial benefit that time-of-use tariffs can provide them?

INFORMATION AND SET UP
To inform the participants about the experiment, they received a short written explanation via email. It informed them about the experimental set-up, the requirement to send data about their energy usage and the two moments of interaction between the researcher and the participant at the start and end of the experiment.

The setup of this experiment can be divided in roughly three phases; the pre-experiment phase, the experiment phase, and post-experiment phase. The three phases are summarized to the right.

Pre-experiment phase
Goal: prepare the participant for the experiment

- Information is sent via email
- Schedule check-in moment
- Conduct check-in moment

During check-in, participants were given the opportunity to ask questions about the experiment. Also, it was clearly communicated which data participants needed to send at the end of the experiment. Lastly, the date and the goal of the last interview were briefly discussed.

Experiment phase
Goal: participants experience the new TOU tariff

- 2 week period to experience new tariff
- E-mail with reminder is sent after 1 week, including a video link for the meeting for the final interview
- At the end, participant sends electricity consumption

To (passively) remind participants of the experiment, an email is sent after 1 week. In this email some guiding questions that might be asked during the final interview are provided to make participants aware and keep them informed

Participants send their hourly electricity consumption for the entire experiment phase. This enables an analysis of potential financial savings they might have achieved, which are in fact reimbursed to the participant after the experiment

Post-experiment phase
Goal: retrieve information to get an answer to the research questions and finish experiment

- Analysis of electricity consumption
- Conduct final interview
- Participants receive financial compensation

FINAL INTERVIEW

The insights of this experiment are retrieved by conducting a final interview. The interviews lasted approximately 25 minutes. Some of the questions that were asked during the final interview, are as follows:

- How did you experience the new tariff?
- Which changes in behaviour have you adopted with the new tariff?
- Which changes did you not expect beforehand?
- What kinds of energy consumption have you shifted?
- In what way did you make use of your solar power to use energy?

After communicating the potential financial savings that this tariff might bring them

- What do you think of the financial savings?
- How appealing is this reward, in perspective to the effort it required?

RESULTS

Experience of new TOU tariff

Participants were generally positive about the experiment, and experienced little effort to make (small) changes in their behavior. *"really enjoyable actually!" [1]*

- P1 experienced freedom to use electricity during the day for appliances that they would normally shift to weekends. *"For example the laundry, that we used to do in the weekend, we have shifted it to 11h in the morning a few times, so that gives some freedom"[1]*
- P2 experienced some behaviors were easier to change than others. *"My wife was even more enthusiastic than I had expected! [...] we have shifted charging the car to the night, but the dishwasher did not really work out."*
- P3 did not experience many changes in behavior, as their previous / current behavior already matches the new tariff. *"We did the things like we used to do; charging the car during the day. However, we would sometimes run the dishwasher in the evening, so we tried to shift that one to daytime."*

Experience of timing

P2 experienced difficulty to use the dishwasher after 21h (after peak tariff), as they want it to be finished before going to bed. This was clearly a consequence of the specific timing of the peak tariff in Tariff Short Peak.

Steering energy

P1: some household appliances that would normally be used in the weekend, were now used during low tariff during workdays. Also this participant experimented with scheduled charging using his car app. Lastly, this participant mentioned shifting the use of the vacuumcleaner one time.
P2: was aware that the car is the biggest consumer, and was able to steer it away from peak tariff to low tariff during the night. Other household appliances were a bit more difficult to change, but were also partly shifted to night tariff. Even some smaller energy consumers, such as charger for laptops and phones were shifted away from peak tariffs.
P3: (and his wife): were already used to consuming their energy during the day due to their solar panels, so not much changed in their behavior. They shifted the dishwasher from the evening hours to the low tariff during the day. Furthermore, because the peak was quite long (17h - 22h), not much changed during the peak.

Unexpected outcomes

P1 shifted the dishwasher and tried to use it in the low tariff period during the day. However, this new behavior did not fit with other behaviors, such as their cooking routine, and therefore they disliked their new behavior and discontinued it.

P2 also experienced a behavior more difficult to change related to the dishwasher. Also in this case, it was part of other routines, which made it difficult to change without interfering with the other routines.

Financial savings

P1 thinks €200 is large amount of money which requires only little behavioral changes. Mainly appreciates the freedom of a low tariff during the day, which is why financial advantage is not really important. "the new system gives us a lot

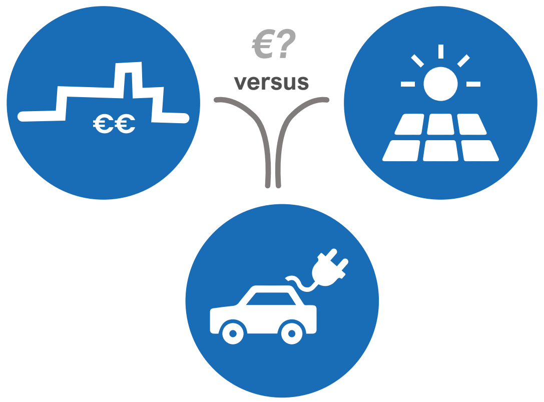
of freedom, but financially it will have hardly any consequences"

P2 clearly made the comparison between potential discomfort and financial advantage. He stated that a reduction of €50 would be too little to make it interesting, and savings of €100 would be just enough to make it interesting. Savings of €200 (on a €2000 yearly energy bill) are definitely worth to adopt the tariff.

P3 was doubtful if a reduction of €120 a year would be worth the constant 'effort'. His spouse on the other hand thought it was simply worth it, because the small behavior changes are simply a matter of getting used to things.

Other insights

- Participants became more aware of energy consumption in general
- P2 made the explicit comparison between charging his car on off-peak tariff or using his solar panels during peak tariff (solar panels are not sufficient to charge his car at normal speed, so additional electricity from the grid is needed and paid for as peak tariff)



CONCLUSION

The tariffs were positively experienced. Perhaps, this can be partly explained by the fact that participants were allowed to adopt the tariff they preferred. As a consequence, the tariff was befitting to their personal situation. Participants 1 and 3 were indeed able to make use of the low tariff during the day, due to their lifestyle. This apparent connection between type of person and type of TOU has been briefly discussed before and will be discussed in further detail in chapter *4.4 Conclusion*.

With regards to behavior changes, it became clear that behavior changes that had little impact on a daily routine were easy to adapt. However, if certain behavior is embedded into other routines, such as the dishwasher, it might be more difficult to change. An overview of electricity consuming activities and the difficulty to shift are shown in figure 35 on the next page.

Furthermore, the financial savings that came from the TOU tariffs were perceived as valuable depending on the type of tariff. In general, savings of approximately 10% of the total energy bill (which amounted to respectively €200, €200 and €100 for participants) were perceived as valuable and worth the effort. It is difficult to conclude if this is a matter of percentage or that the absolute amount is important, as the amounts are quite a well-rounded. Furthermore, for the Daytime Plunge tariff, the financial savings did not seem to be as important as for Short Peak, as the tariff itself provided the advantage of a low tariff during the day.

Shiftable electricity consumption
The figure 35 shows a summary of which behavior is easier to shift, according to its connectedness to other behaviors. "Connected to routines" is defined as activities that require previous and/ or consequent actions within a relative short time-frame. This is the reason why the dishwasher is qualified as highly connected to routines, as it requires loading and unloading of the dishwasher that encompasses the energy consumption of the event itself. So even though charging the EV is connected to coming home and leaving the house again, these activities have a large time-frame and are therefore less connected to the energy consuming charging session.

