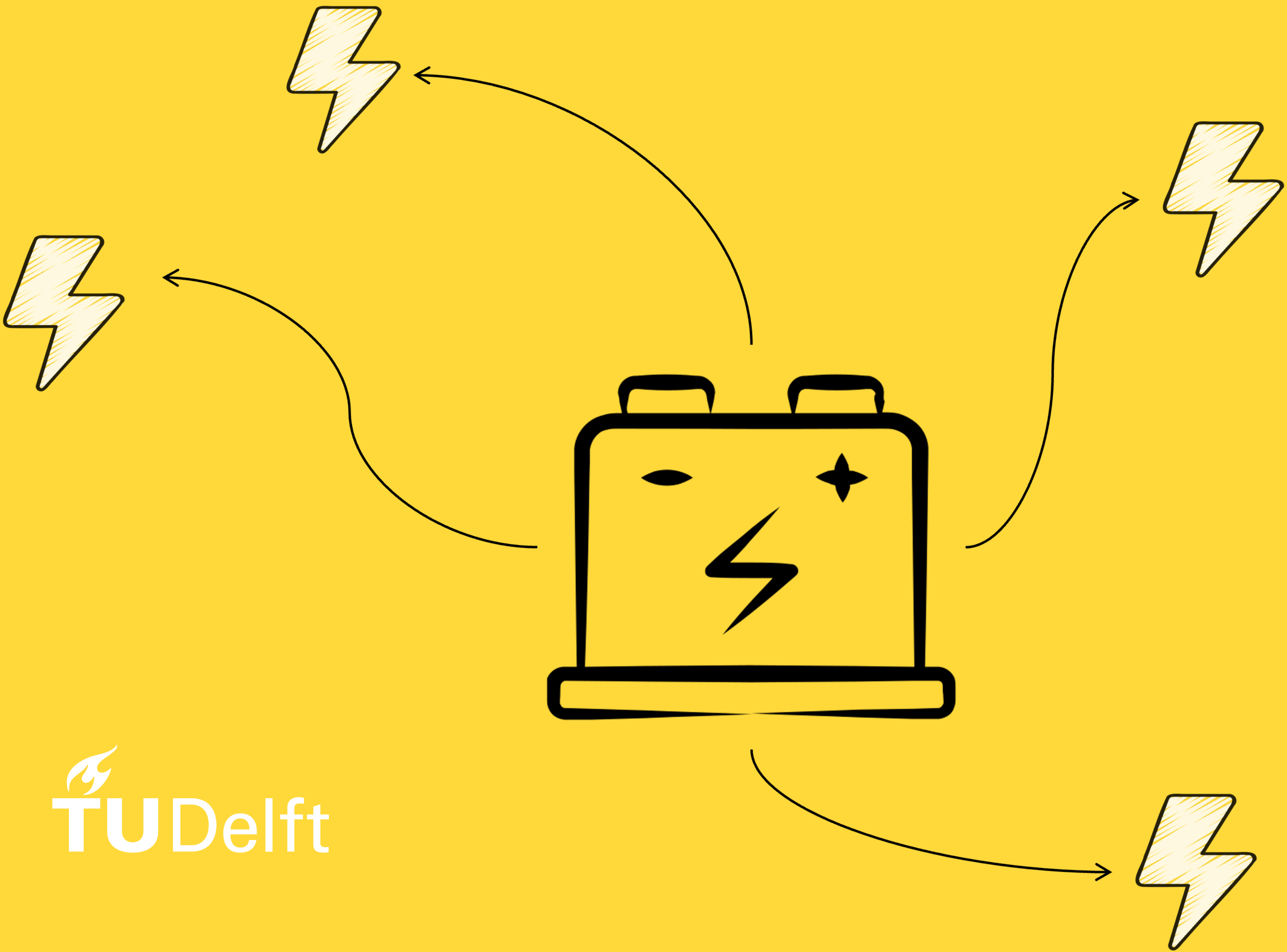
STORE YOUR POWER!

Exploring various neighborhood batteries and the influence of values on technology support

MSc Complex Systems Engineering | TU Delft
Jori Damond



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Exploring various neighborhood batteries and the influence of values on technology support

Master thesis submitted to Delft University of Technology

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MASTER OF SCIENCE

in **Complex Systems Engineering and Management**

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by

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ACKNOWLEDGEMENTS

These are the last words I'll probably write as a student, and the first words from my thesis you are reading. This thesis concludes my time as a student and means the end of a very enjoyable time in Delft. Working on my project for the last few months has been an inspiring and fun process, but I did not achieve this alone. During the last few months, I was helped, advised, and improved by multiple people around me who should certainly be thanked. First of all, I want to thank Andrik and Alexander for their weekly consults. Without your advice and suggestions, I would not have come this far. Also, you ensured I had a great and meaningful time at Accenture. Next, I would like to thank Amineh and Ibo. Thank you both for your much-needed critical notes during the last few months. You were always positive but pushed me to critically review my work all the time.

Lastly, there was always one person beside me who was the most critical, and at the same time the most supportive. Without her support over the last few years, I would not be where I am today. Merci Joëlle.

Jori Damond
Delft, August 2022

SUMMARY

As our electricity system becomes more complex, decentralized, and unstable, research on solutions to relieve the grid are needed. Congestion problems are growing in The Netherlands on the high voltage grid and is also expected to increase in the coming years on the low voltage grid. So, more solutions to react to the volatility of the supply are therefore needed. While demand is changing due to the more electrical assets such as electric vehicles and heat pumps, local energy storage could contribute significantly to balance supply and demand. This study focused on one solution in particular: the neighborhood battery.

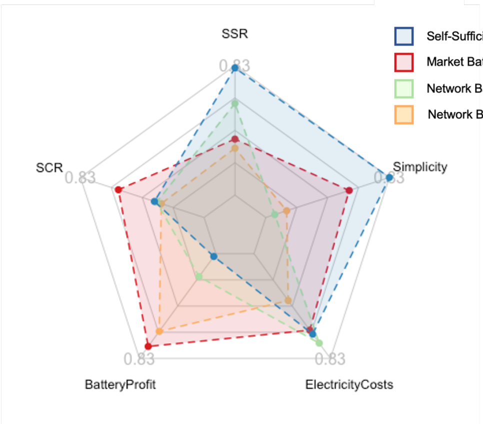
Neighborhood batteries are emerging as a technical and social innovation for smart neighborhoods, which enable to share and store energy collectively. However, sharing and storing energy within a local community challenges our current electricity system. Since each neighborhood has its own characteristics, different technical needs, and economic conditions, the fitability of the battery will also differ. A way to better fit the energy project with the stakeholder is by considering their values. If stakeholder values are taken into account during a project, the technology can have more support from the citizens. Therefore, technology support can be considered as an important aspect of the success of new projects to succeed. In this thesis, it is considered neighborhood batteries have embedded values, such as the values sustainability or fairness, and can satisfy the demands of different actors. The theory of Responsible innovation tries to align technological innovations with the technical, socio-economic and institutional aspects of the innovation. However, neighborhood batteries are an unknown socio-technical technology with the potential to benefit local communities. There exists limited research on the integration of neighborhood batteries in the current energy system. In addition, the different energy consumption profiles, social preferences, and battery functionalities make the implementation of neighborhood batteries highly complex. Citizens already play a stronger role in the energy system due to the ownership of PV systems and their views and values can become more embedded in new energy innovations. For that reason, community characteristics and values are to be considered when designing decentralized energy innovations.

This thesis focuses on the practical implementation of neighborhood batteries and the unknown dynamics of citizens' values and their interactions. The objective of this study is to better understand the alignment of technical functionalities of the batteries and citizens' values. Accordingly, neighborhood batteries are not only assessed on a technological and economical performance indicator, but ethical aspects provide a wider understanding of the development of neighborhood batteries. The outcome of this study is a simulation model which provides insight into the influence of values and community characteristics on the technology support of neighborhood Batteries from the households.

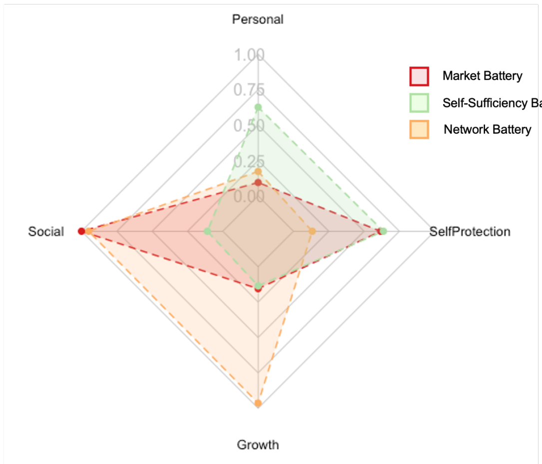
In this thesis, an explorative modeling approach is used in order to understand how storage configurations perform technological and economical and influence technology support. This approach combines social science research on energy technologies and energy technology modeling concepts. In addition, this research uses Schwartz values to model values. For modeling purposes, Schwartz's values are very pragmatic as he provides functional reasoning behind human values. Agent-Based Modeling is used to model the batteries in the neighborhood and study the influence of values and interactions on the technology support. The objective of the agent based model is to show the influence of different battery configurations on technology support of the battery by the neighborhood and on the technological and economical performance of the battery. The outputs can be compared to see if value orientations match the outputs from the economical and technical performance of the battery. During the experiments, households interact and influence each other's value orientations. Moreover, pre-defined characteristics of the households (e.g. PV production, values, being part of a community, and social network) influence the output variety.

The performance of the three batteries are summarised in a comparison where the evaluative param-

eters are used to score the batteries. The Self sufficiency rate, Self Consumption rate, Total Electricity costs and Battery profit are used as metrics. Additionally, the metric *Simplicity* is included to the comparison. This metric scores the explainability to households, but also the technical and institutional implementation of the battery. Also, the technology support of the three batteries is shown for the four value scenarios. All metrics are standardized such that a comparison can be made, see figure 6.12.



(a) Comparison of the different neighborhood batteries against the five techno-economical metrics



(b) Comparison of the technology support of neighborhood batteries in four different value orientation scenarios

Figure 1: Summary of the results by comparing the metrics and value orientations scenarios

The results from this thesis show the multi-functional usability of neighborhood batteries. The batteries can be used for trading on the balancing market or intraday market and can be used to increase the self-sufficiency of the neighborhood. However, the results from this study suggest neighborhoods batteries need to have trade-offs between profit and Self-Sufficiency in the neighborhood. The amount of PV ownership has a large influence on the performance of the batteries and should therefore always be considered. Moreover, different sizes of communities suggest a large influence on the technology support depending of the value scenario. More dissimilar neighborhoods decrease the support of the model in almost all scenarios in the model used. Only in cases where the scenarios where the technology support is already low, the results show no difference.

In conclusion, more research needs to be done on this subject. Future use cases can be the congestion market, which is also growing and could be an interesting operating market for the battery. Currently, congestion is limiting grid connections and renewable energy growth, and operating the battery to prevent congestion can possibly satisfy multiple actors. However, single-use business cases will be difficult to implement. The neighborhood battery is a better contender for multi-use functionality than home batteries and is therefore more future-proof. Heterogeneous customers could join the neighborhood battery project and their use case could be considered with a larger battery. Even more so, further research should focus on the possibilities and implementations when stacking multiple functions in a battery and implementing case-specifics neighborhood batteries. Also, empirical research on the values of households towards energy storage can expand current research.

In short, a neighborhood battery should be optimized for the needs of the neighborhood. The diverse functionalities of the neighborhood battery show advantageous technical capabilities. For that reason, more projects should be encouraged where batteries are implemented in diverse neighborhoods to demonstrate how equal distribution of profits and costs can be achieved. The current rules and regulations enable battery projects, but still battery models that achieve large-scale implementations are missing. Therefore it is necessary to expand the amount of neighborhood battery projects in The Netherlands that focus on equal benefits for all energy users. Within these project value-based decisions can help the process of implementing the neighborhood battery. It is important to pay attention to the social dimensions of neighborhood batteries and responsible innovations can help to do so. If

more attention will be payed to local developments and the role of all energy users, the neighborhood batery will provide a platform to store and share your power.

Keywords
Neighborhood Batteries; Community Energy Storage; Renewable Energy; Agent-Based Modelling; Responsible Innovation; Value-Based Design

CONTENTS

NOMENCLATURE

ABBREVIATIONS

Abbreviation	Definition
ABM	Agent Based Model
AC	Alternating Current
aFRR	automatic Frequency Restoration Reserve
CAPEX	Capital Expenditures
CES	Community Energy Storage
DC	Direct Current
DSO	Distributed System Operator
EPEX	European Power Exchange
EU	European Union
FCR	Frequency Containment Reserve
GW	Gigawatt
GWh	Gigawatt-hour
HES	Household Energy Storage
ID	Intra day market
Hz	Hertz
kW	Kilowatt
kWh	Kilowatt-hour
LCOS	Levelized Cost of Storage
LHS	Latin Hypercube Sampling
MW	Megawatt
MWh	Megawatt-hour
NSB	Neighborhood-Scale Battery
TSO	Transmission System Operator
PCC	Partial (Rank) Correlation Coefficient
PV	Photovoltaic (system)
RES	Renewable Energy System
RQ	Research Question
SCR	Self Consumption Rate
SSR	Self Sufficiency Rate
SOC	State of Charge
SQ	Sub Question

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1 INTRODUCTION

In this chapter neighborhood scale batteries are introduced and three aspects of this innovation are be discussed. The technological developments of neighborhood batteries are discussed, how battery initiatives can create engagement and dynamics within the neighborhood, and finally how neighborhood batteries should be designed as a responsible technology. Finally, the research objective, research question and study relevance are presented.

