INDIVIDUAL AND CONTEXTUAL BARRIERS TO SOLAR SELF-CONSUMPTION

A qualitative and quantitative assessment of laundry loadshifting behavior in Dutch households

Name: Naomi Hubert
Student ID: 5193567 (TU Delft) & 1493191 (LU)
MSc program: Industrial Ecology
Supervisors: dr. G. de Vries & dr. L. M. Kamp
Practical guidance: dr. Katharina Biely

Date of submission: August 16th, 2022
Date of defense: August 23rd, 2022

TU Delft

Universiteit Leiden

Individual and contextual barriers to solar self-consumption

A qualitative and quantitative assessment of laundry loadshifting behavior in Dutch households

By

Naomi Hubert

in partial fulfilment of the requirements for the degree of

Master of Science
in Industrial Ecology

at the Delft University of Technology,
to be defended publicly on Tuesday August 23rd, 2022, at 15:00 PM.

Supervisors:	Dr. G. de Vries,	TU Delft
	Dr. L.M. Kamp,	TU Delft
Practical guidance:	Dr. K. Biely,	TU Delft

TU Delft

Preface

First and foremost, an enormous thank you to my supervisors for your thorough feedback, time, and patience. You've taught me not only how to *do* research, but also what it *means* to be a researcher. I consider you to be admirable researchers and steadfast women, who will no doubt continue to inspire me throughout my career. Gerdien, thank you for always taking me seriously, and for showing me that being a psychologist involved in the energy transition isn't so crazy after all. Linda, for always being straightforward with me and keeping me realistic. Katharina, for your countless helpful comments and personal guidance, and for caring not just about my thesis but also about my wellbeing (which should be self-evident, but often is not).

In many ways, my thesis was a fitting end to the Industrial Ecology adventure I started when I set foot on TU Delft's campus as an outsider (a Psychology graduate). Both IE and my thesis confronted me not only with the added value of my background, but also with all the things I needed to *un*learn. That not all master theses are created equal. That it is not possible to know everything or do everything. That social scientists and engineers need each other more than they'd like to admit. That doing anything in the field of sustainability (and in academia) means valuing *progress*, not perfection.

And perhaps most astounding to me, that statistics is in fact *not* the holy grail. Unlearning all these notions whilst also figuring out who I am as a sustainability expert was sometimes difficult, but always worthwhile. I am extremely grateful for everything the people at TU Delft and those of the Industrial Ecology programme have taught me. Most of all, I am grateful to have been given the chance to step outside of my comfort zone (over and over). And to have been brave enough to do so, considering I had a very different path in mind when I started studying 8 years ago.

Thank you also to my family, friends, and flatmates (who are both family and friends) for all your formidable support. To my parents, who always cheer me on even from 8000 kilometers away. To my island of Aruba, for being a home to return to when the stress gets too much (as I told my interviewees, my love for the sun goes beyond its ability to produce energy). To my ~~colleagues~~ friends of the GreenTU 21-22 board, who were never mad at me for slacking at work when a deadline was approaching. And finally, to my partner, who has celebrated all my highs and supported me through all my lows. You are perhaps the second-best thing IE has brought me… the first being my hard-fought for diploma.

Naomi Hubert
Delft, August 2022

Abstract

To use self-produced solar energy efficiently, as well as reduce emissions and net congestion problems, prosumer households should substitute grid-consumed energy with self-consumption. Unlike technical solutions such as storage, loadshifting is a low-cost behavioral measure to increase self-consumption. Loadshifting refers to the shifting of energy-intensive behaviors (such as running the laundry machine) to periods of time when energy is produced. Research on the behavioral foundation of loadshifting is scarce, thus it is not well understood why many prosumers struggle to loadshift. At a time of growing PV integration, leading to a debate on balancing responsibility and the dismantling of the Dutch net-metering scheme, the Netherlands makes for an interesting case to study this issue of loadshifting. Thus, this study aims to assess the barriers limiting Dutch prosumer households from loadshifting the use of their laundry machine to a time when their solar PV system is producing energy.

Literature research shows that loadshifting not only depends on the individual performing the behavior, but also on the material and institutional context. Therefore, combining the individual-focused theory of planned behavior and context-focused social practice theory in a single model is deemed useful to study barriers to loadshifting. Such a novel model is created for the purpose of this study, consisting of 10 measurable constructs possibly underlying barriers to loadshifting. The included constructs are sufficiency attitude, motivation, user beliefs, know-how, monitoring skills, habits, hassle, practical knowledge provided, institutional policies and regulations, and feedback provision by system design. To test this model in practice a mixed-methods approach is taken. Qualitative data is obtained through six semi-structured interviews with solar energy experts and is analyzed through thematic content analysis using ATLAS.ti. The quantitative data encompasses 283 survey responses from Dutch prosumers, analyzed mainly through a multiple regression analysis in SPSS. A preparatory exploratory factor analysis, reliability analysis and bivariate correlation analysis are also conducted.

Qualitative findings largely verify the model. According to experts, a low sufficiency attitude, passive user beliefs, limited practical knowledge, strong habits, hassle, limited know-how, low monitoring skills, financial motivation and low feedback provision are all relevant barriers to loadshifting behavior. Barriers found in addition to the predefined model include high age, panel orientation, a lack of clear policy, safety concerns, outdated machinery, and low interpretability of energy bills. On the other hand, only low monitoring skills, strong habits, limited practical knowledge, and passive user beliefs significantly limit loadshifting behavior in the

quantitative analyses. Thus, these four barriers that were expected based on the predefined model are confirmed by both the interviewed experts and the surveyed prosumers themselves.

Findings highlight the need for cooperation amongst the energy sector, home appliance producers, policymakers, consultants, researchers, and prosumers. Furthermore, technology should support human behavior, rather than expecting behavior to adjust to technology. For example, technical measures that do not require dramatic habitual change can easily support loadshifting, such as panel orientation. If the encouragement of habitual change is desired, dismantling the Dutch net-metering scheme in combination with providing a monetary self-consumption bonus is recommended to simultaneously reduce the effect of multiple barriers. Moreover, prosumer knowledge on self-consumption and prosumers' monitoring skills should be increased.

Notable strengths of this study include its mixed-methods approach, the large quantitative sample size and the novel combination of TPB and SPT. However, not all relevant barriers could be considered, and policymakers were not interviewed directly. Lastly, the study treated Likert-scale survey questions as interval data, and most constructs were quantitatively measured using two questions only. Future research is needed mainly to assess potential interaction effects between habits, hassle, and know-how. Additionally, potential barriers not included in this study can be assessed, such as the effects of motivation or values on loadshifting.

Table of Content

LIST OF TABLES **8**
LIST OF FIGURES **8**
LIST OF ABBREVIATIONS **9**

CHAPTER 1: INTRODUCTION **10**
1.1. Problem statement 10
1.2. Scope 12
1.3. Societal & scientific relevance 13
1.4. Knowledge gap 15
1.5. Research objective & research questions 17
1.6. Research outline 18

CHAPTER 2: THEORETICAL BACKGROUND **20**
2.1. Current state of self-consumption 20
2.2. Measures to increase self-consumption through DSM 20
2.2.1. Technical measures: storage systems 20
2.2.2. Behavioral measures: loadshifting 21
2.3. Policies to encourage self-consumption 23
2.4. Case selection: The Netherlands 25

CHAPTER 3: THEORETICAL FRAMEWORK **27**
3.1. Literature research: Factors impacting energy (self-)consumption 27
3.2. Constructing the appropriate model 30
3.2.1. Individual focus: The theory of planned behavior (TPB) 30
3.2.2. System focus: Social practice theory (SPT) 32
3.2.3. Combined model 34

CHAPTER 4: OVERARCHING METHODS **37**
4.1. Outline: Qualitative method applied in this thesis 37
4.2. Outline: Quantitative method applied in this thesis 37
4.3. Combining methods: the mixed-methods approach 38
4.4. Overall approval by the Human Research Ethics Committee (HREC) 39

CHAPTER 5: QUALITATIVE METHODS **40**
5.1. Qualitative research method: semi-structured interviews 40
5.1.1. Participants 41
5.1.2. Procedure 43
5.2. Qualitative tools: ATLAS.ti 44
5.3. Qualitative analysis: Thematic content analysis 44

CHAPTER 6: QUALITATIVE RESULTS **46**

6.1. Qualitative results: constructs and barriers found deductively 46
6.2. Qualitative results: constructs and barriers found inductively 47
6.3. Additional qualitative results: the importance of self-consumption 47

CHAPTER 7: QUANTITATIVE METHODS 57
7.1. Quantitative research method: survey 57
7.1.1. Participants 57
7.1.2. Procedure: survey building 58
7.1.3. Procedure: survey distribution 67
7.2. Quantitative analyses 67

CHAPTER 8: QUANTITATIVE RESULTS 69
8.1. Description of the included sample 69
8.2. Exploratory factor analysis 70
8.3. Reliability analysis of the computed scales 73
8.4. Bivariate correlation analysis between the computed scales 75
8.5. Multiple regression analysis 77

CHAPTER 9: CONCLUSIONS 80
9.1. Review 80
9.2. Conclusions from literature 81
9.3. Qualitative conclusions 82
9.4. Quantitative conclusions 83
9.5. Main conclusion 84

CHAPTER 10: DISCUSSION 87
10.1. Strengths 87
10.2. Limitations 88
10.3. Implications & recommendations 90
10.4. Suggestions for further research 93

REFERENCES 96
APPENDICES 104
APPENDIX A: Informed consent forms 104
APPENDIX B: Complete interview questions 107
APPENDIX C: Codebook 109
APPENDIX D: Complete survey questions 112
APPENDIX E: Testing the assumptions of a regression analysis 118

List of tables

Table 1. *Research questions* 18
Table 2. *Combining the TPB and SPT into a new model* 35
Table 3. *Overview of the six semi-structured interviews* 42
Table 4. *Thematic content analysis* 45
Table 5. *Elements, constructs, and barriers found in the six interviews* 49
Table 6. *Survey structure* 62
Table 7. *Frequency table for the categorical characteristics of the included participants* 69
Table 8. *Results of the exploratory factor analysis* 72
Table 9. *Results of the reliability analysis* 74
Table 10. *Correlations between loadshifting and the eight computed constructs* 76
Table 11. *MRA results on the relationship between the eight constructs and loadshifting* 79

List of figures

Figure 1. *The research flow diagram* 19
Figure 2. *Factors impacting (solar) self-consumption or general energy consumption in similar studies* 29
Figure 3. *The theory of planned behavior* 31
Figure 4. *The social practice theory* 33
Figure 5. *SPT as applied by Frances & Stevenson to study PV engagement* 33
Figure 6. *The constructed model* 36
Figure 7. *Overview of the methods and their relations* 39
Figure 8. *The constructed model, combining elements and constructs from TPB and SPT* 82
Figure 9. *Constructs of the model verified by the qualitative and/or quantitative assessments* 85

List of abbreviations

Abbreviation	Definition
CEP	Clean Energy Package
DSM	Demand side management
EFA	Exploratory factor analysis
ETLab	Energy Transition Lab
EU	European Union
HREC	Human Research Ethics Committee
IE	Industrial Ecology
IPCC	Intergovernmental Panel on Climate Change
MLP	Multi-level perspective
MRA	Multiple regression analysis
MSc	Master of Science
PV	Photovoltaic
SPT	Social practice theory
TPB	Theory of planned behavior
TPM	Technology, Policy and Management
UNFCCC	United Nations Framework Convention on Climate Change
VIF	Variance Inflation Factors

CHAPTER 1: INTRODUCTION

1.1. Problem statement

To begin on a hopeful note: Since discovering the global warming potential of gases such as carbon dioxide (CO_2), intentions to lower CO_2 emissions have been declared both nationally and globally. Following the formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, the United Nations Framework Convention on Climate Change (UNFCCC) came into being in 1994. In 1997, the Kyoto Protocol first committed industrialized countries and economies to limit and reduce emissions. The movement culminated in the legally binding Paris Agreement, adopted by nearly every country in 2015. The goal of the Paris Agreement is to reduce (CO_2) emissions enough to limit global warming to 1.5 degrees Celsius compared to pre-industrial levels. Unfortunately, the most recent IPCC report predicts we are unlikely to reach this goal at the rate we are progressing (IPCC, 2022). An important contributor to global warming is energy consumption, which continues to increase together with emissions from the energy sector (ibid.).

Households are responsible for 26.1% of final energy consumption in the European Union (EU), mainly relying on natural gas (32.1%) and electricity (24.7%) generated from fossil fuels (Eurostat, 2020). For instance, electricity production in the Netherlands still relies mainly on natural gas (46,5%) and coal (12%) (CBS, 2022, June 17). Burning these fossil fuels to meet household energy demand is considered one of the main drivers of climate change (Bushan et al., 2021). For example, literature shows that family energy use accounts for about 20% of CO_2 emissions (Hu et al., 2022).

Encouraging the switch to renewable energy technologies such as photovoltaic (PV) solar panels is an effective way for households to reduce the CO_2 emissions associated with their energy demand (Bushan et al., 2021; de Vries et al., 2020). Switching to solar panels to reduce emissions is especially effective if households substitute the indirect consumption of fossil fuels from the grid with the direct consumption of clean, self-produced energy. This is referred to as self-consumption. In line with previous research, this thesis defines self-consumption as the electricity produced by the household PV system that is directly consumed by the prosumer (Wittenberg & Matthies, 2016). Similarly, Luthander et al. (2015) formulate the degree of self-consumption as the share of total electricity generated from PV which is consumed at home. Whilst self-consumption can also be studied on a regional scale, for this thesis self-consumption is studied only on the household level (van der Kam et al., 2018). Self-consumption thus refers to the ability of households with PV to adapt their energy consumption patterns by influencing the shares of energy used from the grid and from their own PV system (Wittenberg & Matthies, 2016).

Roldan-Fernandez et al. (2021) found that self-consumption could decarbonize the Iberian electricity market with an average rate of 300[1] tCO_2-eq[2]/year for each GWh/year of self-consumed energy. Additionally, utilizing solar energy at the last point in the energy transmission and distribution network (at home) could help reduce energy losses in the system and reduce congestion problems at peak daylight hours (Roldan-Fernandez et al., 2021). However, if self-consumption of self-produced solar energy is low, drawbacks come into play.

On average, Luthander et al. (2015) found that only 35% of self-produced electricity is self-consumed, whilst excess electricity is mainly exported to the grid. The intermittency of solar energy availability results in peaks in production that are difficult to predict, requiring significant flexibility from the grid (Buijze et al., 2021). Grid reinforcement is needed to handle such unpredictable power injections, which comes at a substantial cost (Gautier et al., 2019). Moreover, too much export of solar energy to the grid during low demand periods can cause operational issues such as power loss and voltage fluctuations (Sharma et al., 2020). Prolonged overvoltage decreases the life span of appliances and can result in PV curtailment, meaning panels are disconnected from the grid to prevent voltage limit violations (Sharma et al., 2020). If PV curtailment occurs, this portion of self-produced electricity is lost (Gautier et al., 2019). An Australian study by Sharma et al. (2020) states this loss due to grid disconnection may be as high as 625 MWh if PV penetration is at 40%, representing an annual financial loss of $106,000 in energy export revenue. Lastly, redistributing locally produced electricity across the grid is considered inefficient due to energy distribution losses (Öhrlund et al., 2020). Thus overall, prosumers should ideally self-consume their solar energy to help alleviate the grid and maximize emissions reduction. This topic will be the focus of the current thesis study.

1.2. Scope

Many researchers and policymakers have started to realize the importance of increasing solar self-consumption amongst prosumer households (Roldan-Fernandez

[1] On average, the fuel-fired share of the Iberian electricity market emits $42.87 \cdot 10^6$ of tCO_2-eq per year (Roldan-Fernandez et al., 2021).

[2] tCO_2-eq stands for tonnes of CO_2 equivalent. The unit of CO_2 equivalent compares different gases in terms of their global warming potential. tCO_2-eq signals the environmental impact of one tonne of any greenhouse gas in comparison to the impact of one tonne of carbon dioxide.

et al., 2021). Increasing the share of self-consumed energy at prosumer households essentially calls for demand response. Demand response is defined as "the practice of managing electricity demand in a way that peak energy use is shifted to off-peak periods, enabling higher rates of self-consumption" (Dehler et al., 2017, p. 6). The main approach to demand response is demand side management (DSM) (Wolsink, 2020). DSM has been used by grid managers since the early 1980s to financially stimulate non-renewable energy absorption at night (Wolsink, 2020). However, a decentralized and renewable energy system requires a different, more flexible DSM approach. DSM nowadays refers to all deliberative actions households take to achieve energy savings and higher energy efficiency (Motlagh et al., 2015). Households can engage in DSM by using renewable energy technologies, retailer products, choices in appliances and time of use (Motlagh et al., 2015). The latest IPCC report considers this DSM approach to be important in mitigating the effects of climate change (IPCC, 2022).

There are two distinct measures to increase solar self-consumption through DSM. These are referred to as technical measures and behavioral measures. Both measures are discussed in more detail in Chapter 2 (see section 2.2.) but are briefly introduced here. Firstly, an example of a technical measure is the use of storage systems, which allow prosumers to use their self-produced energy later. However, the management (charging, storing, discharging) of storage devices is always accompanied by energy loss due to the repetition of chemical reactions which deteriorate the battery from the inside (Luthander et al., 2015). Moreover, storage systems are still too expensive for most households to afford (Gautier et al., 2019; Luthander et al., 2015) (see section 2.2.1.). The more efficient and less costly option would be to use the generated PV electricity directly. Meaning, to realize the full potential of PV panels, households should be consuming their self-produced electricity when it is available (Bushan et al., 2021; Peters et al., 2019).

This is where behavioral measures to increase self-consumption come into play. An important example of such a behavioral measure is loadshifting. Loadshifting means demand patterns are adapted to the variable electricity supply (Wolsink, 2020). Put differently, the demand for electricity is shifted to those periods of time when electricity is produced (Wittenberg & Matthies, 2016). In the case of PV, this means household energy demand is shifted to the daytime instead of nighttime. Prosumers can engage in loadshifting by e.g., manually or (semi-)automatically switching on the laundry machine or dishwasher during the daytime (see section 2.2.2.). Increasing self-consumption in this way, without relying *solely* on technical solutions such as storage or automatic timers, essentially calls for some degree of behavioral change.

Overall, assessing and integrating the behavioral dimensions of sustainable energy transitions is becoming increasingly apparent and important (Nielsen et al., 2021). In fact, the IPCC estimates that global warming may reach 4 to 5° degrees if current behavior remains unchanged (Tam et al., 2021). Behavioral approaches may also help increase the societal acceptability and efficacy of new energy policies needed to combat the effects of climate change (Steg et al., 2015). Due to these advantages of behavioral approaches, as well as the disadvantages of battery storage systems (mainly their high costs), the focus of this study will be on the behavioral measure of loadshifting instead of technical measures. Technical and behavioral DSM measures are compared in more detail in section 2.2.

Moreover, the focus on loadshifting is further narrowed down to laundry behavior. Namely, the behavior to be assessed is delimited to the practice of switching on the laundry machine during the day (when solar energy is produced) instead of during the nighttime. The selection of this delimitation was firstly based on the assumption that nearly all modern households now use a laundry machine. Secondly, doing the laundry represents a substantial share of direct household impacts regarding energy consumption and emissions (Klint et al., 2022). Potential impact reduction may be limited by laundry behavior rather than machine design, considering the increase in overall energy consumption associated with washing despite significant improvements in the energy efficiency of laundry machines (ibid.). Laundry behavior also seems to be persistently habitual, allowing for the application of several interesting theories (see Chapter 3).

Finally, the scope of this study is restricted to the geographical location of the Netherlands. The selection of this delimitation is based mainly on the current state of self-consumption policies (and consequent public debate) in the Netherlands. To properly understand this argument in favor of selecting the case of the Netherlands more background knowledge on Dutch policymaking is needed, which can be found in Chapter 2 (see section 2.4.).

1.3. Societal & scientific relevance

In essence, the energy grid aims to always maintain an exact balance between production (supply) and consumption (demand) (Buijze et al., 2021). Traditionally, every industrial grid user is responsible for maintaining this balance between supply and demand through careful documentation in a daily energy program. If a user diverts from their program, they pay the costs the system administrator makes to adjust supply and demand, which is called balancing responsibility (ibid.). Due to their minimal contribution to grid functioning, small scale consumers (including households) were exempted from this balancing responsibility (ibid.). This exemption was based on the fact that small scale consumers originally did not supply energy to the grid, and their demand was considered easy to predict (ibid.).

However, the rise of active prosumerism instead of passive consumerism changes matters. By installing solar panels, households actively contribute to the decarbonization and decentralization of electricity supply, no longer affecting only demand but also the supply of energy (Buijze et al., 2021). Households' active role is further stimulated by the ever-increasing role of computers and the internet, with devices such as smart meters providing direct and real-time insight into energy production and consumption (ibid.). Due to the increased involvement of the prosumer and the imbalances they can now cause when exporting self-produced electricity to the grid, policymakers may feel the need to make changes to a prosumer's role and responsibility. Following the introduction of the Clean Energy Package (CEP) of the EU, small scale consumers (including households) may in fact have to start carrying out balancing responsibilities (Buijze et al., 2021). Suppose prosumers do become financially responsible for balancing their supply and demand. In that case, self-consumption (instead of grid export) should become an important tool to uphold this responsibility. Then, self-consumption would not just be in the best interest of the grid but also of the prosumer.

As described in section 1.2. moreover, the focus of the current thesis study is on the behavioral measure of loadshifting to increase self-consumption, and not on technical measures (requiring no behavior change). However, realizing behavior change in transitions is notoriously challenging, due in part to the variety of underlying processes involved in behavior (de Vries et al., 2021). Ideally, processes occurring at the level of the individual, group, and system must be integrated through interdisciplinary research to properly analyze the role of behavior in sustainability transitions (Whitmarsh et al., 2021). Such research could find explanations for behavior whilst acknowledging its roots and context in large-scale systems (de Vries et al., 2021). One of the groups conducting such interdisciplinary research on behavior in the energy transition is the Energy Transition Lab (ETLab) at the faculty of Technology, Policy and Management (TPM) of TU Delft. The ETLab studies the development of new approaches, methods and tools for an effective and fair energy transition. The ETLab firmly believes in multi- and interdisciplinary research rather than discipline-specific expertise. Due to the similarities between this thesis and the research conducted at the ETLab, e.g., the interdisciplinary nature and behavioral focus, the current study is carried out in collaboration with the ETLab.

Lastly, the research topic is also relevant to Industrial Ecology (IE), which is the field of the eponymous Master of Science (MSc) program offered by TU Delft and Leiden University for which this thesis is written. IE is highly interdisciplinary by nature: technical, environmental, and social science perspectives are combined to study sustainability problems. Studying the role of people and social processes is considered a critical component of the application and implementation of IE (Cohen-Rosenthal, 2000). As human behavior and its interaction with technology is placed within the context of environmental science, this thesis aims to establish the interdisciplinary connection that is so important to IE (Xu et al., 2016).

1.4. Knowledge gap

The sections above highlight the importance and relevance of increasing solar self-consumption amongst households, both in the interest of the grid and the prosumer. However, there are important knowledge gaps pertaining to this topic, which must first be better understood.

Firstly, since the topic of self-consumption is relatively new, previous studies are scarce. Nonetheless, the matter is increasingly receiving attention as the number of installed PV panels grows. Self-production on the other hand has been studied more extensively for some time. For instance, Ebrahimigharehbaghi et al. (2021) assessed the behavioral factors influencing the decision made by Dutch households to install PV panels at home. However, the matter of synchronizing energy consumption to production goes beyond a conscious one-time purchasing decision, calling for changes in households' daily routines (Milieu Centraal, 2016; Oberst et al., 2019). Still, the focus on the adoption of PV technology is understandable. Researchers and policymakers aim to accelerate the energy transition by encouraging as many households as possible to install solar panels. Yet now that the cost of PV panels is decreasing rapidly due to governmental subsidies and the production of more affordable technology, such a push towards self-production may not be necessary anymore. PV installation is now profitable and attractive to many (Roldan-Fernandez et al., 2021). Moreover, recent geo-political conflicts such as the war in Ukraine and the consequent high energy prices may act as further motives for people and countries to want to reduce their dependency on fossil fuels even more. Nonetheless, it takes time for research and policy to adapt to this turning point of moving away from the focus on PV installation, and towards a better understanding of PV usage. Therefore, the potential for self-consumption has received limited attention both in research and in policy (Gautier et al., 2019).

Secondly, the few studies concerning the synchronization between self-production and self-consumption mainly focus on the *level* of self-consumption, rather than its behavioral foundation. It should be noted that such studies often find contradictory results. Studies using qualitative self-reporting measures suggest that solar prosumers often *want* to and *can* change the timing of their electricity use to better synchronize production and consumption (Gautier et al., 2019; Öhrlund et al., 2020). However, studies using quantitative data on actual electricity use often find no evidence of such a shift in self-consumption behavior (Bushan et al., 2021; Öhrlund et al., 2020). Bushan et al. (2021) analyzed smart meter data of Dutch households to find that although households with PV unsurprisingly consume less electricity from the grid than those without PV, these differences diminish during moments of low PV production. Moreover, Peters et al. (2019) found that whilst many new prosumers intend to match self-consumption to self-production to reduce their consumption levels, most fail to realize this intention. In fact, the behavior of many prosumers even reflects a rebound effect, meaning households *increase* their energy consumption levels compared to before PV installation (Galvin et al., 2022). These contradictory results between studies, as well as between prosumers' intention and action, may indicate that the foundation of self-consumption behavior is not yet fully understood.

Synchronizing self-production and self-consumption thus seems to be difficult even for prosumers with good intentions (Peters et al., 2019). It is therefore important to find out which strategies could support prosumers to increase their level of self-consumption. As a starting point, more understanding is needed of the reasons *why* households fail to match self-consumption to self-production (ibid.). Do people know what self-consumption is, or why it matters in the first place? Research by Niamir et al. (2020) suggests that they do not, as respondents did not distinguish between energy produced for self-consumption and overall energy produced.

In a study by Öhrlund et al. (2020) Swedish householders were asked what barriers they had experienced when trying to adapt their energy use to the availability of solar energy. Unfortunately, most surveyed respondents did not answer this question or failed to specify. Do psychological, socio-demographic, or structural characteristics perhaps play a role, as we know they do in overall household energy behavior not specific to PV prosumers (Bhushan et al., 2021; Niamir et al., 2020)? Are households not motivated enough to adjust their energy demand, or is doing so too costly in terms of time or effort (Peters et al., 2019)? Whilst one could hypothesize which barriers play a role in matching self-consumption to self-production based, no study has yet aimed to combine and structure barriers for this topic. Again, the few studies which do combine different barriers often focus on the *adoption* of PV technology (Ebrahimigharehbaghi et al., 2021), or behavior change regarding energy use in *general* (Niamir et al., 2020). Thus, these studies are not specific to PV prosumers or to self-consumption.

1.5. Research objective & research questions

This thesis project aims to understand the barriers that make it difficult for Dutch prosumer households to match self-consumption to self-production, in order to ultimately be able to help prosumers overcome these barriers. More precisely, potential barriers are explored that make it hard for Dutch prosumer households to loadshift the use of their laundry machine from nighttime to daytime.

To adequately explore these potential barriers, one must keep in mind that individual choices regarding energy consumption are at all times influenced through psychological, cultural, socio-economic, and institutional forces (Maréchal, 2010; Shrivastava et al., 2020). Hence, not only potential barriers focused upon the individual (e.g., habit or skill) should be considered, but also contextual barriers *surrounding* an individual (e.g., institutional policies or design of the PV system) (see Chapter 3). Table 1 displays the research questions and respective methods central to the current thesis project. Sub-questions 1 and 2 focus on establishing a theoretical framework for analysis. Sub-questions 3, 4, and 5 aim to test the theoretical framework in practice.