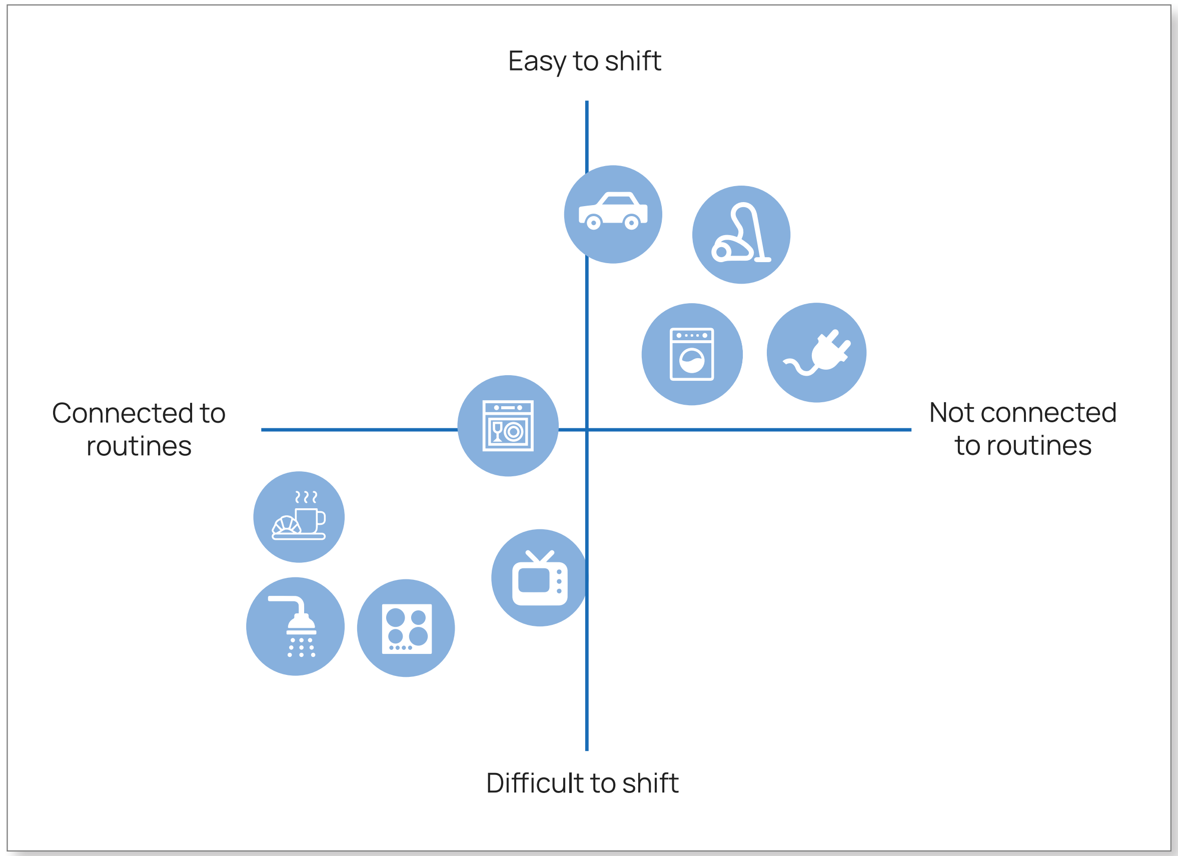


Figure 35: electricity consuming activities at home plotted according to difficulty to shift and connectedness to routines

REFLECTION OF THE METHOD
The method in this experiment is a form of giving financial incentives to induce behavior change. Providing a financial incentive to change behavior is deemed effective, although some studies argue the extent of its effectiveness is limited (Unal, 2017). For example, one study showed that a financial incentive changed people's behaviour, however, once the financial incentive is taken away, people fall back into their previous behaviour. Also, by providing a financial incentive, which can be seen as external motivator, the internal motivation of people might be suppressed (Frey & Oberholzer-Gee, 1997). This provides us two important aspect to consider when introducing such tariffs; marketing the tariffs should not only focus on the financial benefits but also highlight the other advantages for the grid and energy resources in order to induce people's internal motivation for such tariffs. Secondly, the financial benefit should be ensured in the long term and not reduced in any way, to keep people interested and keep up the behavior changes.

To further reflect on the method, it is interesting to look at a framework that looks at behavior change from a theoretical point of view and analyze how it applies in this case.

Theory of planned behavior
According to the theory of planned behaviour (Ajzen, 1991) (see figure 36), behavior can be predicted by the *intentions* to perform that behavior. Intentions are on its turn influenced by three variables: 1) behavioral attitude, 2) subjective norms and 3) perceived (behavioral) control. *Behavioral attitude* is the belief that certain behavior is enjoyable or not, and to what extent it is beneficial to the person. *Subjective norms* is the perception of what others think of the behavior. And *perceived control* is about the ability to perform the behavior. Changing the financial aspect of electricity consumption by introducing new tariffs influences the behavioral attitude, as it provides a financial benefit if behavior is changed accordingly. On the other hand, changing your behavior potentially negatively influences the enjoyability, and therefore behavioral attitude, as the new behavior might limit people in their freedom of energy consumption. This is something that appeared from the experiment as well; changing the tariff structure for people is not only about the financial advantages it can provide, but it involves a more difficult consideration between financial benefits and enjoyability of new behavior.

Furthermore, regarding the *perceived control,* something that emerged from this experiment is that the energy consumption of certain appliances are unknown, which makes effective behavior change more difficult, as participants are uninformed of what entails improved energy behavior and therefore cannot perform the behavior. To support behavioral changes to the TOU tariffs to the fullest, this is something that should be considered as well.

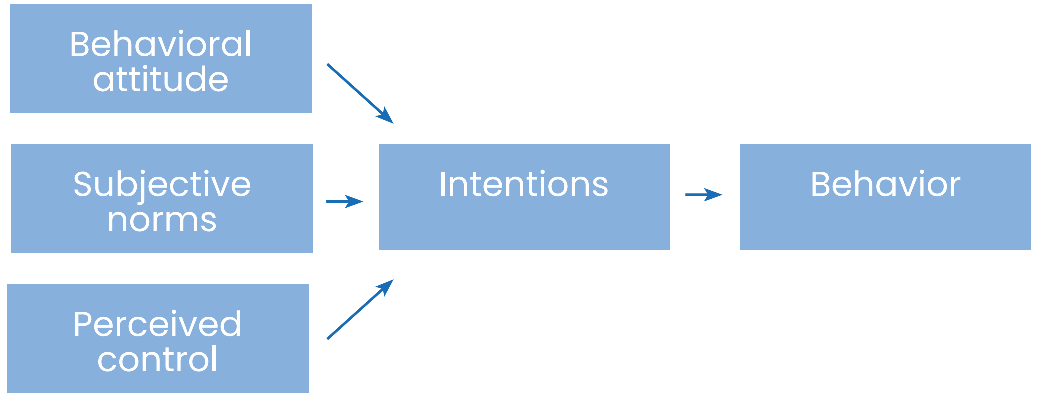


Figure 36: theoretical framework of Theory of planned behavior (Ajzen, 1991)

4.3 DESIRABILITY OF SMART CHARGING SCENARIOS

New TOU tariffs are not the only way to offer smart charging. As discussed before, there are two other scenarios that can be part of a smart charging proposition. To repeat, the three scenarios of smart charging are the following:

- TOU Tariffs
- (Compensatio for) charging on solar power
- (Compensation for) Direct Load Control

The question is; what scenarios, or combination or scenarios, do consumers prefer? To test that, the three scenarios were discussed in the previously mentioned interviews from section *4.2.1 Qualitative interview on desirability of tariffs*. From these interviews, the results show no clear preference for one scenario, nor for a particular combination. Therefore, subsequent quantitative testing is needed. This chapter describes the results from the interviews and the quantitative experiment that was consequently executed.

4.3.1. RESULTS OF INTERVIEWS ON SMART CHARGING SCENARIOS

During the interviews, the three elements of smart charging were explained to the participants, after which they were asked for their preference and motivation.

RESULTS

- A few participants showed no preference (P2, P11, P12) or preferred a combination of all three (P4)
- Two participants thought the TOU tariffs is something inevitable / something that you can't choose (P8, P13)
- P1: prefers solar & DLC
- P6 & P10: prefers DLC
- P3: prefers DLC and tariffs over solar
- P5: prefers tariffs (and would also like solar)
- P7 & P13: prefers tariffs (P7: solar over DLC)
- P8: thinks solar is more interesting in summer, and DLC in winter

CONCLUSION

From the interviews, no clear preference can be distinguished. Also, there is no clear combination of scenarios that appeals more than others.