1.1. BACKGROUND

Renewable energy is growing rapidly worldwide and while this is creating a positive impact on reducing greenhouse emissions, it is demanding large changes for electricity networks, energy usage and polices (IEA, 2021). Many barriers need to be addressed to continue fast sustainable energy developments. Due to the intermittency of renewable energy, the imbalance of energy supply and demand could affect continuous energy availability. Moreover, renewable energy developments in the Netherlands are impaired by the lack of grid capacity and regulatory risks (Netbeheer Nederland, 2021). Energy storage could be an essential link to provide flexibility, security and increased sustainability to the energy system (Netbeheer Nederland, 2021). Adding energy storage can be valuable at every level of the system, from industrial large-scale, to residential households batteries. However, (inter)national policies and academic research emphasize the importance of the involvement of citizens for each solutions as this will lead to a more effective, democratic and inclusive energy transformations (Bidwell, 2016; Koirala et al., 2021).

With current technological developments, such as demand-response, distributed generation, smart-meters, and alternative heat generation, the energy system is more decentralized than ever and allows consumers to become active in the market. Hence, communities have taken more initiative to be energy independent, just[1] and sustainable (Savelli and Morstyn, 2021). While renewable energy is becoming big business for large energy companies, local community energy initiatives have increased to 3500 in Europe in the last decade (European Commission, 2020). Community energy can become increasingly important in future energy systems, as they could enhance the local energy infrastructure, increase investments in local renewable energy technologies, and create better social relationships within a neighborhood (Savelli and Morstyn, 2021). Empowerment of citizens and local communities can support sustainability goals of municipalities and accelerate national sustainable transitions. Besides, current community-driven initiatives create more engagement and social cohesion within a neighborhood (Koirala, van Oost, et al., 2018; Savelli and Morstyn, 2021). Therefore, local-based sustainable innovations, such as community storage, should be explored further to understand their implementation and impact within a neighborhood and for the energy network.

Community energy storage is emerging as a technical and social innovation for smart neighborhoods, and could perform better than residential balance solutions (Barbour et al., 2018; Parra, Norman, et al., 2017). As Community Energy Storage can be used by multiple stakeholders, i.e. consumers, utility companies or DSO's, several applications and added values can be considered. In addition, the optimal type of batteries and configuration is not yet certain, given different possible ownership structures, and value-streams are feasible and could lead to multiple battery designs. Therefore, the definition of Neighborhood Scale Battery is preferred in this report, since a community does not necessarily needs to be involved. According to Koirala et al., 2021 developing neighborhood battery innovation can create

[1] Energy justice concerns the field of energy systems to be fair, and aims for equal distribution of costs and benefits of energy production and consumption, such that the society as a whole can benefit equally (Sovacool and Dworkin, 2014).

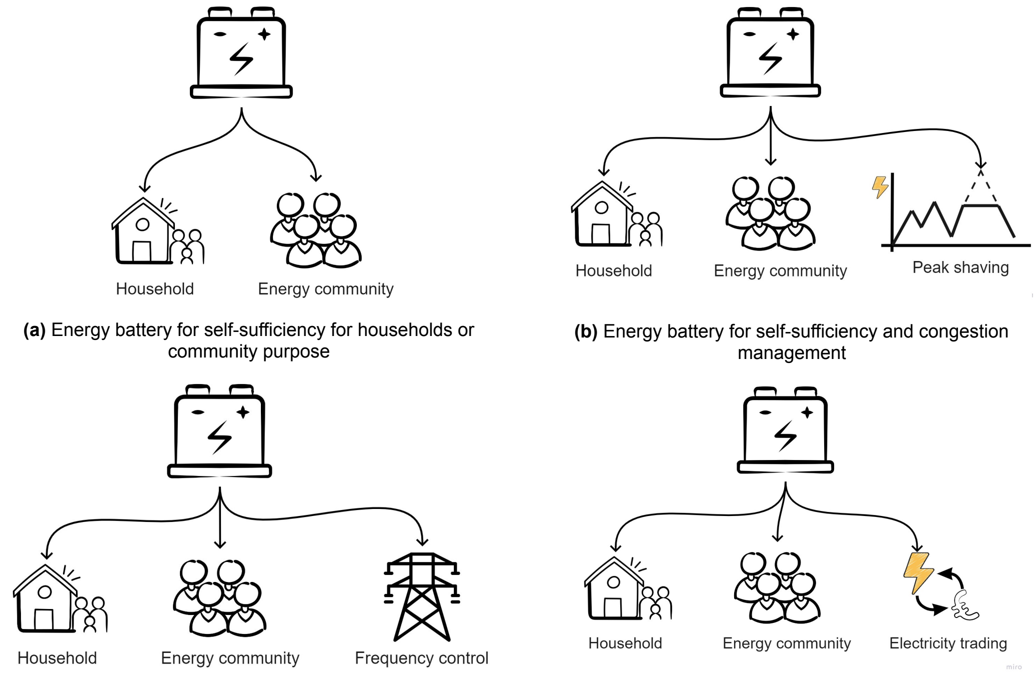
significant value for the energy system. The possible varieties due to community values and the regulatory uncertainty will conceive many opportunities for neighborhood batteries and should be further studied (Koirala et al., 2021).

Neighborhood Scale Batteries

Energy storage can help align peak demand and intermittent electricity generation. Parra, Swierczynski, et al., 2017 mentions residential PV adoption is growing, through strong governmental support, decreasing solar panel prices and favorable opinions towards solar energy. This has led to an increased interest in energy storage systems, as renewable energy technologies could be combined in more integrated energy system. Neighborhood batteries can be an effective energy storage technology since it could be implemented close by consumers and help to further increase the penetration of renewable energy into the electricity grid (Parra, Swierczynski, et al., 2017). Yet, there does not exist a general design or concept of a neighborhood battery. Barbour et al., 2018 uses the definition *an energy storage system with community ownership and governance for generating collective socio-economic benefits such as higher penetration and self-consumption of renewables, reduced dependence on fossil fuels, reduced energy bills, revenue generation through multiple energy services as well as higher social cohesion and local economy.*, however this definition assumes community ownership and governance, while energy could also be shared among the community without all consumers being owners of the battery. Other examples such as virtual energy sharing are being developed, where digitalization enables residential storage to be virtually connected and to be shared among the members (sonnen, 2021). Also, the battery could provide ancillary services to DSO's. Energy companies could be procured by the utility service provider. The battery can thus be company owned, state-owned and other hybrid-ownerships structures can be used (Barbour et al., 2018). Therefore, neighborhood batteries will be defined as *an energy storage system that can be shared among the community, who are not necessarily locally connected and the storage system is not necessarily locally owned* (Koirala et al., 2021).

Three concepts of neighborhood batteries are discussed in literature, namely, shared residential, local and virtual neighborhood batteries. Residential and local batteries are location-bound and the community involved is within a certain proximity, while virtual batteries are not location specific and the community could expand to a national level. In the case of residential energy storage, the batteries are installed behind-the-meter and are mostly owned by the consumers themselves, although this is not always the case (Koirala, van Oost, et al., 2018). Few pilot projects exist where small batteries are installed at consumers homes, while the utilities or private companies keep ownership of the storage systems, e.g. GridFlex, 2021 and SolShare, 2021. Currently, most existing pilots install one large central battery for the whole community and experiment with multiple use cases (e.g. GridFlex, 2022; Tegenstroom, 2018). When multiple stakeholders are involved, combined functions can be thought-about for neighborhood batteries. In figure 1.1 four use cases are shown. The first is the base case where the battery's electricity is supplied by the neighborhood and later used for self-sufficiency purposes. This could be for household demand or for community-based purposes. Barbour et al., 2018 emphasizes DSO's could use neighborhood batteries for frequency control and congestion management due to its larger size than residential storage. Frequency control is done on the Frequency Containment Reserve (FCR) and automatic Frequency Restoration Reserve (aFRR), and both markets are remunerative for balancing providers (Jongsma et al., 2021). The congestion management market is currently less defined, but will be increasingly important for flexibility providers, DSO and TSO's (Jongsma et al., 2021). In the last use case the battery is used for the electricity demand of the neighborhood and electricity trading on the day-ahead market.

Multiple studies have researched the benefits of neighborhood batteries. For instance, Barbour et al., 2018; Dong et al., 2020; Lombardi and Schwabe, 2017; Parra, Norman, et al., 2017; van der Stelt et al., 2018 compared the performance of both neighborhood batteries and residential storage, and explored different battery technologies. All studies concluded neighborhood batteries are more effective than residential storage when PV penetration is high, and significant economical opportunities are identified with neighborhood batteries. They can increase the self-sufficiency compared to residential storage, as household batteries are scheduled according to the needs of the individual households, and thus often store excess solar when it could be used by neighboring households Barbour et al., 2018. Dong



(a) Energy battery for self-sufficiency for households or community purpose

(b) Energy battery for self-sufficiency and congestion management

(c) Energy battery for self-sufficiency and frequency control

(d) Energy battery for self-sufficiency and trading on the market

Figure 1.1: Community Energy Storage Use Cases

et al., 2020 emphasizes in his study the same effective storage capacity can be provided with less installed capacity compared to residential storage. As battery materials are scarce and limited, this can be a major drawback for residential storage. Although neighborhood batteries are performing better in multiple studies, the costs of batteries do not make it currently feasible for consumers to install these batteries (Parra, Norman, et al., 2017; van der Stelt et al., 2018). Whether energy storage will be more economically feasible in the future, current challenges lie with regulatory issues, determining ownership, and sharing the generated and distributed revenue of the storage system (van der Stelt et al., 2018). In technical and economic literature, it is highly recommended to further study the different use cases possible and how different combined applications of neighborhood batteries can add more value. Interestingly, residential storage and neighborhood storage are compared in the literature, but a comparison between different configurations of neighborhood batteries could not be found in literature.

Community dynamics

The willingness of people to be part of NSB initiatives could depend on demographic, socio-economic, socio-institutional, and environmental factors. Koirala, Araghi, et al., 2018 used a large survey to predict which factors can determine the willingness of people to participate in a community initiative or technology, such as community energy storage. They found people are mainly driven by environmental factors (i.e. environmental concern) and socio-institutional factors (i.e. community trust, energy independence) and showed demographics - age, gender, income, house-ownership, etc. - are not statistically good predictors. Although, Ambrosio-Albala et al., 2020 confirmed most of these findings within their study, they showed the likelihood of younger participants installing a neighborhood battery was higher. Furthermore, value orientations can be a determining factor in the willingness to install a battery for a consumer, as for wider acceptance it will be necessary to ensure that the benefits are ensured for the local area (Ambrosio-Albala et al., 2020). For instance, the values of older and younger participants can differ, and so showing differences in participation willingness. People will engage with community energy initiatives for the benefit of the public good and other community members (Ghorbani et al., 2020). Hence, pro-active citizens have a determining role to increase initiatives, yet this is equally a bottleneck as not many citizens want to steer the project (Ghorbani et al., 2020; Koirala, Araghi, et al., 2018). In addition, both studies from Ambrosio-Albala et al., 2020 and Ghorbani et al., 2020 used the Theory of Planned Behaviour[2] to understand and simulate bottom-up initiative formation. By implementing the right policies and regulations, community willingness and benefits could be better enabled (Ambrosio-Albala et al., 2020). Yet, how to create engagement within the current institutional framework is unclear.

The energy system should be designed to drive engagement by using new business models, regulations, and governance. NSB shows both economic, and non-economic values are combined for a viable business case (Koirala et al., 2019). For instance, economic value is added by NSB applications such as increased self-consumption of local generation, peak shaving of both generation and demand, emergency services for critical infrastructures, short- and long-term decoupling of energy supply and demand, energy and network services as well as costs saving through grid reinforcement deferrals (Koirala et al., 2019. Non-economic value streams, such as sustainability, community engagement, energy democracy, a sense of community, energy security as well as a resiliency complement local community goals. In Acosta et al., 2018, technical and social factors are equally weighted and used to design the governance for community energy systems. By analyzing community energy systems with the socio-ecological system's framework from Ostrom, 2009, they showed the system greatly benefited from considering social factors, in parallel to the techno-economical approach. The characteristics of NSB need to be adequately considered in new regulations, as the ownership of NSBs is influenced by economical requirements, operational requirements, social welfare issues, as well as risk perceptions (Koirala et al., 2019).

Responsible Innovation

New energy projects are often confronted with problems of social acceptance as new initiatives always have an impact on the activities of local populations, industry, and governments (Correljé et al., 2015). Although new flexibility regulations are creating market-driven incentives for storage (Article 32 and 36 EU, 2020), to focus only on market incentives and regulation will not be enough for a successful implementation of new energy initiatives (Correljé et al., 2015). Correljé et al., 2015 mentions multiple examples of new developments which demonstrate how the interaction between citizens, businesses, and local authorities can become problematic due to stakeholder controversies (e.g. on-shore wind farm locations, shale gas drilling). This shows how stakeholder values should be considered during the process and initiation of an energy project. If stakeholder values are well considered during a project, the technology could have more support from citizens. Therefore, technology support can be considered an important aspect of the success of new projects to succeed.

Next to that, Value embeddedness in technology is widely acknowledged by literature and recent studies in institutional economics argue institutions can encourage or harm certain values in society (Milchram et al., 2019). In the framework of Milchram et al., 2019, they show how values can be used as evaluative criteria. It also helps to explain how some values can become relevant and how this influences shared values and institutions (Milchram et al., 2019). Responsible innovation has been applied to the algorithm design of neighborhood-scale batteries (Ransan-Cooper et al., 2021). They show trade-offs that need to be made between different kinds of algorithms for the battery (e.g. *Self-sufficiency*, *Battery revenue*, or *Simplicity*), and that neither algorithm design creates the best battery to integrate all citizens' preferences and concerns (Ransan-Cooper et al., 2021). When methods could be used to enable the decision-making of stakeholders, they could be more engaged in the energy system and ensure the system reflects their values (Ransan-Cooper et al., 2021). In this research, values will similarly be used as evaluative criteria for the performance of the battery. Additionally, values are the drivers of behavior for users of NSB. According to Schwartz, 1992, ten universal values can be attributed to people and people can prioritize these values differently. Schwartz and Bilsky, 1987 defines values as (i) concepts or beliefs (ii) about behavior or desirable end states (iii) which transcend specific situations, (iv) guide selection and evaluation of behavior, and (v) are ordered by relative importance. In chapter 2, a framework is discussed on modeling values as a driver for behavior.