By exploring the barriers limiting laundry loadshifting behavior the key antecedents of failing to loadshift may be discovered, which in turn can ensure strategies encouraging solar self-consumption are tailored to these antecedents. For example, if adapting use patterns costs too much hassle in terms of time or effort, energy management systems that automatically regulate use could be an option (Peters et al., 2019). However, such an option might be less suitable if a lack of motivation, knowledge, or awareness plays a role.

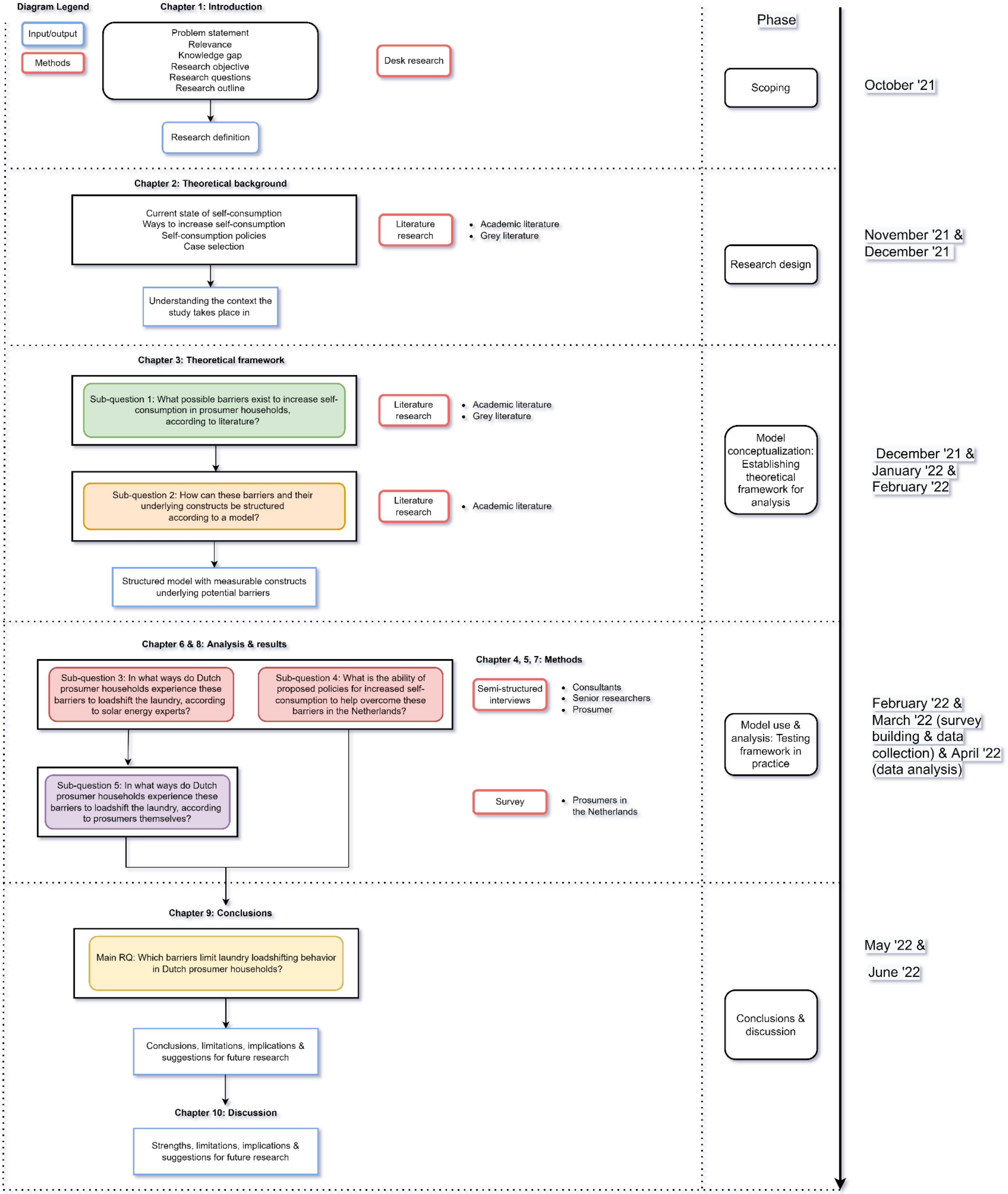
Table 1. *Research questions.*

Main research question: Which barriers limit laundry loadshifting behavior in Dutch prosumer households?	
Sub-questions	**Method**
1. What possible barriers exist to increase self-consumption in prosumer households, according to literature?	Literature research
2. How can barriers and their underlying constructs be structured according to a model?	Literature research
3. In what ways do Dutch prosumer households experience these barriers to loadshift the laundry, according to solar energy experts?	Semi-structured interviews with solar energy experts
4. What is the ability of proposed policies for increased self-consumption to help overcome these barriers in the Netherlands?	Semi-structured interviews with solar energy experts
5. In what ways do Dutch prosumer households experience these barriers to loadshift the laundry, according to prosumers themselves?	Survey distributed amongst Dutch prosumers

1.6. Research outline

The research flow diagram in Figure 1 provides the outline of this thesis study. The nature of this study is exploratory, aiming to provide a preliminary clarification of why Dutch prosumers struggle to loadshift. A mixed-methods research approach is taken to realize this aim (see Chapter 4). The first chapters introduce the study (Chapter 1) and its theoretical background (Chapter 2). Data from similar studies are then gathered in Chapter 3, ultimately constructing a theoretical model appropriate for testing. Chapter 4 provides a general overview of the applied methods, whilst Chapter 5 discusses the *qualitative* methods in more detail. Qualitative results can be found in Chapter 6. Then, the *quantitative* methods are discussed in Chapter 7, of which the results can be found in Chapter 8. Finally, Chapter 9 provides conclusions to the aforementioned (sub-)research questions. Lastly, Chapter 10 discusses the implications of these conclusions as well as the strengths and limitations of this study.

Figure 1. *The research flow diagram.*



CHAPTER 2: THEORETICAL BACKGROUND

This second chapter provides the theoretical background in which the thesis project is placed. The current state of self-consumption as well as relevant definitions, concepts, and applicable policies are elaborated upon.

2.1. Current state of self-consumption

As introduced in Chapter 1, benefits of self-consumption relate to both the *efficient* and *sustainable* use of a domestic PV system. Moreover, because self-consumption enables prosumers to take responsibility for their own energy production and consumption, higher levels of self-consumption can lead to more efficient usage of energy at the household level overall (Dehler et al., 2017). Unfortunately, the actual level of self-consumption is estimated to be no more than 35% of self-produced solar energy (Luthander et al., 2015). Overall, the potential for self-consumption is estimated to vary between 17% and 44%, depending on factors such as household size, irradiation exposure, and measures for demand side management (ibid.). Motlagh et al. (2015) have separated self-consumption levels per season, finding that self-consumption ranges between 13% in spring, 19% in summer, 9% in autumn, and 10% in winter.

Levels of self-consumption are thought to be relatively low mainly due to the disparity between PV power generation and prosumer demand (Dehler et al., 2017). PV panels generally produce the most power at midday, when residents are usually not at home. As introduced in Chapter 1, DSM approaches can be utilized to overcome this problem by practicing demand response. As briefly mentioned in section 1.2., DSM approaches to increase self-consumption are divided into technical measures and behavioral measures. An important example of a technical measure is to use storage systems, whilst a behavioral measure is to encourage loadshifting. Both options are discussed in more detail in the next section.

2.2. Measures to increase self-consumption through DSM

2.2.1. Technical measures: storage systems

The first option to increase self-consumption through DSM is to employ technical measures, such as battery storage systems (Wittenberg & Matthies, 2016). By using batteries, prosumers can store PV electricity produced during the day for later use in the evening, increasing self-consumption and reducing excess electricity fed to the grid (Wittenberg & Matthies, 2016). Thus, storage systems offer a technical solution to the self-consumption problem without requiring prosumer behavior change. Instead, energy storage simply adapts PV production to prosumer energy demand (Dehler et al., 2017). The potential of storage systems to increase self-consumption seems promising: Luthander et al. (2015) found the use of batteries could increase self-consumption by 13-24%. However, due to their high investment and installation costs, batteries generally do not pay off within a reasonable time period: prices would have to drop significantly to break even (Kemmler & Thomas, 2020). In the Netherlands for example, a home battery currently costs between 3000 to 9000 euro[3], resulting in a payback period of about 15 years (de Jonge Baas, 2021, July 5; Simpel Subsidie, 2021). Thus, this is not an attractive investment for many prosumers, especially considering that a battery's average lifespan is also about 15 years (Simpel Subsidie, 2021).

Some countries offer financial incentives to stimulate prosumers to invest in a battery storage system despite their high costs. For instance, in 2016 the German KfW Bankengruppe[4] and the Federal Ministry for the Environment already offered low-interest loans and repayment subsidies for newly installed PV panels with a fixed battery storage system (Wittenberg & Matthies, 2016). Prosumers who received this funding were required to feed no more than 60% of their nominal capacity into the grid. About half of German prosumers investing in batteries made use of this funding program at the time (Wittenberg & Matthies, 2016). In 2019, the German Federal Ministry for Economic Affairs and Energy announced a similar subsidy program to improve battery production (Energy Reporters, 2019, February 26). Still, many countries do not have such funding programs to stimulate the production or adoption of batteries. Despite pleas from grid operators, the Dutch government for example has explicitly stated that it is not considering a battery subsidy, preferring to rely on the market instead of supplying additional stimulants (Staatssecretaris van Economische Zaken en Klimaat, 2021).

2.2.2. Behavioral measures: loadshifting

The second option to increase solar self-consumption amongst prosumer households is through behavioral efforts such as loadshifting, adapting demand patterns to the variable electricity supply (Wolsink, 2020). Through loadshifting, the demand for electricity is shifted to those periods of time when electricity is produced

---

[3] The average disposable income in the Netherlands was 17.015,4 euro per person in the year 2020, corrected for differences in size and composition of households (CBS, 2021, December 22).

[4] The KfW Bankengruppe is a large development bank in Frankfurt, Germany (KfW, n.d.).

(Wittenberg & Matthies, 2016). Thus, in the case of PV energy, household energy demand is shifted from nighttime to daytime.

Unlike the use of storage systems, loadshifting requires prosumer households to adapt their behavior, which can be achieved manually or through (partial) automation (Staats et al., 2017). If done manually, loadshifting is driven purely by prosumers' own decision making and behavior (Motlagh et al., 2015). For example, prosumers who manually switch on their laundry machine or dishwasher during the day instead of night. If achieved through automation, prosumers allow technologies to have (partial) automatic control over the household energy demand. For example, prosumers who make use of a laundry machine or dishwasher which switches on automatically during the day (Castillo-Cagigal et al., 2011). The former (manual loadshifting) has received less attention as a potential DSM strategy, due in part to difficulties in quantifying its benefits (Khan, 2019). Nevertheless, manual loadshifting should not be overlooked. Especially since automated DSM, whilst more reliant on technology, depends largely on prosumer acceptance (Wolsink, 2020).

Compared to batteries, which as aforementioned can increase self-consumption levels by 13-24%, the potential of loadshifting for increased self-consumption is found to range from 2 to 15% (Luthander et al., 2015). Nonetheless, encouraging loadshifting has benefits, namely due to the high costs of battery storage systems (as previously described). Yet to be fair, nearly all DSM options require some degree of investment. For example, automated loadshifting is highly dependent on enabling technologies to allow for the remote control of end-uses (Wolsink, 2020). Smart grids are an example of such an enabling technology, defined as energy management systems consisting of a set of software and hardware tools capable of routing power more efficiently (Staats et al., 2017). These smart grids can be used by prosumers to automatically switch on wet appliances such as the laundry machine, tumble dryer, or dishwasher when the sun is shining (ibid.). On the other hand, manual loadshifting requires less investment into such enabling technologies.

Moreover, the cost of any DSM strategy is only one of the challenges to be faced, other challenges being technology availability and compatibility, system complexity, and consumer response (Khan, 2019). The latter is not to be underestimated, as most (if not all) DSM strategies require active prosumer participation and acceptance to be successful (ibid.). Wolsink (2020) highlights the willingness to accept, the level of intrusion, and clarity over who controls the DSM system to be relevant for prosumer acceptance. Thus, even if technical measures to increase self-consumption are preferred, behavioral insights must always be considered. Therefore, the focus of this thesis study is narrowed down to the behavioral measure of loadshifting, as has been aforementioned in section 1.2.

2.3. Policies to encourage self-consumption

As stated in Chapter 1, self-production has been widely and effectively encouraged through policymaking, whilst initiatives to promote self-consumption have been sparse (Gautier et al., 2019). Still, such initiatives do exist and have been on the rise in recent years. Namely, since the European Commission introduced the "winter package" as part of the CEP in 2016, countries have taken it upon themselves to encourage renewable self-consumption (ibid.). For example, Germany has introduced funding to incorporate battery storage systems, and France has gone so far as to provide a legal framework for self-consumption (Gautier et al., 2019). One self-consumption policy relevant to all (non-)European countries is the concept of net-metering schemes versus net-purchasing schemes.

For some time, policymakers have employed net-metering schemes as a tool to support and finance decentralized energy production, encouraging consumers to purchase solar panels for their homes (Gautier et al., 2018). Net-metering means a single electricity meter runs backwards, valuing both imports and exports of electricity at the retail price (Gautier et al., 2019). As such, prosumers receive credit for the electricity they inject into the grid, allowing the grid to function as a storage device (Gautier et al., 2019). As such, it has been claimed that net-metering does not incentivize prosumers to loadshift, with all the negative consequences that entails (see Chapter 1) (Gautier et al., 2018). Therefore, many countries have shifted from a net-metering scheme to a net-purchasing scheme since the self-production of electricity has become profitable, even without an extra financial incentive (Luthander et al., 2015). Under a net-purchasing scheme, two meters track imports and exports of electricity separately, differentiating the prices (Gautier et al., 2019). Since self-consumption reduces necessary grid exchanges and thus the household energy bill, such a net-purchasing scheme may thus be able to encourage loadshifting (Gautier et al., 2019).

The switch from a net-metering to a net-purchasing scheme is currently a hot topic especially in the Netherlands (see section 2.4.). Under the current Dutch net-metering scheme[5] prosumers receive the same monetary compensation for energy exported to the grid as they pay for energy withdrawn from the grid, namely about 22

[5] The net-metering scheme is referred to as the "salderingsregeling" in Dutch.

cents/kWh (Milieu Centraal, n.d.). However, this regulation is planned to be phased out from 2025 onwards, and by 2031 it should be completely replaced by a net-purchasing scheme [6] (Milieu Centraal, n.d.). Then, prosumers will receive about 6 cents/kWh for self-produced electricity exported to the grid (Milieu Centraal, n.d.), which is thus less than the price paid for electricity *extracted* from the grid. Therefore, it should become financially attractive for prosumers to use their electricity *directly*, instead of delivering to the grid during the day and needing to withdraw at night (Omlaag Die Meter, n.d.).

In public minutes of a recent (July 2021) meeting the Dutch government explicitly states that dismantling the net-metering scheme is indeed intended to financially incentivize prosumers to deliver *less* electricity to the grid, directly using or storing electricity instead (Staatssecretaris van Economische Zaken en Klimaat, 2021). However, this assumption does not come without critique (and over 60 questions) from the other political fractions. There are concerns that the shift to net-purchasing should be accompanied by a proposal to stimulate or subsidize household storage options, as is the case of Germany. Furthermore, net-purchasing schemes require the use of smart meters or energy management systems able to separately record the import and export of electricity, which still seem to trigger privacy and digital safety concerns (Staatssecretaris van Economische Zaken en Klimaat, 2021). This is not a new concern: the Dutch Senate blocked two smart metering proposals back in 2009, as household energy consumption reveals privacy-sensitive details of personal life (e.g., indicates when people are at home or away). (Cuijpers & Koops, 2013; Van Aubel & Poll, 2019).

Overall, shifting from net-metering to net-purchasing seems to be a (politically) sensitive topic in the Netherlands. But what may be even more important is that policies intended to increase self-consumption *only* through financial incentives may not be enough. Gautier et al. (2019) state the importance of not ignoring other behavioral barriers or drivers when creating policies to financially encourage self-consumption. Studies show that too generous financial incentives may even backfire and negatively affect non-financial motivations (Braito et al., 2017; Gautier et al., 2019). Such studies plead that whilst financial incentives may work, they should be combined with e.g. awareness-raising measures to increase prosumer understanding of the benefits of self-consumption (Gautier et al., 2019). Similarly, Braito et al. (2017) state people may have different motivations to install PV panels in the first place, implying that both monetary and non-monetary incentives should be balanced to attract a broad

[6] The net-purchasing scheme is referred to as the "terugleververgoeding" in Dutch.

spectrum of society. The same applies to self-consumption policies, which should be based on a good understanding of why people do (or do not) self-consume before assuming a financial incentive is sufficient to resolve these (possibly diverse and manifold) barriers.

2.4. Case selection: The Netherlands

Although topics such as self-consumption and loadshifting are relevant to all countries moving towards a decentralized renewable energy system, the Netherlands has been chosen as the focus of the current study. Firstly, as aforementioned, the Netherlands is set to move from a net-metering to a net-purchasing scheme to encourage self-consumption. As this policy change is currently in motion and triggering substantial debate and concern from prosumers as well as politicians, the Netherlands is at an interesting time and place to study the transition towards solar self-consumption.

Secondly, net congestion is currently a prominent topic of conversation in the Netherlands. Dutch grid operators are repeatedly featured in the media to discuss the increasing pressure on the electricity grid, and the negative impacts this will have on Dutch daily life if nothing is done soon. The demand for electricity has been growing immensely due to the energy transition and consequent electrification, with grid operators struggling to provide large businesses and new residential areas with sufficient electricity to fulfill their energy requirements (NOS, 2022, May 1). At the same time, grid operators have stopped connecting companies wishing to export (renewable) energy to the grid in the Dutch provinces of Limburg and Brabant, due to an immense shortage of space on the grid (NOS, 2022, June 8). To combat the issue, grid operators plan to invest billions of euros to further expand, maintain, and reinforce the grid (NOS, 2022, April 11). Still, investments alone are unlikely to be enough. The Chair of the Dutch Climate Agreement has called for further actions, such as more central governance, faster granting of permits, more technical professionals, or an emergency law to prevent further problems on the grid (NOS, 2022, April 11).

Regardless, the growing electricity demand is only part of the net congestion problem. As aforementioned, issues on the supply side also play a role. The growing number of solar panels offloading large and sudden electricity peaks from prosumer homes onto the grid further destabilize the already overloaded grid. Therefore Liander, one of the Netherlands' largest grid operators, explicitly calls to slow down the encouragement of purchasing new solar panels (NOS, 2022, January 17). Liander states that about 20% of the households and businesses in the provinces of Friesland, Flevoland, Noord-Holland, Gelderland and Zuid-Holland now possess solar panels. On sunny days the thin cables in residential neighborhoods cannot handle the large inflow of electricity to the grid, leading to substantial PV curtailment to prevent damage to cables and household appliances (NOS, 2022, January 17). Liander therefore calls for a faster dismantling of the net-metering scheme and the implementation of a subsidy for household energy storage, to increase the level of self-consumption at prosumer homes.

The developments described above regarding upcoming policy changes and changes to the role of small-scale consumers (see Chapter 1), combined with the public and political debate, make the Netherlands an interesting and timely case to study solar self-consumption. Importantly, although these changes are intended to directly affect prosumers, little is known about what prosumers themselves think. Specifically, it is important to assess whether any non-financial barriers to self-consumption may be overlooked, especially since Dutch policymakers are focusing only on the implementation of financial incentives such as net-purchasing schemes.

CHAPTER 3: THEORETICAL FRAMEWORK

The previous chapters have elaborated upon the topic and focus of the thesis study, as well as the background in which it is set. Now, the need arises to construct a theoretical framework through which the research questions can be studied. Building such a theoretical framework is the focus of this third chapter. First, literature research is conducted to create an overview of factors with the potential to act as barriers to loadshifting behavior. Second, results of the literature research are used to select two suitable theories which can be combined into a new model. By defining the measurable constructs of this model laundry loadshifting behavior can be studied in practice. Ultimately, the findings of this chapter are used to answer sub-question 1 and 2:

- Sub-question 1: What possible barriers exist to increase self-consumption in prosumer households, according to literature?
- Sub-question 2: How can barriers and their underlying constructs be structured according to a model?

3.1. Literature research: Factors impacting energy (self-)consumption

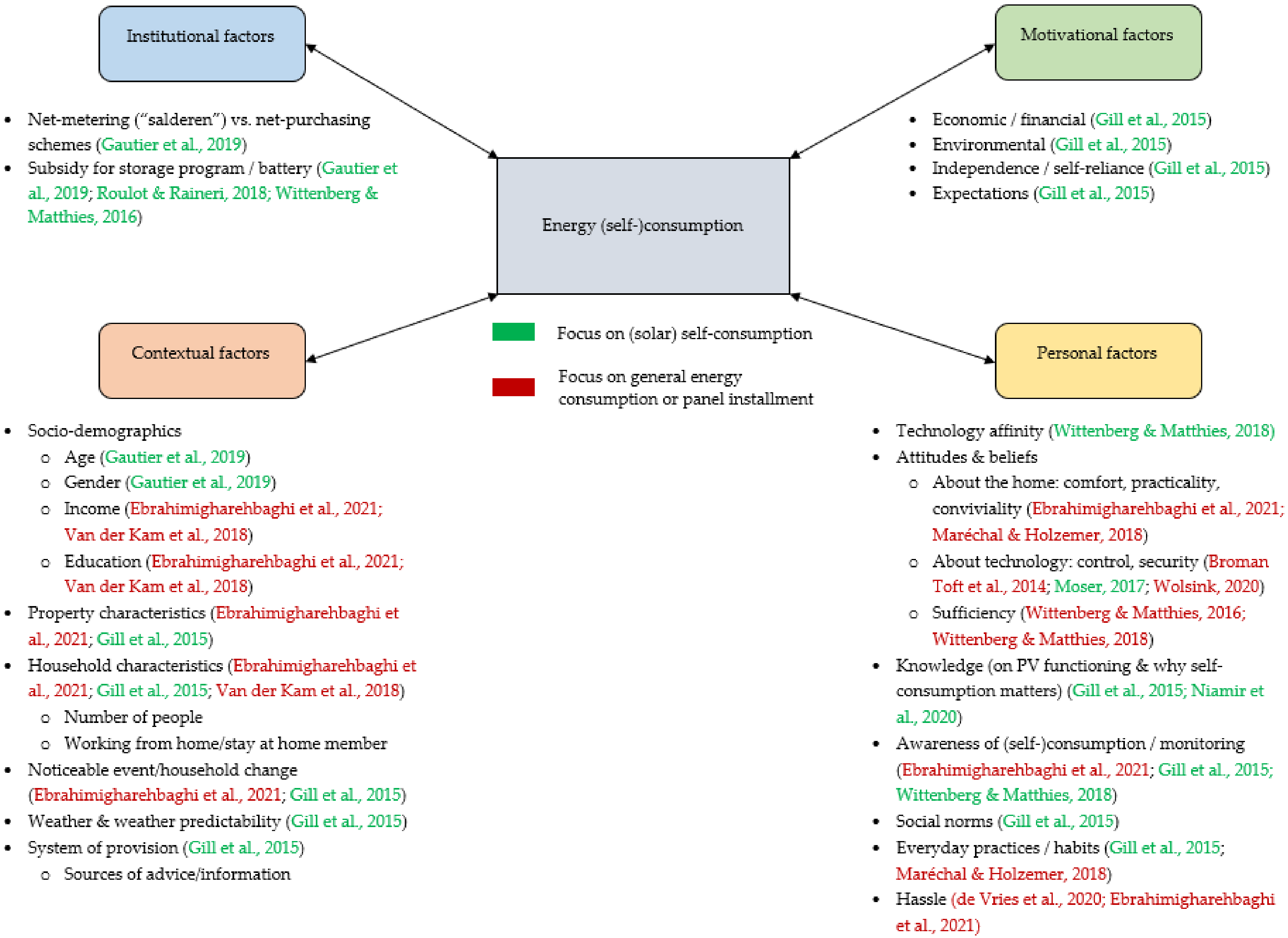
Before a suitable theoretical framework can be selected, insight must be gained into factors impacting self-consumption and loadshifting behavior in previous studies. Otherwise, there is no way to know which factors a framework should be able to cover. In this thesis study, factors are defined as characteristics of the individual prosumer or of their surroundings (the context), which may positively or negatively impact loadshifting behavior. Factors thus have the potential to act as barriers inhibiting a certain behavior (such as loadshifting). For example, if the factor of age is found to impact a certain behavior, old age may be a barrier inhibiting this behavior. Consequently, young age may be a driver enforcing the specific behavior. However, barriers and drivers are not always complementary, meaning a factor which is a barrier in one direction is not automatically a driver in the other direction. The focus of this thesis study is only on factors which can act as barriers to laundry loadshifting behavior. Whilst several examples of such factors have been suggested in previous chapters, a structured overview has not yet been provided. A brief literature research was conducted to create such an overview.

I conducted the literature research using Web of Science, entering search strings such as: (PV OR solar) AND (self-consum* OR "load shift*") AND barrier*. Articles were selected based on whether their abstracts contained the key terms. Additional articles were found by snowballing through selected articles. Note that the selected studies are not exclusively performed in the Netherlands, nor are they all about the self-consumption of *PV* energy or about laundry loadshifting behavior. For example, Gill et al. (2015) studied why Australian households struggle to use their solar hot water systems efficiently. Nonetheless, factors impacting self-consumption are expected to share some overlap between different renewable energy technologies and countries. Thus, these studies were not automatically excluded from the literature research. Similarly, some studies focus on factors impacting the *adoption* of PV technology instead of the self-consumption of PV energy, such as the research by Ebrahimigharehbaghi et al. (2021). Since it has not been investigated yet whether such factors may apply to the topic of self-consumption (as mentioned in section 1.4.), these factors are nonetheless included in the literature research.

Following the literature search, a format is needed to display the found factors in a structured manner. For this purpose, a similar approach to Ebrahimigharehbaghi et al. (2021) was chosen, dividing factors into institutional, contextual, motivational and personal factors. However, whilst Ebrahimigharehbaghi et al. (2021) group policy incentives under contextual factors, the format used in the current study groups policies under the added institutional factors. This helps separate the factors occurring in near proximity to the individual acting out the behavior (contextual factors) and those occurring at a further distance from the individual (institutional factors).

Figure 2 below displays the results of the literature research, summarizing some of the factors frequently found to impact energy (self-)consumption or loadshifting in similar studies. Text in green indicates that the factor in question has been found in a study focusing on household self-consumption of renewable energy, in line with the focus of the current study. Text in red indicates that the factor has been found in a study with a different focus than the current study, focusing instead on e.g., the installment of solar panels or on energy consumption behavior in general, rather than solar self-consumption through loadshifting.

Figure 2. *Factors impacting (solar) self-consumption or general energy consumption in similar studies.*



Although Figure 2 gives a structured overview of factors potentially impacting loadshifting behavior, it does not yet provide a model able to function as a proper foundation for further research yet. Such a model will require the inclusion of *constructs*, which operationalize factors. These constructs should be measurable in practice, helping to identify barriers limiting laundry loadshifting behavior. Hence, only once the measurable constructs have been defined and selected, the appropriate model can be built and tested in practice in order to answer the research questions central to this thesis study.