> *"Those two ways of smart charging [compensation for charging on solar energy and DLC] really interest me!" P1*
>
> *"Charging using solar power is something we already do as much as possible, so whether that is rewarded or not, does not matter to us." P4*
>
> *"[regarding the preference for TOU tariffs] You are more in control. So you are aware of the price you pay and the time you charge. So you intentionally choose to pay more if you need your car charged." P5*
>
> *"The second [compensation for charging on solar power] is by bar the most interesting in summer. The third [compensation for DLC] is something that could be offered in winter." P8*
>
> *"I think that one [compensation for DLC] is simply brilliant" P10*

4.3.2 QUANTITATIVE EXPERIMENT ON SCENARIOS OF SMART CHARGING

As we have seen from the results of the interviews, it remains unclear what scenario(s) or combination of smart charging people prefer. Therefore, a quantitative experiment is set up to find out preference for (a combination of) smart charging scenarios. Also, this can provide a quantitative answer to the question to what degree people are interested in new TOU tariffs. Using a quantitative experiment, the following research questions are explored:

- What combination of smart charging scenarios is preferred?
- How high is interest in new TOU tariffs among Dutch EV drivers?

SET UP OF EXPERIMENT

To quantitatively test above mentioned questions, four 'propositions' are turned into Facebook appropriate advertisements. Each advertisement proposes a different combination of the three charging scenarios, an overview is provided in figure 37. Each ad shows a button 'More information', which can be clicked on, and which will be measured to determine the level of interest of people.

> **1:** TOU tariffs + compensation for charging on solar energy
>
> **2:** TOU tariffs + compensation for charging using DLC
>
> **3.** Compensation for charging on solar energy + DLC
>
> **4:** only TOU tariffs

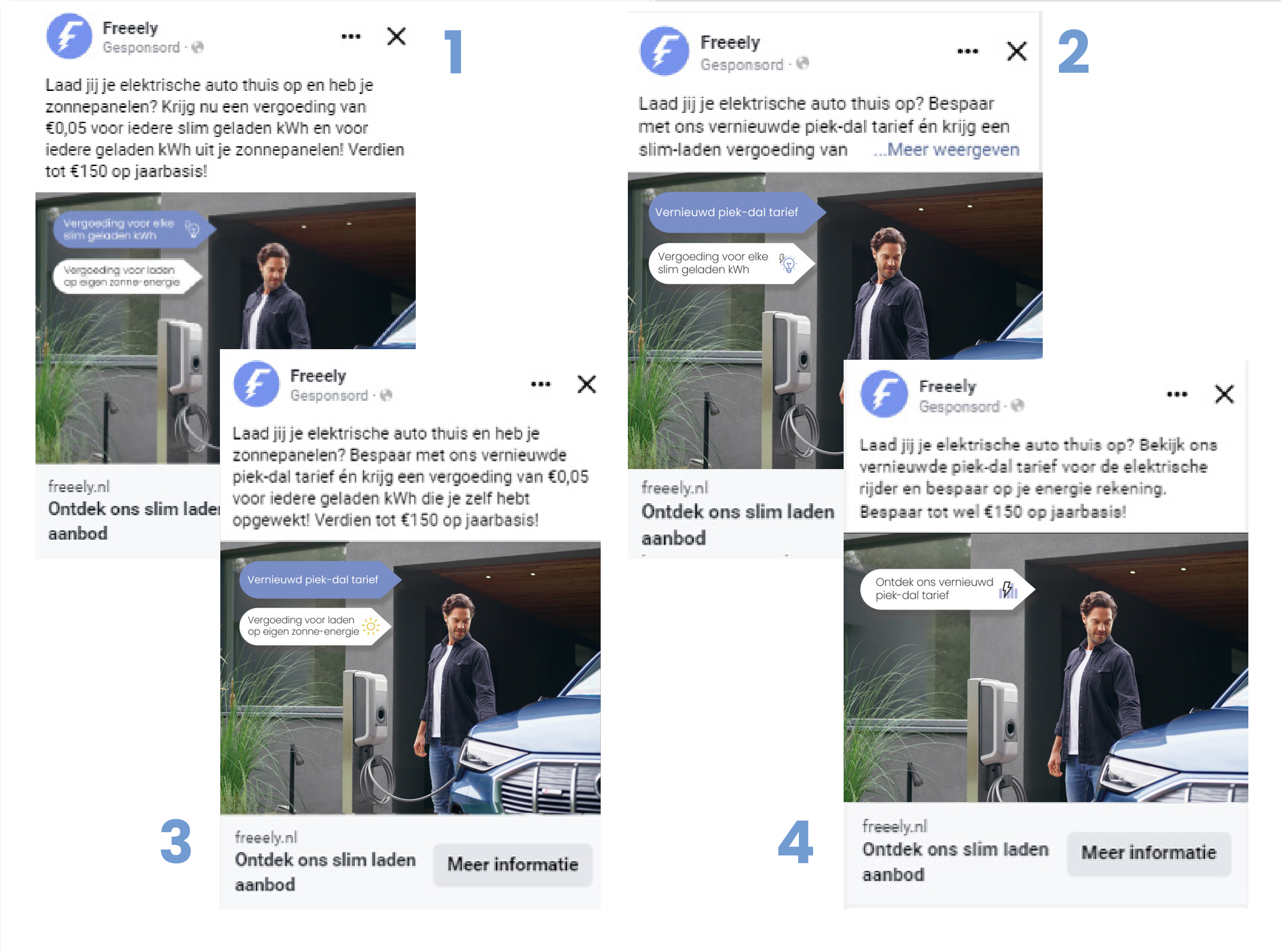


Figure 37: four different Facebook advertisements

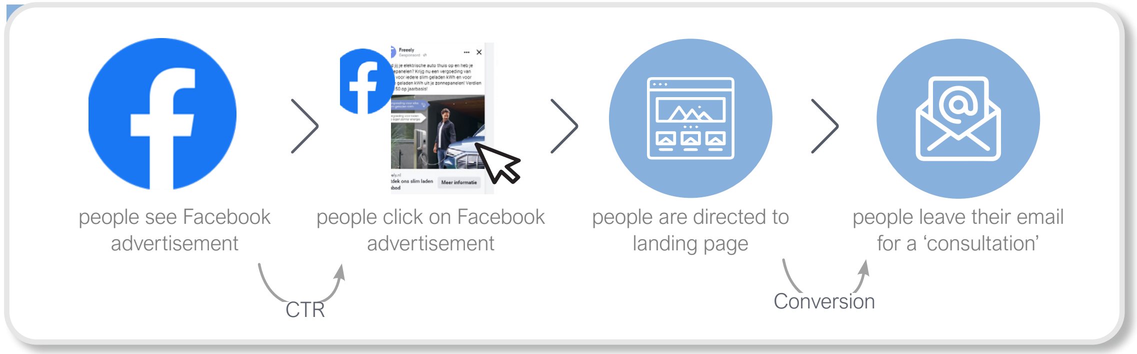


Figure 38: overview of journey from Facebook ads to landing pages and leaving an email for consultation

Clicking on the button 'learn more' will lead people to a landing page, where the proposition is explained in more detail (see figure 39) as if it is actually a real-life offer. Consequently, on the landing page there is also a button with 'Schedule a consultation' - for which people would need to fill in their email address. This journey from Facebook ads to consultation button is visualized in figure 38.

TARGET AUDIENCE

To target the right audience for the advertisement, the audience is customized according to a number of characteristics. The goals of these characteristics is to target EV drivers, with or with out solar panels. The following characteristics are applied:

- Age: >28 years old
- Location: The Netherlands
- Language: Dutch
- Interests: "Electric vehicle" / "Electric car" / "Solar panels"

The minimum age ensured the ads target people who are more likely to own a(n) (electric) car and charge point. Furthermore, the location was added because it targets Dutch people. And a language was added because it is mostly appropriate for people who live here for a long period of time. Additionally, the interests were added to target a more customized audience who are interested in the topic, and are therefore more likely to own an EV or solar panels.