In other words, neighborhood batteries could demand different types of values, such as affordability

[2]The Theory of Planned Behaviour states intentions for behavior can be predicted by the attitudes toward the behavior, subjective norms, and perceived behavioral control (Ajzen, 1991). These intentions, together with perceived behavioral control, can accurately predict changes in behavior.

and sustainability, to satisfy the demands of different actors to be a responsible innovation (Koirala, van Oost, et al., 2018). Figure 1.2 shows how responsible innovation tries to align and improve technological innovation to societal demands and values and thus form a link to the different aspects shown in the figure. This framework shows the importance of socio-technical alignment for all the different elements in such a complex system for the successful implementation of NSB (Koirala et al., 2020). Responsible innovation can help structure and align the technical, socio-economic and institutional aspects of neighborhood batteries.

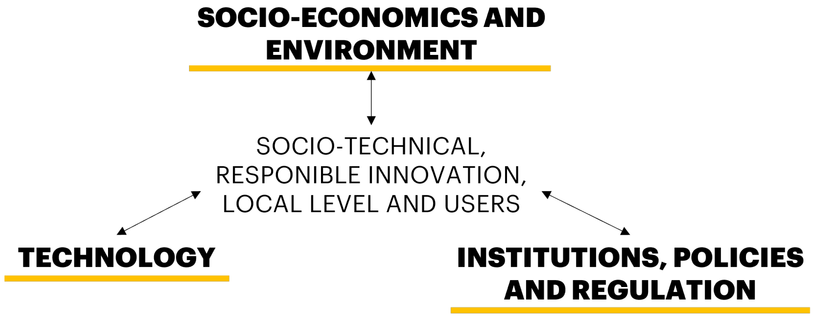


Figure 1.2: Responsible Innovation framework adapted from Koirala et al., 2020

1.2. RESEARCH OBJECTIVE

Knowledge Gap

Neighborhood batteries are an unknown socio-technical innovation that could benefit local communities. However, limited research exists on the integration of neighborhood batteries in the energy system. More research on the technological and economical performance of neighborhood batteries could improve the implementation of batteries for different neighborhood characteristics. More specific, different energy consumption profiles, social preferences, and battery functionalities make the implementation of neighborhood batteries very complex.

Besides, this study focuses on the unknown dynamics of citizens' values and their interactions when neighborhood batteries are integrated into the energy system. Citizens play a stronger role in the energy system and values become more embedded in new energy innovations. Community characteristics and values are to be considered when designing decentralized energy innovations. This plays an important role with neighborhood batteries as interaction with households is inevitable. This study focuses on both knowledge gaps, about the practical implementation and the impact of the batteries in the neighborhood.

Research Objective

The objective of this thesis is to better understand the alignment of technical functionalities of the batteries and citizens' values. The neighborhood batteries are not only assessed on a technological and economical performance indicator, but ethical aspects provide a wider understanding of the development of neighborhood batteries.

The outcome of the thesis is a simulation model which provides insight into the influence of values and community characteristics on the technology support of neighborhood batteries from the households. The degree to which the battery is supported by the actor's values is defined by the technology support. The technological and economical performance of the battery configurations is used to compare the neighborhood batteries. Together with the insights from the influence of the batteries on the technology support the different neighborhood batteries is evaluated and compared. The different aspects of the thesis and influence are depicted in figure 1.3.

Research Question

This research focuses on different neighborhood battery configurations and compares their technological and economical performance. As values and community characteristics are important to consider,

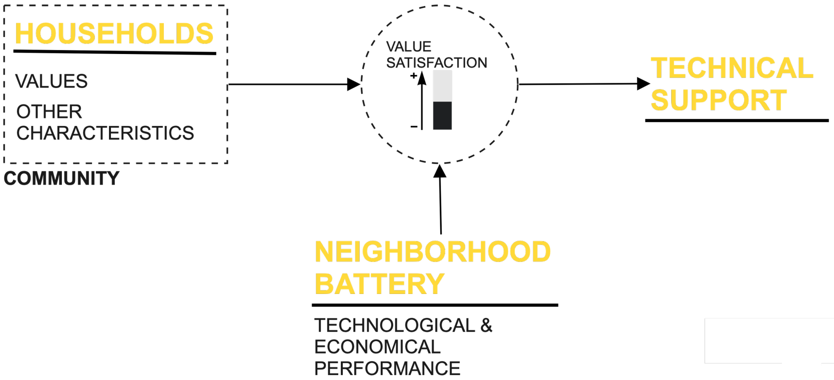


Figure 1.3: Conceptual diagram of thesis focus aspects

the value satisfaction of the energy innovation is considered. The implementation of the neighborhood battery within a community is analyzed to understand the influence of values on the support of batteries. Therefore, the following research question will be addressed:

How do different neighborhood batteries influence value satisfaction and technological and economic performance?

Sub-questions
To answer the research question six sub-questions have been formulated. Each sub-question answers a different aspect of the research question and addresses a part of the research objective. The first question elaborates on the current state of technology for neighborhood batteries in the Netherlands: *What institutional and technical designs of neighborhood-scale Batteries currently exist in The Netherlands or are being developed?*

In literature there do not exist clear metrics for value satisfaction or technology support, therefore a part of the project is dedicated to conceptualizing adequate metrics for value satisfaction and/or technology support. The second question addresses this part of the research: *How can metrics be defined for technology support and value satisfaction?*

Using the information of the first question, the electricity system, battery configurations, and citizens' perspectives can be conceptualized. The third question addresses the conceptualization and formalisation phase and creates the foundation for the simulation model: *How can values, neighborhood battery designs and characteristics of The Netherlands be specified in a simulation model?*

Since a simulation model is used, different scenarios can be experimented with and more insights can be gathered on (not existing) neighborhood battery configurations or implementations. Using the simulation model, the value embeddedness of the technology is explored and the influence of citizens' values on neighborhood battery implementation is simulated. The fourth question helps answering this aspect: *What neighborhood characteristics (values, social network, PV ownership) influence technology adoption and value satisfaction?*

Lastly, the simulation model focuses on the technological and economical performance of the battery. Besides, running experiments for the support of citizens, the different battery configurations are explored on their economical and technological performance: *How do the various battery configuration perform technically and economically?*

1.3. RELEVANCE

The goal of the research is to analyze the influence of different values and community characteristics on the implementation of neighborhood batteries. Sharing energy within a local community challenges our current energy system design. Subsequently, multiple socio-technical issues are involved in the

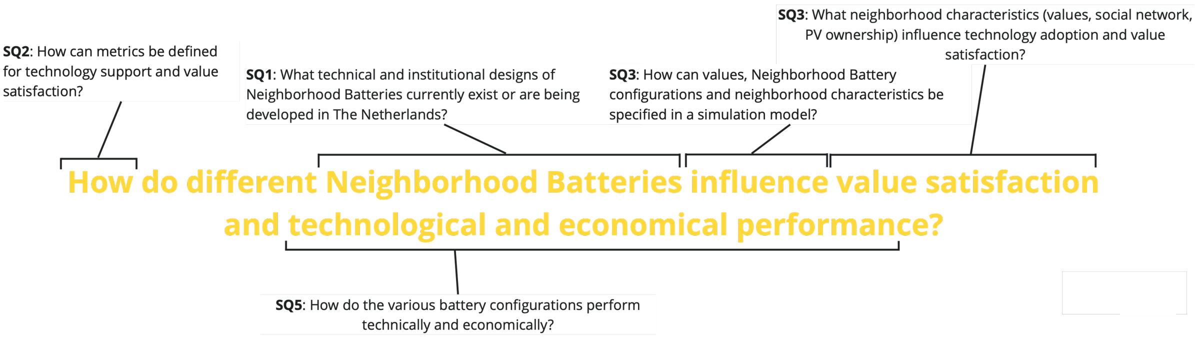


Figure 1.4: Relevance of Sub-questions

implementation of new, innovative technology, such as neighborhood-scale storage systems.

This research contributes to current research, existing and future policies, and the societal discussion on community storage. First, current research on neighborhood batteries is limited and the consequence of the novelty of this technology means multiple aspects deserve more research. Accordingly, analyzing neighborhood batteries with methods and approaches learned at the Master of Complex Systems Engineering can contribute to current literature. In Koirala et al., 2021, the challenges of neighborhood batteries regarding the complex interactions of technology, economic and institutional aspects are emphasized. Similar challenges were continuously addressed throughout our Master's. While some researchers address this challenge with a technical lens, the contribution to the literature of this thesis could be a combined technical, institutional, and economic approach. Neighborhood batteries are especially a complex problem due to their dependence on other systems, such as renewable energy systems or community initiatives, thus becoming a system of systems. Second, policies on neighborhood batteries are lacking, and understanding the value streams of different implementations of the batteries could help the implementation of the right regulations for these systems. The uncertainty within current policies and institutions does not help push forward this social innovation. Therefore, the outcome of this thesis can be helpful for policy-makers or influential actors within the energy system. This research will contribute to the current discussion on the design of future energy systems and how citizen values will influence this design. Acknowledging the urgency of citizen engagement and participation is crucial when introducing innovative systems. Lastly, this research could create stronger strategies for the (institutional) design of neighborhood batteries and in particular for the implementation and functional usage of neighborhood batteries. With the insights from the link with values, a strategy could be made which reflects the values. In conclusion, this subject is an appropriate extension of the Master's program. The subject contributes to the existing literature in a novel way, to future policy-making and the societal discussion of storage. Therefore, this Master's Thesis subject is considered relevant.

1.4. THESIS STRUCTURE

Figure 1.5 shows the structure of the project. The project is divided in four phases, each addressing one or two sub-questions. The four phases are *Exploring and Information Collecting*, *Model Conceptualisation and Formalization*, *Model Implementation* and *Model Synthesis* (Nikolic and Ghorbani, 2011)). Each phase uses different methods and the output of each previous phase can be used in the successive phase. In phase three, an iteration is done for the implementation of the model. In figure 1.5 the iterative process is visualised.

The project had a duration of 25 weeks, starting from the kick-off, and was planned between mid-February and August. The timeline is adjusted to the four phases from the structure. Each phase has a duration of approximately one month and a half. The project planning can be found in figure 1.6.

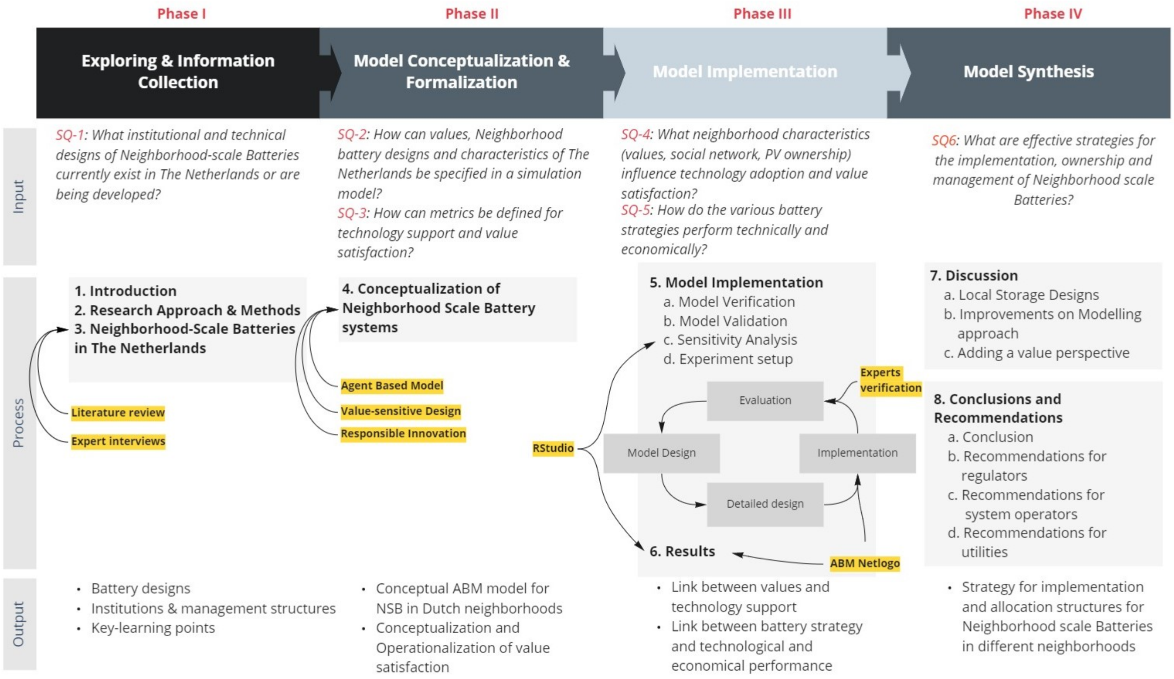


Figure 1.5: Process flow diagram of the project

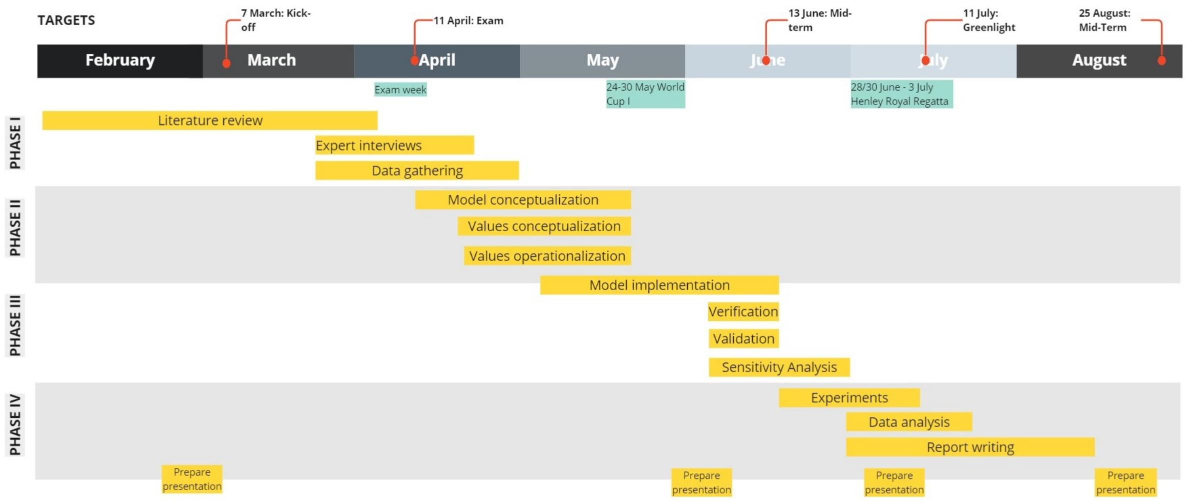


Figure 1.6: Timeline of the Thesis project

2
RESEARCH APPROACH & METHODS

In this chapter, the research approach to answer the research question is discussed, followed by a brief description of research and data gathering methods. Additionally, the data requirements are discussed.