3.2. Constructing the appropriate model

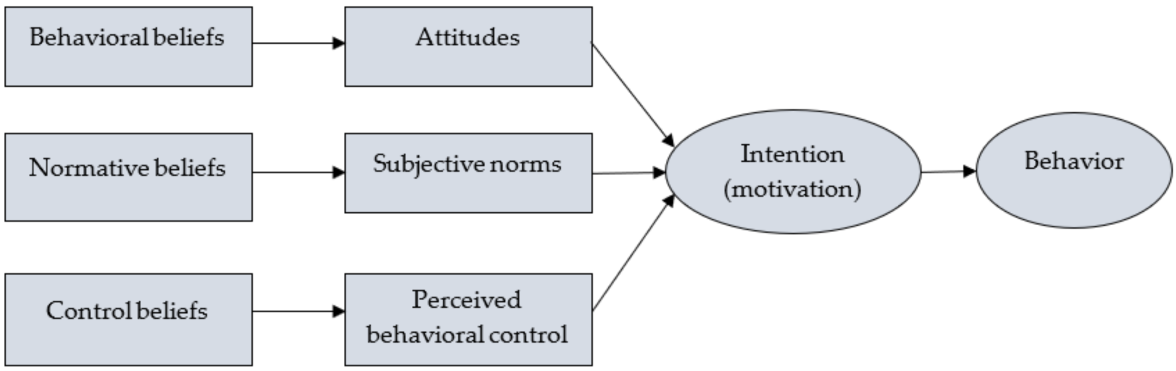
In general, constructs are considered the building blocks of theories, explaining how and why certain behavior occurs. To aid in identifying and selecting measurable constructs it is therefore wise to first search for any existing theories applicable to the behavior in question. To study laundry loadshifting behavior, meaning self-consumption is matched to self-production by shifting laundry machine use from night- to daytime, no one theory is likely to cover all underlying constructs. As the literature research has shown in section 3.1., barriers are expected to be diverse and manifold, thus the same is bound to apply to their underlying constructs. For instance, the theoretical model should not only include constructs focused on the individual, but also those focused on the context or system an individual behaves in. In the current study specifically, the nature of the behavior (laundry loadshifting) and the structurization of the literature research findings (into institutional, contextual, motivational and personal factors) called two different theories to mind. The following sections describe these two behavioral theories which may best be able to fulfill the specifications of the required model.

3.2.1. Individual focus: The theory of planned behavior (TPB)

Traditionally, many psychological theories studying human behavior have focused heavily upon the individual, the TPB being perhaps the most well-known of all. The TPB has frequently been used in various fields and has been the starting point from which many novel theories have emerged. In fact, most behavioral change methods within environmental policy have been built upon the TPB (Sniehotta et al., 2014). Essentially, the TPB focuses on the *individual* who is acting out a voluntary behavior. As such, the TPB relies on a purely psychological approach, assessing personal constructs such as values and attitudes.

According to the TPB, behavior is a direct function of the intention to perform said behavior. This intention is in turn a direct function of attitudes, subjective norms, and perceived behavioral control (ibid.). Moreover, beliefs (behavioral, normative, and control) are thought to shape these attitudes, norms and perceived behavioral control (ibid.). Hence, the TPB model is both hierarchical and linear, with e.g., normative beliefs imposed by society leading to the formation of a person's own subjective norms. Figure 3 displays this basic model of the TPB and its underlying constructs.

Figure 3. *The theory of planned behavior.*



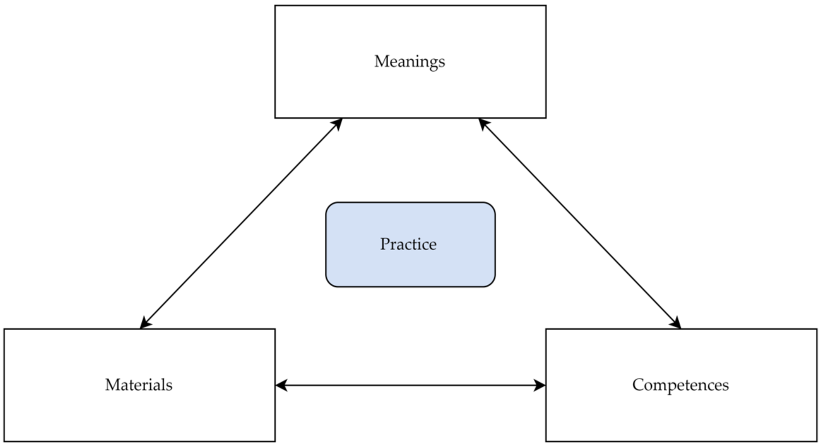
To study loadshifting behavior however, the TPB alone will not suffice. Firstly, there is significant criticism on the validity of the TPB, especially from researchers who believe most of human behavior is *in*voluntary rather than voluntary. Since the TPB focuses exclusively on rational reasoning leading to voluntary behavior, it generally disregards unconscious influences on behavior or the role of emotions (Sniehotta et al., 2014). For the current study a model is needed that does take this involuntary aspect of behavior into account. Because when it comes to household energy consumption, studies have shown that many behaviors are routinized: habits and routines embedded in everyday life instead of deliberative actions (Hess et al., 2018; Kurz et al., 2015). In fact, Wood et al. (2002) state that up to 88% of hygiene and appearance related behaviors such as doing the laundry are habitual, meaning these behaviors are performed frequently and in stable contexts (Hess et al., 2018).

Thus, for the vast majority of people energy consumption is defined by inconspicuous routines embedded into their everyday lives, rather than rational behavior in itself. For example, people consume energy to do the laundry so they can wear clean clothes, they do not consume energy simply to consume energy. This routinized nature of energy consumption behavior clashes with several assumptions underlying the TPB. Firstly, it explains why the provision of information is not directly related to behavior change, as linear rational choice theories like the TPB would claim (de Vries, 2020). On the contrary, consumption levels continue to increase despite new awareness and knowledge about how to save energy (Hess et al., 2018). Secondly, it explains why actual PV usage behavior can differ significantly from the intended use before installation, referred to as the intention-action gap (Peters et al., 2019). The intention-action gap forms a recurring problem for the TPB, as intention alone (irrespective of the beliefs which shaped it) does not always lead to the behavior in question (Ajzen, 2011; Sniehotta et al., 2014). Possibly, the TPB fails to account for other variables influencing intention, such as environmental or economic factors at play beyond the individual.

3.2.2. System focus: Social practice theory (SPT)

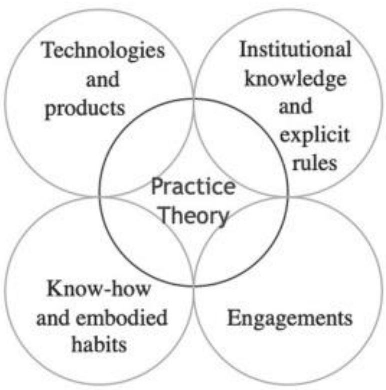
Although the TPB could be helpful to some extent in operationalizing solar self-consumption, its shortcomings need to be overcome. It may help to supplement the TPB with a theory that takes both the broader system beyond the individual as well as the routinized nature of energy consumption behavior into account. SPT could be of use to fulfill this purpose. In short, SPT focuses on the everyday practice itself rather than the individual performing the practice (Hess et al., 2018). A practice is hereby defined as a socially shared convention or pattern of behavior, routinized due to the interconnectedness of the different elements the behavior consists of (Hess et al., 2018; Shove, 2003). Shove et al. (2012) divided several features of such a social practice into three main constructs: materials (infrastructures, tools, hardware), meanings (mental activities, emotions, motivation) and competences (know-how, background knowledge, specific skills) (Hess et al., 2018). Unlike the TPB, the model in SPT is circular rather than linear, meaning the elements do not act in isolation but all affect each other as well as the practice itself (Frances & Stevenson, 2020). Figure 4 displays the basic model of SPT as depicted by Shove et al. (2012).

Figure 4. *The social practice theory.*



SPT has already been applied in many empirical studies on routinized behaviors, including washing clothes, line drying and showering (Hess et al., 2018). Moreover, SPT has been applied numerous times in the field of sustainability. For instance, SPT has been used to study the practice of doing the laundry more sustainably in the sense of using less resources (Klint et al., 2022; Shove, 2003). However, SPT has not yet been applied to the practice of doing the laundry more sustainably by increasing the level of self-consumption amongst prosumer households. Nonetheless, Frances and Stevenson (2020) did have a similar aim, studying the degree of PV engagement and whether this engagement is needed for the matching of consumption to production. The application of SPT by Frances and Stevenson (2020) leads to a model adapted from the one by Shove et al. (2012) and is depicted in Figure 5.

Figure 5. *SPT as applied by Frances & Stevenson (2020) to study PV engagement.*



Note: Interrelated practice elements for data analysis. Reprinted from "A relational approach to understanding inhabitants' engagement with Photovoltaic (PV) technology in homes", by Frances & Stevenson, 2020, *Architectural Science Review, 63*, p. 309.

The conceptualization of SPT by Frances & Stevenson (2020) has many similarities to the model by Shove et al. (2012). In the model by Frances & Stevenson (2020), "technologies and products" refer to materials whilst "engagements" refer to meanings. However, the meaning element as defined by Shove et al. (2012) has been extended, including not just the symbolic meaning of PV engagement but also purposes, beliefs, and social expectations (Frances & Stevenson, 2020). Furthermore, Frances & Stevenson (2020) divided the competences element of the SPT model by Shove et al. (2012) into two separate constructs, with "know-how and embodied habits" referring to more internal or implicit competences, and "institutional knowledge and explicit rules" referring to more external or explicit competences.

By expanding on the SPT model by Shove et al. (2012), Frances & Stevenson (2020) seem to have chosen an approach which combines the context-oriented focus of SPT with a more individual or psychological focus. This approach can adequately be applied to study the engagement of prosumers with their domestic PV system. Still, relations between elements are not further assessed, nor have these relations been quantified in this previous study. Moreover, the direction of these relations was not studied, explaining why the model in Figure 6 does not contain any arrows. The current thesis study has a similar aim but does wish to assess and quantify these relations between barriers inhibiting laundry loadshifting behavior specifically.

3.2.3. Combined model

Although different and at times conflicting, more individualistic theories like the TPB and more systemic theories like SPT can both benefit from each other (Hess et al., 2018). Whilst the TPB can benefit from considering the material or institutional context impacting everyday practices, SPT can engage with the TPB to better understand the personal aspects impacting the individual who carries out the practice (Kurz et al., 2015). Therefore, the current study will utilize not just one of these two theories but combines them into a newly constructed model.

In essence, this newly constructed model firstly combines the individualistic elements of TPB (attitudes and beliefs) into the "meanings" element of SPT. This way, a strength of the TPB (its extensive focus on the individual) supplements a limitation of the SPT (omitting the role of the individual performing the practice). Secondly, both the "materials" and "competences" elements of the SPT are expanded to study laundry loadshifting behavior, similar to the approach taken by Frances and Stevenson (2020). This way, the broader context in which the practice of doing the laundry occurs can be understood in more detail. Table 2 summarizes how the original TPB, original SPT, and SPT by Frances & Stevenson (2020) are combined into the new model. Table 2 also indicates the methods which will be used in the current study to measure the 10 constructs of the new model in practice (see Chapter 4).

Table 2. *Combining the TPB and SPT into a new model.*

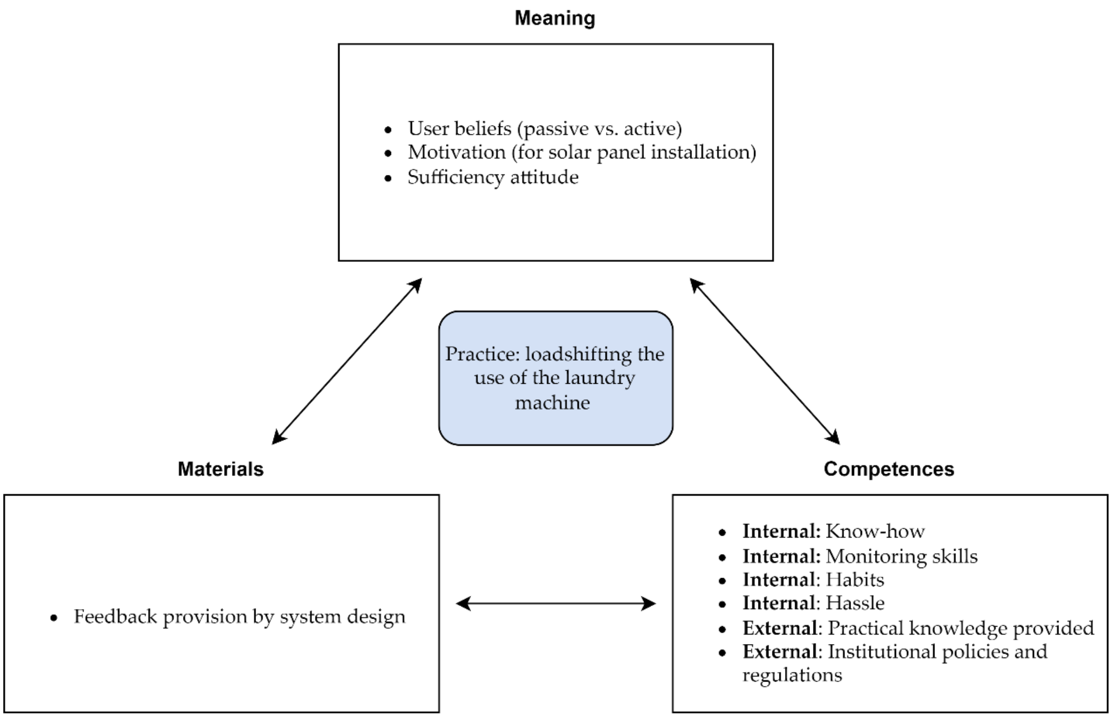
TPB elements	SPT elements	SPT elements (Frances & Stevenson, 2020)	Constructs of the new model	Method
Attitudes	Meanings	Engagements	Sufficiency attitude	Survey & interviews
Subjective norms			Motivation	
Perceived behavioral control			User beliefs	
	Competences	Know-how and embodied habits (internal)	Know-how	Survey & interviews
			Monitoring skills	
			Habits	
			Hassle	
		Institutional knowledge and explicit rules (external)	Practical knowledge provided	
			Institutional policies and regulations	Interviews
	Materials	Technologies and products	Feedback provision by system design	Survey & interviews

The final model is visualized in Figure 6, with its 10 constructs indicated using bullet points. Before this final model can be tested in practice however, its 10 included constructs require an operational definition in order to be measurable. These operational definitions are provided below:

1) **Feedback provision by system design:** Design elements of the PV system providing visual, direct, and synchronous feedback regarding energy production and consumption (Frances & Stevenson, 2020; Gill et al., 2015).
2) **Know-how:** The ability prosumers have or acquire in terms of how to carry out the practice of (laundry) loadshifting (Frances & Stevenson, 2020).

3) **Monitoring skills:** Prosumers' ability to monitor their PV energy production and consumption regularly (Frances & Stevenson, 2020).
4) **Habits:** Behaviors that are performed frequently and consistently in stable contexts (Shove et al., 2012; Maréchal & Holzemer, 2018).
5) **Hassle:** The degree to which prosumers anticipate (laundry) loadshifting to be a hassle, leading to stress and avoidance of this behavior (de Vries et al., 2020).
6) **Practical knowledge provided:** Written advice, technical knowledge or documents regarding the use of the PV system, provided to prosumers by e.g., governments, consultants, or technicians (Frances & Stevenson, 2020).
7) **Institutional policies and regulations:** Governmental policies influencing PV installation and use, and formal rules prosumers must adhere to (Frances & Stevenson, 2020).
8) **User beliefs:** Whether a prosumer believes to be an active *or* passive user of the grid and their own PV system, believing PV technology to be an active (or passive) tool to (dis)engage with (Frances & Stevenson, 2020; Gill et al., 2015).
9) **Motivation:** The reasons which moved prosumers to purchase solar panels in the first place (Gill et al., 2015).
10) **Sufficiency attitude:** The degree to which prosumers aspire to live a sufficiency-oriented lifestyle, referring to a total reduction of resource consumption (Verfuerth et al., 2019).

Figure 6. *The constructed model.*



CHAPTER 4: OVERARCHING METHODS

Now that the theoretical model has been built, displaying the constructs underlying potential barriers to laundry loadshifting behavior, the model can be tested in practice. As briefly mentioned in Chapter 1, a mixed-methods approach will be taken for this purpose, applying both qualitative and quantitative methods. This chapter first elaborates upon the research outline in more detail. That is, a general description of the two applied methods is provided, as well as how they are combined in the current thesis study.

4.1. Outline: Qualitative method applied in this thesis

Qualitative research aims to gather data through e.g., document analysis, observation or interviews (Kılıçoglu, 2018). Thus, qualitative research generally uses verbal or written data rather than numerical data, gathered through conversational communication and trying to understand how people experience certain matters (Kılıçoglu, 2018; Mohajan, 2018).

For this thesis study, qualitative data is gathered by the author through six semi-structured interviews with solar energy experts (see Chapter 5). The data is analyzed by the author through thematic content analysis, of which the results are used to answer sub-questions 3 and 4. Furthermore, the author compares the initial qualitative results to the theoretical model before moving on to the quantitative part of the study, providing a preliminary opportunity to validate the model. Additionally, the qualitative results help the author determine the exact questions to be asked in the (quantitative) survey. Ultimately, the qualitative findings are used by the author to test the theoretical model, answering the main research question. Detailed information on the qualitative methods of the current thesis study can be found in Chapter 5. Qualitative results are then discussed in Chapter 6.

4.2. Outline: Quantitative method applied in this thesis

Quantitative research refers to the collection and analysis of numerical data to find patterns, make predictions or test causal relationships (Bhandari, 2021). By collecting numerical data and analyzing such data using mathematically based methods (particularly statistics), quantitative research can help explain a wide range of phenomena (Muijs, 2010).

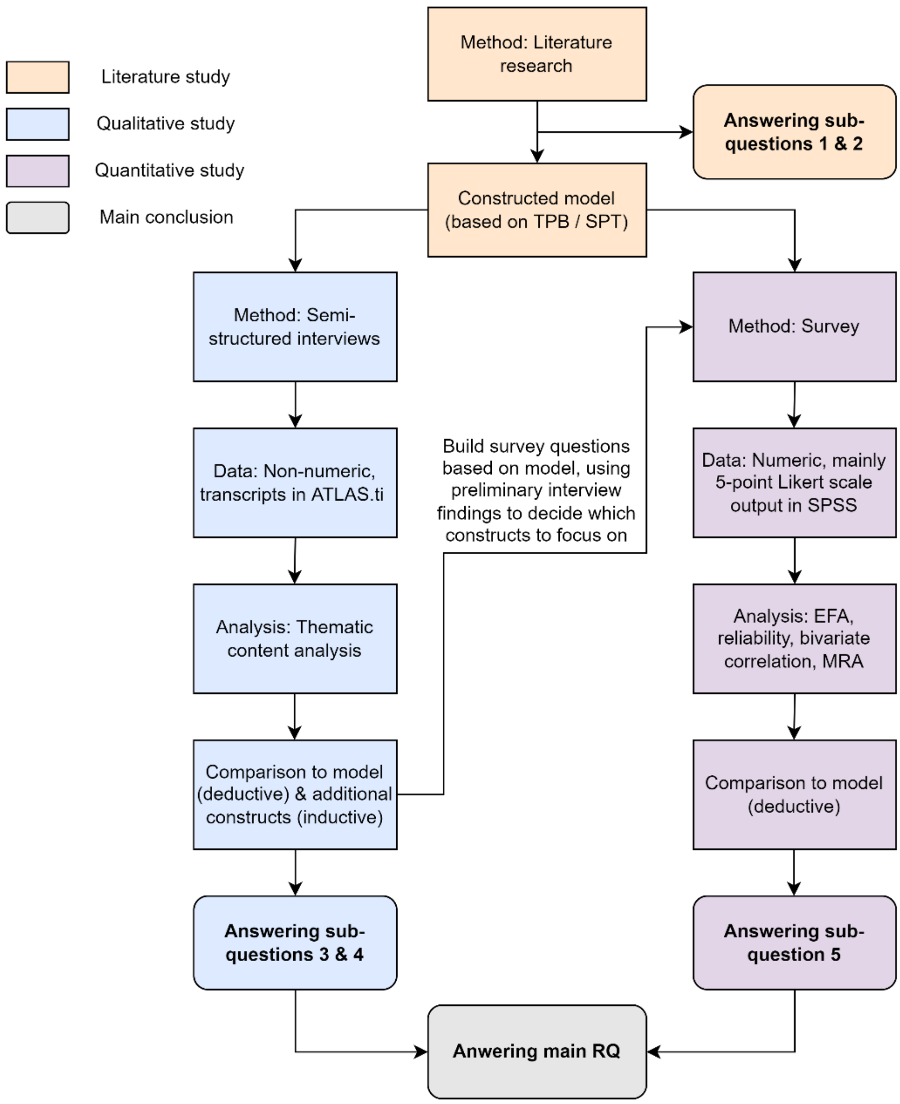
In this thesis study, quantitative data is gathered after the qualitative data collection. The quantitative data is collected by a commercial data platform through a survey distributed amongst Dutch prosumers (see Chapter 7). The survey is designed by the author of this thesis, with input from the rest of the research team. Such a survey is a good addition to this study following the conduction of the semi-structured interviews, since the research questions focus explicitly on barriers experienced by *prosumers*. Therefore, it is vital to assess not only how experts view self-consumption and loadshifting behavior, but mainly how prosumers *themselves* experience this specific behavior. Rather than interviewing a substantial number of prosumers however, conducting a survey is a more suitable method to collect a large amount of data regarding prosumers' opinions and feelings (Muijs, 2010). This provides the author with the opportunity to make more generalizable statements regarding a representative sample of prosumers, compared to doing only interviews.

The quantitative data is analyzed through an exploratory factor analysis, a reliability analysis, a bivariate correlation analysis and a multiple regression analysis. The results are firstly used to answer sub-question 5. Ultimately, the qualitative findings are used to test the theoretical model and answer the main research question, complementing the qualitative findings. Detailed information on the qualitative methods can be found in Chapter 7. Quantitative results are discussed in Chapter 8.

4.3. Combining methods: the mixed-methods approach

Although most studies on practices remain qualitative, some researchers argue for the use of quantitative methodologies to assess how such practices emerge and persist (Browne et al., 2014). Better yet, many researchers advise to combine both qualitative and quantitative methodologies in a mixed-methods approach (as is the case in this thesis). The debate between quantitative and qualitative methods may even be divisive and counterproductive for advancing the social and behavioral science field (Onwuegbuzie & Leech, 2005). By applying a mixed-methods approach in this thesis study, it may be possible to explore how patterns of individual practices such as laundry loadshifting behavior emerge and are performed by households at a population level (Browne et al., 2014). Figure 7 summarizes the mixed-methods approach taken by the author in this thesis project. As can be seen in this figure, the qualitative findings provide input for the construction of the quantitative survey. Specifically, by providing a preliminary comparison with the constructed model, the qualitative findings help emphasize which constructs of the model are likely to impact loadshifting behavior. Following the survey, I can then assess whether

Figure 7. *Overview of the methods and their relations.*



4.4. Overall approval by the Human Research Ethics Committee (HREC)

Both the qualitative and quantitative parts of this thesis study were approved by the HREC of TU Delft. The required checklist, a detailed data management plan, and the informed consent materials (see Appendix A, Figure A1 and A2) were submitted separately for both methods. Thus, the overall thesis study was deemed to be in alignment with the ethical considerations and data management considerations of the HREC.

CHAPTER 5: QUALITATIVE METHODS

This chapter describes the qualitative research methodology of this study in more detail, before presenting the qualitative results in the next chapter. This description includes the applied method, tools, and analyses. First, the chosen qualitative research method of semi-structured interviews is discussed, including a description of the participants and interview procedure. Second, the selected qualitative tool of ATLAS.ti is briefly introduced. Third, the chosen qualitative analysis (thematic content analysis) is elaborated upon. As aforementioned in Figure 7 and Table 1 above, the qualitative methodology will ultimately be used to answer the main research question by answering sub-question 3 and 4:

- Sub-question 3: In what ways do Dutch prosumer households experience these barriers to loadshift the laundry, according to solar energy experts?
- Sub-question 4: What is the ability of proposed policies for increased self-consumption to help overcome these barriers in the Netherlands?

5.1. Qualitative research method: semi-structured interviews

For this thesis I gathered qualitative data by means of six semi-structured interviews with professional experts working in the field of solar energy. Semi-structured interviews allow researchers to assess the thoughts and feelings of participants regarding a certain topic (DeJonckheere & Vaughn, 2019). In semi-structured interviews participants are free to share their own opinions instead of having to give right or wrong answers (ibid.). This method follows a flexible interview protocol and entails the asking of open-ended questions to create a dialogue, meaning room is left for follow-up questions (ibid.).

I considered semi-structured interviews with solar energy experts a suitable method to gather the qualitative data needed for sub-question 3 and 4. Firstly, the focus of sub-question 3 is on exploring the opinions of solar energy experts regarding if and how prosumers experience barriers when trying to loadshift the laundry. Although barriers are expected to be structured according to the underlying constructs of the model discussed in section 3.2.3., the focus is not on confirming or disproving a set of predetermined barriers. Barriers are still likely to be manifold or may overlap, and additional barriers may well be found when asking experts for their opinion.

Secondly, as discussed in Chapter 3, many energy consumption behaviors (including doing the laundry) are thought to be routinized practices rather than deliberative or rational actions (Hess et al., 2018; Kurz et al., 2015; Wood et al., 2002).

Because of this routinized nature, prosumers themselves may not be aware of all the barriers limiting their own loadshifting behavior if some of these barriers occur subconsciously. For instance, should the construct of habit indeed emerge as a barrier, it is possible that prosumers underestimate the importance of such a subconscious construct as a potential obstacle to behavior change (Maréchal, 2010). Although people are often aware of the habitual nature of their behavior (ibid.), experts observing or researching the behavior in question may be more able to discuss the *degree* to which such subconscious constructs truly influence self-consumption.

Thirdly, I felt experts would be more able than prosumers to reflect upon the proposed policies for increased self-consumption referred to in sub-question 4. As discussed in section 2.3. and 2.4., these proposed policies (mainly the dismantling of the net-metering scheme) have been causing quite a stir amongst prosumers and politicians, but they will not actually enter into force for some time. I expected it would be difficult for prosumers to objectively discuss the behavioral workings and outcomes of a policy which has not yet come into force. Especially now that emotions are running high, and a lot of ambiguity persists regarding e.g., the exact starting date of these policies and the reasoning underlying their design. Experts, who busy themselves with objectively understanding and perhaps even contributing to these policies due to their profession, may be in a more suitable position to discuss these policies. The selection of interview participants is discussed in more detail in the next section.

5.1.1. Participants

The selection of expert participants was mainly based on their professional function, or the role of the organization they represent. Instead of interviewing experts who all share the same function, I chose to interview three different functions: consultants, researchers, and experts who are also prosumers. By interviewing experts covering different aspects of the PV sector, I felt I could provide a more comprehensive view on the matter of self-consumption and loadshifting. For example, whilst researchers may possess a lot of in-depth (theoretical) knowledge on these matters, consultants have more direct contact with prosumers and may thus have a better idea of how the application of this knowledge plays out in practice. An overview of all interviewees is provided in Table 3, depicting interviewees' respective codes, functions, and why they were included in the research project.

Table 3. *Overview of the six semi-structured interviews.*

Code	Function	Reason for inclusion
PP1	Consultant	Direct contact with prosumers, organization advises municipalities on policy.
PP2	Senior researcher at independent research organization	Area of expertise is PV and self-consumption, plus the organization advises municipalities on policy.
PP3	Senior researcher at Dutch university	Area of expertise is energy systems, plus the interviewee fulfills an advisory role on behalf of the IPCC.
PP4	Consultant	Direct contact with prosumers, organization advises municipalities on policy.
PP5	Prosumer	To include at least one explicit prosumer perspective.
PP6	Senior researchers (2) at independent research organization	Area of expertise is PV (integration), plus the organization advises the Dutch government on policy.

Before settling on the interviewees depicted in Table 3, I first created a list of potential participants by searching online for relevant organizations, companies or individuals in my target groups (consultants and researchers working in the PV sector). Potential participants were also added to this list through tips and suggestions from people in my network. Moreover, I sent out a LinkedIn post, summarizing the purpose of my thesis study and inviting interested solar energy experts to contact me via email. This is how two of the selected participants were found, including the prosumer. Initially, I tried to contact all the potential participants on my list, not expecting all of them to reply. The six participants that did reply were ultimately selected for participation. The description of the interview procedure is continued in the next section (5.1.2.).