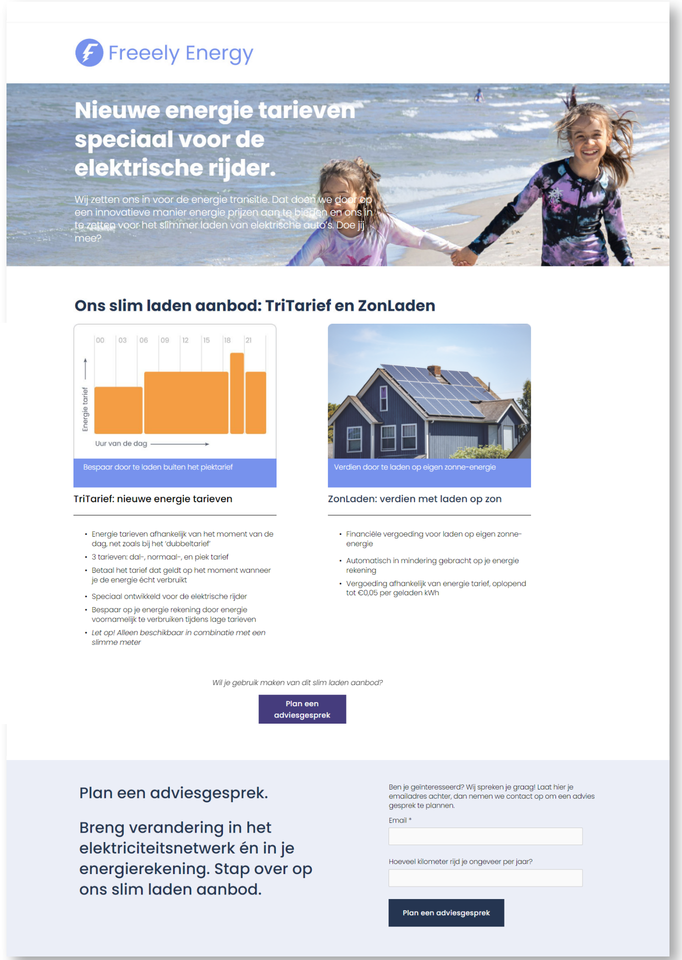


Figure 39: One of the landing pages

Advertisement	Number of views	Clicks	CTR	Emails	Conversion
Advertisement 1: Tariffs + solar	1.829	27	3,23%	0	0
Advertisement 2: Tariffs + DLC	1.187	15	2,36%	0	0
Advertisement 3: Solar + DLC	24.355	397	5,81%	2	0,5%
Advertisement 4: TOU Tariffs	14.405	231	4,92%	2	0,9%

Table 5: Results from data from the Facebook advertisements, including number of clicks, and CTR's

RESULTS

The results of the experiment are summarized in table 5. It should be noted that the large difference in number of views for the ads is because all ads were optimized for link clicks. This means Facebook tries to increase the number of clicks, which results in a 'push' of advertisements with (initially) higher CTR's (Meta Business Help Centre, n.d.). This is important to note because the number of views do not correspond directly to preference among the audience, instead the *CTR's* should be compared to understand which proposition is most appealing. What can be seen from the results, is that the two advertisement of 'Solar + DLC' and 'TOU Tariffs' had significant higher CTR rates compared to the other two propositions (highlighted in table 5). Also, on those landing pages, an email address was left in two cases.

Level of interest

To determine the level of interest, the CTR's should be compared to benchmarks. Examples of benchmarks for good CTR's of Facebook ads in the Netherlands vary quite a bit, but two that were found mentioned percentages of 1,92% (Van Lent, 2021) and 2,7% (Aanpoters, n.d.). Compared to these benchmark numbers, it can be concluded that the CTR's from the two most popular advertisements are high, and therefore these proposition interests the target audience. The two advertisements with lower CTR's (ads 1 and 2) are not very high, or even below these benchmarks, meaning that interest is average.

CONCLUSION

Although a combination of a TOU tariff and a reward for either solar energy or DLC can be financially beneficial, those two combinations don't seem to appeal to consumers. A plausible explanation might be that the combination is difficult to understand and therefore appeals less. This is supported by the finding that the visiting time of the landing page of these two propositions were also the longest among the four. Perhaps, consumers might simply prefer to adapt one novelty at the same time. Also, the concept of TOU tariffs versus giving rewards for charging sessions have a different behavioral approach; TOU tariffs require behavioral changes whereas rewards do not necessarily require behavioral changes.

DISCUSSION OF THE RESULTS

The results of this experiment might have been influenced by a number of factors, with either a potential negative or positive effect.

Firstly, the brand behind the new propositions ("Freeely") was hypothetical and therefore did not evoke any brand associations to people. With similar advertisement testing in the past, adding the brand of Vattenfall could increase CTR's up to two times. Therefore, the absence of a renown brand (such as Vattenfall) could have negatively influenced CTR rates.

Secondly, the current situation of the energy market around the time of testing might make people much more interested in energy related propositions. This might have impacted the CTR rates in a positive way.

It is hard to conclude how much both of these factors have affected the CTR rates. We can, however, conclude that the influence is limited as the two have an opposite effect.

One last factor that might have played a role in the results of this experiment is the level to which people actually understood what the proposition is about. Due to limited information in the advertisements, it is difficult to fully explain the propositions in a few sentences and an image.

4.4 CONCLUSION

Part 4 of this project, Develop, aimed to explore three main topics:

- The most promising TOU tariff for Dutch EV drivers
- Interest and experience of a TOU tariff
- Interest of the various smart charging scenarios; TOU tariffs and rewards for charging using solar energy or charging using DLC

TOU TARIFFS

An exploration and analysis of literature, TOU tariffs as applied abroad, user preferences and trends of energy market prices inspired three promising TOU tariffs; T1 Evening Peak, T2 Two Peaks and T3 Daytime Plunge. Consumer interviews deep dived into the perception and preference and discovered the value of T3 Daytime Plunge mainly depends on the opportunity that people see to actually make use of the low tariff during (work) days. Those that chose T3 Daytime Plunge were retired, had irregular working hours or could leave their car at home during (regular) working hours. On the other hand, all participants that chose T1 Evening Peak or T2 Two Peaks were close to the 'traditional' EV driver persona, and were restricted to a regular working routine and used the car for commuting. Furthermore, preference for each tariff was quite evenly distributed. However, it was also discovered that T1 Evening Peak and T2 Two Peaks could better be combined into a new tariff; Tariff Short Peak.

From a behavioral experiment in which consumers actually adopted the tariffs, it became clear participants are generally positive about the experience of a TOU tariff. Willingness to accept TOU tariffs in the future depend on the type of tariff and financial benefit that can be achieved.

Both Tariff Short Peak and Tariff Daytime Plunge are interesting tariffs that can serve as a smart charging proposition, if consumers are financially better off.

SMART CHARGING SCENARIOS

From the quantitative experiment that tested four different propositions among a large group of consumers, it can be concluded that new TOU tariffs perform worse when combined with rewards for charging on solar energy or using DLC. The advertisements that offered only TOU Tariffs ór a combination of rewards for DLC and charging on solar interest people. This means, if TOU tariffs and any financial reward for charging sessions are being offered in the future, it might be best not to offer it as a combined proposition. However, due to the high interest in both the tariffs and rewards for charging, it is still interesting to offer all three scenarios as separate elements in the future.
It is difficult to conclude which of the two rewards was more appealing.