2.1. MODELLING APPROACH

In this research, an explorative modeling approach is used to understand how storage configurations perform technological and economic and influence technology support. This approach combines social science research on energy technologies and modeling energy technology concepts. The model's narrative includes conceptualizations from Responsible Innovation and Value-Sensitive Design (Correljé et al., 2015). In that way, the outcome of the study is achieved using this approach. Responsible innovation considers the values of the actors, as stated before:

> "...for the successful initiation of an energy project, it is important to pay attention to the process through which the project becomes established and to the stakeholders' values that are addressed in this process." (Correljé et al., 2015)

The model could provide simulations to create a shared understanding between stakeholders. The sources to support the model can be expert opinions (Edmonds et al., 2019).

Agent-Based Modelling (ABM) is well suited to explore emergent behavior arising between actors within a larger complex system (Nikolic and Ghorbani, 2011). Nikolic and Ghorbani, 2011 introduce a structured methodology to create an ABM. The five steps are as follows: System analysis, Model Design, Detailed Design, Software implementation, and Model evaluation. This study uses a four-phase approach that resembles this methodology. Figure 2.1 shows the four phases. In 2.2 the ABM steps are further explained. Since interdisciplinary research is required for this thesis, for instance technical, institutional, and social/behavioral research, integrating all related disciplines can be difficult (Cohen et al., 2021). This model uses real-world technical data for technical modeling of the neighborhood battery and uses the Theory of Schwartz and Bilsky, 1987 for modeling values and to easily vary the value homogeneity and heterogeneity of values in the neighborhood.

Besides, translating values to the ABM can be a limiting factor, as overcoming the operationalization of values for the ABM could be difficult (Heidari et al., 2020). Moreover, validation of the ABM can be difficult as no existing projects exist besides pilots, and therefore no comparable data is available.

Figure 2.1: Research approach in four phases

Model Storyline

Developing a model needs an elaborated storyline to support the modeling process. Although this is specified in further chapters, an initial abstract is given in this paragraph. Within the simulation, various configurations of neighborhood batteries can be placed in the neighborhood. Three configurations can be placed: a neighborhood independence battery, a market-oriented battery, and a network service-focused battery. All three batteries are based on different strategies and values and therefore fulfill different values. Households are given sets of value orientations and other neighborhood characteristics which influence the support of the various kind of battery configurations. Interactions between the households influence the value satisfaction of the households. As such, being part of a community will influence the support of a household for the battery (see figure 1.3). The performance of the configuration is modeled and measured on economical, social (value-based), and technical indicators. After implementation of the storage, the system is evaluated and assessed on these indicators.

So, this storyline consists of three layers: the technical, economic, and social layers. Each sub-model has important outputs which help answer the research question. The data and methods required for this approach and model is discussed in the next section.

2.2. RESEARCH METHODS

Multiple sub-questions (SQ) have been derived to answer the research question. As mentioned before, this study is divided into four phases: (i) Exploring & Information Collecting, (ii) Model Conceptualization & Formalization, (iii) Model Implementation, and lastly (iv) Model Synthesis. Each phase uses one, or several methods to provide information for the subsequent phase. All sub-questions tackle a different aspect of the research, therefore several methods are required to answer the sub-questions. Table 2.1 shows all sub-questions with the necessary research methods.

SQ	Description	Research Method
1	What institutional and technical designs of Neighborhood-scale Batteries currently exist in The Netherlands or are being developed?	Desk Research, (Expert) interviews
2	How can metrics be defined for technology support and value satisfaction?	Desk Research, Responsible Innovation
3	How can values, Neighborhood battery designs, and characteristics of The Netherlands be specified in a simulation model?	Desk Research, Responsible Innovation
4	What neighborhood characteristics (values, social network, PV ownership) influence technology adoption and value satisfaction?	Agent-Based Model, data analysis
5	How do the various battery configuration perform technically and economically?	Agent-Based Model, data analysis

Table 2.1: Sub-questions and related research methods

Desk Research & Interviews

In the first phase, Exploring & Information Collecting, the Desk research is of significant value for all other phases. Literature review provides a lot of data about neighborhood battery configurations and value influences. More information is found on potential multi-applications of NSB designs and the influence of institutions and values in general. Although the literature review provides the most information for sub-questions one, two, and three, additional data is gathered through expert opinions. Literature reviews can miss certain papers and, more importantly, lack relevance to practical implementations or decision-makers. Therefore, expert interviews are conducted to fill any relevance gap the literature lacks. Distributed system operators, energy retailers, and energy cooperatives are considered experts in the field of community energy storage. Neighborhood battery pilots are done in collaboration with these parties, therefore it is interesting to interview people involved in storage technology and projects. The goal of the interviews is to explore the role of these stakeholders in the storage market. Also, literature can be verified due to the interviews. As storage is relatively new in the energy system, the role of storage is uncertain. Therefore, the questions during the exploratory interviews were about the role of neighborhood scale batteries in the energy system and their point of view. This is also one of the main research gaps in literature.

Beyond desk research and expert interviews, the first phase is important to gather data for the model. Data about values and opinions considering storage is not widely available but is important in this study. Also, supply and demand data to create an energy grid is required. Certainly, assumptions need to be made, and using papers that used surveys on neighborhood batteries can help create stronger assumptions about the importance of values for neighborhood batteries. (Ambrosio-Albala et al., 2020; Dong et al., 2020; Hoffmann and Mohaupt, 2020).

Agent-Based Modelling
In the Model Implementation phase, an Agent-Based model is built using the methodological framework of Nikolic and Ghorbani, 2011 and Van Dam et al., 2012. In chapter 1, already a short description of the frameworks include several steps to cover the model design, structuring, experimentation, verification, and validation, and including a value lens implementation, the framework could be capable to explore social and techno-economic performance modeling. Agent-Based modeling can deal with complex systems, and therefore create large design spaces with many parameters and outputs (Nikolic and Ghorbani, 2011). Agent-Based modeling is particularly useful for modeling interaction between agents. As the implementation of the model requires heterogeneous households, ABM is a favorable method. Other methods are suitable, but Mittal et al., 2019 shows the possible application of storage modeling and social interactions within an ABM.

Before creating the simulation, the model conceptualization is made where all sub-models and interactions within the model are elaborated. Figure 2.2 shows the 'inside' of the agent-based environment. The environment of the model influences the agent, while actions from the agent can influence the environment. More importantly, the agents receive inputs from other agents and consequently perform actions on themselves or other agents. In Chapter 4 the interactions, inputs from environments, and states of agents are further elaborated. Experts about storage technology are included during the conceptualization and verification phase, to further strengthen the model and increase its explanatory capacity (Nikolic and Ghorbani, 2011). The resource used for the Agent-Based modeling is Netlogo (Wilensky, 1999).

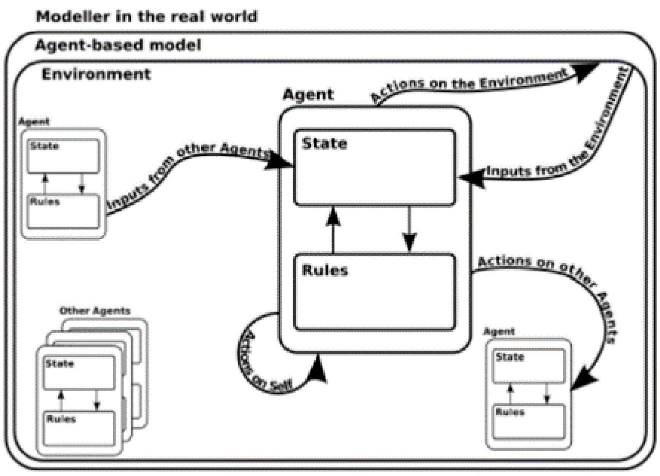


Figure 2.2: Agent Based Model System View (Van Dam et al., 2012)

Value Modelling
In the Agent-based simulation model, the agents prioritize their support for battery configurations based on shared strategies and values. As a neighborhood battery can be seen as a common or shared good, institutional frameworks could help analyze this innovation. Therefore some general theories are first discussed.

Milchram et al., 2019 highlighted the importance of values in institutional analysis for the responsible design of new energy systems and provided a framework in addition to Ostrom's IAD framework. Milchram et al., 2020 compared multiple smart grid projects on distributive, procedural, and recognition justice indicators and then provides recommendations on how to design 'just' smart grids. They show how values can influence institutions and become embedded in the energy project process. Responsible innovation considers key stakeholders and takes into account their values in the design of technology.

To model values in ABM, the framework of Schwartz will be used to assign the prioritization of values to the agents (Schwartz, 1992). In section 1 the definition for values from Schwartz is mentioned and the framework can be seen in figure 2.3. ABM models have used Schwartz's framework to implement values in ABM (Burken et al., 2020), however some extra steps are required to operationalize the abstract values to use them for behavior choices (Heidari et al., 2020). Value trees can help define more abstract values to concrete values which can be used for behavior choices (Heidari et al., 2020). The value tree create a value system where institutions and battery functions can be related to more abstract values. If it is known which values the agent complies with the most, his behavior choices can be related to the value system to be consistent throughout his actions (Heidari et al., 2020). Schwartz values are suitable to be evaluated for their satisfaction with the values of the agents. Value satisfaction can be used to define the technological support of the households for the batteries. This could be combined with social, technical, and economical parameters to measure the complexity of a socio-technical system. Using this method, values are inputs for the model to create heterogeneous agents, and value satisfaction and technological support are outputs as performance indicators to measure the NSB functional design (see figures 1.3 and 4.1).

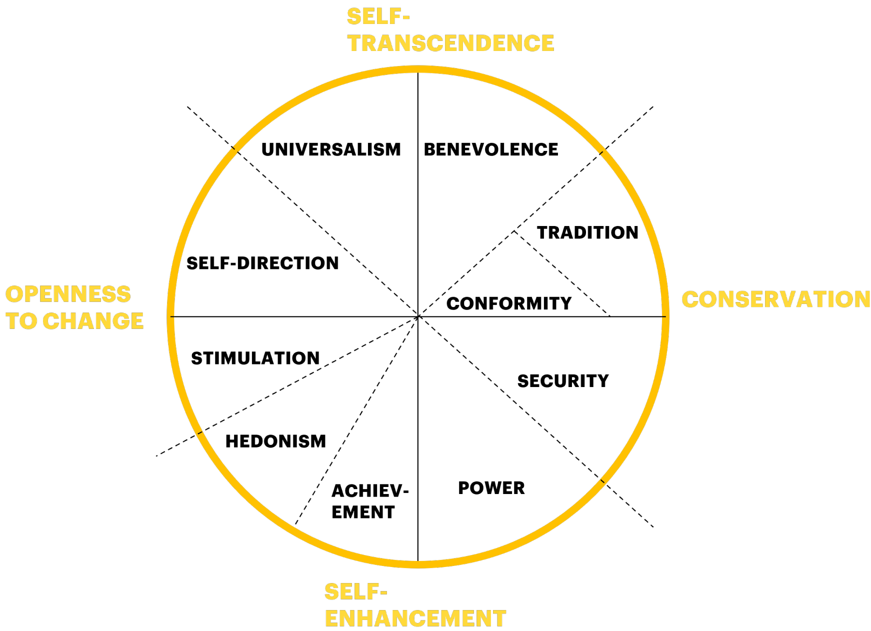


Figure 2.3: Schwartz value circumplex (adapted from Schwartz, 1992

Data Requirements & Analysis

Multiple types of data are required for this study. As three aspects are modeled, technological, economic, and social, the model inputs also differ. These data types are mostly quantitative and some assumptions are made. The assumptions made are clearly stated when relevant. The literature review is used to design the battery configurations and find qualitative data for value-based decision-making. Literature including case studies, comparative analyses, or based on theory needs to provide data for agent-based rules and requirements. Most importantly, data regarding the views or opinions of citizens are necessary for the formulation of values. These views should preferably be on storage systems but can be on any related renewable energy system (RES) topic. However, data should not be too dated as current opinions on RES can change over the years. Also, expert opinions on these topics contributed to more knowledge about these topics. Performance data for small-scale storage technologies can be found on numerous (semi)-state websites or energy institutional sites (Danish Energy Agency, 2021; EESI, 2019; IRENA, 2017). Whereas information about community demographics and current community storage cases can be found on other Dutch websites (CBS, 2022; HIER Opgewekt, 2022).

Besides, technical descriptive information, quantitative data on the electricity market, electricity demand, and supply are required for the simulation model. Household electricity demand and supply (in the case of PV) profiles can be found on NEDU, 2021, which publishes new profiles each year.