I considered a total of six interviews to be doable given the time constraints of the current thesis study. Furthermore, a selection of six participants allows for a balanced distribution between consultants, researchers and prosumers. I conducted three interviews with researchers, of which one is allied to a Dutch university and two are employed by independent research organizations. It should be noted that one (PP6 in Table 3) of these three interviews was conducted with two researcher participants instead of one, per their own preference. Other than needing more time for the interview, this was not thought to affect the interview procedure itself. Moreover, I conducted two interviews with commercial consultants providing solar panel advice to Dutch households. Yet only the remaining interviewee was explicitly selected for their prosumer function. Although this interviewee did happen to work on the energy transition professionally, they were selected primarily to allow for at least one in-depth interview from a prosumer perspective. Nonetheless, several of the other interviewees also happened to be prosumers, although this only became apparent during the interview instead of beforehand and was thus not the focus of said interviews.

5.1.2. Procedure

Potential participants were initially reached out to by the researcher via email or phone, often by first contacting the representative organization before being connected to the appropriate person to be interviewed. Once participants were informed on the research goal and expressed their interest in participating, the interview's time and date was set via email. Then, a week before the interview all participants were provided with the informed consent form via email, to be signed by the participant as well as the researcher before the interview could take place (see Appendix A, Figure A1).

The stated goal of the interviews was the mapping of barriers which make self-consumption (and loadshifting in particular) difficult for Dutch prosumer households. Participants were informed that self-consumption refers to prosumers using their self-produced energy as much as possible, for instance by doing the laundry during the daytime. Participants were asked to share their opinion on the importance of self-consumption, the role of self-consumption in their work, whether prosumers seem to value self-consumption, barriers inhibiting self-consumption, and how these barriers may be overcome (e.g., through policymaking). See Appendix B for all questions asked during the interview.

All interviews took 45 minutes to one hour and were conducted online via video call using MS Teams. This was preferred over in-person interviews, as data collection took place for three weeks in February 2022 when COVID regulations were still uncertain in the Netherlands. Furthermore, interviews could easily be recorded within MS Teams and automatically uploaded to my personal TU Delft OneDrive account for backup, making sure the recordings are only accessible by me. Additionally, MS

Teams can transcribe recordings, saving time and effort. Transcripts were ultimately saved as Word files, where I could make corrections if there were inaccuracies in the automatic transcription, as well as remove names and any other personally identifiable data. Following full transcription, the completed transcripts were emailed to participants for final approval. The following section discusses the next steps toward qualitative data analysis in more detail.

5.2. Qualitative tools: ATLAS.ti

Once completed, the six anonymous transcripts were transferred to ATLAS.ti version 22 for further data analysis. Designed at the Technical University of Berlin, ATLAS.ti is used to store, centralize, manage and organize all information collected for qualitative research (Soratto et al., 2020). The data analysis is always mediated by the researcher as the critical thinker, who selects and applies the appropriate analysis to the data stored within ATLAS.ti (ibid.). Thus, ATLAS.ti is more of an organization tool guiding and simplifying the analysis, rather than an analysis program itself. A description of the analysis I selected and carried out follows in the next section.

5.3. Qualitative analysis: Thematic content analysis

I analysed the interview data with a combination of content analysis and thematic analysis. Content analysis refers to the process of categorizing verbal or behavioral data in order to classify, summarize, and evaluate the data in a structured manner (Kalpokas, n.d.). Content analysis is used in both qualitative and quantitative research, although techniques vary. One of these techniques used only for qualitative research is thematic analysis (Soratto et al., 2020). Thematic analysis is defined as a method for the identification, analysis, and documentation of themes in a qualitative data set (Kalpokas, n.d.). In this study, the themes are the measurable constructs of the newly constructed theoretical model (see section 3.2.3.) as well as demographics and the dependent variable (loadshifting).

Thematic content analysis is conducted in three phases. During pre-analysis documents containing the data (the six transcripts, in this case) are added to ATLAS.ti and read in full (Soratto et al., 2020). During material exploration, textual data segments are selected as quotations and assigned to a code. In this study, a codebook guided this phase, which was based on the theoretical model constructed in section 3.2.3. The codebook (see Appendix C) shows that code groups refer to the elements of meaning, material, internal and external competences of the theoretical model. The codes within these code groups refer to the 10 measurable constructs [7]. Since the model and accompanying codebook were initially created *before* the interviews took place, the qualitative analysis was mainly conducted through a deductive approach. The deductive approach means a predetermined theory is applied to the data to test this theory (Bingham & Witkowsky, 2022). In the current study, the predefined constructs of the model (the codes) are applied to the transcribed data to test this model in practice. Nonetheless, there was a possibility of finding additional constructs inductively (see also Chapter 6). Through an inductive approach additional constructs *not* included in the predetermined model can be coded (Bingham & Witkowsky, 2022). Finally, during the interpretation phase of thematic content analysis the coded data is compared to the theoretical model. Soratto et al. (2020) provide an overview of the phases and steps for conducting a thematic content analysis in ATLAS.ti. Table 4 summarizes this overview as applied in the current study.

Table 4. *Thematic content analysis.*

Phases	Steps in ATLAS.ti
First phase: Pre-analysis	Creating the project Adding documents Writing memos on the project aim & research questions
Second phase: Material exploration	Selecting data segments Creating quotations Creating and applying codes Grouping codes
Third phase: Interpretation	Exploring the coded data using analysis tools Linking quotations codes on the conceptual level Generating network views Extracting reports

Note: Adapted from "Thematic content analysis using ATLAS.ti software: Potentialities for researchs in health", by Soratto et al., 2020, *Rev. Bras. Enferm.*, *73*(3).

[7] As can be found in section 3.2.3., these 10 measurable constructs are sufficiency attitude, motivation, user beliefs, know-how, monitoring skills, habits, hassle, practical knowledge provided, institutional policies and regulations, and feedback provision by system design.

CHAPTER 6: QUALITATIVE RESULTS

The qualitative results of the thematic content analysis are provided in this sixth chapter. Most of the chapter is dedicated to a summary of the measurable constructs and accompanying barriers to loadshifting behavior that were found by means of the interviews (see Table 5). Additionally, some additional qualitative results are discussed in this chapter as well. Note that the full interpretation of the results will follow in the conclusion (Chapter 9) and the discussion (Chapter 10).

6.1. Qualitative results: constructs and barriers found deductively

As described in the previous chapter, the semi-structured interviews are analyzed mainly deductively using the code groups and codes stated in the codebook (see Appendix C). This codebook was created *before* the interviews took place and is based on the model constructed in Chapter 3. Namely, code groups refer to the predetermined elements of the model (materials, meaning, internal and external competences) and codes refer to the measurable constructs expected to underly different barriers to self-consumption.

Constructs which were found in at least one of the six interviews are displayed in Table 5 below. Table 5 also summarizes in how many of the interviews the construct was mentioned, what I consider the construct to entail, and a selection of interviewee quotes giving an impression of the construct. Furthermore, Table 5 also includes the factors from the literature research (see section 3.1. and Figure 3) which may overlap with the constructs and barriers found in the interviews. Note that although all interviews were conducted entirely in Dutch, the quotes used in Table 5 have been translated to English.

Overall, all interviewees recognized the difficulty in firstly making prosumers aware of the importance of self-consumption, and secondly in helping prosumers realize their intention to self-consume. The barriers making this difficult can indeed largely be connected to the underlying measurable constructs listed in the theoretical model built for this study (see Table 5). Thus, most barriers and their underlying constructs were found through deductive reasoning, comparing the transcripts with the constructed model and codebook. Consequently, many of the deductively found constructs and related barriers share some overlap with a factor found through the literature research. This is not so strange, considering the literature research findings were used as a starting point to build the model and its constructs.

One barrier to loadshifting behavior clearly stood out in all interviews: the net-metering scheme itself (the underlying construct being institutional policies and regulations). Many interviewees feel that since net-metering does not (financially) motivate prosumers to self-consume, this policy is an important barrier to loadshifting behavior. Therefore, interviewees all seem to support the proposed policy changes to the net-metering scheme.

6.2. Qualitative results: constructs and barriers found inductively

Moreover, six additional constructs and related barriers were found inductively. Meaning, these constructs were discovered *during* the coding of the interviews rather than based on the model and codebook established beforehand. For instance, although all interviewees feel that the net-metering scheme indeed limits loadshifting and should thus be changed, they also feel the proposed policy changes lack clarity. This leads to the inductive discovery of an important additional construct, which can be referred to as clear policymaking (see Table 5). If policies lack clarity, certainty, direction, or urgency, interviewees feel they are unlikely to benefit loadshifting.

Other inductively found constructs underlying barriers to loadshifting include age, the interpretability of bills, panel placement, the state of machinery and safety. Again, these are all summarized in Table 5 below. Although not originally included in the constructed model and codebook, most of the inductively found constructs and barriers can be confirmed by overlapping factors found in the literature research. As such, they could have been included in the model beforehand, especially since many inductive constructs can also be fitted under one of the model's elements and thus fit the model design. For example, the inductive construct of "panel placement" can easily be thought of as part of the "materials" element. Nonetheless, it is understandable not all possible constructs and barriers were included in the model beforehand, considering the time and financial constraints of the current study (see Chapter 10).

6.3. Additional qualitative results: the importance of self-consumption

In addition, whilst the constructs and barriers that were mentioned did vary per interviewee, *all* interviewees believed in the overall importance of self-consumption. Consultants described how self-consumption and loadshifting are now regularly addressed when talking to (potential) prosumers. Consultants felt this is due in part to prosumers who frequently bring up questions on their own accord, especially regarding the proposed changes to the Dutch net-metering scheme. Although these questions consultants receive often stem from financial concerns, e.g., prosumers are worried about their return on investment if net-metering is stopped, consultants also try to make the environmental benefits of self-consumption clear. PP1 summarized the issue, saying: *"It is of course not sustainable to produce energy, then transport it away, and then once you need it to transport it back to your own home."*

Like the consultants, interviewed researchers also recognized the importance of self-consumption in terms of sustainability and efficiency. However, researchers did emphasize the need to place the issue in a broader perspective. Namely, researchers feel the gap between supply and demand will inherently remain part of a system built on renewable energy such as solar or wind (PP2). Closing this gap based on human behavior alone will be nearly impossible (PP2). The balancing of supply and demand could be achieved even without optimizing behavioral self-consumption, using other approaches to demand response instead (PP3). Furthermore, some researchers feel complete self-consumption may not even be the most efficient approach to close the supply-demand gap, as the resources provided by the existing energy grid are then not capitalized upon anymore (PP6). Nonetheless, PP3 stated that *"in all cases you are more flexible, more robust if you do involve people."* Similarly, PP2 said: *"This is something prosumers themselves can have a big influence on, in terms of their behavior and thinking differently about how they use energy."*

Lastly, storage and automatic loadshifting are often listed by interviewees as solutions to overcome the mentioned barriers and increase self-consumption and loadshifting behavior. However, these solutions are once again hindered by their own barriers, such as the high price of storage solutions or the technological development still needed to realize efficient automatic loadshifting (see Chapter 2). Since manual loadshifting is the focus of the current study, the specifics of these solutions and their respective barriers are however not discussed further in this thesis.

Table 5. *Elements, constructs, and barriers found in the six interviews.*

Barrier	Frequency & interviewee(s)	Description	Quotes	Overlap with factors from literature research
ELEMENT: MEANING				
Measurable construct: Sufficiency attitude (deductive)				
Low sufficiency attitude	1/6 (PP3)	People seem to appreciate energy which comes from (close to) home, parallel to people appreciating e.g., food that is produced in their own region.	PP3: *"See how important people find it to eat locally… people think that's nice… that is something which speaks to their imagination."*	Sufficiency attitudes & beliefs (Wittenberg & Matthies, 2016; Wittenberg & Matthies, 2018)
Measurable construct: User beliefs (deductive)				
Passive user beliefs	1/6 (PP3)	Prosumers may become more active, which if combined with improved monitoring skills or know-how, could benefit loadshifting. However, most prosumers may continue to have a systematic rather than individual view on the energy system.	PP3: *"You often hear that people with solar panels also become more involved with their usage. Because they get a feeling for quantities, what appliances use, or they use a smart meter for that."* PP3: *"I think people do not really think beyond the system."*	Technology affinity (Wittenberg & Matthies, 2018)
Measurable construct: Motivation (deductive)				

High financial motivation	6/6	Prosumers who are mainly financially motivated may be less likely to loadshift since there is no financial incentive to do so (due to the current net-metering scheme).	PP3: *"…I don't have any financial incentive to. I can do all these difficult things to increase self-consumption, but I could also invest extra in things that reduce my consumption instead …people need to be able to earn something, otherwise it's just not fun to self-consume."*	Economic/financial motivation (Gill et al., 2015)
Low environmental motivation	4/6 (PP1, PP2, PP4, PP5)	Prosumers who are mainly environmentally motivated may be more likely to loadshift since they may be more aware of the issue. However, this varies per prosumer.	PP1: *"If people really care about the environment, then generally they are up to date. You don't have to inform them as much."* PP5: *"… even though we did this (installing solar panels) just because we find it necessary, we do still use the grid as a battery."*	Environmental motivation (Gill et al., 2015)
Low self-reliance motivation	5/6 (PP2, PP3, PP4, PP5, PP6)	Prosumers who are mainly motivated by the wish to be self-reliant may be more likely to loadshift, due e.g., to a mistrust of the government or energy companies, or due to the rising energy prices.	PP4: *"Some clients just don't trust the government. They want to be independent, and they want a battery or something else because they're afraid something is going to happen."* PP5: *"I think it has to do with the dependence on large companies. If you see what's happening with the*	Independence / self-reliance

			gas prices, you're really at the mercy of these companies."	
Measurable construct: Age (inductive)				
Older age	2/6 (PP1, PP4)	Older prosumers may have more difficulty loadshifting, because the optimal time to consume energy is the opposite of what they were used to in the past.	PP1: *"If you've been told for 20 or 30 years to do your laundry at night, it is harder to get out of your head."* PP4: *"The day-night tariffs from the past, that is exactly the other way around with solar panels. But many older clients still think it's cheaper to use energy at night."*	Age (Gautier et al., 2019)
ELEMENT: MATERIALS				
Measurable construct: Interpretability of bills (inductive)				
Low interpretability of data on energy bills	3/6 (PP3, PP4, PP5)	Prosumers do not seem to consistently look at their bills to interpret their production and consumption. Data on bills is not suitable to make these kinds of interpretations, and prosumers do not want to analyze their bills often.	PP3: *"I suspect people underestimate this, that they say I deliver back but it's not that much. It's on the energy bill, but only how much you delivered. You can't relate it to what you used yourself."* PP4: *"The first 2 or 3 months it's fun, but after that they only notice if their bills are high."* PP5: *"Every year I check the total bill… I check if the panels are working, but I don't feel like monitoring every day."*	System of provision (Gill et al., 2015)

Measurable construct: Panel placement (inductive)				
Panels traditionally placed on south-facing roofs only	2/6 (PP1, PP6)	Panels on south-facing roofs may make loadshifting difficult, as the peak will occur at midday. Panels on east-west facing roofs could help match supply to demand.	PP1: *"Consider an east-west placement… then you are producing at the moments when you are using."* PP6: *"…then you have a morning peak and an evening peak which match better with the standard user profile."*	Property characteristics (Ebrahimigharehbaghi et al., 2021; Van der Kam et al., 2018)
Measurable construct: Feedback provision by the system (deductive)				
Lack of feedback provided in real time	1/6 (PP2)	Providing real time feedback on energy production and consumption could help improve loadshifting, especially for those with lower monitoring skills and those who find it difficult to interpret their bills or meters.	PP2: *"…you shouldn't just be providing general information, but help people self-consume in real time… show the way in a more playful manner… an app that gives people a sign when it's beneficial to self-consume."*	System of provision (Gill et al., 2015)
Measurable construct: State of machinery/tech (inductive)				
Older machinery/tech	4/6 (PP1, PP2, PP3, PP6)	Tools to help prosumers loadshift (manually or automatically) can be limited by the availability and development pace of technology.	PP2: *"…many appliances don't have those possibilities yet, so maybe there's some low-tech tools that can give people a sign that it's smart to switch on their appliance."* PP3: *"That's also a technical barrier, you don't just need the components but they also need to be able to communicate with each other, so the*	

			solar panels can talk to the laundry machine."	
ELEMENT: EXTERNAL/EXPLICIT COMPETENCES				
Measurable construct: Clear policymaking (inductive)				
Policies which lack clarity, certainty, direction, or urgency	6/6	Policies must provide direction and certainty, so consultants can communicate clearly with their clients. Specification is needed regarding role and task division, so the necessary systems can be ready in time. Lastly, changes to the net-metering scheme should be explained well to improve acceptability.	PP1: *"We are waiting for the next policy… really there should be a new policy ready by now, how are we going to continue?"* PP4: *"It's going to cost me clients if net-metering changes, but it will also bring me new clients because there is clarity then. People are not buying (panels) now because they have no clarity."* PP2: *"For me the question is, which party is going to pick things up?... I feel these are all question marks and open endings."* PP5: *"If we explain why this is happening, it will become a lot simpler. And if people understand things, there is less resistance."*	
Measurable construct: Practical knowledge provided (deductive)				

Little to no practical knowledge provided to prosumers	4/6 (PP1, PP2, PP4, PP5)	Consultants feel they have an important role in distributing information regarding self-consumption, and do this through webinars, municipal meetings, or at prosumer homes. However, not every prosumer is provided with this knowledge.	PP1: *"Information spreading would begin at organizations like X. Occupants value our opinion, because we are independent."* PP5: *"We had a consultant back then, who made beautiful calculations, but he didn't say you should do this or this… But I think that would be a good tip… it's not just about awareness, it's also about selling the message, people need to see the benefits of it."*	Sources of advice/information (Gill et al., 2015)
Measurable construct: Institutional policies and regulations (deductive)				
Net-metering scheme	6/6	The current net-metering scheme in the Netherlands provides no financial incentive for prosumers to self-consume, thus most prosumers do not feel the need to change their behavior.	PP1: *"Net-metering has made us lazy. That laziness has resulted in an unsustainable society, in terms of solar production."* PP2: *"The financial situation in the Netherlands is actually a barrier for self-consumption… but for prosumers it's perfect."* PP6: *"And net-metering, that is of course not helping now. That is not stimulating a movement the other way around."*	Net-metering vs. net-purchasing schemes (Gautier et al., 2019)
ELEMENT: INTERNAL/IMPLICIT COMPETENCES				

Measurable construct: Habits (deductive)				
Strong laundry habits	4/6 (PP2, PP3, PP4, PP5)	Prosumers may not consciously think about the issue of self-consumption, or are not aware of the issue, or are forgetful about the issue.	PP4: *"…many people who say they will do it (loadshift), they work during the day and forget to press the button."* PP5: *"We're not consciously thinking, let's not switch the laundry on tonight… You just do things the way you always did."*	Everyday practices / habits (Gill et al., 2015; Maréchal & Holzemer, 2018)
Measurable construct: Hassle (deductive)				
Loadshifting the laundry feels is perceived to be a lot of hassle	5/6 (PP1, PP2, PP4, PP5, PP6)	Prosumers may want to loadshift but they do not want to think about it too much, preferring to live their lives as usual. Automatic loadshifting is often discussed to relieve prosumers of this burden.	PP1: *"People prefer to be lazy instead of tired... they're just waiting to see what happens."* PP2: *"People want convenience, they don't want to worry about it and just want it to work. It's easiest if the system does this automatically so you can relieve people… for a large group of people it may be too complex or abstract or boring…"* PP5: *"We try to live as consciously as possible, but I don't want to measure or regulate myself to death."*	de Vries et al., 2020; Ebrahimigharehbaghi et al., 2021
Measurable construct: Know-how (deductive)				

Little know-how	2/6 (PP3, PP4)	Prosumers may lack a degree of know-how which could improve loadshifting, e.g., how the energy system works and how appliances relate to each other in terms of energy consumption.	PP3: *"I think people have no clue… Electricity comes out of the socket, but they don't know what's behind it all… People also don't have insights into what makes a difference, they don't have feeling for how much an appliance uses or how a car or fridge relate to each other."*	Knowledge on PV functioning and why self-consumption matters (Gill et al., 2015; Niamir et al., 2020)
Measurable construct: Monitoring skills (deductive)				
Low monitoring skills	4/6 (PP3, PP4, PP5, PP6)	Prosumers may not be skilled enough to monitor their levels of production and consumption. Exceptions exist, e.g., prosumers interested in tech who keep track of their patterns using an app.	PP4: *"People never know their KWh usage; they just think it's average but don't know quantities."* PP6: *"…you really need to look closely, when are you producing and using? That becomes complicated."* PP6: *"I do look at my production patterns on my mobile, and not just because I'm a nerd, also the non-technocrats enjoy doing that I think."*	Awareness of (self-)consumption through monitoring (Ebrahimigharehbaghi et al., 2021; Gill et al., 2015; Wittenberg & Matthies, 2018)
Measurable construct: Safety (inductive)				
Running appliances whilst away from home is not perceived to be safe	1/6 (PP1)	Running the laundry machine whilst away from home can make prosumers feel unsafe.	PP1: *"If we say do your laundry during the day, people say but I'm not home… I can't check if it's safe."*	Attitudes and beliefs about technology, control, safety (Broman Toft et al., 2014; Moser, 2017; Wolsink, 2020)

CHAPTER 7: QUANTITATIVE METHODS

The previous two chapters focused upon the qualitative part of the current study. Now, the following two chapters will focus on the quantitative part of this study. This seventh chapter first focuses on the qualitative research methodology in more detail. Specifically, the qualitative research method is discussed, including a description of participant selection, the procedure of survey building and distribution, and the chosen analyses. As aforementioned in Figure 7 and Table 1, the quantitative methodology will be used to answer sub-question 5:

- Sub-question 5: In what ways do Dutch prosumer households experience these barriers to loadshift the laundry, according to prosumers themselves?

7.1. Quantitative research method: survey

The quantitative data for this thesis was collected using a survey. A survey suits this research best as the research questions are descriptive, aiming to assess relationships between variables occurring in a particular real-life context (the household) (Muijs, 2010). As already mentioned in section 4.2., a survey is also a suitable method to collect a large and representative sample of prosumer responses within the limited time frame of the current study, since the focus of sub-question 5 and the main research question is ultimately on barriers experienced by *prosumers*. Lastly, the use of a survey allows for the statistical quantification of the barriers and their underlying constructs, providing insight into the extent to which these constructs and barriers do or do not impact loadshifting behavior.

Like the interviews, the model constructed in section 3.2.3. formed the main foundation for the building of the survey questions. As mentioned in section 4.3. however, part of the structure of the survey was built on the qualitative results from the interviews. The following sections first describe how participants were sampled, before providing a more detailed description of how the survey was built and distributed.

7.1.1. Participants

A common issue when using surveys is a high non-response rate, which can significantly lower the statistical power if the final sample is too small to draw conclusions from (Muijs, 2010). To guarantee the desired number of responses the research team collaborated with Dynata, a large commercial data platform. This collaboration was made possible through funding provided by the ETLab. Dynata was responsible for data collection, referring to participant recruitment and the gathering of valid responses. Since Dynata's responsibility was limited to data collection only, they had no access to the collected responses.

Dynata agreed to deliver at least 200 valid survey responses to adequately represent the population of Dutch PV prosumers. Although participants for this quantitative study were thus not recruited by the research team, clear in- and exclusion criteria were determined beforehand in consultation between Dynata and the research team. Firstly, participants were excluded if they took less than 60 seconds to complete the survey, as the survey was deemed too long to complete in one minute if one would take the time to read carefully. Secondly, participants were included if they lived in the Netherlands and had at least one solar panel already installed at their home. If participants had zero solar panels installed at their home during participation, they were excluded through a loop-out built into the survey. Specifically, these participants automatically exited the survey when filling in "0" at the question asking for the number of installed solar panels. Thirdly, participants were excluded if they did not complete the survey, resulting in missing data. Fourthly, participants were excluded if they appeared to have straightlined. Straightlining is a common phenomenon in survey research, occurring when respondents provide (nearly) identical answers to consequent questions using the same response scale (Kim et al., 2019).

Following the application of the in- and exclusion criteria, Dynata ultimately gathered 316 survey responses. Of these 316 responses, 33 were excluded according to the in- and exclusion criteria, leaving 283 responses available for the analyses. The reasons for exclusions were:

- 18 participants took less than 60 seconds
- 3 additional participants had 0 panels
- 11 additional participants did not complete the survey (missing data)
- 1 additional participant seemed to have straightlined (entered "31" for number of panels, year of installation, and household size)

7.1.2. Procedure: survey building

For this thesis I built the survey using Qualtrics, a widely used web-based software for creating surveys. As described above and in Chapter 4, the survey was mainly built based on the model constructed for the purpose of this thesis. In essence, this means the model depicted in Figure 6 and its 10 measurable constructs described in Table 2 served as a guideline for survey building. However, due to time constraints and feasibility, it is not considered possible to collect quantitative data on all constructs and barriers which may affect loadshifting behavior (see Chapter 10). In fact, due to Dynata's requirement regarding survey length (see section 7.1.3.), it was not feasible to extensively measure all 10 constructs listed in the model.

To decide which constructs to focus on in the survey, I made use of the qualitative results of the semi-structured interviews conducted prior to survey building. Firstly, since all interviewees so clearly considered the Dutch net-metering scheme to be an important barrier, I felt the expected effect of the proposed policy changes needed no further exploration at this point. Moreover, as already stated, it may be difficult for prosumers to estimate the behavioral effect of policies which have not been implemented yet. Thus, I decided not to measure the construct of "institutional policies and regulations" further in the survey.

Secondly, the remaining nine constructs included in the model were all thought to affect loadshifting behavior by at least one interviewee (see Chapter 6). It is thus likely that all constructs influence loadshifting to some degree, making it difficult to decide which (if any) to exclude from the survey. Since the focus of the main research question is on barriers experienced *by prosumers*, and to limit the risk of disregarding an important underlying construct, I decided to be lenient and include all nine constructs in the survey. Furthermore, this approach fits the exploratory nature of the current study, providing initial insights into barriers limiting loadshifting behavior. Should the results of this study be noteworthy, future studies could focus more extensively on those constructs requiring a deeper understanding (see Chapter 10).

Thirdly, it has been stated in Chapter 6 that the impact of some constructs operating subconsciously may be observed more objectively by interviewees than prosumers themselves. However, drawing conclusions regarding these constructs based *only* on an interviewee's perspective is also a risk. Regarding user beliefs for example, interviewees cannot directly observe prosumers' beliefs but only their own second-order beliefs: beliefs about the beliefs of others (Taddicken et al., 2019). Research has shown that second-order beliefs can be inaccurate, over- or underestimating the beliefs of others (ibid.). Therefore, complementing interviewees' perspectives with prosumers' perspectives is more likely to provide an accurate, comprehensive understanding of the constructs underlying loadshifting behavior.

Fourthly, as many as six additional constructs underlying barriers to loadshifting behavior were found inductively during the interviews (as discussed in Chapter 6). Unfortunately, due to restrictions regarding survey length (see section 7.1.3.), most of these additional constructs could not be analyzed further in the survey. The exception is the additional construct of age, which was included in the survey to control for barriers which cannot be influenced (see section 8.5.). The main foundation for the survey continues to be the model constructed for this study. Considering the model already contains quite many constructs, and none of these constructs were disproved during the interviews, I chose not to replace any of the initial constructs with those found in addition. Nonetheless, it may be worthwhile to study the additional constructs in new research (see Chapter 10).

Ultimately, the survey was designed to measure nine of the constructs included in the model established for the purpose of this study. Each construct was measured using two questions, except for motivation (one ranking question) and sufficiency attitude (three questions). Furthermore, eight questions were included to measure demographics and control variables[8]. Lastly, three questions measured the dependent variable referred to as laundry loadshifting behavior, necessary for the conduction of the quantitative analyses discussed in the next chapter.