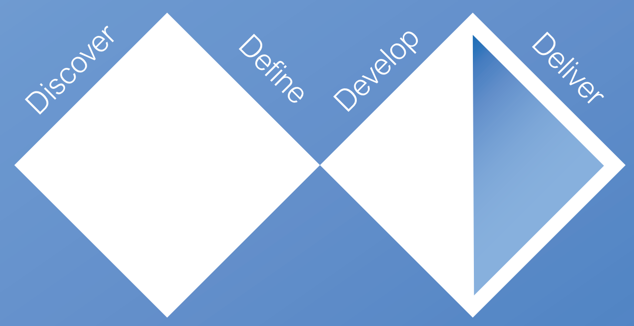
DIVERSITY OF CONSUMERS

Looking back at all these results, it appears that preference and ability to adapt to one of the tariffs may depend on the type of person and associated weekly routines. Also preference for TOU tariffs or compensation for charging using DLC or solar power might depend on the type of person. There might not be 1 solution to all EV drivers, as there are different groups of EV drivers, characterized by their own needs and weekly routines. Besides the typical EV driver as portrayed by the persona of Pieter in part *3. Define*, a number of other groups of consumers can be distinguished. These groups of consumers will be portrayed by another three persona's, which will be introduced in the next chapter, and will form the foundation of what Vattenfall should offer in the future.

5. DELIVER

5.1 THE CUSTOMER
5.2 IMPLEMENTATION ROADMAP
5.3 CONCLUSION

The previous part has discovered preferences of EV drivers' about potential smart charging propositions. This part puts these findings into context of a implementation plan. It describes how Vattenfall should offer TOU tariffs, DLC, solar compensation and additional services to successfully implement a smart charging proposition over time.



5.1 THE CUSTOMER

As concluded in the previous chapter, a smart charging proposition might not simply have a *one size fits all* solution. It is crucial to consider the diversity of people. Therefore, this part will first introduce the four persona's of EV drivers that were encountered during this project. These persona's depict the different groups of the EV drivers, and influence the order in which the TOU tariffs should be introduced to the market. It provides an impression of the customer of smart charging propositions, which is part of the implementation plan introduced in the next chapter.

PERSONA'S

Not all EV drivers are male, around 50 years old, wear a blue suit, and represent the persona of Pieter, even though it may appear like that looking at the photograph taken on an Emobility event that the researcher attended (see figure 40). Although many EV drivers may have one or more of these characteristics, there are certainly other types of people within the total group of EV drivers. Next to the persona of Pieter, three additional persona's are created and displayed in figure 41 and 42, which are created based on all interviews conducted in this project, and / or derived from findings from EV driver research (Wolterman et al., 2022).

Figure 40: People at an smart charging event

Pieter

Age	55
Occupation	Software developer
Status	Married
Location	Hillegom

Goals

- Wants to retire early
- Prefers high quality food and products
- Save up money for holiday home

Personality

- Strong minded
- Has his things in order
- Likes to optimize his life

Needs

- Luxury
- Ease
- Comfort

EV driver since 2018

Solar panels, since 2019

Lives semi detached house

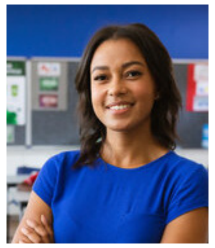
Bio

Pieter is married and has 3 kids who moved out a few years ago. He and his wife both work 4 to 5 days a week. In general, they live a normal to luxurious life, and do not have to worry about money. In their free time, they like to go to museums.

In daily life, they pay little attention to the environment. However, as they are a wealthy couple, they have invested in solar panels and drive an electric vehicle.

Figure 41: Persona Pieter, as discussed previously

Anne



Age	40
Occupation	Teacher
Status	Married
Location	Soest

Goals

- Save up money for travelling
- Wants to become 'special needs coordinator'
- See friends more often

Personality

- Creative
- Caring
- Energetic

Needs

- Support

EV driver since 2021

Solar panels since 2020

Lives in terraced house

Bio

Anne is married and has 2 small kids. She loves her job as a primary school teacher. Depending on the weather, she likes to travel by bike or car to school. Her life revolves around her kids, and in the future she would like to see friends more often.

She acquired an EV because she is environmentally aware and it pays off in the long term.

Lars

Age	34
Occupation	Construction worker
Status	Girlfriend
Location	Zaandam

Goals

- Attend a football match this year
- Buy a boat
- Become Team manager

Personality

- Habitual
- Technology enthusiast
- Tough

Needs

- Flexibility
- Entertainment

EV driver since 2019

No solar panels

Bio

Lars lives with his girlfriend in their small family home in Zaandam. They have been together for several years, and don't have kids (yet). He works irregular work shifts as a welder for large construction sites. He likes his job and the irregular work shifts. At the weekend, he likes to go to festivals, hang out with friends or do little home repairs.

Hans

Age	67
Occupation	Retired
Status	Married
Location	Almelo

Goals

- Enjoy life
- Visit friends abroad
- Stay healthy for his grandchildren

Personality

- Laissez-faire
- Protective

Needs

- Freedom
- Weekly activities
- Physical exercise

EV driver since 2020

Solar panels, since 2019

Lives semi detached house

Bio

Hans has been married for 38 years. After living in Amersfoort, he and his wife moved to Almelo, to enjoy their retired life. Their grandchildren visit often. Also, he has taken up new hobbies.

Figure 42: Three persona's of EV drivers; Anne, Lars and Hans

Persona group sizes and future development

To introduce a new product or service, it is important to get an understandig of the group size of your customer. Therefore, an estimation of the group sizes of each persona is made, based on data from a recent EV driver research of Wolterman et al. (2022), and on obtained knowledge from user interviews conducted in this project. The estimation of the group size of persona 'Hans' is mostly based on demographic data from Wolterman et al. (2022), which indicates 7% of the EV drivers is older than 70 years old, and 16% is between 60 and 69 years old. Therefore, it is estimated approximately 10% is older than 66 years old (the average age to retire (Trading Economics, 2022)). The estimates of the other group sizes are based on personal experience gained through this project, as well as some additional data like type of work schedule (regular vs. irregular work schedule is approx. 60% vs 40% (CBS, 2017).

The estimated group sizes show that the persona of Pieter is the largest group of current EV drivers, followed by the persona of Anne. Previous interviews have shown people with a regular working schedule, which applies to both Pieter and Anne, prefer the Tariff Short Peak. However, the persona of Anne might also prefer Tariff Daytime Plunge, due to her non-reliance on the car for commuting. The persona's of Lars and Hans also prefer this tariff, due to their ability to make use of the low tariff during the day. Combining these insights provides an estimated size of the total addressable market for both tariffs; (90.000 + ½*30.000) 105.000 for Tariff Short Peak and (½*30.000 + 15.000 + 15.000) 45.000 for Tariff Daytime Plunge. The size of the potential consumer group of these tariffs influence the order in which they are introduced. This will be discussed in the next section.

	Pieter	Anne	Lars	Hans
Estimated percentage of total EV population	60%	20%	10%	10%
# EV drivers (= % x 300.000)	180.000	60.000	30.000	30.000
# EV drivers who charge at home (50% of total)	90.000	30.000	15.000	15.000

Table 6: an overview of the share of each persona in the total EV population and resulting number of EV drivers per group