These profiles can be multiplied by the expected yearly power demand or supply. Electricity demand published on Liander, 2022 is used. Day-ahead prices and balance market prices are published on ENTSO-E, 2022.

Complementary software is used for sensitivity and data analysis. This is done using R and RStudio. R is a computing language used for statistical analysis, while RStudio is a platform where the language R is used. RStudio is used to write and program statistical analysis of the data from Netlogo.

3
NEIGHBORHOOD SCALE BATTERIES IN THE NETHERLANDS

This chapter answers the first sub-question: *What institutional and technical designs of Neighborhood-scale Batteries currently exist in The Netherlands or are being developed?* So, in this chapter, the existing Dutch energy storage projects are explored and the differences in NSB configurations are discussed. Also, the values considered by the pilots are discussed.

3.1. ENERGY STORAGE NETWORK

The implementation of neighborhood-scale energy batteries is done at the lower level of the electricity network. The high voltage grid is maintained by the transmission system operator (TSO) for the security of supply on a national (and international) scale and where cross-national agreements are made by grid operators to assure this. In figure 3.1, a system overview can be seen from the electricity grid. On the left of the figure, the high voltage grid is shown which connects large (de-)centralized energy resources. The Transmission System Operator (TSO) is responsible for operating the core systems services, such as maintenance, connecting new assets, and balancing the supply and demand in the grid. In the Netherlands, TenneT is the responsible operator. On the right of figure 3.1, the medium voltage and low voltage grids are represented. Neighborhoods and smaller decentralized resources are connected to the low and medium-voltage grid. In the Netherlands, the responsibilities for operating the low and medium voltage grid are split up into four parts with four responsible Distribution System Operators (DSO). If a neighborhood battery is connected to the distribution system, it could serve 50 to 250 households.

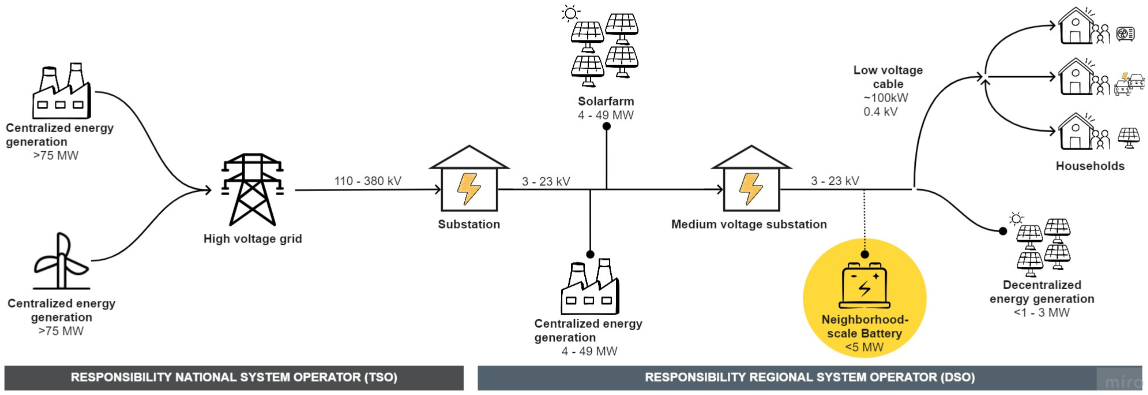


Figure 3.1: Electricity system view overview

Energy markets

The Dutch electricity market is fully liberalized and open for anyone to participate. Various markets exist, the bilateral market, the spot market, and the balancing market (see figure 3.2). Bilateral agreements are made between large suppliers and consumers. These contracts are made from years to weeks before electricity trading. As batteries are more useful in short-term markets due to their characteristics, the bilateral is not interesting. The second market, the spot market, is divided into two auctions. Firstly, the day-ahead market (DAM) is auctioned each day for each hour the next day. For each hour electricity volumes and prices are determined. Electricity suppliers are paid by MWh delivered. Secondly, the intraday market auctions electricity volumes closer to real-time (15-minute intervals), as a mismatch between demand and supply can still be expected after the volumes are traded in the day-ahead market. The DAM and intraday have quite similar prices, although prices from the intraday can have wider ranges. For batteries, both intraday and DAM markets are interesting as the battery can quickly react to price changes and charge or discharge.

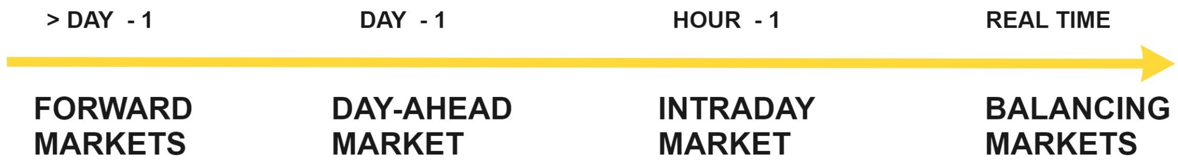


Figure 3.2: Energy Markets at different time frames

The TSO is responsible for the last market, the imbalance market, also called ancillary services or balancing markets. As it is not possible to fully predict supply and demand, balancing is needed to create a stable grid. In the Netherlands, the grid is stabilized on 50 Hz. So, three imbalanced reserve markets exist, frequency containment reserve (FCR), automatic frequency regulation reserve (aFRR), and manual frequency regulation reserve (mFRR). FCR is automatically activated if any imbalance occurs in the grid (TenneT, 2022). Market participants can place a bid by offering capacity. Accepted bids need to be available for 15 minutes. Four-hour block auctions are done for balancing market participants. Also, the FCR is an interesting market for batteries, which were traditionally operated by conventional power plants (DNV, 2021). The minimum bid size in the FCR market is 1 MW, which can be done by a single unit or a pool of combined units (DNV, 2021). Combining multiple units can benefit small-scale batteries or smaller neighborhood batteries. Although prices are decreasing last years, price volatility in the FCR market has increased (DNV, 2021).

Battery services

A neighborhood battery could provide many different services. Table 3.1 shows a full list of all possible battery services. To the local grid operator, the battery could provide local congestion management and voltage quality control or optimize grid connection by peak shaving (DNV, 2018). To nearby consumers and producers, the battery can increase own solar consumption or enable energy arbitrage (DNV, 2018). Currently, congestion management problems do not occur on the lower voltage grid but are expected to occur in the future. Grid operators are preparing the grid and exploring the range of solutions to increase flexibility. The neighborhood battery is a viable option. For consumers, multiple battery services from the list in table 3.1 can become interesting when the feed-in tariff is replaced with other regulations. New battery players start to be involved in the electricity market as aggregators and are operating the battery for flexibility services for the TSO. Interestingly, the new battery market players can aggregate their batteries and create a network of batteries. This aggregated community of batteries allows them to operate on the higher voltage grid and be more flexible.

Recent studies have shown that interesting business cases are possible with battery energy storage (Australian National University Canberra, 2020a; DNV, 2018; Jongsma et al., 2021). These market opportunities lie in providing balancing services and battery trading opportunities. FCR is currently the most interesting market with high prices, short bidding blocks, and a fast response time (DNV, 2018; Jongsma et al., 2021). Using the battery on the intraday market can offer some interesting opportunities as prices can be more volatile than in the day-ahead market and volumes are expected to increase (DNV, 2018). For this research, three battery services are compared and explored. As FCR is a promising market, one battery is modeled to trade for the FCR market. A second configuration is made for trading in the intraday market. Lastly, one battery providing its full service to the neighborhood is modeled. This can decrease the peaks of the neighborhood and increase the self-consumption of

Index	Type	Service	Description
1	Balance	Primary Reserve (FCR)	In the case of an unforeseen event, such as power loss, the primary reserve is activated to compensate for and stabilize the sudden discrepancy in grid frequency.
2	Balance	Secondary Reserve (aFRR)	Secondary reserve will be activated within 15 minutes of primary reserve being activated with the purpose to return any grid discrepancy to its original level.
3	Bulk Energy Services	Energy Arbitrage	The storage system is charged when prices are low and discharged when prices are high. Thus the moment of energy supply is shifted.
4	Sustainable Energy Optimisation	Imbalance Reduction	Using a storage system to reduce the difference between the forecast and actual output of an renewable energy source, which will reduce the amount of imbalances.
5	Consumer Services	Personal Consumption (PV)	Reduction of own's energy consumption by storing surplus of generated energy from PV and using it shortage of PV power production.
6	Consumer Services	Grid Connection Reduction	The storage system can be used to reduce the grid connection size and therefore reduce costs.
7	Consumer Services	Peak Reduction	The storage system can be used to reduce peak demand which leads to grid losses and can prevent overloading the network.
8	Consumer Services	Emergency Power Supply	In the event of power outage, a storage system can provide emergency power at locations where continuous current is vital (e.g. hospitals).
9	Consumer Services	Power Quality	Storage systems can reduce or remedy grid disturbances (e.g. voltage dips or flicker) for stable power supply.
10	TSO & DSO Services	Congestion Management	The storage system can reduce congestion issues in the transmission and distribution network when these networks reach their maximum capacity and cause the occurrence of voltage problems.

Table 3.1: Overview of storage system services (DNV, 2018)

the neighborhood.

3.2. STORAGE PILOTS

Figure 3.3 shows a 'buurtbatterij' (NSB) in Rijsenhout, The Netherlands. Although not many neighborhood batteries exist, some pilots have been started in some municipalities and are testing the performance and operation of the batteries. Moreover, the pilots considered the technology support from the neighborhood in each project. Table 3.2 shows an overview of all implemented pilots of neighborhood batteries in The Netherlands.

Pilot	Description	Stakeholders
Gridflex Heeten	Different pricing mechanisms tested to increase self-sufficiency and peak-shaving, 9 batteries for 49 households (100% participation)	DSO, Energy cooperative, Retailer
Buutbatterij Rijsenhout	Demonstration of ancillary grid services with large Li-ion Battery, high acceptance and 100% participation	DSO, Energy cooperative, Municipality
Interflex Eindhoven	Large battery to provide flexible energy for EV Charging stations and provide grid services and energy arbitrage	Battery Provider
Weert Energie	Combined battery and solar farm. Reducing electricity supply costs from the large solar farm, increase market revenue and provide flexibility services. Participation through energy cooperative	Energy Cooperative
Buurtbatterij Voorhout	Combined battery and EV-charger, which is used for households, EV charging, and market revenue. Used by 17 households	Battery providers

Table 3.2: Neighborhood Battery Pilots in The Netherlands

Multiple pilots were done in collaboration with the DSO or even by the DSO, to explore flexibility options in the future. This will not be allowed in future regulations, but the DSO will be involved in locating the battery, creating flexibility contracts, and possibly managing the battery. A new party in the energy system is the Battery Provider, which in most cases is also a Balance Service Provider, which allows them to bid on the balancing reserve markets. In both pilots where the battery provider was involved, the battery was placed combined with EV chargers. This allowed the battery to use a smaller grid connection and pay fewer transmission costs to the operator.

In three of the five pilots, an energy cooperative was collaborating or leading the project. Consequently, households part of the energy cooperative were easily convinced to participate in the project and a movement was easily started. In two pilots 100% participation was reached. Koirala et al., 2020 concluded energy cooperatives will be a stimulating factor around energy transition innovations. Figure 3.4 shows all initiated solar projects in The Netherlands by energy cooperatives. Neighborhood batteries will likely be combined at locations where such an initiative was already done. These solar projects have high enthusiasm, and participation and can be open to new technologies like NSBs. However, market-based trading and providing balancing services to the grid are complex and not easily organized by an energy cooperative solely. Collaborations between DSOs or other market actors are needed to enable these battery functions.

Figure 3.3: Pilot of Neighborhood battery in Rijsenhout (Liander, 2017)

3.3. RESPONSIBLE BATTERIES

The impact of neighborhood batteries on the energy system, and whether this development is in the public interest, is being explored by using the approach of Responsible Innovation. Studies from Koirala et al., 2021 and Ransan-Cooper et al., 2021 explore the range of values that should be incorporated into neighborhood battery design. By exploring the benefits and risks of neighborhood batteries, Ransan-Cooper et al., 2022 created a list of 'public' values to consider when implementing these batteries. In table 3.3 the six mentioned values from their study are listed and described.

Firstly, *Efficiency* is mentioned and refers to the economy of scale of larger batteries concerning smaller residential batteries. Neighborhood batteries could offer more effective capacity with the same capacity size compared to residential batteries (Dong et al., 2020). Moreover, the operation of the battery could be much easier and more efficient with a larger battery connected to multiple households, than to aggregate many households for the same functionalities. *Environment and nature* is an important value to consider when designing the neighborhood battery. Households perceive the implementation of the battery to increase (local) renewable energy generation (Ambrosio-Albala et al., 2020; Ransan-Cooper et al., 2022). Neighborhood batteries could create a secure and stable provision of electricity when PV can not supply. *Security and stability* is thus also an important value. *Social justice & fairness*

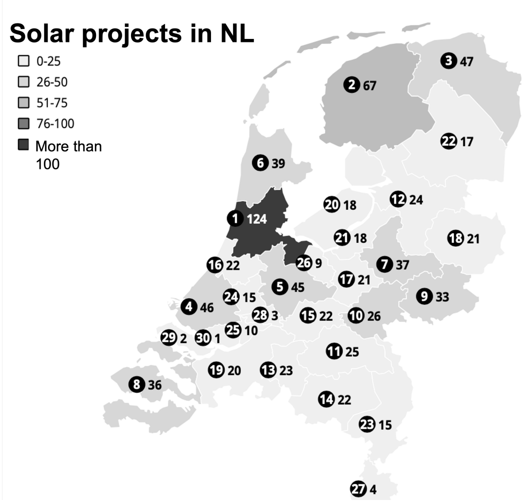


Figure 3.4: Total number of energy community projects in The Netherlands HIER Opgewekt, 2022

is considered for battery implementation to create equal benefits and costs for households with and without PV. *Social Capital* resembles the last value, however, it also emphasizes the importance of community bonding with the neighborhood battery. Lastly, *Autonomy and Power* is considered as the neighborhood battery is a decentralized solution that can be owned and managed within the community. These values are connected to the neighborhood battery configurations in the next chapter. This helps to connect the batteries' values to the Schwartz values introduced in chapter 1.