Nearly all questions were formulated by me, with input and feedback from the rest of the research team. Thus, most of the survey questions are phrased in an original manner rather than based on existing measurement scales. Instead, I phrased the questions based on the operational definitions of their respective constructs, provided in previous studies (see Table 2). Only the questions intended to measure sufficiency attitude are an exception to this approach. Namely, Verfuerth et al. (2019) have already created a short survey on sufficiency attitude, which only needed slight adaptations in phrasing to apply to the current study. Since sufficiency attitude refers not just to scarcity in using resources, but also the use of one's own resources *and* wastage, three questions were included in the current survey to cover all three aspects.

The final survey for this thesis study consists of 29 questions. Table 6 displays the structure of the final survey including the survey questions and response options, as well as the model's elements and constructs the questions are thought to represent. To add to the column referring to the response options, two slightly different variations of 5-point Likert scales were used in the survey. Specifically, for the laundry loadshifting variable (question 4, 5 and 6 in Table 6) the response options were: never, rarely, sometimes, often, always. For all other constructs measured on a 5-point Likert scale the response options were: strongly disagree, disagree, neutral, agree, strongly agree. Scores thus ranged from 1 to 5, with higher scores indicating a stronger presence of the construct the question refers to. To remain consistent in the interpretation of scores, question number 8 and question number 16 were reverse coded for further

[8] These are age, gender, number of panels installed, year of installation, household size, occupant status, storage, and intention at time of installation. Each is measured using a single question.

analysis. Note that although Table 6 shows the questions and responses in English, the actual survey was distributed in Dutch. See Appendix C for the complete survey questions including their Dutch translation. In addition, Table 6 includes the name each question was given in SPSS, which will be useful to interpret the tables in the next chapter.

Table 6. *Survey structure.*

Measurable construct	**Survey question**	**Response options (*and measurement scale*)**	**Question number**	**SPSS codename**
		Demographics & control variables		
Age	Please select your age group.	Multiple choice (*ordinal*): • 18-24 years • 25-34 years • 35-44 years • 45-54 years • 55-64 years • 65 years or older	29	Age
Gender	Please select your gender.	Multiple choice (*nominal*): • Male • Female • Other	28	Gender
Number of solar panels	Please fill in the number of solar panels installed at your household.	Open (*ratio, > 0*)	1	Panels
Year of installation	Please fill in what year the first solar panels were installed at your household.	Open (*interval, > 0*)	2	Year
Household size	Please fill in the number of people in your household.	Open (*ratio*, > 0)	26	Household_size
Occupant status	Are you a:	Multiple choice (*nominal*): • Homeowner • Renter	27	Occupant_status

		• I don't know		
Storage	Do you make use of a storage device to store the energy produced by your PV system?	Multiple choice (*nominal*): • Yes • No • I don't know	3	Storage
	If yes, why do you make use of this storage device? Select the option that is most applicable to you.	Multiple choice (*nominal*): • To further increase the savings on my energy bill. • To use the energy myself when I need it, instead of feeding it back into the grid. • To use my energy more efficiently. • Other.	3a	Why_storage
Intention (at time of installation)	When I got my solar panels installed, I intended to adapt my energy consumption to mostly use my self-produced energy.	5-point Likert scale (*interval*)	25	Intention
Dependent variable				
Laundry loadshifting	When choosing a moment to do my laundry, I consider the electricity production of my PV system first.	5-point Likert scale (*interval*)	4	Loadshifting_manual
	I make use of an automated program/timer on my laundry machine so that it runs at a time when my PV system is producing energy.	5-point Likert scale (*interval*)	5	Loadshifting_automated

	By adjusting the use of the laundry machine to the energy production of my solar panels I try to utilize my own self-produced energy as much as possible.	5- point Likert scale (*interval*)	6	Loadshifting_attempt
		ELEMENT: MEANING		
Motivation (for installation)	Listed below are a number of possible reasons for installing solar panels. Sort how important these reasons were for you to install solar panels, from most to least important.	Ranking (*ordinal*): I installed my solar panels because • I wanted to produce my own electricity, instead of having to rely on the grid. • I wanted to reduce my carbon emissions and live more sustainably. • it was a good investment, with the added benefit of helping me save money on my electricity bill. • I am interested in technical innovations.	7	Motivation
User beliefs	My solar panels require little engagement from me.	5-point Likert scale (*interval*)	8	Beliefs_passive
	My solar panels require me to engage with them by routinely monitoring and managing my energy generation and consumption patterns.	5-point Likert scale (*interval*)	9	Beliefs_active

Sufficiency attitude	Through my lifestyle, I want to use as little resources as possible (water, energy).	5-point Likert scale (*interval*)	10	Attitude_use
	I find it appealing to use my own resources as much as possible.	5-point Likert scale (*interval*)	11	Attitude_own
	I find it desirable to collect as much dirty laundry as possible to not waste resources (water, energy).	5-point Likert scale (*interval*)	12	Attitude_waste
ELEMENT: EXTERNAL/EXPLICIT COMPETENCES				
Practical knowledge provided	I have been provided with information on ways to use my own self-produced energy.	5-point Likert scale (*interval*)	13	Knowledge_howto
	I have been provided with information on the benefits of consuming my self-produced energy.	5-point Likert scale (*interval*)	14	Knowledge_benefit
ELEMENT: INTERNAL/IMPLICIT COMPETENCES				
Know-how	To not overload the electricity grid it is best to use energy when it is produced by my	5-point Likert scale (*interval*)	15	Knowhow_congest
	It does not matter whether I use my own self-produced electricity or electricity imported from the grid; electricity is	5-point Likert scale (*interval*)	16	Knowhow_differ
	I often track my electricity data, or use an online portal such as an app to do so.	5-point Likert scale (*interval*)	17	Monitoringskill_app

Monitoring skills	I often check the (current or forecast) weather to estimate if and when my solar panels are producing energy.	5-point Likert scale (*interval*)	18	Monitoringskill_weather
Habits	I don't give much thought to the specific timing of my laundry; I simply wash when I need the clothes to be clean.	5-point Likert scale (*interval*)	21	Habits_think
	When I do the laundry is dependent on my household's routine, from which I rarely	5-point Likert scale (*interval*)	22	Habits_routine
Hassle	It is too complicated to plan the laundry in such a way that it matches the availability of self-produced energy.	5-point Likert scale (*interval*)	23	Hassle_complicated
	Checking whether my solar panels are producing enough energy to do the laundry	5-point Likert scale (*interval*)	24	Hassle_work
ELEMENT: MATERIALS				
Feedback provision by system design	The display of my solar panels provides me with a good understanding of my electricity production and consumption.	5-point Likert scale (*interval*)	19	Design_clear
	The display of my solar panels is placed somewhere where I can easily read it, or is easily accessible in another way.	5-point Likert scale (*interval*)	20	Design_accessible

7.1.3. Procedure: survey distribution

As aforementioned, whilst the research team oversaw survey building and data analysis, Dynata was responsible for the survey distribution (data collection). The contractual agreement for data collection as signed by Dynata and the research team was built on two conditions. Firstly, it was assumed that the percentage of households in the Netherlands with solar panels is 20% of the general population, or one in five households (NOS, 2022, August 2) . Secondly, the average time needed to complete the survey should not exceed 10 minutes, to lower the chance of participants quitting the survey prematurely. Once I had built the survey according to these conditions, the survey was ready to be distributed via Dynata's own respondent platform.

Data was collected in two rounds. During the first round the survey was distributed from March 25th (2022) until March 29th (2022), after which 216 responses had been collected. Following the application of the in- and exclusion criteria however, the number of participants recruited during this initial release dropped below the agreed upon 200. Therefore, Dynata continued to run the survey for a second round in order to improve the data quality, until the aforementioned 316 responses were reached on April 1st (2022). Thus, Dynata collected all responses in a total timespan of one week. As described in section 7.1.1., 283 collected responses were ultimately available for the analyses. The quantitative analyses to be conducted are introduced in the next section.

7.2. Quantitative analyses

I analysed the survey data with four different analyses, all conducted using IBM SPSS version 26. Of these four, the multiple regression analysis (MRA) forms the main analysis, able to identify which (if any) of the model constructs can predict laundry loadshifting behavior. The three preceding analyses mainly serve an exploratory purpose, allowing for data inspection before the MRA is conducted. Note that the four analyses are only briefly introduced in this section, stating their purpose for this study. Detailed information on the conduction of the analyses will follow in Chapter 8.

Firstly, an exploratory factor analysis (EFA) is conducted to assess whether the survey data initially agrees with the model constructed in Chapter 3. Secondly, a reliability analysis is conducted to assess the reliability of the constructs as based on the model. Thirdly, a bivariate correlation analysis is conducted to inspect the relationship between the constructs based on the model, as well as with the loadshifting variable. Finally, the MRA is conducted to assess whether any of the constructs (referred to as independent variables) can predict loadshifting behavior (referred to as the dependent variable). Thus, the MRA assesses the influence of the constructs (user beliefs, sufficiency attitude, practical knowledge provided, know-how, monitoring skill, feedback provision by system design, habits, and hassle) on loadshifting.

In a final note, it should be stated that although motivation was one of the measured constructs in the survey, this construct was not included for analysis. This decision was purely a practical one, relating to the specific way this construct was measured in the survey. Specifically, several interviewees stated that most prosumers are motivated by environmental, financial, *and* self-reliant reasons rather than by one of these reasons alone. Often it is a matter of finding out which of these reasons motivates a prosumer the most. This explains why the survey question relating to motivation was formatted as a ranking question (see Table 6). However, to include the output of such a ranking question in the analyses calls for extra statistical measures. For instance, respondents who rank financial reasons at the top must be split into a different group than those who rank environmental reasons at the top. Since as many as four analyses are already to be conducted for the current study, such additional analyses are not feasible due to time constraints. Regardless, motivation was discussed extensively in most of the interviews and is thus likely able to act as an important barrier for loadshifting behavior. Thus, this construct was measured in the survey nonetheless to allow for further assessment in a potential future study (see Chapter 10).

CHAPTER 8: QUANTITATIVE RESULTS

This chapter describes the results of the quantitative analyses. Firstly, the included sample is described. Secondly, the results of the exploratory factor analysis are provided. Thirdly, the reliability of the selected constructs is discussed. Fourthly, the correlations between the constructs are assessed. Finally, the results of the multiple regression analysis are described, analyzing the relation between the constructs and loadshifting. The interpretation of all quantitative results follows in Chapter 9.

8.1. Description of the included sample

Table 7 presents the categorical characteristics (frequencies) of the included participants (n = 283). These characteristics include whether participants use storage, their occupant status, gender, and age. A fifth of included participants were 65 years or older (21.9%), and 53.7% were male. Additionally, 30% of participants stored their energy, and the vast majority were homeowners (72.4%).

Table 7. *Frequency table for the categorical characteristics of the included participants.*

Variable	Frequency (n)	Percent (%)
Storage (n = 283)		
Yes	85	30.0
No	162	57.2
I don't know	36	12.7
Occupant status (n = 283)		
Homeowner	205	72.4
Renter	73	25.8
Other	5	1.8
Gender (n = 283)		
Female	131	46.3
Male	152	53.7
Other	0	0
Age (n = 283)		
18 – 24 years	19	6.7
25 – 34 years	44	15.5
35 – 44 years	56	19.8
45 – 54 years	45	15.9
55 – 64 years	57	20.1
65 years or older	62	21.9

8.2. Exploratory factor analysis

As described in section 7.2., I first investigated the survey data using EFA. Conducting an EFA is often the first step when building new metrics, exploring whether the metric (such as the survey designed for this study) is measuring the underlying constructs a researcher *wants* it to measure (Yong & Pearce, 2013). In other words, EFA evaluates whether e.g., survey questions really represent the underlying construct a researcher is interested in, referred to as construct validity (Taherdoost et al., 2014). Survey questions measuring the same underlying construct are highly cohesive in terms of shared variance and are grouped together into a factor (ibid.). The extent to which a survey question contributes to a factor is quantified as the factor loading (Yong & Pearce, 2013).

As aforementioned, the EFA conducted for the purpose of this study assesses whether the survey data agrees with the model constructed in Chapter 3. Put differently, by means of the EFA analysis I can evaluate whether the survey items indeed reflect the loadshifting variable and the eight model constructs I expected to measure. To be clear, these eight constructs are user beliefs, sufficiency attitude, practical knowledge provided, know-how, monitoring skill, feedback provision by system design, habits, and hassle. If these underlying constructs are statistically confirmed, the EFA should thus show eight distinct factors, ideally grouping together the survey questions as divided per construct in Table 6 above.

Regarding the chosen technical approach, in this study the EFA was performed using principal component analysis (PCA) extraction. PCA is the most used method in EFA to statistically extract factors from the data (Taherdoost et al., 2014). Following the initial factor extraction, several survey questions loaded into more than one factor. Whilst common, this lowers the discriminatory value of the EFA and is thus not ideal (ibid.). Rotation can help produce more interpretable and simplified results by maximizing high loadings and minimizing low loadings (Taherdoost et al., 2014). Varimax rotation is the most common rotational method for EFA and was thus applied in the current study. Lastly, rotated factor loadings lower than 0.4 were suppressed, to exclude any survey questions which do not significantly contribute to a factor (Yong & Pearce, 2013).

Results of the EFA are displayed in Table 8. All 17 survey questions loaded on at least one factor with a factor loading larger than 0.4, thus no questions were eliminated. The EFA extracted five factors from the data, in contrast to the eight expected factors based on the model. Yet overall, the EFA results show a statistic cohesion between survey questions and constructs similar to what I had expected based on the model. Especially Factors 2, 3, 4 and 5 agreed with the underlying constructs of the model. Namely, Factor 2 measured sufficiency attitude. Although the "knowhow_ congest" question also loaded (weakly) onto this factor, this question continued to cross-load on two different factors even after rotation. This may be due to the phrasing of the question rather than a truly shared construct (see Chapter 10). Moreover, Factor 3 measured practical knowledge provided, although the "design_accessible" question also loaded onto this factor. Furthermore, Factor 4 measured monitoring skill. Although the "design_clear" question also loaded (weakly) onto this factor and continued to cross-load on two different factors, phrasing issues may again provide an explanation (see Chapter 10). Lastly, Factor 5 measured user beliefs. Overall, the rotated factor model consisting of the five factors accounted for 63.07% of the variance.

Although the EFA indicated just five underlying constructs, the decision was made to continue onto further analyses using the eight predefined constructs rather than the re-defined constructs of the EFA. As described above, the EFA showed an overall statistic cohesion between survey questions and constructs similar to those in the model. Specifically, the EFA agreed with four of the expected underlying constructs (sufficiency attitude, practical knowledge provided, monitoring skill, and user beliefs). Furthermore, only Factor 1 combined two underlying constructs which were kept separate in the model, namely habits and hassle. Regardless, the decision was made to keep these constructs apart, based on previous research and theory (see Chapter 10). Finally, phrasing issues could explain the discrepancy between the composition of the remaining constructs in the EFA versus the model. Thus, to continue with the analyses the stand-alone survey questions are computed into eight constructs in SPSS, adding together the respective questions per construct as envisioned in Table 6.

Table 8. *Results of the exploratory factor analysis.*

Questions	Factor					Re-defined construct *(of which element)*
	1	2	3	4	5	
Hassle_complicated	0.817					Habits & resistance to changing them *(of the internal/implicit competences element)*
Habits_think	0.765					
Habits_routine	0.734					
Knowhow_differ (reversed)	-0.665					
Hassle_work	0.632					
Attitude_use		0.774				sufficiency attitude *(of the meaning element)*
Attitude_own		0.731				
Attitude_waste		0.670				
Knowhow_congest*		0.462		0.420		
Knowledge_how to			0.864			Provided knowledge & accessibility *(of the external/explicit competences element)*
Knowledge_benefit			0.848			
Design_accessible			0.513			
Monitoring skill_app				0.804		Monitoring skill *(of the internal/implicit competences element)*
Monitoring skill_weather				0.582		
Design_clear*			0.439	0.577		
Beliefs_passive (reversed)					0.809	User beliefs *(of the meaning element)*
Beliefs_active					0.620	

* Item continues to load on two different factors even after rotation.

8.3. Reliability analysis of the computed constructs

Since the computed constructs (based on the model) somewhat differ from the factors found in the EFA, it is important to first assess the reliability of these computed constructs to better understand whether their respective questions measure the same construct. In the current study, the reliability of the computed constructs is analysed using two different reliability measures, since the scales consist of either two or three questions each.

Firstly, Cronbach's alpha is used to test the reliability of the three-question constructs (loadshifting and sufficiency attitude). Cronbach's alpha measures internal consistency, referring to how closely related a set of questions are as a group: it inspects the relation of each question to all other questions (McNeish, 2018). Table 9 displays Cronbach's alpha for the three-question constructs. The reliability of the loadshifting scale was found to be fairly high (α = 0.791) (Taber, 2018). The reliability of the sufficiency attitude construct was found to be reasonable (α = 0.687) (Taber, 2018).

Although well-known and commonly applied, there has been considerable debate about the use of Cronbach's alpha as a reliability measure, especially for scales consisting of only two items (Eisinga et al., 2013). Namely, Cronbach's alpha may underestimate the true reliability of a two-item scale due to the measure relying on relatively strict assumptions (ibid.). Therefore, the Spearman-Brown correlation coefficient (also called Spearman's rho) is calculated for the two-question constructs instead. Spearman's rho is generally less biased if the correlation between questions is relatively strong (ibid.). The two-question constructs are those of beliefs, knowledge, know-how, monitoring skill, design feedback, habits and hassle. The Spearman-Brown correlation coefficients for these seven two-question constructs are also displayed in Table 9. According to Spearman's rho the correlations between questions intended to measure the same construct are all significant, thus all two-question constructs are thought to be sufficiently reliable.

Table 9. *Results of the reliability analysis.*

Construct	Mean (SD)	Spearman's rho	Cronbach's alpha
Loadshifting			0.791
Manual	2.80 (1.324)		
Automated	2.05 (1.286)		
Attempt	2.89 (1.356)		
Sufficiency attitude			0.687
Use	3.62 (0.892)		
Own	3.67 (0.844)		
Waste	4.02 (0.881)		
Beliefs		-0.253**	
Passive	4.00 (0.783)		
Active	2.83 (0.970)		
Knowledge		0.698**	
How to	3.06 (1.086)		
Benefit	3.27 (1.018)		
Know-how		-0.279**	
Congest	3.77 (0.838)		
Differ	2.68 (1.123)		
Monitoring skill		0.429**	
App	3.58 (1.073)		
Weather	3.11 (1.174)		
Design feedback		0.473**	
Clear	3.61 (0.940)		
Accessible	3.49 (1.040)		
Habits		0.506**	
Think	3.03 (1.207)		
Routine	3.20 (1.105)		
Hassle		0.444**	
Complicated	3.07 (1.117)		
Work	2.89 (1.106)		

** Correlation is significant at the 0.01 level.

8.4. Bivariate correlation analysis between the computed constructs

In addition to the reliability analysis, a bivariate correlation analysis was conducted to assess the relationship between the eight newly computed constructs as well as the loadshifting scale. This correlation analysis is preliminary to the MRA and allows for data inspection. Correlations are reported using Pearson's correlation coefficient. Results of the bivariate correlation analysis are displayed in Table 10.

Loadshifting correlated with all constructs except hassle (r = -0.104, p = 0.082). Most significant correlations were found to be low to moderate (r = 0.213 to r = 0.495), yet the correlation between loadshifting and the monitoring skill construct was high (r = 0.517, p < 0.001). Correlations amongst the eight constructs were numerous, although most of these correlations were low to moderate (r = 0.003 to r = 0.467). However, the correlation between hassle and know-how (r = -0.511) as well as between hassle and habits (r = 0.565) were found to be high.

Table 10. *Correlations between loadshifting and the eight computed constructs.*

Variable or construct	Mean (SD)	Pearson's correlation coefficients								
		Loadshifting	Beliefs	Attitude	Knowledge	Know-how	Monitoring	Design	Habits	Hassle
Loadshifting	2.58 (1.12)	1	0.334**	0.304**	0.495**	0.213**	0.517**	0.324**	-0.253**	-0.104
Beliefs	2.42 (0.70)	0.334**	1	0.118*	0.229**	0.020	0.195**	0.038	0.024	0.003
Attitude	3.77 (0.68)	0.304**	0.118*	1	0.249**	0.467**	0.365**	0.250**	-0.169**	-0.233**
Knowledge	3.17 (0.97)	0.495**	0.229**	0.249**	1	0.146*	0.392**	0.411**	-0.048	-0.030
Know-how	3.54 (0.78)	0.213**	0.020	0.467**	0.146*	1	0.267**	0.127*	-0.452**	-0.511**
Monitoring	3.35 (0.97)	0.517**	0.195**	0.365**	0.392**	0.267**	1	0.431**	-0.227**	-0.118*
Design	3.55 (0.84)	0.324**	0.038	0.250**	0.411**	0.127*	0.431**	1	-0.049	-0.004
Habits	3.12 (1.01)	-0.253**	0.024	-0.169**	-0.048	-0.452**	-0.227**	-0.049	1	0.565**
Hassle	2.98 (0.95)	-0.104	0.003	-0.233**	-0.030	-0.511**	-0.118*	-0.004	0.565**	1

*Correlation is significant at the 0.05 level.

**Correlation is significant at the 0.01 level.

8.5. Multiple regression analysis

Finally, a MRA is conducted to assess whether any of the eight computed constructs (referred to in the MRA as independent variables or predictors) can predict loadshifting behavior (referred to as the dependent variable). Thus, the MRA assesses the influence of user beliefs, sufficiency attitude, practical knowledge provided, know-how, monitoring skill, feedback provision by system design, habits, and hassle on loadshifting.

I chose a MRA instead of a simple linear regression firstly because there are eight potential predictors in my model instead of one. Secondly, the bivariate correlation analysis described in the previous section shows significant correlations between some of the constructs. When constructs correlate with each other, simple regressions may only detect the relationship between predictors, rather than between predictors and the dependent variable. A MRA assesses the relationship between a predictor and the dependent variable whilst keeping the other predictors constant and is thus preferred.

Before running the MRA, I checked whether three main assumptions were met. First, the data appeared to be normally distributed, based on a plot of the standardized residuals (assumption of normality) (see Appendix E, Figure E1). Second, the independent variables did not appear to correlate too highly with each other, based on the calculation of the variance inflation factors (VIF) (assumption of no multicollinearity) (see Appendix E, Table E1). Third, the variance of errors did not seem to differ at different values of the independent variables, based on a plot of the standardized predicted values (assumption of homoscedasticity) (see Appendix E, Figure E2) (Osborne & Waters, 2002). Thus, none of the assumptions were violated.

For this thesis the MRA consists of three different regression models, needed to account for different variations of potential covariates in the data. Covariates are not constructs but independent variables that are not of direct interest, which could nonetheless influence the outcome of the MRA. No covariates were added in the first model, meaning only the eight constructs were added as predictors. Due to the exploratory nature of this study there is no expectation as to which predictor affects the regression model the most, thus predictors were entered into the analysis simultaneously according to the enter method (rather than one-by-one, referred to as the stepwise method[9]).

[9] To be sure, the MRA was run once more using the stepwise method to allow for a comparison with the results of the enter method. Yet, results were similar for both methods.

In the second model, age and gender were added as covariates in addition to the eight scales. In the interviews, age was found to impact other constructs and. Moreover, since age and gender are difficult to influence and thus not of immediate interest, it is wise to control for the effect of such demographics on loadshifting. In the third model, all remaining variables were also added as covariates, to assess whether occupant status, household size, intention for self-consumption, number of panels, year of panel installation or the use of storage could affect loadshifting. Such rigid household and property characteristics are also not of immediate interest but were found to influence (self-)consumption in the literature (see Figure 2).

Results of the multiple regression analysis are displayed in Table 11. According to the first model, which was not adjusted for any covariates, there was a significant relationship between the eight constructs as independent variables and the dependent variable of loadshifting, R^2 = 0.440, F(8, 274) = 26.934, p < 0.001. Thus, the eight constructs together are adequately able to predict loadshifting, explaining 44% of the variance observed in loadshifting behavior. Although both age and gender appeared as covariates in the second model the results persisted , R^2 = 0.480, F(10, 272) = 25.154, p < 0.001. As such, controlling for the effects of age and gender increases the variance in loadshifting behavior that is explained by the eight constructs *and* these demographics to 48%. Lastly, the results remained robust after adjusting for all included covariates in the third model, R^2 = 0.544, F(16, 266) = 19.796, p < 0.001. Meaning, the eight constructs together with all included covariates explain as much as 54% of the variance in loadshifting behavior. However, only storage was a significant covariate in the third model.

Now to the predictive effect of each separate construct. The four constructs of user beliefs, practical knowledge provided, monitoring skills, and habit significantly predicted loadshifting in all three regression models. Meaning, these four constructs predict loadshifting behavior regardless of any covariates in the data. Additionally, sufficiency attitude emerged as a fifth significant predictor of loadshifting in the third model. Since this construct only emerged in the third model, in which only storage appeared as a coviariate, a relationship between sufficiency attitude and storage seems apparent. It is possible prosumers with a strong sufficiency attitude are more likely to use a storage device, or the other way around (prosumers with a storage device possess a stronger sufficiency attitude). Finally, the three constructs of know-how, feedback provision by system design, and hassle remained insignificant predictors of loadshifting in all three models. Therefore, these three constructs cannot predict loadshifting behavior regardless of any covariates in the data.

Table 11. *MRA results on the relationship between the eight constructs and loadshifting.*

Predictor	Beta	SE	t	P-value
User beliefs				
Model 1	0.207	0.075	4.391	**<0.001***
Model 2***	0.194	0.073	4.217	**<0.001***
Model 3****	0.146	0.071	3.267	**0.001***
Sufficiency attitude				
Model 1	0.079	0.088	1.464	0.144
Model 2***	0.103	0.086	1.955	0.052
Model 3****	0.113	0.082	2.233	**0.026****
Practical knowledge provided				
Model 1	0.293	0.060	5.571	**<0.001***
Model 2***	0.258	0.059	5.002	**<0.001***
Model 3****	0.179	0.059	3.488	**0.001***
Know-how				
Model 1	-0.010	0.086	-0.166	0.868
Model 2***	0.015	0.083	0.251	0.802
Model 3****	0.015	0.080	0.262	0.793
Monitoring skill				
Model 1	0.275	0.064	4.952	**<0.001***
Model 2***	0.273	0.062	5.083	**<0.001***
Model 3****	0.208	0.062	3.896	**<0.001***
Feedback provision by system design				
Model 1	0.048	0.070	0.915	0.361
Model 2***	0.035	0.068	0.685	0.494
Model 3****	0.015	0.065	0.297	0.767
Habits				
Model 1	-0.209	0.064	-3.651	**<0.001***
Model 2***	-0.213	0.062	-3.837	**<0.001***
Model 3****	-0.191	0.060	-3.558	**<0.001***
Hassle				
Model 1	0.069	0.069	1.176	0.241
Model 2***	0.016	0.068	0.277	0.782
Model 3****	0.009	0.066	0.159	0.874

*Significant predictor at the 0.01 level.
**Significant predictor at the 0.05 level.
***Model 2 is adjusted for age and gender.
****Model 3 is adjusted for age, gender, occupant status, household size, intention, number of panels, year of installation and storage.

CHAPTER 9: CONCLUSIONS

This chapter returns to the aim and research questions stated at the beginning of the thesis. The main research question and sub-questions are answered based on the qualitative and quantitative results described in Chapter 6 and 8:

- **Sub-question 1:** *What possible barriers exist to increase self-consumption in prosumer households, according to literature?*
- **Sub-question 2:** *How can barriers and their underlying constructs be structured according to a model?*
- **Sub-question 3:** *In what ways do Dutch prosumer households experience these barriers to loadshift the laundry, according to solar energy experts?*
- **Sub-question 4:** *What is the ability of proposed policies for increased self-consumption to help overcome these barriers in the Netherlands?*
- **Sub-question 5:** *In what ways do Dutch prosumer households experience these barriers to loadshift the laundry, according to prosumers themselves?*
- **Main research question:** *"Which barriers limit laundry loadshifting behavior in Dutch prosumer households?"*

9.1. Review

The aim of this master thesis study was to explore the barriers that make it difficult for Dutch prosumer households to match their self-consumption to their self-production of solar energy. This matching between self-consumption and self-production could be attempted using technical measures (e.g., storage systems) and/or behavioral measures, with the latter having been the focus of this thesis. Namely, prosumers can shift energy-intensive behaviors to moments when their PV panels are producing energy, referred to as loadshifting. In this thesis, the use of the laundry machine has been selected as an example of loadshifting behavior. Loadshifting can reduce the amount of energy prosumers export to the grid but appears to be difficult for many households. Understanding the barriers to loadshifting could provide insight into strategies to encourage self-consumption. Considering net congestion issues and the proposed changes to prosumers' balancing responsibility, as well as the upcoming dismantlement of the Dutch net-metering scheme, the Netherlands makes for an interesting case to study loadshifting.