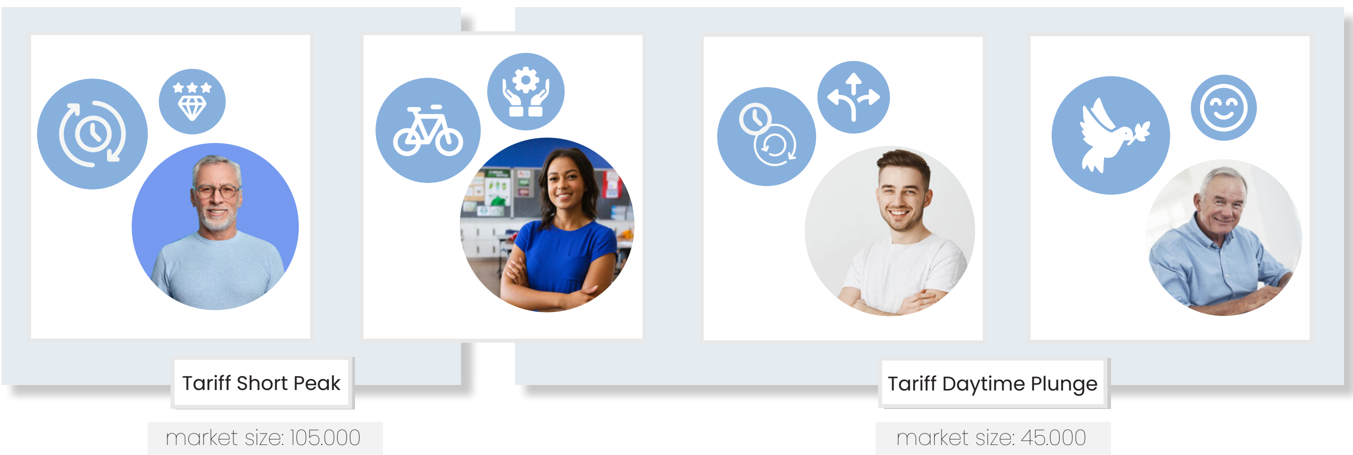


Figure 43: the four persona's of EV drivers, their preferred tariff and the size of the total addressable market for both tariffs

5.2 IMPLEMENTATION ROADMAP

A roadmap helps to put the introduction of new products and services into context with an ambition of a company along a timeline of the future. Following a framework of three horizons (Baghai et al., 1999), the future can be divided into three horizons; the first horizon is a short term future, the second horizon is a few years from now, and the third horizon depicts the envisioned far future. Both the pacing as well as the vision of each horizon are influenced by current and future trends. Therefore, the most influential trends will first be briefly discussed. Then, each horizon is briefly introduced, after which the roadmap is presented.

5.2.1 TRENDS

SMART METER ROLL-OUT
Smart meter roll-out in the Netherlands has reached 80% (Vitiello, 2022), and is aimed to reach 100% in the coming years. This is a supporting trends, as a smart meter is required for any static TOU tariff.

ELECTRIFICATION OF CARS & OTHER APPLIANCES
The number of electric vehicles will continue to increase in the future. The predicted number of EV's in 2025 is 1 million, and will reach 1,9 million in 2030 (Refa et al., 2021). In addition, the household becomes more reliant on electricity in general, due to the electrification of heating and cooking installations (Zonneplan, n.d.). Due to these developments, the average electricity demand of households will continue to increase the coming years.

NET METERING LEGISLATION
The most important changes in net metering legislation that will influence the pacing of the roadmap are the numbers from the years 2025 and 2030. In 2025 the percentage of your solar production eligible for deduction from your total energy consumption is reduced to 64%, after which it gradually decreases, until in 2030 it reaches 0%.

DECENTRALIZATION OF ELECTRICITY GRID
Following the increase of sustainable energy production, the electricity grids are changing from a centralized to a decentralized system (Baker, 2022). This also relates to the trend that households are becoming more energy self-sufficient, enabled by solar panels and power storage systems such as a home battery or the battery of an EV. Battery's of EV's will be able to apply Vehicle 2 X (V2X), which relates to the concept in which EV's delivers electricity back to the grid, home or any other appliance.

DEVELOPMENT OF PERSONA GROUPS
As the number of EV's, and therefore the number of EV drivers, is expected to grow a lot, this also enlarges the diversity of EV drivers. Consequently, the distribution of EV drivers among each persona group (as portrayed in previous chapter) may slightly shift. In addition, new types of persona's may arise.

GROWING NETWORK PROBLEMS
Network congestion and imbalances are going to be a big problem in the coming years (NOS, 2022). Especially congestion is a problem that stakeholders needs to work together to solve the problem.

The various trends are in included in the roadmap presented in figure 45 to indicate in which horizon the trends plays an important role.

5.2.2. INTRODUCTION TO EACH HORIZON & OTHER ELEMENTS OF THE ROADMAP

According the trends that have been discussed, and Vattenfall's ambition for a fossilfree future, an ambition for each horizon is formulated.

The **first horizon** focusses on encouraging improved energy consumption by introducing the first new TOU tariff - Tariff Short Peak. Improved energy consumption means energy consumption during more optimal hours for the grid and for energy market prices.

The **second horizon** focusses on the maximization of solar power. As many of the EV drivers that charge at home have solar panels, there is a large potential to make better use of their generated solar power. Tariff Daytime Plunge is introduced, to financially stimulate this behavior. Precedingly, a solar compensation should be introduced to support people in their transition to optimized solar consumption.

The third horizon is a future vision in which Vattenfall should support decentralized electricity grids in which the EV battery enables homes to become more self-sufficient. Vattenfall should take control in charging and discharging EV's according to optimal times through DLC. TOU tariffs will be integrated into DLC as part of the data input, as well as solar generation data.

ORDER OF INTRODUCTION TOU TARIFFS
There are two main reasons why Tariff Short Peak should be introduced first, before introducing Tariff Daytime Plunge. First of all, the persona that is most likely interested in Tariff Short Peak is currently the largest group among the persona's, as it represents the 'typical' current EV driver. Therefore, the target audience of Tariff Short Peak is the largest, making this the most viable proposition to be introduced. Secondly, Tariff Short Peak is the most similar to the TOU tariff currently known in the Netherlands as 'dubbeltarief', and as a consequence might be easier to adopt. Carmichael et al. (2021) suggest that introducing simple TOU tariffs before introducing more complex tariffs is desirable because experience with TOU tariffs will positively influence perception of TOU tariffs, and people can be guided from simple solutions to more complex ones using small changes.

DLC AS SUPPORTING TECHNOLOGY TO OTHER SCENARIOS OF SMART CHARGING
Even though DLC has been described as a smart charging scenario in itself, it can be leveraged as a building block to integrate the other smart charging scenarios as well. In essence, DLC can be seen as a technology that integrates various data inputs to control the charging session of an EV. So at first, DLC might be used to pause or slow down charging sessions based on data of imbalance and congestion. After introduction of the new TOU tariffs, these will also be integrated into this system, as well as data about solar generation (which already seems to be possible (Stekker.app.nl).

SOLAR COMPENSATION
Compensation for charging on solar power should be introduced shortly before horizon 2 kicks in. This is because consumers will most probably be looking for solutions for their solar power before legislation is actually put into place. Furthermore, it should be discontinued once the Tariff Daytime Plunge is introduced, as this already offers a low tariff during hours when solar production is high which should encourage people to charge during daytime.

MONITOR & INSIGHT
According to interviews from *2.5 User interviews,* EV drivers monitor their solar generation and charging sessions. Furthermore, from *4.2.2. Behavioral experiment,* participants expressed a need for some additional insights for effective behavior changes. Therefore, a row of 'monitor & insight' in the roadmap specifies additional requirements related to monitoring & insights that support the TOU tariffs, DLC and solar compensation.

5.2.3 THE IMPLEMENTATION ROADMAP

This figure (44) displays the implementation plan for smart charging propositions over time.