Value	Description
Efficiency	Economies of scale drives down battery costs and avoid waste
Environment & nature	Support more renewables and decarbonization of electricity network
Security & stability	Create more reliable control than residential batteries
Social Justice & fairness	Increase trust, transparency, and equality in energy system
Autonomy & Power	Local energy self-sufficiency
Social Capital	Community bonding

Table 3.3: Values

4
MODEL CONCEPTUALISATION

In this chapter the second and third sub-questions are addressed: *How can values, Neighborhood Batteries and characteristics of The Netherlands be specified in a simulation model?* and *How can metrics be defined for technology support and value satisfaction?* The conceptualisation is divided into three sections below which corresponds to a sub-model in the agent based model: technical, economical and social sub-models.

4.1. MODEL OBJECTIVE

Figure 4.1 shows the overview of the conceptual model. The outputs are highlighted in red and are important to answer the research question. The arrows between model elements and outputs illustrate the influence between model aspects. The battery configuration and having a PV system influence all three outputs. The value orientation and being part of an energy cooperative are the other two variables which influence technology support. Technology support is defined in this study as "the evaluation of all households to positively or negatively support and adopt newly introduced technology". This output is further discussed in this chapter. Interactions between households influence the value orientation of the neighborhood and therefore indirectly influence value satisfaction. The more the values are satisfied, the more the technology is supported.

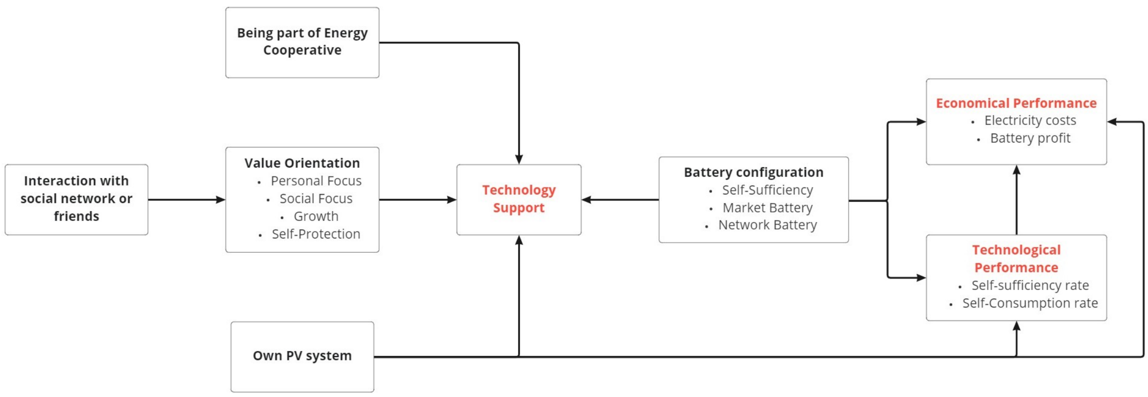


Figure 4.1: Conceptual Model overview

The objective of the agent based model is to show the influence of different battery configurations on technology support of the battery by the neighborhood and on the technological and economical performance of the battery. The outputs of the model can be compared to see if value orientations match the outputs from the economical and technical performance of the battery. During the experiments, households will interact and influence each other's value orientations. Moreover, pre-defined characteristics of the households (e.g. PV production, values, being part of a community, and social network) influence the output variety.

4.2. TECHNICAL SUB-MODEL

Modelling the Grid

The electricity network is modelled using a 15-minute profile from NEDU, 2021 for the household demand and PV production. By multiplying the profiles to the yearly load or supply, the household demand and supply for every 15 minutes are obtained. The household yearly demand differs per user and therefore three different users are chosen based on the data from Liander, 2022: 'single', 'family', 'elderly'.

These are chosen as their yearly total household demand differ significantly. Data about demand is obtained from Liander, 2022, while the yearly PV production can be obtained with the following equation (Consumentenbond, 2022):

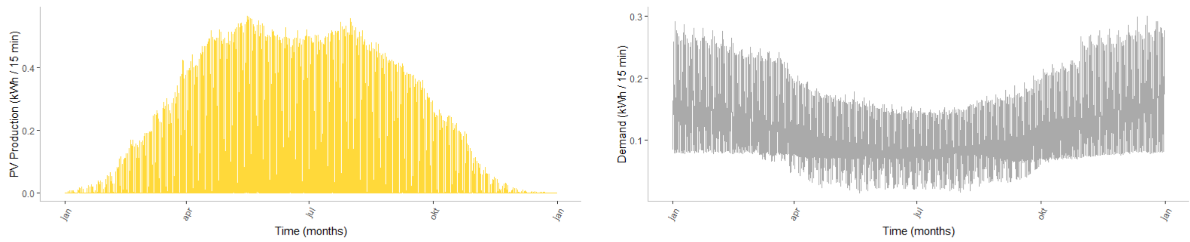
$$E_{PV_{year}} = n * P_{nom} * \eta_{PV} \tag{4.1}$$

where n is the number of panels, P_{nom} is the nominal power of a panel and η_{PV} is the performance factor of the system. The parameters used for the household demand and PV production can be found in 4.1. The electricity import from the grid is calculated by subtracting E_{PV} and $E_{Battery}$ from household

Parameter	Value	Unit
Household Yearly Demand Family	4100	kWh
Household Yearly Demand Single	3394	kWh
Household Yearly Demand Elderly	2471	kWh
Nominal power per PV module	300	W
Number of PV panels	10	–
Performance factor PV system	0.85	–

Table 4.1: Household and PV parameters assumed for the model

E_{demand}. The amount of households in the model can be adjusted with the parameter $AMOUNT-HOUSEHOLDS$, while PV penetration in the neighborhood is adjusted with $PV-HOUSEHOLDS$. In figure 4.8 both the profiles modelled for PV production (left figure 4.2a) and households demand (right figure 4.2b) are shown. The seasonal mismatch between supply and demand is clearly visible.



(a) PV production

(b) Household demand

Figure 4.2: Household Electricity Demand and Supply Profiles

Modelling the Battery

The neighborhood battery used in this study is based on lithium-ion battery technology, as this technology is widely used for residential and utility applications (Dong et al., 2020). This means the battery data and operations are based on this technology. The modeled battery is a large battery which is connected to all households and can be owned by the community itself, energy retailer or a third party. Determining the battery sizing is key for the technical sub-model and for making an economic analysis in the economic sub-model. The assumption is made that the feed-in power from PV will not be subsidised in the future. Therefore the battery sizing is based on optimizing maximum self-consumption with the method of van der Stelt et al., 2018. Each household needs to be able to store their injected surplus power a certain percentage of the time in the neighborhood battery. The formula for required battery capacity per household can be determined using the formula from van der Stelt et al., 2018:

$$Cap^{i}_{NSB} = \frac{E^{i}_{grid,inj}}{(SoC_{max} - SoC_{min}) * \eta_{cha}} \tag{4.2}$$

where $E^{i}_{grid,inj}$ is the maximum power grid injection from household i, SoC_{max} and SoC_{min} are the maximum and minimum state of charge of the battery respectively, and η_{cha} is the charging efficiency. For the total capacity of the battery the sum of all required household capacity is used:

$$Cap_{NSB,agg} = \sum_{i \in N} Cap^{i}_{NSB} \tag{4.3}$$

Parameter	Value	Unit
SoC_{min}	25	%
SoC_{max}	90	%
SoC_0	50	%
$\eta_{ch} = \eta_{dis}$	0.95	–
Battery degradation	0.008	%/battery cycle

Table 4.2: Battery parameters assumed for the model

The battery's technical configurations can be found in table 4.2.

In section 3.3 three different neighborhood batteries have been described, as these have been from current neighborhood battery developments. All three batteries are designed with different strategies, therefore the operationalisation of the battery in the model differs per battery. Below the description per battery:

- **Market Battery** The market battery buys electricity on the grid when the price is low, and sells electricity when the price is high. The goal of this configuration is minimising the total electricity costs for all households by shifting the supply load to moments of high demand and creating higher battery profits. An advantage with this battery, is that every households with and without PV can participate. The battery can already operate on the market without PV production. This should create a equitable opportunity for every household to use the battery.

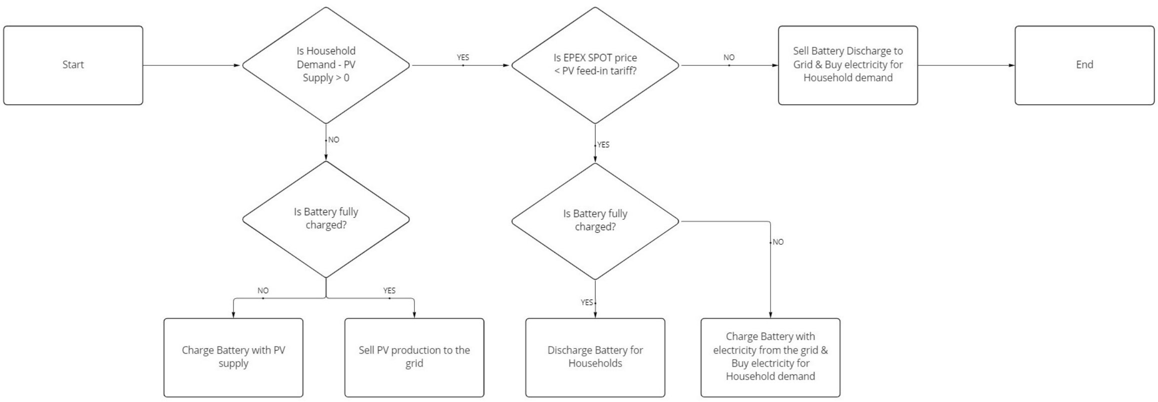


Figure 4.3: Market Battery decision process

- **Network Battery** This configuration is optimised to serve the balancing market and provide services for congestion management. Therefore, the neighborhood is indirectly linked to this battery, however the network operator would be an important actor for this battery. Any electricity left on the battery is used to lower demand peaks of the neighborhood. In the model the balancing market is conceptualised by using the data on the balancing capacity dispatched in 2021. This data can be found at TenneT, 2022, which includes FCR prices per 15 minute. Two scenarios are made for the battery: (i) The battery places a bid twice a day: between 4:00 and 8:00, and 18:00 and 22:00. Between these hours the battery can be used for the households under certain limits. (ii) The Battery is able to place bids the whole day long on the FCR market. SOC can not be lower than 35% and not more than 65%. This ensures the battery can be used during the FCR balancing blocks. Also, before starting a new bid, the SOC levels must have returned to these limits before the battery can participate again. Figure 4.4 shows the network battery decision flow diagram which is followed in the model.
- **Self-Sufficiency Battery** Lastly, this configuration increases the independence of the neighborhood by storing locally produced energy and maximizing local energy usage. The electricity on the battery is discharged when demand in the neighborhood is high and solar energy production

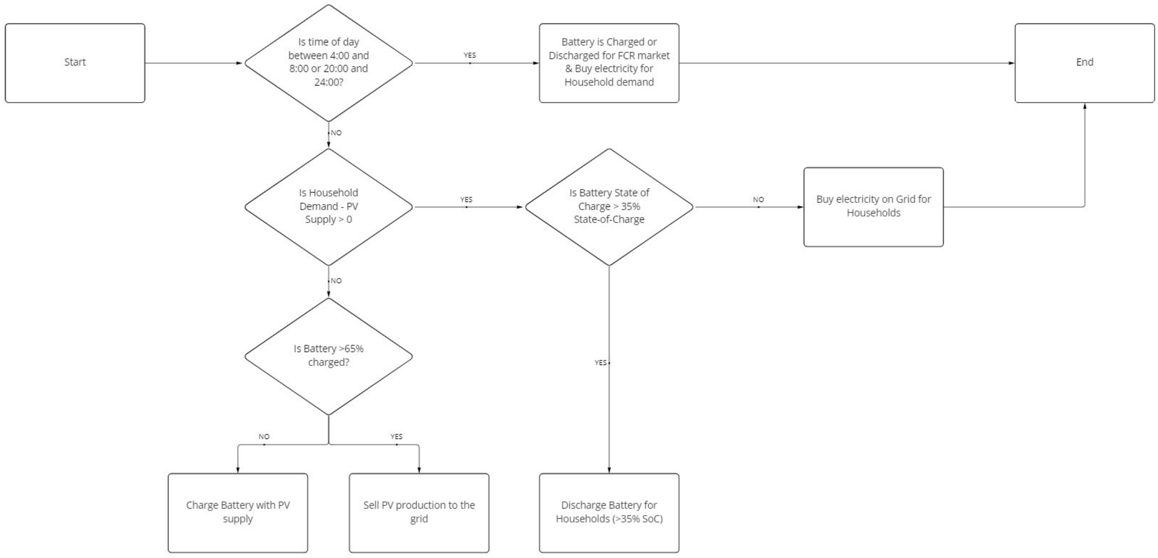


Figure 4.4: Network battery decision process

is low. The goal of this battery is to increase local electricity usage. The decision flow diagram for the Self-sufficiency battery can be found in figure 4.5.