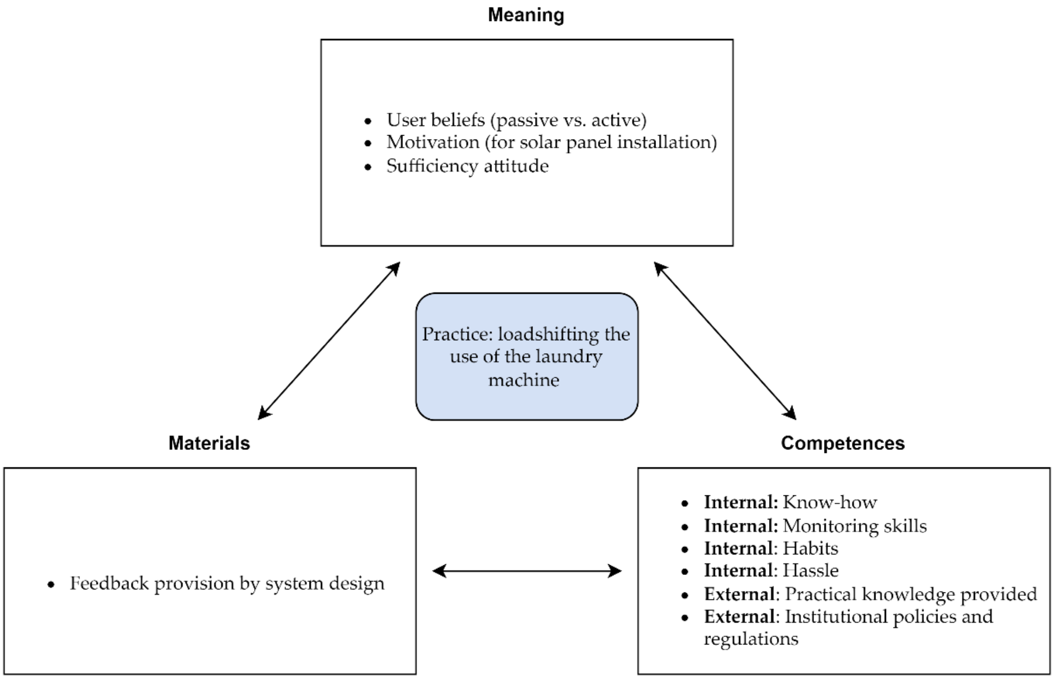
Although research on loadshifting is scarce, barriers were expected to be diverse. This thesis took an exploratory approach to firstly structure potential barriers, and secondly to analyze the extent to which these potential barriers apply to Dutch prosumer households in practice. Structuring the barriers was done through literature research, which led to the creation of a new model combining the (individual-focused) TPB with the (system-focused) SPT. The new model based on these two theories was analyzed in practice using a mixed-methods approach. Qualitative data was obtained through six semi-structured interviews with solar energy experts, leading to a preliminary confirmation of the model. The qualitative findings and the constructed model were used to build a survey, which was distributed amongst Dutch prosumer households to gather quantitative data on the barriers they experience. The next sections detail the conclusions found according to the different methods.

9.2. Conclusions from literature

Literature research was conducted to assess the barriers to self-consumption found in similar studies. These findings answer the first sub-question posed in this thesis: "*What possible barriers exist to increase self-consumption in prosumer households, according to literature?*" Institutional barriers included net-metering schemes or the lack of subsidies for storage. Motivational barriers included financial, environmental, or self-reliant motives of a prosumer. Contextual barriers included prosumer socio-demographics such as old age, household characteristics, or weather unpredictability. Lastly, personal barriers included attitudes, beliefs, and everyday practices or habits.

Next, these potential barriers needed to be structured in order to answer the second sub-question posed in this thesis: "*How can barriers and their underlying constructs be structured according to a model?*" To enable further qualitative and quantitative analyses, such a model needed to include measurable constructs underlying the possible barriers. Both TPB and SPT were found to be useful for this purpose, yet a combination of these two theories was decided to be best. Such a combination could overcome the overly individual focus of the TPB as well as the overly systemic focus of the SPT. The final model (displayed in Figure 8 below) combined the individualistic elements of TPB into the "meanings" element of SPT, and expanded on the "materials" and "competences" elements of the SPT. Specifically, the "meanings" element of the newly constructed model consisted of the measurable constructs of user beliefs, motivation, and sufficiency attitude. The competences element consisted of both internal/implicit competences (knowhow, monitoring skills, habits and hassle constructs) and external/explicit competences (practical knowledge provided and institutional policies as constructs). Finally, the "materials" element consisted of feedback provided by system design.

Figure 8. *The constructed model, combining elements and constructs from TPB and SPT.*



Note: Identical to Figure 6.

9.3. Qualitative conclusions

The constructed model guided the questions asked during the semi-structured interviews with six solar energy experts. The interviewees came from different backgrounds (consultants, senior researchers, prosumer) to create an in-depth and comprehensive view of the issue. The external/explicit competences element was emphasized in the interviews. As aforementioned, this element consisted of the two constructs of practical knowledge provided and institutional policies. The other constructs might be more difficult to evaluate unless experts were prosumers themselves. Similarly, the construct of institutional policies might be more difficult for prosumers to evaluate, as the dismantling of the net-metering scheme has not yet been implemented in the Netherlands.

The qualitative data obtained in the interviews answer the third sub-question posed in this thesis: "*In what ways do Dutch prosumer households experience these barriers to loadshift the laundry, according to solar energy experts?*" Barriers to loadshifting as stated by solar energy experts were found to largely agree with the constructed model (see Table 5). Especially the current net-metering scheme itself was found to be an important barrier according to all interviewees, falling under the institutional policies construct in the model. Additionally, nearly all constructs of the model were mentioned at least once as potential barriers, including sufficiency attitude, user beliefs, practical knowledge provided, habits, hassle, know-how, monitoring skill, motivation, and feedback provision by system design.

Six additional constructs appeared inductively during the interviews. These are referred to as age, interpretability of bills, panel placement, clarity of policymaking, state of machinery and safety concerns of prosumers. These findings help answer the fourth sub-question posed in this thesis: "*What is the ability of proposed policies for increased self-consumption to help overcome these barriers in the Netherlands?*" All interviewees were clearly in favor of dismantling the Dutch net-metering scheme to increase self-consumption levels, despite concerns and criticism from prosumers themselves. Interviewees ascribe these prosumer concerns to the additional barrier of unclear policymaking. Without clear policies to provide direction and certainty to all involved parties, other barriers to self-consumption may persist.

9.4. Quantitative conclusions

The constructed model as well as the qualitative findings guided the questions asked in the survey distributed to prosumers. The quantitative data obtained in the survey was statistically analyzed to answer the fifth sub-question posed in this thesis: "*In what ways do Dutch prosumer households experience these barriers to loadshift the laundry, according to prosumers themselves?*" Barriers to loadshifting behavior experienced by prosumers were found to largely agree with the constructed model.

The main quantitative results indicated that loadshifting behavior is indeed influenced by different barriers. Specifically, the MRA showed that together, the eight constructs measured in the survey predicted loadshifting behavior. These predictive effects remained robust after adjustment for age, gender, and all other covariates. Individually however, only monitoring skill, habits, practical knowledge provided, and user beliefs were found to influence loadshifting behavior (in that order of importance). Firstly, prosumers with stronger monitoring skills (such as those who use an app or the weather to interpret their solar production and consumption) loadshift more. Secondly, prosumers with stronger habits were found to loadshift less. Thirdly, prosumers with more knowledge regarding the benefit of self-consumption (and ways to increase it) loadshift more (practical knowledge provided). Fourthly, prosumers who believe it is important to actively engage with their PV panels and the energy system (active user beliefs) were found to loadshift more. In addition, sufficiency attitude only significantly predicted loadshifting in the third model, with storage appearing as a covariate.

The fact that the constructs of know-how, feedback provision by system design, and hassle were not found to influence loadshifting behavior in the MRA is in line with the EFA findings. However, the findings of the EFA and MRA differ slightly in regard to the constructs that *do* limit loadshifting. As aforementioned, both the EFA and MRA found significant effects for user beliefs, practical knowledge provided and monitoring skill. Yet, the EFA found sufficiency attitude as an underlying construct, whereas the MRA only found this construct to be a predictor after adjusting for all covariates. More importantly, the MRA found habits but *not* hassle to be a predictor in all models, whereas the EFA grouped these two constructs together in a single underlying factor.

Thus, hassle as a separate construct does not appear to have a direct effect on loadshifting behavior. Put differently, the hassle prosumers anticipate when considering to do their laundry during solar production, does not seem to directly impact actual loadshifting behavior. This finding is surprising, since previous research does find hassle to be an important barrier for several sustainable behaviors (Ebrahimigharehbaghi et al., 2021).

As findings regarding the effects of habits and hassle are unclear and somewhat unexpected, further research is needed to help understand the impact of these two constructs on loadshifting (see section 10.4). Still, insights gained in this study provide potential hypotheses which could explain these unclear findings. Namely, the lack of effect of hassle on loadshifting could be due to statistical reasons. The significant positive correlation found between habits and hassle (see Table 9) shows that in the case of strong habits, people would find loadshifting to be a lot of hassle. This correlation could indicate that in the current study, the effect of hassle is (partially) omitted by habits. In other words, the effect of habits might be so strong it masked the effect of hassle, possibly explaining why hassle was found to be the only construct not significantly correlating with loadshifting (see Table 9). This hypothesis is further supported by the EFA, which grouped habits and hassle together due to their high underlying correlation. Additionally, the lack of effect of hassle on loadshifting behavior could also be explained by methodological reasons. Survey questions intended to measure hassle may have been oversimplified (see section 10.2.).

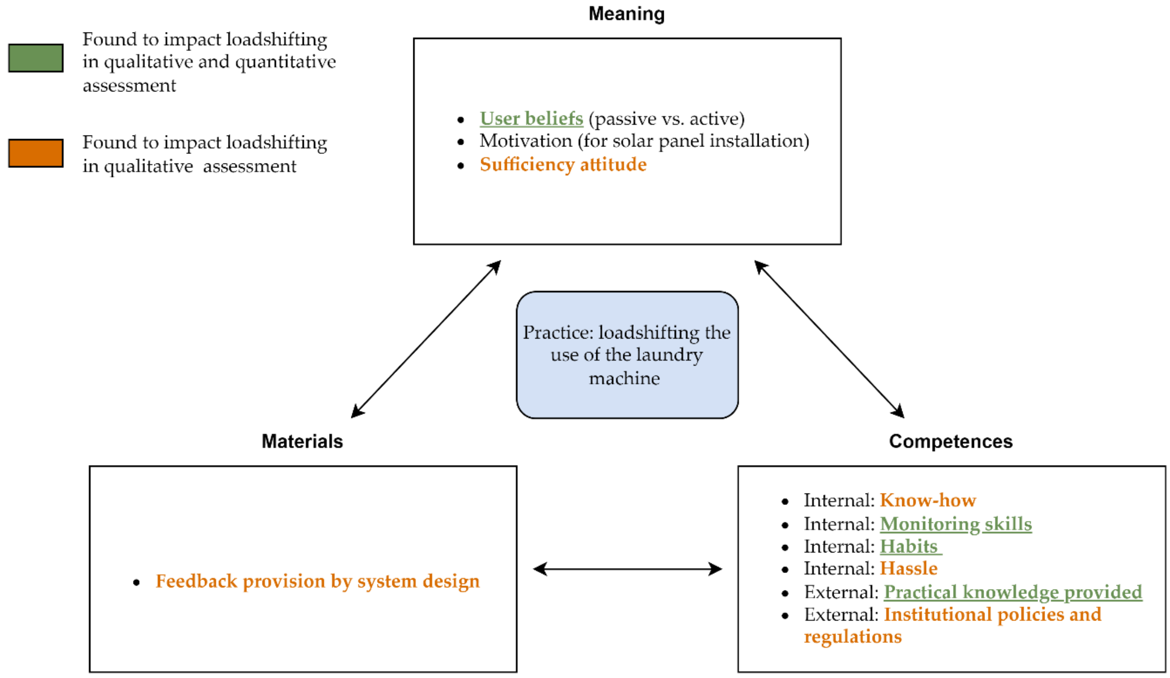
9.5. Main conclusion

Taken together, the qualitative and quantitative conclusions discussed in the sections above can be used to answer the main research question of this thesis:

"Which barriers limit laundry loadshifting behavior in Dutch prosumer households?"

Findings of the current study show that, as expected, several barriers limit loadshifting behavior of Dutch prosumer households to do the laundry when producing solar energy. Importantly, nearly all the constructs in the constructed model were found to act as potential barriers limiting loadshifting, often confirmed by both the qualitative and quantitative assessment. Figure 9 displays the constructs of the model that were confirmed in the assessments. The four constructs that are both **bold** and underlined in green text were found to impact loadshifting in the qualitative as well as the quantitative assessment. The five constructs that are **bold** in orange text were found to impact loadshifting only in the qualitative assessment.

Figure 9. *Constructs of the model verified by the qualitative and/or quantitative assessments.*



The qualitative findings indicate that nearly all the constructs in the model can act as a barrier limiting loadshifting behavior. Especially the current Dutch net-metering scheme itself was found to be an important barrier. Moreover, six additional barriers not listed in the model were found inductively during the interviews. Firstly, a lack of clear policy further enhances the negative effects of the Dutch net-metering scheme as a barrier. Secondly, safety concerns of prosumers act as a barrier, limiting the possibilities for automatic loadshifting. Thirdly, old age can limit the potential for loadshifting. Fourthly, placing panels only on south-facing roofs can make loadshifting more difficult. Fifthly, if energy bills are not easily interpretable regarding production and consumption, this will limit loadshifting. And sixthly, if machinery or technology is in an obsolete state, this will make loadshifting more difficult.

Furthermore, the quantitative findings confirmed that of all the measured constructs, the most important ones affecting loadshifting behavior are monitoring skills, habits, practical knowledge provided, and user beliefs (in that order). Thus, limited monitoring skills regarding PV production and consumption, strong habits, limited knowledge regarding self-consumption and its benefits, and passive user beliefs are found to be the most important barriers. Hassle may also be an important construct underlying the data, yet the conflicting findings between the EFA and MRA hint that the hassle construct may have overlapped too much with habits in the current study.

CHAPTER 10: DISCUSSION

This final chapter addresses the strengths and limitations of the methodologies and thesis study overall. In addition, the implications of the findings are discussed, based on which recommendations for the industry and policymakers are provided. Lastly, suggestions for further scientific research are given.

10.1. Strengths

Firstly, the application of a mixed-methods approach is a notable overall strength of this thesis study (as aforementioned in Chapter 1 and 4). Specifically, a mixed-methods approach allows for the triangulation of qualitative and quantitative data and analyses. Triangulation has been found to help understand complex social phenomena in more depth compared to the use of a single method (Jogulu & Pansiri, 2011). In the current study, triangulation took place by combining statistics with a thematic approach, meaning "hard" data gathered in the survey could be supplemented by "soft" data gathered in the interviews. This triangulation should strengthen the real-world implications of mixed-methods studies like the one conducted for this thesis (ibid.).

Moreover, a mixed-methods approach advocates for the use of both inductive and deductive logic, again strengthening the research design of this study (Jogulu & Pansiri, 2011). Whilst the quantitative conclusions of this study were reached using deductive reasoning (testing the predefined model), some of the qualitative conclusions were reached inductively (discovering additions to the model). As such, the mixed-methods approach combining both forms of reasoning allows for theory generation as well as hypothesis testing without needing to compromise (ibid.).

Secondly, the survey was filled in by a substantial number of respondents, leading to a large sample size for the quantitative analyses. Such a large sample size provides the quantitative analyses with more statistical power, meaning the likelihood that the analyses were able to detect a true effect increases (Kyriazos, 2018).

Thirdly, the current study has relied on two existing and commonly applied theories (TPB + SPT), yet their combination into a model which includes both individual and contextual elements is novel. As described in Chapter 3, this combination should make the SPT more applicable to the individual, as well as the TPB more applicable to the system in which routinized behavior is embedded.

Finally, most of the qualitative findings are supported by previous studies and literature (as shown in Table 5), meaning some of the conclusions are verifiable. Similarly, some of the qualitative findings are confirmed by the quantitative findings. Additionally, findings of the current study not only verify results found in previous research but have also led to new conclusions, such as the further expansion of the newly constructed model with barriers found inductively.

10.2. Limitations

In addition to strengths, several limitations of the current study should be considered. Overall, it is a given that not all relevant barriers to loadshifting have been taken into consideration. Due to time constraints of the thesis project and to maintain focus, a selection of relevant constructs underlying barriers ultimately had to be made (based upon the constructed model). Thus, some constructs leading to barriers to loadshifting are bound to have been excluded. For example, culture has not been considered, although its influence on technologies and behavioral practices has been shown to guide sustainable transitions (Sovacool & Griffiths, 2020). Consequently, the current study is specific to the case of the Netherlands, thus findings may not directly apply to other countries.

Limitations specific to the *qualitative* part of this study firstly include that policymakers have not been interviewed directly. Considering that the interviews were intended to focus especially on the construct of institutional policies and regulations, it is a shortcoming that policymakers were not interviewed to directly discuss these effects. Unfortunately, time constraints from the end of the research team as well as policymakers made scheduling an interview difficult. Nonetheless, several parties advising governmental municipalities have been interviewed, thus there is still an indirect link to policy. A second limitation is that results of the interviews were not discussed with the interviewees before drawing conclusions, whilst it may have been interesting to gain their feedback once more. Due to time and financial constraints this was not possible.

Lastly, some limitations of the *quantitative* part of this study should be considered. First, one could argue in favor of a confirmatory factor analysis instead of an EFA, since the former is more commonly applied to confirm a predetermined model or theory (Ceniza-Bordallo et al., n.d.). Nonetheless, the choice for an EFA was well-reasoned considering the model constructed for this study was entirely new, meaning the research was exploratory. Second, all 5-point Likert scale questions of the survey were treated as interval data for the analyses. Yet, whether Likert scale questions should be considered ordinal data instead is a recurring debate among statisticians (Watkins, 2018). If treated as ordinal however, the possibilities of arithmetic operations become restricted, since ordinal items will not meet the assumptions required of e.g., EFA (ibid.). Therefore, Likert scale questions are often treated as interval data in many similar studies too. Third, I attempted to measure most underlying constructs using 2-question scales. Using scales of only two questions has consequences for their reliability and validity. Arguebly, more questions per construct leads to better construct representation, and increasing the number of questions is the primary way to make scales more reliable (Eisinga et al., 2013). This limitation was partially addressed in the current study by reporting the Spearman-Brown coefficient, which is a more adequate measure of the reliability of a two-question scale than the Pearson coefficient (ibid.).

Finally, the way survey questions were phrased could be considered a limitation of the quantitative part of this study. As aforementioned in section 9.4. for example, the lack of an effect of hassle on loadshifting behavior may have been due to an oversimplification of what hassle truly means. Namely, the two survey questions intended to measure hassle translated the construct to two specific aspects: complexity and work. These questions were phrased as:

- Hassle_complicated → "It is too **complicated** to plan my household's laundry routine so that it matches the availability of self-produced solar energy."
- Hassle_work → "Checking whether my PV system is producing enough energy to do the laundry is too much **work**."

Perhaps a less specific translation of hassle, such as the hassle (to be) experienced when installing an automated timer on the laundry machine, would have been interpreted more clearly as a burden by respondents. Likewise, phrasing may be a limitation for other survey questions too. For instance, there may have been too much overlap in the phrasing of the the "design_clear" question (intended to measure the construct of feedback provision by system design) and the questions measuring the construct of monitoring skill. This overlap in phrasing could explain why the EFA grouped these questions together under one factor (see Table 7). Specifically, these three questions were phrased as:

- Design_clear → "The display of my PV system provides me with a good understanding of my electricity production and consumption."
- Monitoring skill_app → "I often track my electricity data or use an online portal such as an app to do so."

- Monitoring skill_weather → "I often check the (current or forecast) weather to estimate if and when my PV system is producing electricity."

Whether the display provides prosumers with a "good" understanding of production and consumption is likely to be related to how developed their monitoring skills are. Therefore, the "design_clear" item could have been phrased differently to distinguish it from monitoring skills more clearly. Considering that the author of this thesis phrased nearly all survey questions herself, meaning the questions have not been standardized, phrasing issues were perhaps unavoidable. Nonetheless, this limitation ought to be kept in mind when interpreting results.

10.3. Implications & recommendations

Findings of the current study have important implications for policymakers as well as for the solar energy industry overall. As aforementioned, barriers for loadshifting behavior were found to be diverse and manifold, relating not only to the individual prosumer but also to external competences and materials. This is in line with the combined model of TPB and SPT and implies that there is not one targeted solution able to overcome all barriers. Rather, encouraging self-consumption through loadshifting will require cooperation among multiple sectors and actors.

For instance, if the energy sector wishes to change consumption patterns through *automatic* loadshifting, some sort of guarantee needs to be provided that the technology necessary for this automatization is safe. Thus, overcoming the barrier of safety concern will not only require effort from the energy sector, but is in this case also dependent on laundry machine producers. These producers will have to enable their machines to allow for easy automatization and be able to offer clear safety guarantees (e.g., backups in case of short circuiting or overheating). Going beyond this example, loadshifting can be increased further by involving and integrating the solar energy sector and general home appliances' sector overall to enable safe, trustworthy, and smart automatization systems.

Related to the above, findings of the current study strongly support the notion that technology should support human behavior, rather than simply asking human behavior to adjust to technology. The example described in the previous paragraph highlights that unless the home appliances sector truly addresses safety concerns, people will not make use of automatization even if it is technically feasible. Better yet, the application of behavioral insights across sectors is recommended regardless of whether automatic or manual loadshifting is desired. For instance, this study shows that manual loadshifting becomes easier if installers or consultants recommend to position panels in a way which helps users match production and consumption patterns. This measure supports self-consumption without requiring major behavioral change, targeting a newly discovered material barrier instead.

Technical measures to support prosumers (such as panel orientation) may be more efficient than simply asking prosumers to change, especially since this study found strong habits to be an important barrier limiting loadshifting behavior. Removing this barrier quickly may be challenging, since habits are known to be notoriously difficult to change (Thomas et al., 2016). Still, policy tools may be considered to reshape prosumer habits, for instance through nudging. For example, a recent study by Colasante et al. (2021) argues in favor of a monetary incentive such as a bonus per self-consumed kWh to nudge prosumers towards self-consumption. Such a (temporary) incentive may help reshape consumption habits and could be discontinued once self-consumption behavior has been sufficiently rewarded to replace old consumption habits (Colasante et al., 2021).

The matter of financial incentives connects to the next implication of the findings, namely that the dismantling of the Dutch net-metering scheme is indeed advised. As indicated by all interviewees, the current net-metering scheme does not promote loadshifting because it provides no financial incentive to self-consume. Instead, self-consumed energy and energy off-loaded to the grid are assigned the same economic value (22 eurocent/kWh). This equal value does not signal to prosumers that energy produced by/for themselves is *not* the same as energy produced by the grid. Without such a signal to trigger prosumers to think differently about energy, the constructs found in this study are likely to continue to be important barriers to loadshifting. Namely, prosumers are not triggered to change their passive user beliefs and strong consumption habits. Likewise, this equal value does not instill a need for prosumers to improve their monitoring skills, since financially there is no advantage to a better understanding of one's consumption patterns.

Regarding the exact way such a financial incentive can be given in the future, Colasante et al. (2021) found that Italian respondents did not distinguish between a subsidy for energy *production* and a subsidy for *self-consumption*. Rather, both subsidies strongly affected respondents' willingness to increase self-consumption (ibid.). If this is the case, a subsidy for self-consumption may be preferred over a subsidy for production, as the former may prompt prosumers to adopt an energy consumption pattern promoting decentralized systems (ibid.). Unlike the latter subsidy, which will continue to promote new PV installations without requiring changes in consumption patterns (similar to the current net-metering scheme). However, the Dutch government seems to lean towards a self-*production* bonus instead, offering prosumers 6 eurocents for every kWh off-loaded to the grid (as described in Chapter 1) once the net-metering scheme is fully dismantled by the year 2031. This value is similar to what is proposed by Colasante et al. (2021) as a self-*consumption* bonus: respondents quantified a bonus as low as 4 eurocents per self-consumed kWh sufficient to increase self-consumption. Thus, as a replacement to the Dutch net-metering scheme, one may consider a self-consumption bonus rather than a self-production bonus if the willingness to self-consume is to be increased.

Furthermore, the study by Colasante et al. (2021) hints that such a self-consumption bonus could help prosumers differentiate between self-produced energy and grid-produced energy. Although the current study did not find this differentiation to contribute significantly to loadshifting in itself (know-how), its relationship to self-consumption may be more complex than this study was able to assess. As described above, knowing the difference between self-produced and grid-produced energy could relate to some important barriers found in this study (e.g., no need to change passive user beliefs, strong habits, or low monitoring skill). In favor of this argument, the EFA and bivariate correlation analysis did imply a connection between knowing this differentiation, habits, and hassle (see Chapter 8). Specifically, it seems prosumers who do differentiate between self-produced and grid-produced energy are *less* restricted by habits and hassle when it comes to loadshifting. This connection implies that researching the exact nature of the relationship between these different constructs could help reduce more than one barrier to loadshifting behavior (see section 10.4.).

Furthermore, measures supplementary to a monetary incentive are also recommended based on the findings of this study. For instance, less knowledge on self-consumption and ways to increase it, as well as lower monitoring skills were both found to be important barriers to loadshifting behavior. This was confirmed by both the qualitative and quantitative analyses. These findings imply that increasing prosumer knowledge on the issue and improving their monitoring skills could help encourage loadshifting. Herein lies an important role for consultants and/or policymakers to actively distribute practical information to prosumers. Several interviewees indicated to do so already, such as consultants organizing informational meetings on behalf of municipalities, or research organizaions providing self-consumption tips via their website (see Chapter 6). This distribution of information should be continued and strengthened. Considering that existing distribution channels may primarily target prosumers already interested in self-consumption or solar PV engagement, ways could be found to inform a wider audience of prosumers. For example, solar panel installers could provide some basic information regarding self-consumption to each new prosumer. The prosumer interviewed for the current study argued in favor of such an approach (see Chapter 6).

Additionally, the qualitative findings hint at even more barriers which could be addressed. For instance, the interviewed consultants stated they try to make prosumers aware of the environmental benefits of self-consumption (see Chapter 6). Thus, it is assumed that strengthening prosumers' environmental values could increase their motivation to self-consume. Unfortunately, due to time constraints the effect of motivation for panel installation was not assessed further, yet additional research on this matter could be worthwhile (see section 10.4.).

Overall, all the implications circle back to the initial statement made in the beginning of this section. That is, encouraging loadshifting and general self-consumption will require communication and cooperation across sectors and actors (e.g., consultants, policymakers, researchers, installers, appliance producers and prosumers). Due to the connections between different barriers, solutions will have to address these connections rather than a singular barrier. For example, whilst the provision of information alone is known to be insufficient to change habitual behavior (Thomas et al., 2016), such a solution could be effective if combined with other measures. The provision of practical information should underscore the importance of self-consumption and increase knowledge on what behaviors matter. To offer insight and guidance during the application of this knowledge, monitoring skills should be enhanced. In addition, monetary incentives such as a self-consumption bonus can reward the shaping of new self-consumption habits.