TO CLARIFY "REQUIREMENTS"

KWO: *KlantWaardeOptimalisatie. Team responsible to determine prices for the consumer, based on wholesale market prices.*

Digital: *Team responsible for the application (and functionalities) of Vattenfall.*

	2024 HORIZON 1	2025 HORIZON 2	2030 HORIZON 3
VISION	**Encourage improved electricity consumption**	**Support maximization of solar power consumption**	**Enable a self-sufficient home energy system and make EV's part of the decentralized grid**
TRENDS			
EXPLANATION	Due to the development of electrification and the desire to save on electricity bills, Vattenfall should offer EV drivers TOU tariffs that encourage improved electricity consumption. 'Improved' means to avoid periods when wholesale prices are usually high and risk of local congestion is high. Also DLC is introduced to keep up with competition and adopt the technology that is needed in future horizons	The future changes of net metering legislations establishes the introduction of this new horizon, that focusses on solar energy. Although in the future the new legislation naturally provides a financial incentive for people to maximize consumption of solar energy, Vattenfall should support their customers. Therefore, the focus of the second horizon is to focus on solar energy maximization. Tariff Daytime Plunge is the TOU tariff that should be introduced, as the low tariff during the day can further incentivize people to make use of electricity during hours that solar panels usually generate electricity.	Once the majority of EV's and charge points are able to comply with V2X technology, the third horizon will make its introduction. The battery of the car is charged and discharged during optimal hours, and functions as battery to the home and local distribution network. Vattenfall still delivers energy on times that solar panel production is low, or when wholesale prices are low. New TOU tariffs are introduced according to current market prices and congestion situations.
INTRODUCTION OF SMART CHARGING PROPOSITIONS	TARIFF SHORT PEAK; DLC	TARIFF SHORT PEAK; solar compensation; TARIFF DAYTIME PLUNGE; DLC	TARIFF DAYTIME PLUNGE; NEW TOU TARIFF; DLC
CUSTOMER	market size: 105.000	market size: 280.000; market size: 170.000	total market size: 900.000; ?
MONITOR & INSIGHT	Provide insight in appliances with high energy consumption in the home to support effective behavior changes.	Provide insight in how much solar energy is being used by the home, and what for. Enable multi tariff entry for charging schedules.	Enable functionalities that give people freedom to choose to what extent their EV battery is available to their home and to other homes.
REQUIREMENTS	**KWO**: establish tariff prices, and investigate potential solar compensation for next horizon **Marketing**: Develop storytelling around TOU tariffs for effective communication **Digital**: Integrate DLC functionality into VF app (by collaborating with Jedlix)	**KWO**: establish tariff prices, investigate new interesting TOU tariffs according to new market prices **Marketing**: distinguish and target customer group with high solar **Digital:** integrate solar as data input for charging application (e.g. into DLC functionality)	Outside the organisation: requirement of high penetration of smart charge points & smart cars

Figure 44: implementation roadmap of smart charging propositions according to three horizon model

5.3 CONCLUSION

VALUE OF (SMART) CHARGING

To give insight into the potential market value of the roadmap, not only market size is relevant, but also the amount of MegaWatts (MW) that is involved. The total amount of MW of charging sessions at home for Vattenfall consumers is calculated for 2025 and 2030. The average annual kilometers driven by an EV is around 15.000 km (according to CBS (2021), or 17.500 km according to Wolterman et al., (2022). Assumed an average of these two numbers, and assumed the percentage of at-home charging sessions remains at around 50%, and a market share of 25% for Vattenfall, a total amount of MW's of charging EV's can be calculated (16.000 km = 2720 kw, multiplied by the number of cars, multiplied by the percentage at-home sessions, and then multiplied by the marketshare of Vattenfall). It comes down to a total of **340.000 MW in 2025** and **646.000 MW in 2030.** These numbers display the total value of the charging sessions of EV's, and give an indication of how much energy Vattenfall can allocate to TOU tariffs, steer using DLC or encourage to charge as much with solar power. In case of a V2H situation, these numbers will be even higher.

In addition to this, the government wants 60% of charging sessions to be smart in the near future (NAL, 2022). As discussed before, they might be giving out financial rewards for smart charging sessions to stimulate this. This will further enlarge the value of the smart charging proposition, especially with regards to DLC.

However, value should not only be expressed in MW's. By offering TOU tariffs and solar compensation, Vattenfall can differentiate from other smart charging providers and become preferred supplier of EV drivers. Also, TOU tariffs might even become more valuable in horizon 3, where V2X technology further increases potential financial benefits.

VALUE OF DLC

Furthermore, an important indirect value pool is churn reduction. In Sweden, where dynamic contracts are more prevalent, consumers are switching to Tibber as it offers automatic steering according to dynamic tariffs whereas Vattenfall does no offer this. As seen in the *2.2 Competitor Analysis*, in the Netherlands, organisations are offering DLC already and more are expected to do so too. DLC might become a requirement rather than competitive advantage. By offering DLC, Vattenfall avoids churn, which is of large value in the energy supplier domain (H Berendsen, personal communication, November 2022). In addition, as suggested by the roadmap, DLC is needed for the future horizon to play a significant role in the flexmarket, and is best introduced in advance to build the solution.

PART 6. DISCUSSION

6.1 LIMITATIONS
6.2 FURTHER RESEARCH

Now that the final design has been presented, it is time to discuss some of the results. In this part, I will highlight some of the limitations of this project, as well as suggest areas for further research.

6. DISCUSSION

This project has been completed within a limited amount of time, and under certain circumstances. In this chapter, a number of limitations are discussed that might have influenced the results of this project. In addition, a number of areas for further research are recommended for further development of the outcomes of this project.

6.1 LIMITATIONS

INFLUENCE OF A GLOBAL ENERGY CRISIS

At the time of conducting this research and writing this report, the energy market experienced unique developments. Not only in the Netherlands, but worldwide, a global energy crisis is going on (IEA, 2022). At the time of writing, wholesale energy prices have gone up ten fold compared to 1 year before, and consumer prices have increased around three times (Parool, 2022). The Dutch government even interfered and imposed a price cap, and monetary compensation was given out to every bill payer in the country (Garnier, 2022).

The energy crisis made the subject of energy prices the talk of the day (see figure 45 for numerous news items). Consumers were highly aware of the increased energy prices and people are increasingly seeking for opportunities to save energy (Kassa, 2022). This situation will have definitely influenced consumer perspective in all the interviews and experiments that were conducted in this project. Due to the high price of electricity, participants might have expressed more willingness to adapt new ways to reduce their electricity bill. However, if prices decrease it is unclear if this willingness remains as high.

Although all results from activities as part of this project will have been influenced by these developments in some way, results from previously conducted researches have not been impacted by these developments in any way. Also, some argue that the energy crisis did not only have a temporarily effect, but induced a definite change in the energy environment (IEA, 2022).

SELECTION OF PARTICIPANTS

The selection of participants for the various interviews and behavioral experiment in this project was based on convenient sampling and self-selection sampling. These recruiting methods were chosen because of the qualitative nature of the research, but may not result in participants that are representative of the entire population (EV driver that charges at home) (Sharma, 2017). Self-selection sampling may attract participants with a strong opinion about the subject (Gill, 2020), and convenience sampling was simply limited to the people known to the researcher, which may restrict the variety of participants. It should be considered these sampling methods may have had an influence on representability of the results for the entire population.

AT-HOME-CHARGING SITUATION

An EV can be charged at home through a charge point or simply by plugging the charger into a socket in the house. Of the Dutch EV drivers who charge their car at home, approximately 18% uses the regular socket to do so (Wolterman et al., 2022). The way that the car is charged influences some possibilities for smart charging. For the subject of tariffs, the way of charging is of no importance, but to apply DLC, charging the EV from the socket is not compatible, as the charging power is too low and the car needs the entire plug-in-time to be fully charged. Therefore, it is not possible to lower or stop the charging session, making DLC irrelevant. In this report, no distinction was made between the two ways of charging. Consequently, the market size for DLC is lower than anticipated.

SMART HARDWARE

In addition to the charging method used at home, also the charge point and car technology can be limited to adopt DLC. Newly build cars and more advanced charge points are able to connect to the internet, thereby enabling DLC. However, older EV's or simple charge points are not able to connect and communicate with other devices, making it impossible to apply DLC. This thesis has not considered these limitations in the design of the roadmap.