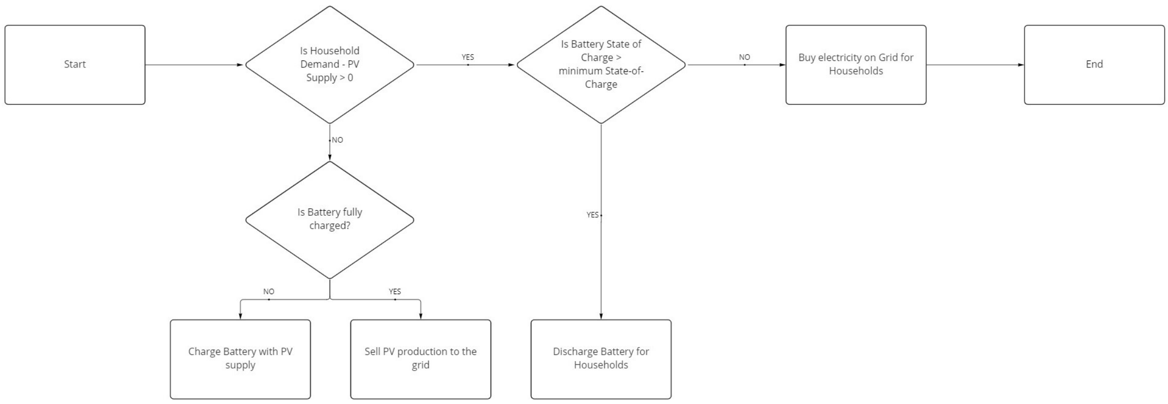


Figure 4.5: Self-sufficiency Battery decision process

Evaluation parameters

The technical performance indicators used are $SELF - CONSUMPTION\ RATE$ and $SELF - SUFFICIENCY\ RATE$. The SCR is the the share of PV electricity that is used to cover one's own demand and the SSR is the total demand that is covered by household PV generation (Dong et al., 2020). The following equations are used:

$$SCR : Self - consumption - rate = \sum_{i=0}^{t} \frac{E_{PV_i} - E_{export_i}}{E_{PV_i}} \tag{4.4}$$

$$SSR : Self - sufficiency - rate = \sum_{i=0}^{t} \frac{E_{demand_i} - E_{import_i}}{E_{demand_i}} \tag{4.5}$$

where E_{PV_i} is the total generation of PV, E_{export_i} is the electricity not used to charge the battery or by the households and thus exported to the grid, E_{import_i} is the electricity needed by the household when neither PV or the battery can fulfill the demand and E_{demand_i} is the demand of a household (Dong et al., 2020).

4.3. SOCIAL SUB-MODEL

The social sub-model determines the decision-making process of the community for the neighborhood battery configuration. Although no wide-scale implementation of neighborhood batteries exist in the Netherlands, the social sub-model is supported by multiple theories. As households have different electricity demand E_{demand}, are part of a $SOCIAL-NETWORK$, have solar panels or not ($PV-HOUSEHOLDS$), have $VALUES$, and can be part of an energy community ($COMMUNITY$). Their choice for the kind of battery configuration is influenced differently. More specifically, households are equipped with values using Schwartz values explained in chapter 2 (Schwartz, 1992). The Schwartz values circumplex is used and Heidari et al., 2020 used for the theory on modelling values in Agent Based models. Schwartz identified ten universal values and the priority of these value determines what people strive for in their social environments (Boshuijzen-van Burken et al., 2020). The priorities help creating better predictions about individual's perspectives when modelling decision-making processes (Boshuijzen-van Burken et al., 2020). Schwartz organized the ten universal values in four clusters: Openness-to-change V_{OPEN}, Self-Transcendence V_{TRANS}, Conservation V_{CONS} and Self-Enhancement V_{ENHA}. In the model, combination of the four value clusters are used instead of all ten universal values for computational and simplicity reasons. These combinations are *Growth* (V_{TRANS} and V_{OPEN}), *Personal Focus* (V_{ENHA} and V_{OPEN}), *Social Focus* (V_{TRANS} and V_{CONS}) and *Self Protection* (V_{CONS} and V_{ENHA}) (Schwartz, 1992).

Modelling Values

The modelling of values is done with the method of Heidari et al., 2020. Values are used to guide the decision-making of the households and help prioritize between the different battery configurations the households can pursue. The value clusters with indexes V_{TRANS} = 1, V_{OPEN} = 2, V_{ENHA} = 3 and V_{CONS} = 4 are defined and τ which defines the *Importance* (range [0-100]). If τV_i = 0, than the value cluster is not important for the household, while τV_i = 100 means the value clusters is one of the most important values (Heidari et al., 2020). The relation between value clusters are also considered. Value clusters near each other are positively correlated, while opposite clusters are negatively correlated (see figure 2.3 for full Schwartz circumplex and 4.3). The following condition is used to ensure this in the model:

$$\forall i,j \in [1...4] : 0 \leq \tau V_i - \tau \leq Diss_{i,j} \tag{4.6}$$

where $Dissi,j$ is the upper boundary for the dissimilarity between the importance τ of V_i and V_j. The upper boundary is determined with the index of the value cluster and the parameter c which is set to 50.

$$Diss_{i,j} = \begin{cases} |i-j| * c & \text{if } |i-j| \leq 1 \\ 4 - |i-j| * c & \text{if } |i-j| > 1 \end{cases} \tag{4.7}$$

In the model, one of the value systems is chosen which is than normally distributed over the households.

	Openness-to-change	Self-Enhancement	Self-Transcendence	Conservation
Openness-to-change	-	Positive	Positive	Negative
Self-Enhancement	Positive	-	Negative	Positive
Self-Transcendence	Positive	Negative	-	Positive
Conservation	Negative	Positive	Positive	-

Table 4.3: Correlation between value clusters

The parameters of the normal distribution can be found in table 4.6). By adjusting the $value-std-dev$ the value systems can be more or less heterogeneous. In figure 4.6 an example of the value distribution can be seen which is set to *Personal Focus* in the neighborhood.

Modelling the neighborhood

The initiated households are connected in two ways. Each household has a $SOCIAL-NETWORK$ which is formed by links with households with similar value orientations and random $FRIENDS$. This process is described by Ghorbani et al., 2021 and is based on the principle of homophily, which describes the tendency of people to associate and connect with similar others. $FRIENDS$ ensures the network is connected between the clusters of households within the social network. This is done by creating random links with the parameter $friends-mean$, which can be set between 0 and 1 (Ghorbani

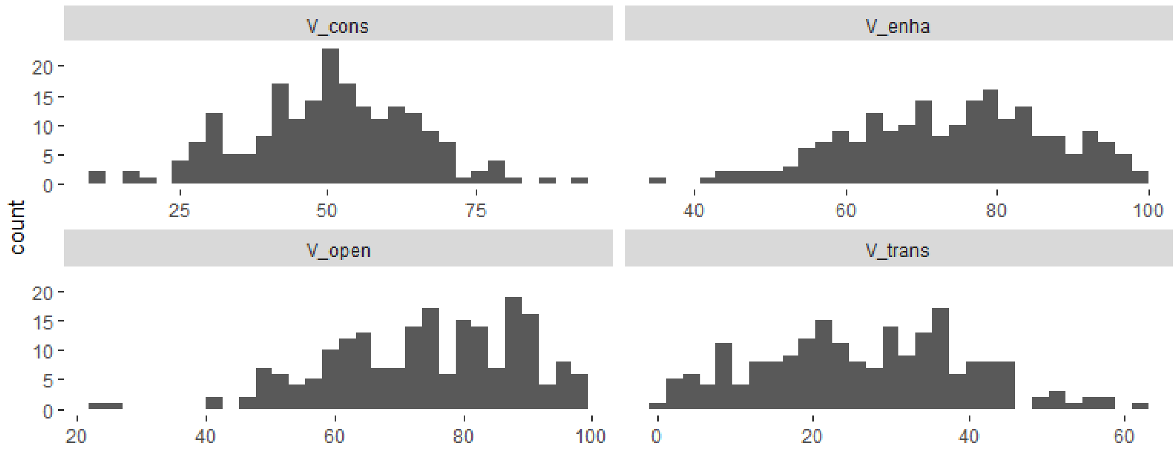


Figure 4.6: Value distribution of all households when Personal Focus (V_{ENHA} and V_{OPEN} dominant) is chosen as value system

et al., 2021). Subsequently, Ghorbani et al., 2021 describes the similarity of two agents by the social distance that exists between two agents. To compute the social distance between two households, the Euclidean Distance between two Value systems i.e. X and Y are calculated.

$$SocialDistance_{X,Y} = \sqrt{\sum_{i=1}^{4}(X_i - Y_i)^2} \tag{4.8}$$

The social distance is used to determine the value system similarity of two households. The households create links with the strongest similar households.

Households can also be connected by a $COMMUNITY$. As described in chapter 3, energy communities are very likely to invest in neighborhood batteries to share electricity within their community. Therefore, $COMMUNITY$ is modelled as such that the household can be part of the energy community or not and $community - size$ determines the size of the energy community.

Modelling value influence

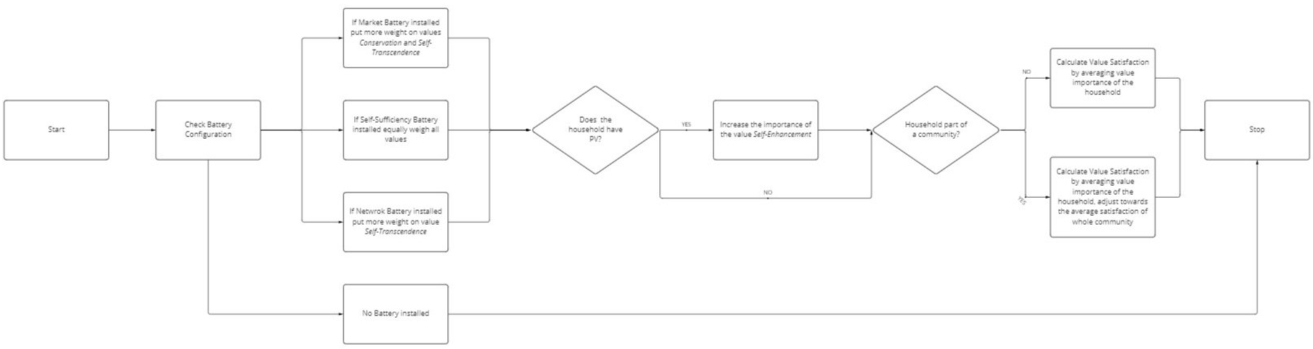


Figure 4.7: Value satisfaction conceptual flow diagram

Figure 4.7 show the flow diagram of a household to determine its value satisfaction. This is used to calculate $TECHNOLOGY - SUPPORT$ which is explained below. Since the three batteries have different purposes, it should be clear which values they satisfy. Consequently, the purpose of the battery can be connected to the more abstract value clusters from Schwartz. Heidari et al., 2020 used the concept of *value trees* to connect actions to more abstract values. This enables to organise actions and more concrete value to the universal clusters from Schwartz. Also, multiple concrete values can be assigned to multiple clusters. Therefore, some battery configurations could be preferred by multiple households. It is important to adequately translate concrete characteristics of some functions of the neighborhood battery to more abstract values. The translation is done by myself. Although multiple perspectives could be given for a battery function or goal, the list of function translations to goals is carefully set up and verified using the papers from Ambrosio-Albala et al., 2020; Hoffmann and Mohaupt, 2020. The more concrete values are based on the study from Ransan-Cooper et al., 2022 which was introduced previous chapter. In table 4.4 the Schwartz values are linked to more concrete values related to the batteries.

Schwartz Values	Public Values	Description
Self-Enhancement	Autonomy & Power	Desire to have social status and prestige, control or dominance over people or resources
Self-Transcendence	Environment & Nature Social Justice & Fairness	Desire to preserve and enhance the welfare of others
Openness-to-Change	Autonomy	Desire to have independent thought and action, choosing, creating and exploring, challenging one-self
Conservation	Security & Stability Social Capital (community feeling)	Desire to maintain social norms and cultural heritage, and stability of society, of relationships and safety

Table 4.4: Value tree links between Schwartz Values and Public Values from Ransan-Cooper et al., 2022

The households want to satisfy their value orientations as much as possible. Certain battery configurations satisfy some values more than others and are therefore preferable for some households depending on their value orientations. Also, it is possible for some value to be connected to multiple Schwartz values. *Self-Enhancement* is connected to Autonomy & Power. *Self-Transcendence* is connected to both Environment & Nature, and Social Justice & Fairness. *Openness-to-change* is connected to Autonomy. Power is not included as it does not match the *Openness-to-change* value. *Conservation* is connected to Security & Stability and Social Capital. Social capital can also translated as the need of community feeling. Although the value *Efficiency* was introduced in chapter 3, it is not included as all three batteries are considered efficient. In table 4.5 below an overview is seen which battery configuration satisfies which public value.

Public Value	Battery configuration	Description
Autonomy & Power	Self-sufficiency	In this configuration the battery supports grid independence and all produced electricity from the neighborhood is used within the community. This ensures more autonomy for the neighborhood. Also, the Self Sufficiency battery could be implemented independently and therefore gives more 'Power' to the neighborhood.
Environment & Nature	Self-sufficiency Network battery	Both these battery configurations could increase the use of renewables within the neighborhood. The Self-Sufficiency battery by decreasing peaks on the grid and making it more tempting to combine with PV. And the Network Battery helps to relief grid congestion and frequency problems, which indirectly helps renewable developments
Social Justice & Fairness	Network Battery Market Battery	These configurations are most 'fair' for PV and not PV users and could divide the battery profits equally. The Market and Network Battery are able to trade on the markets and create a profit without PV production. Therefore, households without PV could benefit from these batteries.
Security & Stability	Self-sufficiency	This configuration ensures supply security when PV can not deliver and thus provides a stable back-up. The Network battery is reserved for grid services and is therefore not providing stability for the neighborhood. The Market Battery is optimized for trading.
Social Capital	Market Battery (Self-sufficiency)	The Market battery creates profit for all participating households and would be easily for a community to join. This could enhance the group feeling of the neighborhood. (The Self-sufficiency configuration could increase community feeling if not-PV households are also benefiting, but this depends on the business-case. (No existing examples are available))

Table 4.5: Value satisfaction by battery configuration

Another assumption is made about the influence of the community on the value satisfaction of a household. When the household is part of a community, it is assumed the value satisfaction is dependent on the average value orientations of the community. As the household is already part of the community they follow the average need and strategy of the whole community. Therefore, households part of a community increase or decrease the value satisfaction depending if it is above or below 50% supportive of the battery. The standard deviation of the community is used to adjust the value satisfaction of community members.