10.4. Suggestions for further research

The final section of this thesis issues some suggestions for further research. Firstly, all unclear or conflicting findings of the current study warrant clarification. For instance, more in-depth research is needed to understand the nature of the relationship between habits, hassle, and loadshifting. Such research could look at the reason why the MRA did not detect hassle as a predictor of loadshifting, whilst the EFA combined hassle and habits. Findings of the current study hint at an interaction effect (see section 9.4.), but this needs clarification. For instance, if habits indeed act as a mediator masking the effect of hassle, further regression analyses or structural equation modelling (using SPSS or R) could be used to test this effect.

Similarly, more in-depth research is needed to understand the nature of the relationship between habit, hassle, and the know-how question measuring the insight that self-produced and grid-produced energy are not the same. Again, findings of the current study hint at an interaction effect (see section 10.3.), but this claim needs further research. For instance, a choice experiment could be used to test if prosumers who *are* aware of the difference between self-produced and grid-produced energy are indeed less restricted by habits and hassle when trying to loadshift. In such an experiment, the hassle required to loadshift could be explicitly emphasized to prosumers, whilst manipulating whether they are notified of the difference between self-produced and grid-produced energy first.

Secondly, as aforementioned in section 10.3., the effect of motivation on loadshifting deserves further research. Specifically, many of the interviewees in the current study hinted at a positive relationship between environmental motivation and loadshifting (see Chapter 6). Interviewees suggest that prosumers who are mainly environmentally motivated are not only more likely to loadshift, but also possess more knowledge and know-how than those mainly financially motivated. Still, further research is needed to assess whether results truly differ between prosumers who are motivated by different reasons. In addition, it is unclear what construct would underly such a potential relationship. Possibly, motivation could relate to values, with e.g., those financially motivated valuing self-interest and those environmentally motivated valuing altruism (Dietz, 2015). If this is the case, the relation between motivation and loadshifting has consequences for the recommendation to provide a monetary incentive. Namely, monetary incentives may then trigger prosumers to think about their consumption as purely a matter of self-interest, disregarding any altruistic appeal (Dietz, 2015). Thus, it may be worthwhile to investigate the relationship between loadshifting, motivation, and/or values.

General suggestions for future studies include the measurement of *actual* self-consumption, instead of relying solely on self-reports. Moreover, constructs should ideally be assessed (again) using more than two questions to help improve validity and reliability. In that case, a more stringent selection of the included constructs should be made, focusing on one or two specific constructs. Furthermore, future studies could choose to focus on the additional constructs found inductively in this thesis.

Lastly, like most similar research, this study applied SPT to repetitive behavior (energy consumption). However, indications are emerging that SPT may be more widely applicable than previously thought. For example, Reindl (2022) used SPT to study PV installation by private businesses, which is a one point in time investment rather than repetitive behavior. Thus, SPT (or adaptions of it) could provide researchers with even more possibilities to look at the interaction between technology and behavior. These possibilities are not restricted to repetitive (residential) behavior such as manual loadshifting only but allow for a better combination of technical and behavioral insights to increase self-consumption *overall* (e.g., regarding the purchase of smart appliances, residential batteries, smart grid integration, etc.).

Ultimately, this combination of technical and behavioral insights is perhaps the most important contribution of the study conducted for this thesis. Because if anything, studies like this one show that though technology and behavior can hinder each other, the stimulation of an effective green energy transition will require us to understand how they complement each other above all else.

REFERENCES

Ajzen, I. (2011). The theory of planned behaviour: Reactions and reflections. *Psychology & Health*, *26*(9), 1113–1127. https://doi.org/10.1080/08870446.2011.613995

Bhandari, P. (2020, June 12). *An Introduction To Quantitative Research*. Scribbr. https://www.scribbr.com/methodology/quantitative-research/

Bhushan, N., Steg, L., Jans, L., & Albers, C. (2021). Does installing photovoltaic panels affect daily electricity usage patterns? A generalized additive model approach. *Energy and Climate Change*, *2*, 100052. https://doi.org/10.1016/j.egycc.2021.100052

Bingham, A. J., & Witkowsky, P. (2022). Deductive and inductive approaches to qualitative data analysis. In C. Vanover, P. Mihas, & J. Saldana (Eds.), *Analyzing and interpreting qualitative data: After the interview* (pp. 133-146). SAGE Publications.

Braito, M., Flint, C., Muhar, A., Penker, M., & Vogel, S. (2017). Individual and collective socio-psychological patterns of photovoltaic investment under diverging policy regimes of Austria and Italy. *Energy Policy*, *109*, 141–153. https://doi.org/10.1016/j.enpol.2017.06.063

Broman Toft, M., Schuitema, G., & Thøgersen, J. (2014). Responsible technology acceptance: Model development and application to consumer acceptance of Smart Grid technology. *Applied Energy*, *134*, 392–400. https://doi.org/10.1016/j.apenergy.2014.08.048

Browne, A. L., Pullinger, M., Medd, W., & Anderson, B. (2014). Patterns of practice: a reflection on the development of quantitative/mixed methodologies capturing everyday life related to water consumption in the UK. *International Journal of Social Research Methodology*, *17*(1), 27–43. https://doi.org/10.1080/13645579.2014.854012

Buijze, A., Winters, E., van der Veen, A., van Gils, M., de Munck, M., Otte, F., & Swanenberg, S. (2021). *Power to the people*.

Castillo-Cagigal, M., Caamaño-Martín, E., Matallanas, E., Masa-Bote, D., Gutiérrez, A., Monasterio-Huelin, F., & Jiménez-Leube, J. (2011). PV self-consumption optimization with storage and Active DSM for the residential sector. *Solar Energy*, *85*(9), 2338–2348. https://doi.org/10.1016/j.solener.2011.06.028

CBS (2021, December 22). *Welvaart van personen; kerncijfers.* https://www.cbs.nl/nl-nl/cijfers/detail/83740NED#Personen_1

CBS (2022, June 17). *Elektriciteit en warmte; productie en inzet naar energiedrager.* https://www.cbs.nl/nl-nl/cijfers/detail/80030ned?q=elektriciteitsproductie%20kolen

Ceniza-Bordallo, G., Gómez Fraile, A., Martín-Casas, P., & López-de-Uralde-Villanueva, I. (n.d.). Validity and Reliability of Spanish PROMIS Pediatric Pain Interference Short Form. *SSRN Journal*. https://doi.org/10.2139/ssrn.4010636

Cohen-Rosenthal, E. (2000). A Walk on the Human Side of Industrial Ecology. *American Behavioral Scientist*, *44*(2), 245–264. https://doi.org/10.1177/00027642000044002007

Colasante, A., D'Adamo, I., & Morone, P. (2021). Nudging for the increased adoption of solar energy? Evidence from a survey in Italy. *Energy Research & Social Science*, *74*, 101978. https://doi.org/10.1016/j.erss.2021.101978

Cuijpers, C., & Koops, B.-J. (2013). *Smart Metering and Privacy in Europe: Lessons from the Dutch Case*. 269–293. https://doi.org/10.1007/978-94-007-5170-5_12

de Jonge Baas, M. (2021, July 5). *Solar Magazine – Jan Willem Zwang: 'Businesscase Voor Thuisbatterij Zonder Subsidie Nog Ver Weg.'* Solar Magazine. https://solarmagazine.nl/nieuws-zonne-energie/i24829/jan-willem-zwang-businesscase-voor-thuisbatterij-zonder-subsidie-nog-ver-weg

de Vries, G. (2020). Public Communication as a Tool to Implement Environmental Policies. *Social Issues and Policy Review*, *14*(1), 244–272. https://doi.org/10.1111/sipr.12061

de Vries, G., Rietkerk, M., & Kooger, R. (2020). The Hassle Factor as a Psychological Barrier to a Green Home. *J Consum Policy*, *43*(2), 345–352. https://doi.org/10.1007/s10603-019-09410-7

de Vries, G., Biely, K., & Chappin, E. (2021). Psychology: The missing link in transitions research. *Environmental Innovation and Societal Transitions*. https://doi.org/10.1016/j.eist.2021.09.015

Dehler, J., Keles, D., Telsnig, T., Fleischer, B., Baumann, M., Fraboulet, D., Faure-Schuyer, A., & Fichtner, W. (2017). *Self-Consumption of Electricity from Renewable Sources*. 225–236. https://doi.org/10.1016/b978-0-12-809806-6.00027-4

Dietz, T. (2015). Altruism, self-interest, and energy consumption. *Proc. Natl. Acad. Sci. U.S.A.*, *112*(6), 1654–1655. https://doi.org/10.1073/pnas.1423686112

Ebrahimigharehbaghi, S., Qian, Q. K., de Vries, G., & Visscher, H. J. (2021). Identification of the behavioural factors in the decision-making processes of the energy efficiency renovations: Dutch homeowners. *Building Research & Information*, 1–25. https://doi.org/10.1080/09613218.2021.1929808

Eisinga, R., Grotenhuis, M. te, & Pelzer, B. (2013). The reliability of a two-item scale: Pearson, Cronbach, or Spearman-Brown? *Int J Public Health*, *58*(4), 637–642. https://doi.org/10.1007/s00038-012-0416-3

Energy Reporters (2019, February 26). *Germany launches battery subsidy package.* https://www.energy-reporters.com/storage/germany-launches-battery-subsidy-package/

Eurostat (2020). *Energy Consumption And Use By Households*. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20200626-1#:~:text=In%202018%2C%20households%20accounted%20for,and%20derived%20heat%20(8.7%25)

Frances, Z., & Stevenson, F. (2020). A relational approach to understanding inhabitants' engagement with Photovoltaic (PV) technology in homes. *Architectural Science Review*, *63*(3–4), 303–315. https://doi.org/10.1080/00038628.2019.1682962

Galvin, R., Schuler, J., Atasoy, A. T., Schmitz, H., Pfaff, M., & Kegel, J. (2022). A health research interdisciplinary approach for energy studies: Confirming substantial rebound effects among solar photovoltaic households in Germany. *Energy Research & Social Science*, *86*, 102429. https://doi.org/10.1016/j.erss.2021.102429

Gautier, A., Hoet, B., Jacqmin, J., & Van Driessche, S. (2019). Self-consumption choice of residential PV owners under net-metering. *Energy Policy*, *128*, 648–653. https://doi.org/10.1016/j.enpol.2019.01.055

Gautier, A., Jacqmin, J., & Poudou, J.-C. (2018). The prosumers and the grid. *J Regul Econ*, *53*(1), 100–126. https://doi.org/10.1007/s11149-018-9350-5

Gill, N., Osman, P., Head, L., Voyer, M., Harada, T., Waitt, G., & Gibson, C. (2015). Looking beyond installation: Why households struggle to make the most of solar hot water systems. *Energy Policy*, *87*, 83–94. https://doi.org/10.1016/j.enpol.2015.08.038

Hess, A.-K., Samuel, R., & Burger, P. (2018). Informing a social practice theory framework with social-psychological factors for analyzing routinized energy consumption: A multivariate analysis of three practices. *Energy Research & Social Science*, *46*, 183–193. https://doi.org/10.1016/j.erss.2018.06.012

Hu, Z., Wang, M., & Cheng, Z. (2022). Mapping the knowledge development and trend of household energy consumption. *Environ Dev Sustain*, *24*(5), 6053–6071. https://doi.org/10.1007/s10668-021-01727-z

Jogulu, U. D., & Pansiri, J. (2011). *Mixed methods: a research design for management doctoral dissertations*. *34*(6), 687–701. https://doi.org/10.1108/01409171111136211

Kalpokas, N. (n.d.). *Qualitative Data Analysis Methods*. ATLAS.Ti – The Qualitative Data Analysis & Research Software. Retrieved June 16, 2022, from https://atlasti.com/research-hub/qualitative-data-analysis-methods#content-analysis

Kemmler, T., & Thomas, B. (2020). Design of Heat-Pump Systems for Single- and Multi-Family Houses using a Heuristic Scheduling for the Optimization of PV Self-Consumption. *Energies*, *13*(5), 1118. https://doi.org/10.3390/en13051118

KfW (n.d.). *KfW – Responsible banking*. https://www.kfw.de/About-KfW/

Khan, I. (2019). Energy-saving behaviour as a demand-side management strategy in the developing world: the case of Bangladesh. *Int J Energy Environ Eng*, *10*(4), 493–510. https://doi.org/10.1007/s40095-019-0302-3

Kim, Y., Dykema, J., Stevenson, J., Black, P., & Moberg, D. P. (2019). Straightlining: Overview of Measurement, Comparison of Indicators, and Effects in Mail–Web Mixed-Mode Surveys. *Social Science Computer Review*, *37*(2), 214–233. https://doi.org/10.1177/0894439317752406

Kılıçoglu, A. (2018b). Qualitative Research for Educational Science Researchers: A Review of An Introduction to Qualitative Research. *TQR*. https://doi.org/10.46743/2160-3715/2018.3352

Klint, E., Johansson, L. O., & Peters, G. (2022). No stain, no pain – A multidisciplinary review of factors underlying domestic laundering. *Energy Research & Social Science*, *84*, 102442. https://doi.org/10.1016/j.erss.2021.102442

Kurz, T., Gardner, B., Verplanken, B., & Abraham, C. (2015). Habitual behaviors or patterns of practice? Explaining and changing repetitive climate-relevant actions. *WIREs Clim Change*, *6*(1), 113–128. https://doi.org/10.1002/wcc.327

Kyriazos, T. A. (2018). Applied Psychometrics: Sample Size and Sample Power Considerations in Factor Analysis (EFA, CFA) and SEM in General. *PSYCH*, *09*(08), 2207–2230. https://doi.org/10.4236/psych.2018.98126

Luthander, R., Widén, J., Nilsson, D., & Palm, J. (2015). Photovoltaic self-consumption in buildings: A review. *Applied Energy*, *142*, 80–94. https://doi.org/10.1016/j.apenergy.2014.12.028

Maréchal, K. (2010). Not irrational but habitual: The importance of "behavioural lock-in" in energy consumption. *Ecological Economics*, *69*(5), 1104–1114. https://doi.org/10.1016/j.ecolecon.2009.12.004

Maréchal, K., & Holzemer, L. (2018). Unravelling the 'ingredients' of energy consumption: Exploring home-related practices in Belgium. *Energy Research & Social Science*, *39*, 19–28. https://doi.org/10.1016/j.erss.2017.10.025

McNeish, D. (2018). Thanks coefficient alpha, we'll take it from here. *Psychological Methods*, *23*(3), 412–433. https://doi.org/10.1037/met0000144

Milieu Centraal. (2016). *Energiebesparing door gedragsverandering*. https://omooc.nl/wp-content/uploads/2016/11/Energiebesparing-door-gedragsverandering-MOOC-Slim-beleid-2016.pdf

Motlagh, O., Paevere, P., Hong, T. S., & Grozev, G. (2015). Analysis of household electricity consumption behaviours: Impact of domestic electricity generation. *Applied Mathematics and Computation*, *270*, 165–178. https://doi.org/10.1016/j.amc.2015.08.029

Muijs, D. (2010). *Doing Quantitative Research In Education With Spss*. SAGE Publications.

NOS (2022, January 17). *Netbeheerder: 'Stroomnet Te Vol, Stop Met Gunstige Regeling Zonnepanelen.'* https://nos.nl/artikel/2413476-netbeheerder-stroomnet-te-vol-stop-met-gunstige-regeling-zonnepanelen

NOS (2022, April 11). *Netbeheerders Investeren Miljarden Door Toenemende Vraag Naar Elektriciteit*. https://nos.nl/artikel/2424736-netbeheerders-investeren-miljarden-door-toenemende-vraag-naar-elektriciteit

NOS (2022, May 1). *Overbelast Stroomnet Raakt Bedrijven En Woningbouw*. https://nos.nl/nieuwsuur/artikel/2427174-overbelast-stroomnet-raakt-bedrijven-en-woningbouw

NOS (2022, June 8). *Stroomnetwerk Limburg en N-Brabant vol, nieuwe bedrijven niet aangesloten.* https://nos.nl/artikel/2431946-stroomnetwerk-limburg-en-n-brabant-vol-nieuwe-bedrijven-niet-aangesloten

NOS (2022, August 2). *Nederland Europees Koploper Zonnepanelen, Maar Hoe Kan Het Beter*? https://nos.nl/artikel/2439211-nederland-europees-koploper-zonnepanelen-maar-hoe-kan-het-beter

Niamir, L., Ivanova, O., Filatova, T., Voinov, A., & Bressers, H. (2020). Demand-side solutions for climate mitigation: Bottom-up drivers of household energy behavior change in the Netherlands and Spain. *Energy Research & Social Science*, *62*, 101356. https://doi.org/10.1016/j.erss.2019.101356

Nielsen, K. S., Clayton, S., Stern, P. C., Dietz, T., Capstick, S., & Whitmarsh, L. (2021). How psychology can help limit climate change. *American Psychologist*, *76*(1), 130–144. https://doi.org/10.1037/amp0000624

Oberst, C. A., Schmitz, H., & Madlener, R. (2019). Are Prosumer Households That Much Different? Evidence From Stated Residential Energy Consumption in Germany. *Ecological Economics*, *158*, 101–115. https://doi.org/10.1016/j.ecolecon.2018.12.014

Öhrlund, I., Stikvoort, B., Schultzberg, M., & Bartusch, C. (2020). Rising with the sun? Encouraging solar electricity self-consumption among apartment owners in Sweden. *Energy Research & Social Science*, *64*, 101424. https://doi.org/10.1016/j.erss.2020.101424

Onwuegbuzie, A. J., & Leech, N. L. (2005). Taking the "Q" Out of Research: Teaching Research Methodology Courses Without the Divide Between Quantitative and Qualitative Paradigms. *Qual Quant*, *39*(3), 267–295. https://doi.org/10.1007/s11135-004-1670-0

Osborne, J. W., & Waters, E. (2002). *Multiple Regression Assumptions*. https://files.eric.ed.gov/fulltext/ED470205.pdf

Peters, A. M., van der Werff, E., & Steg, L. (2019). Mind the Gap: The Implications of Not Acting in Line With Your Planned Actions After Installing Solar Photovoltaics. *Front. Psychol.*, *10*. https://doi.org/10.3389/fpsyg.2019.01423

Reindl, K. (2022, May). *Book of Abstracts*. 20th STS Conference Graz 2022. https://openlib.tugraz.at/download.php?id=626792e340025&location=browse

Roldan-Fernandez, J. M., Burgos-Payan, M., & Riquelme-Santos, J. M. (2021). Assessing the 101ecarbonization effect of household photovoltaic self-consumption. *Journal of Cleaner Production*, *318*, 128501. https://doi.org/10.1016/j.jclepro.2021.128501

Sharma, V., Aziz, S. M., Haque, M. H., & Kauschke, T. (2020). Effects of high solar photovoltaic penetration on distribution feeders and the economic impact. *Renewable and Sustainable Energy Reviews*, *131*, 110021. https://doi.org/10.1016/j.rser.2020.110021

Shove, E, Pantzar, M., & Watson, M. (2012). *The Dynamics of Social Practice: Everyday Life and How It Changes*. SAGE Publications.

Shove, E. (2003). Converging Conventions of Comfort, Cleanliness and Convenience. *Journal of Consumer Policy*, *26*(4), 395–418. https://doi.org/10.1023/a:1026362829781

Shrivastava, P., Stafford Smith, M., O'Brien, K., & Zsolnai, L. (2020). Transforming Sustainability Science to Generate Positive Social and Environmental Change Globally. *One Earth*, *2*(4), 329–340. https://doi.org/10.1016/j.oneear.2020.04.010

Sniehotta, F. F., Presseau, J., & Araújo-Soares, V. (2014). Time to retire the theory of planned behaviour. *Health Psychology Review*, *8*(1), 1–7. https://doi.org/10.1080/17437199.2013.869710

Soratto, J., Pires, D. E. P. de, & Friese, S. (2020). Thematic content analysis using ATLAS.ti software: Potentialities for researchs in health. *Rev. Bras. Enferm.*, *73*(3). https://doi.org/10.1590/0034-7167-2019-0250

Staats, M. R., de Boer-Meulman, P. D. M., & van Sark, W. G. J. H. M. (2017). Experimental determination of demand side management potential of wet appliances in the Netherlands. *Sustainable Energy, Grids and Networks*, *9*, 80–94. https://doi.org/10.1016/j.segan.2016.12.004

Steg, L., Perlaviciute, G., & van der Werff, E. (2015). Understanding the human dimensions of a sustainable energy transition. *Front. Psychol.*, *6*. https://doi.org/10.3389/fpsyg.2015.00805

Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Res Sci Educ*, *48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Taddicken, M., Kohout, S., & Hoppe, I. (2019). How Aware Are Other Nations of Climate Change? Analyzing Germans' Second-Order Climate Change Beliefs About Chinese, US American and German People. *Environmental Communication*, *13*(8), 1024–1040. https://doi.org/10.1080/17524032.2018.1561483

Taherdoost, H., Sahibuddin, S., & Jalaliyoon, N. (2014). Exploratory Factor Analysis; Concepts and Theory. In *Advances in Applied and Pure Mathematics* (pp. 375–382). WSEAS. https://hal.archives-ouvertes.fr/hal-02557344/document

Tam, K., Leung, A. K. -y., & Clayton, S. (2021). Research on climate change in social psychology publications: A systematic review. *Asian J Soc Psychol*. https://doi.org/10.1111/ajsp.12477

Thomas, G. O., Poortinga, W., & Sautkina, E. (2016). Habit Discontinuity, Self-Activation, and the Diminishing Influence of Context Change: Evidence from the UK Understanding Society Survey. *PloS ONE*, *11*(4), e0153490. https://doi.org/10.1371/journal.pone.0153490

Van Aubel, P., & Poll, E. (2019). Smart metering in the Netherlands: What, how, and why. *International Journal of Electrical Power & Energy Systems*, *109*, 719–725. https://doi.org/10.1016/j.ijepes.2019.01.001

Van der Kam, M. J., Meelen, A. A. H., van Sark, W. G. J. H. M., & Alkemade, F. (2018). Diffusion of solar photovoltaic systems and electric vehicles among Dutch consumers: Implications for the energy transition. *Energy Research & Social Science*, *46*, 68–85. https://doi.org/10.1016/j.erss.2018.06.003

Verfuerth, C., Henn, L., & Becker, S. (2019). Is it up to them? Individual leverages for sufficiency. *GAIA – Ecological Perspectives for Science and Society*, *28*(4), 374–380. https://doi.org/10.14512/gaia.28.4.9

Watkins, M. W. (2018). Exploratory Factor Analysis: A Guide to Best Practice. *Journal of Black Psychology*, *44*(3), 219–246. https://doi.org/10.1177/0095798418771807

Whitmarsh, L., Poortinga, W., & Capstick, S. (2021). Behaviour change to address climate change. *Current Opinion in Psychology*, *42*, 76–81. https://doi.org/10.1016/j.copsyc.2021.04.002

Wittenberg, I., & Matthies, E. (2016). Solar policy and practice in Germany: How do residential households with solar panels use electricity? *Energy Research & Social Science*, *21*, 199–211. https://doi.org/10.1016/j.erss.2016.07.008

Wittenberg, I., & Matthies, E. (2018). How do PV households use their PV system and how is this related to their energy use? *Renewable Energy*, *122*, 291–300. https://doi.org/10.1016/j.renene.2018.01.091

Wolsink, M. (2020). Framing in Renewable Energy Policies: A Glossary. *Energies*, *13*(11), 2871. https://doi.org/10.3390/en13112871

Wood, W., Quinn, J. M., & Kashy, D. A. (2002). Habits in everyday life: Thought, emotion, and action. *Journal of Personality and Social Psychology*, *83*(6), 1281–1297. https://doi.org/10.1037/0022-3514.83.6.1281

Xu, W., Zhou, C., Cao, A., & Luo, M. (2016). Understanding the mechanism of food waste management by using stakeholder analysis and social network model: An industrial ecology perspective. *Ecological Modelling*, *337*, 63–72. https://doi.org/10.1016/j.ecolmodel.2016.06.006

Yong, A. G., & Pearce, S. (2013). A Beginner's Guide to Factor Analysis: Focusing on Exploratory Factor Analysis. *TQMP*, *9*(2), 79–94. https://doi.org/10.20982/tqmp.09.2.p079

APPENDICES

APPENDIX A: Informed consent forms

Figure A1. *Informed consent form provided to interview participants.*

Toestemmingsformulier – Online interview

Onderzoek naar: barrières die efficiënte zelf-consumptie van zonnestroom onder Nederlandse prosumers in de weg staan.

Informatie voor de deelnemer

Middels dit toestemmingsformulier wordt u uitgenodigd om deel te nemen aan een onderzoek naar barrières die efficiënte zelf-consumptie van zonnestroom onder Nederlandse prosumers in de weg staan. Dit onderzoek wordt verricht door Naomi Hubert, dr. Gerdien de Vries en dr. Katharina Biely van de TU Delft voor het schrijven van een masterscriptie en eventuele wetenschappelijke publicatie. Het doel van dit onderzoek is het verkrijgen van inzicht in de factoren die het moeilijk maken voor Nederlandse huishoudens om hun opgewekte zonne-energie zoveel mogelijk zelf te gebruiken, in plaats van de energie terug te storten op het elektriciteitsnet.

Om inzicht te krijgen in deze factoren wordt u als expert op het gebied van zonne-energie gevraagd om deel te nemen aan een online interview van maximaal 45 minuten. Er zal niet om persoonlijke informatie worden gevraagd, de vragen gaan uitsluitend over uw werkzaamheden als expert en uw kijk op barrières die ervaren worden door Nederlandse prosumers. Deze informatie kan gebruikt worden om prosumers beter te ondersteunen in het verhogen van hun zelf-consumptie.

Uw deelname aan dit onderzoek is geheel vrijwillig, en u kunt uw deelname op ieder moment afbreken. U bent tevens vrij om vragen onbeantwoord te laten. Voor zover bekend zijn er geen risico's verbonden aan deelname. Echter is het risico van een data inbreuk helaas altijd mogelijk. We zullen uw antwoorden daarom zo vertrouwelijk mogelijk behandelen. De audio van het interview zal worden opgenomen, **enkel** voor het achteraf transcriberen van de informatie in de vorm van tekst. Deze audio opname is alleen toegankelijk voor de master student (Naomi Hubert) die het interview afneemt en wordt verder niet gedeeld. Na afronding van de masterscriptie zal de opname definitief worden verwijderd. Bovendien wordt alle informatie die u verstrekt geanonimiseerd, dat wil zeggen dat uw naam niet vermeld wordt bij o.a. citaten of in transcripten. Tevens mag u direct na het interview of bij het herzien van het transcript (die u toegestuurd krijgt) informatie rectificeren of verwijderen.

De afgeronde masterscriptie en de **geanonimiseerde** transcripten zullen worden opgeslagen in het openbare archief van de TU Delft, zoals verplicht voor inzage en mogelijk verder onderzoek, maar zal **geen** persoonlijke data bevatten waarmee u geïdentificeerd kunt worden. Dergelijke persoonlijke data, zoals uw naam en emailadres, zal namelijk niet gedeeld worden buiten het onderzoeksteam en zal dus niet vermeld worden in de masterscriptie, wetenschappelijke publicatie of de transcripten. Deze informatie wordt uitsluitend gebruikt voor de correspondentie tussen u en de onderzoekers.

Vult u a.u.b. de rest van dit formulier in als u akkoord gaat met uw deelname onder de bovenstaande voorwaarden. Voor verdere informatie, vragen of opmerkingen kan een email gestuurd worden naar Naomi Hubert (n.d.hubert@student.tudelft.nl) of Gerdien de Vries (g.devries-2@tudelft.nl).

Bij ondertekening gaan wij ervan uit dat u instemt met onderstaande punten (vereist voor deelname). Waar nodig, kruis a.u.b. de juiste vakjes aan (deelname is alsnog mogelijk ongeacht uw keuze).