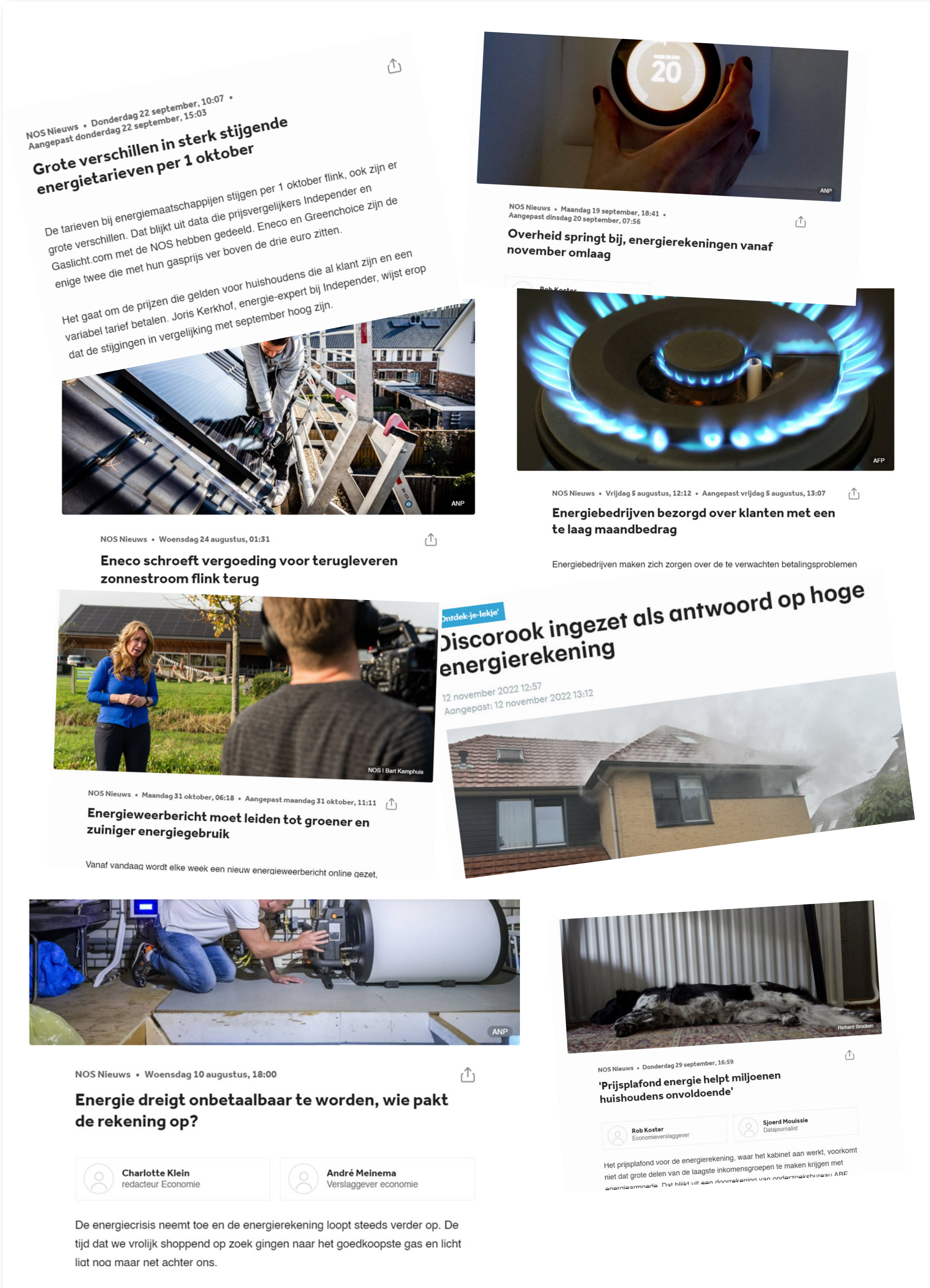


Figure 45: screenshots of numerous news items published in recent months

6.2 FURTHER RESEARCH

POTENTIAL RELEVANCE FOR OTHER CONSUMERS

The newly proposed tariffs are designed to be valuable for EV drivers. However, they might also be valuable to other type of consumers. By using consumption data of Vattenfall consumers, other groups of consumers might pop up that can benefit from these new TOU tariffs as well. For instance, people with solar panels installed might benefit from new TOU tariffs, because part of their energy consumption comes from their solar energy. Also, the concept of DLC can be relevant for people with a heat pump, which is something that can be investigated.

PRICE ELASTICITY

Findings from the behavioral experiment in this project indicate people will be interested in TOU tariffs if financial savings are around 10% of their energy bill. The findings also suggest that the demand for TOU tariffs is somewhat price elastic; demand for such tariffs will decrease if potential financial savings decrease. On the other hand, once on a TOU tariff, behavior seems to be price inelastic; an increase of the difference between peak - and off-peak prices does not lead to a significant change in consumption pattern (Burns & Mountain, 2021). Therefore, consumption behavior in a TOU tariff is easy to predict as it is independent of price differences between the periods. Further research should be focused on assigning appropriate tariffs in order to ensure financial savings sufficient enough to appeal to consumers. What prices should be applied to the pricing periods? What is the amount / percentage of savings that Vattenfall can offer consumers of TOU tariffs according to adapted behavior? And what is the price elasticity to adopt new tariffs?

POTENTIAL SOLAR COMPENSATION

To give financial compensation for charging on solar energy, or offering a low tariff during the day, it must be financially achievable for Vattenfall. It must be further investigated if financial compensation is interesting, and if so, how much can be given? Similarly, a low tariff during the day such as in Daytime Plunge should be further investigated.

MARKETING OF TOU TARIFFS, SOLAR COMPENSATION AND DLC

Consumers can be incentivized by the financial savings that TOU tariffs, solar compensation and DLC can offer, but this might not be the only reason why people adopt them. Also the advantages it brings to the stability of the electricity grid and sustainable energy resources might be important reasons for people to be interested in smart charging. A study among Israeli energy consumers found that benefits to the electricity grid and energy resources had larger influence on willingness to adopt TOU tariffs than potential financial advantanges these tariffs might offer (Parag, 2021). The question for marketing TOU tariffs, DLC and solar compensation among Dutch consumers that remains is: What is the most effective way of marketing new TOU tariffs, solar compensation and DLC to appeal the most, and to the largest group of consumers?

ADDITIONAL TOU TARIFFS

The TOU tariffs in this report have not explicitly differentiated between weekdays or weekends, or summer or winter. Further research could be focused on consumer acceptance to further differentiation of TOU tariffs according to type of day or season. Or perhaps a more dynamic TOU tariff, as we have seen in France. Furthermore, it can be investigated what additional TOU tariffs are relevant in the far future.

POTENTIAL MARKET SIZE AND VATTENFALL CUSTOMERS

Some effort has been made to estimate the potential market size of consumers of new TOU tariffs. Using more statistics and demographic details, a more well-informed guess to estimate the size of the total addressable market, including distribution among persona's, can be made. In addition, what is the minimal market size to make a financially interesting business case?

Furthermore, currently, Vattenfall experiences a smaller number of EV drivers that charge at home

than you would expect based on the total population and the market share of Vattenfall. Therefore, the EV driver within Vattenfall might not represent the general population, and perhaps the different persona's might be differently represented. What consumption patterns does the current EV base of Vattenfall show, and what does this tell about their behavior with regard to charging? Use this data to quantify types of persona's.

PRICE COMPARISON WEBSITE (PCW)

For succesful introduction of new (TOU) tariffs, it is important that consumers take these tariffs into account when choosing a (new) electricity contract. A price comparison website is the most commonly used source of information among Dutch electricity consumers to compare electricity contracts (Van der Grient & Kamphuis, 2021). This poses a problem, as current price comparison websites often do not incorporate TOU tariffs (Carmichael et al, 2021), or only to limited extent. Only one online service was found that offers an in-depth comparison of available tariffs based on an analysis of your electricity consumption pattern (https://save.watiofy.com/). It should be investigated how new TOU tariffs can easily and effectively be incorporated into widely used comparison websites. Other efforts could be focused on which sources of information EV drivers in particular consult to decide on their electricity contracts to discover other strategies next to price comparison websites that can be effective to make TOU tariffs known to EV driver.

V2G

The scope of this project excluded the concept of vehicle to X (grid, home, other appliances) to a large degree. However, in the future, vehicle to X is essential to support a sustainable and profitable electricity network. Therefore, further research should focus more on what role Vattenfall wants to play in the V2X challenges.

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