Deelname aan het onderzoek

Ik heb de beschrijving van het onderzoek (zie eerste pagina, gedateerd 26/1/2022) gelezen en begrepen. Ik heb de mogelijkheid gehad om vragen te stellen en mijn eventuele vragen zijn naar mijn tevredenheid beantwoord.

Ik stem vrijwillig in met mijn deelname aan dit onderzoek, en begrijp dat ik mag weigeren om vragen te beantwoorden en mij op ieder moment mag terugtrekken zonder daarvoor een reden te hoeven geven.

Ik begrijp dat deelname aan dit onderzoek een met audio opgenomen interview betreft, zodat de opname als geanonimiseerde tekst getranscribeerd kan worden. Ik begrijp dat de audio opname na het afronden van het eindresultaat (de scriptie) verwijderd zal worden.

Gebruik van informatie binnen het onderzoek

Ik begrijp dat de informatie die ik verstrek gebruikt zal worden voor het schrijven van een masterscriptie en eventuele publicatie in een wetenschappelijk tijdschrift.

Ik begrijp dat persoonlijke informatie die mij kan identificeren, dat wil zeggen mijn naam en emailadres, niet gedeeld zal worden buiten het onderzoeksteam. Ik begrijp dat deze informatie alleen gebruikt zal worden voor de nodige correspondentie met de onderzoekers.

	Ja	**Nee**
Ik ga ermee akkoord dat de informatie die ik verstrek *anoniem* geciteerd kan worden in de onderzoeksresultaten.	☐	☐

Toekomstig gebruik en hergebruik van informatie

Ik begrijp dat de afgeronde masterscriptie wordt gearchiveerd in het archief van de TU Delft, voor inzage en mogelijk nader onderzoek, waarin enkel de *geanonimiseerde* bevindingen vermeld zullen worden.

	Ja	**Nee**
Ik geef toestemming voor het archiveren van het *geanonimiseerde* transcript in het archief van de TU Delft, voor inzage en mogelijk nader onderzoek.	☐	☐

Handtekeningen

____________________ ____________________ ________

Naam deelnemer *Handtekening* *Datum*

Ik heb de informatie vermeld in dit toestemmingsformulier verstrekt aan de deelnemer en de deelnemer de mogelijkheid gegeven om vragen te stellen en heb, naar mijn beste vermogen, ervoor gezorgd dat de deelnemer begrijpt waar hij/zij/ze vrijwillig mee instemt.

____________________ ____________________ ________

Naam onderzoeker *Handtekening* *Datum*

Figure A2. *Informed consent form provided to survey participants.*

Informed Consent – Online survey

Deze vragenlijst nodigt u uit om deel te nemen aan een onderzoek naar barrières die zelf-consumptie van zonnestroom onder Nederlandse prosumers in de weg staan. Dit onderzoek wordt verricht door Naomi Hubert, dr. Gerdien de Vries en dr. Katharina Biely van de TU Delft.

Het doel van dit onderzoek is het verkrijgen van inzicht in de factoren die het moeilijk maken voor Nederlandse huishoudens om hun opgewekte zonnestroom zoveel mogelijk zelf te gebruiken (zelf-consumptie), in plaats van de stroom terug te storten op het elektriciteitsnet.

Deze vragenlijst zal ongeveer 10 minuten van uw tijd kosten. De data zal gebruikt worden voor het schrijven van een masterscriptie en eventuele wetenschappelijke publicatie. Uw deelname aan dit onderzoek is geheel vrijwillig, en u kunt de vragenlijst op ieder moment afbreken. U bent vrij om vragen onbeantwoord te laten.

Voor zover bekend zijn er geen risico's verbonden aan deelname aan dit onderzoek. Echter is het risico van een data inbreuk, zoals bij iedere online activiteit, altijd mogelijk. Uw antwoorden zijn daarom anoniem, om zo vertrouwelijk mogelijk te handelen. De uiteindelijke masterscriptie zal worden opgeslagen in het openbare archief van de TU Delft, verplicht voor inzage en mogelijk verder onderzoek, maar zal **geen** persoonlijke data bevatten.

Door te klikken op 'volgende' gaan wij ervan uit dat u voldoende bent geïnformeerd en akkoord gaat met het bovenstaande. Bij vragen of opmerkingen kunt u contact opnemen via n.d.hubert@student.tudelft.nl of g.devries-2@tudelft.nl.

APPENDIX B: Complete interview questions

Figure B1. *Interview questions as received by participants in Dutch.*

Begin interview – 5 minuten

- Welkom heten
- Smalltalk
- Herhaling informed consent
- Doel herhalen → duidelijk afbakenen
- "Agenda" bespreken voor het interview (tijd, inhoud, op welke volgorde)
- Mezelf introduceren
- Introductie deelnemer

1. Aan wat voor organisatie (X) bent u verbonden, en wat houdt uw functie in?

Kernvragen – 30 minuten

2. Op wat voor manier houdt u / X zich bezig met zelf-consumptie van zonnestroom?
3. Hoe belangrijk is zelf-consumptie van zonnestroom, naar uw mening?
4. In hoeverre komt het onderwerp zelf-consumptie naar voren in uw onderzoek / contact met prosumenten, en in uw advies voor prosumenten?
5. Hoeveel belang hechten prosumenten aan het gebruik van hun eigen zonnestroom, voor zover u weet?
   a. Merkt u een verschil in het type prosument wat wel of geen belang hecht aan zelf-consumptie?
6. In uw contact met prosumenten / in uw onderzoek, worden er wel eens factoren besproken die zelf-consumptie kunnen belemmeren? Zo ja, wat voor factoren komen er dan naar voren?
7. Hoe denkt u dat beleid, bijvoorbeeld de voorgestelde aanpassing aan de salderingsregeling, deze (eerdergenoemde) belemmeringen beïnvloed?
8. Wat voor factoren die zelf-consumptie belemmeren of juist bevorderen worden, naar uw mening, over het hoofd gezien door beleidsmakers?
9. Hoe probeert u als adviseur / onderzoeker in te spelen op deze (eerder genoemde) belemmeringen?

Afsluiten interview – 5 minuten

- Samenvatten: de belangrijkste takeaways

10. Wilt u nog iets met mij delen wat ik niet mag missen, of wat ik ben vergeten te vragen?
11. Kent u eventueel nog andere waardevolle personen of organisaties die relevant zijn om te spreken?
12. Zijn er nog relevante documenten of rapporten die u kunt aanbevelen?

- Bedanken

Figure B2. *Interview questions translated to English by the author of this thesis.*

Start interview – 5 minutes

- Welcome
- Smalltalk
- Repeat informed consent
- Repeat goal
- Discuss "Agenda" (time, content, order)
- Introduce myself
- Introduce participant:

1. For which organization (X) do you work, and what does your job entail?

Core questions – 30 minutes

2. In which way do you / X concern yourself with self-consumption of solar energy?
3. How important is self-consumption, in your opinion?
4. How important is self-consumption to prosumers, as far as you know?
   a. Do you notice a difference in the type of prosumer who does or does not value self-consumption?
5. To what extent does the topic of self-consumption come up in your research / contact with prosumers and in your advice to prosumers?
6. In your research / contact with prosumers, what kind of factors come up which hinder self-consumption?
7. How do you think policy, such as the proposed changes to the net-metering scheme, influence these (aforementioned) hindrances?
8. What kind of factors which can hinder or promote self-consumption are, in your opinion, overlooked by policymakers?
9. How do you as an advisor / researcher try to influence these (aforementioned) hindrances?

Close interview – 5 minutes

- Summarize key takeaways

10. Is there anything you still want to share with me, which I forgot to ask about?
11. Do you know other people or organizations who could be relevant for me to speak to?
12. Are there any relevant documents or reports you can recommend to me?

- Thank you

APPENDIX C: Codebook

CODE GROUP: CONTROL VARIABLES			
Code	**Code definition**	**Example of words signalling code**	**Reasoning**
Age	Relevance of the prosumer age (group)	Young people, pensioners	
Gender	Relevance of the gender role division in prosumer households	Male of female who is mainly in charge of doing the laundry	
Storage: Home battery	A battery for storing solar energy for a single prosumer household	Battery (to be) purchased by a prosumer household on their own initiative	
Storage: local	Storing solar energy for multiple prosumer households	Multiple prosumer households making use of a shared battery in the neighborhood	
CODE GROUP: DEPENDENT VARIABLE (LOADSHIFTING)			
Code	**Code definition**	**Example of words signalling code**	
Manual: doing laundry when producing	Choosing to manually switch on the laundry machine at a time when self-produced solar energy is available	Switching on the laundry machine on a sunny day, postponing doing the laundry when knowing sunny weather is coming soon	Deductive
Automated: program/timer on washing machine	Allowing the laundry machine to automatically switch on at a time when self-produced energy is available	Using a laundry machine with an automatic timer or program installed to adapt a washing cycle to the availability of self-produced energy	Deductive
CODE GROUP: MEANING ELEMENT			
Code	**Code definition**	**Example of words signalling code**	
Motivation: environmental	Prosumers who have installed solar panels to do good for the environment	Prosumers who care about sustainability, prosumers who want to lower their CO_2 emissions	Deductive
Motivation: financial	Prosumers who have installed solar panels for financial benefits	Prosumers who aim to cut down on the cost of their energy bills, prosumers who (purposely) produce more energy than they need in order to receive compensation for off-loading to grid	Deductive
Motivation: self-reliance	Prosumers who have installed solar panels to be able to rely less on the grid	Prosumers who value independence from the grid, prosumers who do distrust the (stability of) the grid or energy prices or the government	Deductive
User beliefs	Active prosumers feel or act as an active member of the energy system. Passive prosumers do not feel or act as an	Active: Prosumers who ask questions about self-consumption. Passive: Prosumers who do not ask questions about self-consumption, prosumers who do not seem to see the difference	Deductive

	active member of the energy system	between energy from the grid and their self-produced energy.	
Sufficiency attitude	Prosumers who indicate the desire to rely on their own resources or to do with less	Living frugally, being mindful of (unnecessary) resource or energy use, being mindful of waste	Deductive
CODE GROUP: COMPETENCES ELEMENT			
Code	**Code definition**	**Example of words signalling code**	
External/explicit: Practical knowledge provided	Knowledge provided to prosumers about (the importance of) self-consumption or loadshifting	Advisors providing one-on-one information to prosumer households, information provided to prosumer households via neighborhood or municipal gatherings	Deductive
External/explicit: Institutional policies and regulations	Policies such as the current Dutch net-metering scheme, in which grid-exported and grid-imported energy are given the same financial value.	Advisors receiving questions about the upcoming changes to the net-metering scheme, interviewees being in favor/against changes to the scheme, interviewees referring to different schemes in other countries	Deductive
External/explicit: Clear policy	Policy that provides clarity, direction, and urgency	Interviewees referring to policymakers being hesitant, interviewees indicating a hurry to change current policies	Inductive (addition to the model)
Internal/implicit: Know-how	Prosumers who understand the difference between grid-produced and self-produced energy	Good understanding of the (ideal) functioning of solar panels, good understanding of automation or smart possibilities, good understanding of net congestion issues	Deductive
Internal/implicit: Monitoring skills	Prosumers able to use a tool that helps them track energy production/consumption	Prosumers who use an app, prosumers who check the weather predictions, prosumers interested in monitoring their production/consumption patterns.	Deductive
Internal/implicit: habits	Doing the laundry as a routinized behavior, or depending on routinized behaviors of others in the household.	Routine, difficulty adapting, not thinking about doing the laundry, children or other household members seemingly subconsciously discarding laundry in the basket	Deductive
Internal/implicit: Hassle	Hassle experienced by prosumers in their efforts to self-consume or to gain insight in their production/consumption patterns	Prosumers being annoyed by changing laundry patterns, thinking loadshifting will take a lot of time/work/effort, prosumers not wanting to think about their actions consciously	Deductive
CODE GROUP: MATERIALS ELEMENT			
Code	**Code definition**	**Example of words signalling code**	
Feedback provision by the system	Interpretability of bills, meters, or displays of the PV system.	Understandable meters, accessible displays	Deductive

Placement of panels	Panel placement in relation to sun direction	Solar panels placed on the southern facing roof to maximize total sun hours, panels placed on south-west or south-east facing roof to maximize morning or afternoon peak in solar energy	Inductive (addition to the model)
Safety of appliances	Whether appliances such as the laundry machine can be left on safely without supervision	Prosumers feeling uneasy about their laundy machine running whilst they're away from home, prosumers worried about fire or short circuiting.	Inductive (addition to the model)
State of machinery or tech	Whether machines such as the laundry machines are up to date enough to run automatically during PV production	Machines that are outdated, no ability to run programs automatically	Inductive (addition to the model)

APPENDIX D: Complete survey questions

Figure D1. *Survey questions in Dutch (for correct order see Table 6).*

<u>Block: Demographics / controlling variables</u>

1. Selecteer a.u.b. uw leeftijdsgroep.
2. Selecteer a.u.b. uw geslacht.
3. Vul a.u.b. in hoeveel zonnepanelen er op uw huis zijn geïnstalleerd.
4. Vul a.u.b. in in welk jaartal de eerste zonnepanelen op uw huis zijn geïnstalleerd.
5. Vul a.u.b. in uit hoeveel mensen uw huishouden bestaat.
6. Maakt u gebruik van energieopslag om de door u geproduceerde energie op te slaan?
    a. Zo ja: Waarom maakt u gebruik van energieopslag? Selecteer de optie die voor u het meest van toepassing is.
        i. Om (nog) meer te besparen op mijn energierekening.
        ii. Om de energie zelf te kunnen gebruiken in plaats van terug te leveren aan het net.
        iii. Om efficiënter om te gaan met mijn energie.
        iv. Anders ________

<u>Block: Dependent variable (antwoordopties: nooit, zelden, soms, vaak, of altijd).</u>

Instructie: Hieronder volgen een aantal stellingen over het gebruik van de wasmachine. Geef aan hoe vaak u (of iemand anders in uw huishouden) de handeling verricht die in de stelling beschreven staat.

7. Bij het kiezen van een moment om de was te doen overweeg ik eerst de (verwachte) energie opwek van mijn zonnepanelen.
8. Ik maak gebruik van een automatisch programma of timer op mijn wasmachine zodat deze draait wanneer mijn zonnepanelen energie opwekken.
9. Door het gebruik van de wasmachine aan te passen aan de opwek van mijn zonnepanelen probeer ik zoveel mogelijk gebruik te maken van zelfgeproduceerde energie.

<u>Block: Ranking motivation for installation (vraag #10)</u>

Instructie: Hieronder staan een aantal redenen voor het installeren van zonnepanelen. Sorteer hoe belangrijk deze redenen *voor u* waren om zonnepanelen te laten installeren, van meest tot minst belangrijk. <u>Instructie in kleinere tekst onder de vraag:</u> Om te sorteren sleept u de opties in de gewenste volgorde. Daarbij is reden nummer één het belangrijkste, en nummer vier is het minst belangrijk.

- Ik heb zonnepanelen laten installeren om mijn eigen elektriciteit op te wekken, zodat ik minder op het elektriciteitsnet hoef te rekenen.
- Ik heb zonnepanelen laten installeren omdat ik mijn CO2 uitstoot wil verlagen en duurzamer wil leven.
- Ik heb zonnepanelen laten installeren omdat dit een goede investering was, wat mij geld kan besparen op de energierekening.
- Ik heb zonnepanelen laten installeren omdat ik geïnteresseerd ben in technische innovaties.

<u>Block: Instructie voor construct statements</u>

De rest van deze vragenlijst bestaat uit een aantal stellingen over het gebruik van zelfgeproduceerde zonnestroom. Dit kan bijvoorbeeld door de was te doen op het moment dat de zonnepanelen stroom opwekken. Geef aan in hoeverre u het eens bent met onderstaande stellingen. U kunt de vragenlijst op ieder moment sluiten en opnieuw openen.

<u>Block: Construct statements (antwoordopties: sterk mee oneens, oneens, neutraal, eens, of sterk mee eens)</u>

11. Mijn zonnepanelen hebben weinig van mijn inzet nodig.
12. Mijn zonnepanelen hebben mijn inzet nodig om de productie en consumptie van energie goed te monitoren en te beheren.
13. Middels mijn levensstijl wil ik zo min mogelijk grondstoffen gebruiken (zoals water, energie).
14. Ik vind het wenselijk om zoveel mogelijk gebruik te maken van mijn *eigen* grondstoffen.
15. Ik vind het wenselijk om voor het wassen eerst zoveel mogelijk vuile was te verzamelen om geen grondstoffen te verspillen (zoals water, energie).
16. Ik heb informatie ontvangen over manieren waarop ik mijn zelfgeproduceerde energie kan gebruiken.
17. Ik heb informatie ontvangen over de voordelen van het gebruik van mijn zelfgeproduceerde energie.
18. Om het elektriciteitsnet niet te overbelasten is het beter om energie te gebruiken op het moment dat mijn zonnepanelen die produceren.
19. Het maakt niet uit of ik mijn zelfgeproduceerde stroom gebruik of stroom van het elektriciteitsnet; stroom is stroom.
20. Ik houd data over mijn energie opwek en verbruik geregeld bij, of gebruik hier een online portaal zoals een app voor.
21. Ik check geregeld de weersvoorspelling om in te schatten of en wanneer mijn zonnepanelen energie opwekken.
22. Het display van mijn zonnepanelen voorziet mij van een duidelijk overzicht van mijn energie opwek en verbruik.
23. Het display van mijn zonnepanelen is ergens geplaatst waar ik hem makkelijk kan aflezen, of is op een andere manier goed toegankelijk.
24. Ik denk niet veel na over de timing van de was doen; ik was gewoon wanneer ik schone kleding wil.
25. Het moment waarop de was wordt gedaan is afhankelijk van de routine van mijn huishouden, waarvan niet veel afgeweken wordt.
26. Het is te ingewikkeld om het doen van de was zo te plannen dat die overeenkomt met de beschikbaarheid van zelfgeproduceerde energie.
27. Controleren of mijn zonnepanelen genoeg energie opwekken om de was te doen is teveel werk.
28. Toen ik mijn zonnepanelen installeerde had ik de *intentie* om mijn energieverbruik aan te passen zodat ik grotendeels mijn zelfgeproduceerde energie kon gaan gebruiken.
29. TOEGEVOEGD VOOR EEN ANDER ONDERZOEK: Heeft u tot slot, naast het produceren van uw eigen energie, nog andere duurzame consumentenkeuzes gemaakt? Hieronder volgt

een lijst met dergelijke consumentenkeuzes. Selecteer *alle* keuzes waar u in ieder geval regelmatig voor kiest. Als u niet de exacte keuze kunt vinden die voor u van toepassing is, maar wel één die in de buurt komt, selecteert u die optie. Vul alleen een andere keuze in als het echt nodig is.

a. Ik heb geen van deze keuzes gemaakt.
b. Recyclen (het scheiden van uw afvalstromen, b.v. plastic, papier, metaal)
c. Afvalvermindering (u kiest b.v. voor producten die niet verpakt zijn)
d. Vermindering van *plastic* afval (u kiest b.v. voor producten die niet in plastic verpakt zijn)
e. Kiezen voor een plantaardig dieet (u volgt b.v. een vegetarisch of veganistisch dieet)
f. Kiezen voor seizoensgebonden eten (u kiest voor voeding die op dat moment van nature groeit)
g. Kiezen voor regionaal eten (u kiest voor voeding dat in uw nabije omgeving wordt verbouwd)
h. Kiezen voor duurzaam geproduceerd eten (b.v. biologisch, fairtrade)
i. Met de (e-)fiets gaan (b.v. voor woon-werkverkeer)
j. Met het openbaar vervoer gaan (b.v. voor woon-werkverkeer)
k. Delen van een auto (b.v. voor woon-werkverkeer)
l. Reizen met de bus of trein (u neemt b.v. indien mogelijk de trein naar uw vakantiebestemming)
m. Kopen bij kleine lokale bedrijven (b.v. de kleine, lokale boekhandel)
n. Tweedehands kopen (b.v. kiezen voor tweedehands kleding)
o. Refurbished technologie kopen (b.v. kiezen voor een refurbished mobiele telefoon)
p. Re- of upcycled producten kopen (b.v. kiezen voor sieraden gemaakt van papier)
q. Ethische producten kopen (b.v. kleding met het label Fairtrade)
r. Minder kopen (u houdt uw spullen b.v. zo lang mogelijk en koopt alleen als het echt nodig is)
s. Kiezen voor duurzame was- en schoonmaakmiddelen (b.v. kiezen azijn en zuiveringszout)
t. Kiezen voor duurzame hygiëne- en schoonheidsproducten (b.v. kiezen voor een houten tandenborstel)
u. Anders ________________

Figure D2. *Survey questions translated to English (for correct order, see Table 6).*

Block: Demographics / controlling variables

1. Please select your age group.
2. Please select your gender.
3. Please fill in the number of solar panels installed at your household.
4. Please fill in what year the first solar panels were installed at your household.
5. Please fill in the number of people in your household.
6. Are you a: Homeowner, renter, other.
7. Do you make use of a storage device to store the energy produced by your PV system?
    a. If yes: Why do you make use of this storage device? Select the option that is most applicable for you.
        i. To further increase the savings on my energy bill
        ii. To use the energy myself when I need it, instead of feeding it back into the grid
        iii. To use my energy more efficiently
        iv. Other ___________

Block: Dependent variable (answer options: never, rarely, sometimes, often, or always)

Instruction: A number of statements about using the laundry machine are listed below. Indicate how often you (or someone else in your household) engage in the act described in the statement.

8. When choosing a moment to do my laundry, I consider the electricity production of my PV system first.
9. I make use of an automated program/timer on my laundry machine so that it runs at a time when my PV system is producing energy.
10. By adjusting the use of the laundry machine to the energy production of my solar panels I try to utilize my own self-produced energy as much as possible.

Block: Motivation for installation (question #10)

Instruction: Listed below are a number of possible reasons for installing solar panels. Sort how important these reasons were *for you* to install solar panels, from most to least important. (Instruction in smaller font below question): To sort, drag and drop the options in the preferred order. Number one is the most important, number four is the least important.

- I installed my PV system because I wanted to produce my own electricity, instead of having to rely on the grid.
- I installed my PV system because I wanted to reduce my carbon emissions and live more sustainably.
- I installed my PV system because it was a good investment, with the added benefit of helping me save money on my electricity bill.
- I installed my PV system because I am interested in technical innovations.

Block: Instruction for construct statements

The remainder of this questionnaire consists of a number of statements about the use of self-produced solar energy. This can be done by, for instance, doing the laundry when your solar panels are producing energy. Indicate to what extent you agree with the statements listed below. You can close and reopen the questionnaire at any time.

Block: Construct statements (answer options: strongly disagree, disagree, neutral, agree, strongly agree)

11. My PV system requires little engagement from me.

12. My PV system requires me to engage with it by routinely monitoring and managing my energy generation and consumption patterns.

13. Through my lifestyle, I want to use as little resources as possible (water, energy).

14. I find it appealing to use my own resources as much as possible.

15. I find it desirable to collect as much dirty laundry as possible to not waste resources (water, energy).

16. I have been provided with information on ways to use my own self-produced electricity.

17. I have been provided with information on the benefits of consuming my self-produced electricity.

18. To not overload the electricity grid it is best to use energy when it is produced by my solar PV system.

19. It does not matter whether I use my own self-produced electricity or electricity imported from the grid; electricity is electricity.

20. I often track my electricity data, or use an online portal such as an app to do so.

21. I often check the (current or forecast) weather to estimate if and when my PV system is producing electricity.

22. The display of my PV system provides me with a good understanding of my electricity production and consumption.

23. The display of my PV system is placed somewhere where I can easily read it, or is easily accessible in another way.

24. I don't give much thought to the specific timing of my laundry; I simply wash when I need the clothes to be clean.

25. When I do the laundry is dependent on my household's routine, from which I rarely deviate.

26. It is too complicated to plan my household's laundry routine so that it matches the availability of self-produced solar energy.

27. Checking whether my PV system is producing enough energy to do the laundry is too much work.

28. When I got my PV system installed, I intended to adapt my energy consumption to mostly use the energy my PV system is producing.

29. ADDED BUT FOR ANOTHER STUDY: Lastly, apart from producing your own energy, have you adopted any other sustainable consumer choices? Below you can find a list of sustainable consumer choices. Select all those choices that you at least have started to choose on a regular basis. If you do not find the exact sustainable consumer option you have adopted but one that is close to it, select that one. Only provide a different option if really needed.

▢ I have not adopted any of these lifestyles

- ▢ Recycling (separating your waste streams, e.g. plastic, paper, metal)
- ▢ Waste reduction (e.g. you choose products that are not packaged)
- ▢ Plastic waste reduction (e.g. you choose products that are not packaged in plastic)
- ▢ Plant based diet (e.g. you have a vegetarian diet)
- ▢ Choosing seasonal food (you choose food that naturally grows at the time you are buying it)
- ▢ Choosing regional food (you choose food that is grown in close proximity to where you are)
- ▢ Choosing sustainably produced food (e.g. organic, fair trade)
- ▢ Going by (e-)bike (e.g. when you commute to work)
- ▢ Going by public transport (e.g. when you commute to work)
- ▢ Car-sharing (e.g. when you commute to work)
- ▢ Traveling by bus or train (e.g. if possible you take the train to get to your holiday destination)
- ▢ Buying from small local businesses (e.g. buying from the small local book store)
- ▢ Buying second-hand (e.g. choosing second hand clothing)
- ▢ Buying refurbished technology (e.g. choosing a refurbished mobile phone)
- ▢ Buying re- or upcycled products (e.g. choosing jewelry made out of paper)
- ▢ Buying ethical products (e.g. fair trade labeled clothing)
- ▢ Buying less (e.g. you keep your belongings as long as possible and only buy when needed)
- ▢ Choosing sustainable detergents and cleaning products (e.g. choosing vinegar & baking soda)
- ▢ Choosing sustainable hygiene and beauty products (e.g. choosing a wooden tooth brush)
- ▢ Other ____

APPENDIX E: Testing the assumptions of a regression analysis

Table E1. *Tolerance and VIF values to assess the assumption of multicollinearity.*

Predictor	Tolerance	VIF
User beliefs	0.916	1.092
Suffiency attitude	0.696	1.436
Practical knowledge provided	0.739	1.354
Know-how	0.574	1.743
Monitoring skill	0.661	1.513
Feedback provision by system design	0.727	1.375
Habits	0.621	1.611
Hassle	0.592	1.690

Figure E1. *Normal P-P plot of the standardized residuals of the dependent variable (loadshifting) to assess the assumption of normality.*

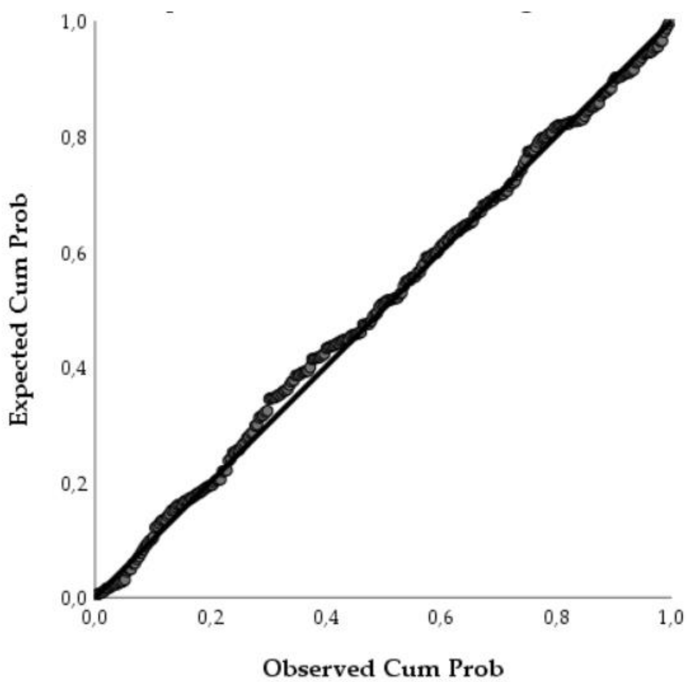


Figure E2. *Scatterplot of the dependent variable (loadshifting) to assess the assumption of homoscedasticity.*