The social network of the household can also influence its value orientations. Each day (every 96 ticks) a random encounter occurs between two connected households which than increase or decrease the value clusters by 10% depending of the value orientation of the other agent (see next chapter for sensitivity analysis) (Ghorbani et al., 2020).

Household PV ownership has an influence on which battery configuration is favored as PV owners would like to use the battery to increase their self-consumption and grid independence (Hoffmann and Mohaupt, 2020). Participation in a neighborhood battery is therefore considered to be mostly favorable when already owning a PV system. In the model, this is incorporated by increasing the value satisfaction levels for Self-Enhancement of PV owners by 25% (see next chapter for sensitivity analysis).

Age, gender, PV ownership, income and house ownership are not considered for the decision making process. In the study of Koirala, Araghi, et al., 2018 these factors were not found to be significant predictors for households to be part of energy community system and therefore age, gender, income and house ownership are not considered in the model. However, PV ownership is considered important for a neighborhood battery as a battery system complements the PV system.

Evaluation parameters
In order to evaluate the social aspect of the model a new parameter is introduced: $TECHNOLOGY-SUPPORT$, which shows the 'fit' of the battery configuration with the neighborhood and is the mean value satisfaction level:

$$Technology - support = \frac{\sum_{i=1}(Value_{sat_i})}{TOTAL - HOUSEHOLDS} \tag{4.9}$$

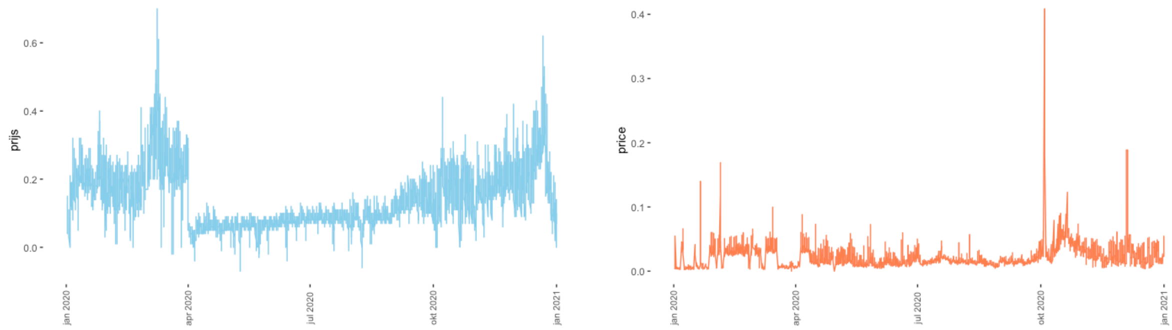
where $Value_{sat_i}$ is the value satisfaction level per household. With this equation the technology support can be evaluated for each different neighborhood value orientation. The average of all households is chosen as this represents the support of the whole neighborhood. As neighborhood battery implementation will have more success with full participation of the community, it is important to compare the batteries in terms of the aggregated satisfaction.

4.4. ECONOMICAL SUB-MODEL

The Economical sub-model provides a good tool to compare the save electricity costs and battery profits for the different scenarios. As three battery configurations have different charging and discharging strategies, their electricity sold differs per configuration. Also, profits earned on the FCR market and intraday market differ. The price time-series of the FCR market and the intraday market can be found in figure 4.8a and 4.8b. The intraday prices make a large drop around April 2020, as the prices from April 2021 to April 2022 were available. The first months of 2022 were used for the beginning of 2021 to fill the data gap. The figures show the difference between the markets, as intraday has higher prices per kWh than FCR. However, assets available for the FCR market are also paid a capacity price for the available capacity in €/MW. In 2021, the average capacity price was 25 €/MW (TenneT, 2022). Three parameters are considered in the model: profit made on the FCR market made by the network battery $Profit_{FCR}$, profit made on the spot market by the market battery $Profit_{spot}$ and finally the costs of electricity for the households $Costs_j$. Last parameter considers all profit from electricity sold to the grid by the households, or the avoided costs by the households due to the battery installed.

Evaluation parameters
To evaluate the performance of the different scenarios, the individual household costs and the aggregated household costs of the households are used, see equations 4.10 and 4.11 below. (Pena-Bello et al., 2021).

$$Costs_j = \sum_{i=1}^{t}(E_{grid-to-house_i} * p_{retail_i} - E_{house-to-grid_i} * p_{feed-in-tariff_i}) \tag{4.10}$$



(a) Intraday prices

(b) FCR price

Figure 4.8: Household Electricity Demand and Supply Profiles

$$Total - costs = \sum_{j=0}^{H}(Costs_j) \tag{4.11}$$

$$Total - profits = Profit_{FCR} + Profit_{spot} \tag{4.12}$$

where, $E_{grid-to-house_i}$ is the electricity demand of the household j at time i and $E_{house-to-grid_i}$ is the electricity supplied back to the grid. p_{retail_i} and $p_{feed-in-tariff_i}$ are the retail electricity price and the feed-in-tariff at time i respectively. The profits of the battery are calculated by measuring the profit made on the FCR or intraday market (see equation 4.12).

4.5. OVERVIEW

Table 4.6 shows an overview of all parameter inputs in the interface of the Agent Based Model. Internal parameters used for functions are not shown, but are described in previous paragraphs. These parameters are used to verify the model, perform the sensitivity analysis and finally, as experiment inputs.

Parameter	Type	Value	Comment
Amount of Households	Range	50-250	TenneT, 2022
Households with PV	Range	0%-100%	Percentage of total households with PV
PV-influence	Range	0-100%	Percentage of change on Self-Enhancement value when having PV
friends-mean	Range	0-1	Ghorbani et al., 2021
social-network-mean	Range	0-1	Ghorbani et al., 2021
interaction-change	Range	0-100%	Percentage of change in value orientation when interacting
community-size	Range	0-100	Percentage of total households part of the energy community
value-mean	Range	1-100	Mean for the Normal Distribution
value-std-dev	Range	1-100	Standard Deviation for the Normal Deviation
Value configuration	Chooser	Social-Focus, Personal Focus, Growth, Self-protection	
Battery-configuration	Chooser	No-Battery, Self-Sufficiency-battery, Market-battery, Network-Battery	

Table 4.6: Agent-Based model parameter overview

Three sub-models were presented in this chapter with evaluation parameters to adequately evaluate the implemented sub-model. These evaluation parameters will be important for the outcomes of the experiments. Below the evaluation parameters are mentioned again:

- Self-Sufficiency Rate SSR (formula 4.5)
- Self-Consumption Rate SCR (formula 4.4)
- $Technology - support$ (formula 4.9)
- $Total - Costs$ (formula 4.11)

5
MODEL IMPLEMENTATION

This chapter discusses the model verification (*is the model built right*) and the validation (*does the model achieves its purpose*). Both steps are done according Nikolic and Ghorbani, 2011 to ensure proper model testing. Furthermore, a sensitivity analysis is done by varying the model input parameters by using Latin Hypercube Sampling and finally the experiment setups are introduced in this chapter.

5.1. VERIFICATION

Model verification is a continuous process when building a (agent-based) model. During the process of model implementation many iterations are done to create a correctly functioning Agent-Based Model. Nikolic and Ghorbani, 2011 define verification to check the model against its conceptual design and see if all sub-models and relevant relationships are correctly implemented into the agent-based model. Three phases are considered for verification complex agent-based models (Nikolic and Ghorbani, 2011):

- Single Agent Testing
- Interaction testing, limited to minimal model
- Multi-agent testing

Single Agent Testing

Single agent testing is used to verify the behaviour of one agent, or in this case, one household. As stochastic uncertainty is implemented in the model, which means random inputs are given, the households outputs should first be tested under normal conditions. Next, household outputs should be checked under extreme value inputs. Single agent testing was repeatedly performed after implementing the sub-models from the conceptual model. By doing so, verification was continuously ensured and modelling errors were avoided.

Interaction Testing

The minimal amount of households in the model is 50 households. All interactions, single agents outputs and model outputs seem correct when repeatedly doing the minimal agent test.

Multi-agent Testing

The last verification step is used to test overall model behaviour and includes variability testing (Nikolic and Ghorbani, 2011). By performing many repetitions (10-500), the variability of the outcomes is tested and could show rare output outliers. The skewness and kurtosis tests helps examine the output variability. The skewness tests the asymmetry of the distribution of the model outcomes. A negative skew means the tail is on the left of the distribution, which indicates more negative values. A positive skewness indicate more positive values of the tail. The kurtosis tests how large the 'tail' of the distribution is. If the Kurtosis is more than 3, the distribution shows more outliers than a normal distribution. If it is less than 3, the produces less outliers than a normal distribution.

The Self-Sufficiency-battery Scenario is chosen to be repeated and the output variables $Total-Costs$, $Technology-Support$, SSR and SCR are measured. The repetition are done with the *Self-sufficiency* Battery and the *Self-Protection* value orientation. In the table below, the skewness and kurtosis values for each repetition can be found.

The SSR and $Total-costs$ show Skewness near 0 and Kurtosis near 3 for all repetitions which correspond to a normal distribution. When repetitions increase, the value is closer to 0 and 3 which show

Repetitions	Metric	Skewness	Kurtosis
10	SSR	0.35	3.11
10	Total Costs	-0.78	3.55
10	Technology Support	2.43	7.38
50	SSR	0.12	2.16
50	Total Costs	-0.06	2.68
50	Technology Support	2.5	7.73
100	SSR	-0.118	2.93
100	Total costs	0.01	2.74
100	Technology support	4.66	25.62
200	SSR	0.21	2.97
200	Total costs	-0.24	2.97
200	Technology support	3.9	18.90
500	SSR	0.01	3.12
500	Total costs	-0.03	3.08
500	Technology support	4.31	19.5

Table 5.1: Skewness and Kurtosis outputs with different repetitions

more constant results. The skewness and kurtosis for $Technology - support$ show the distribution have a long right tail. The outliers are very extreme. When repetitions are increased this distribution is even more emphasized. This should be considered when interpreting the results. Extreme outliers occur more than rarely and are part of the behavior of the model. This effect can be explained through the influence of communities. If the community goes over a tipping point, it can fully support or not support the technology.

5.2. VALIDATION

Validation of the model is done to ensure the outcomes match observed reality and thus achieves its purpose (Nikolic and Ghorbani, 2011). As mentioned in Chapter 1, the objective of the model is to provide insight into the influence and community characteristics on the technology support. With this objective, the model is used to learn from the adoption of various neighborhood batteries in different kind of neighborhoods. Real life validation is very difficult. In The Netherlands, neighborhood batteries only exist due to pilots or other experimental projects. Few pilots have public records of their results and as each pilot has their own assumptions and rules, it is difficult to compare. This study uses trustworthy input data to have more reliable results.

The model has used real-world data on prices and electricity demand and supply from 2021 to resemble the grid as much as possible. Besides, the value part is based on the theory Schwartz and Bilsky, 1987 and responsible innovation from Correljé et al., 2015. Modelling values and value-based decision-making is been supported by studies from Heidari et al., 2020, Mercuur et al., 2019 and Burken et al., 2020. By using their theories and studies, outputs from the study are supported by strong theoretical backgrounds. Lastly, modeling experts have given their expertise to create a more viable model and check the implementation of the sub-models during the modelling process.

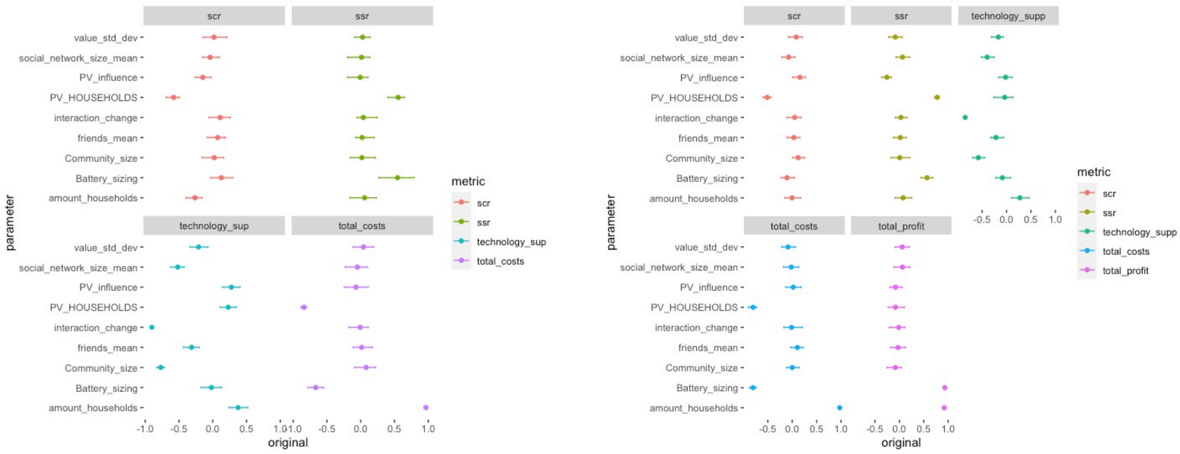
5.3. SENSITIVITY ANALYSIS

In addition to the verification and validation, a sensitivity analysis of the input parameters of the Agent-Based Model is done. A sensitivity analysis would explore the uncertainty of a input variable, however when multiple input parameters can have uncertainty, it becomes more complex. The Netlogo BehaviourSpace allows only full-factorial experiments, where every input possibility is combined with all other input possibilities (Wilensky, 1999). As this model has multiple uncertain input parameters this would take very long computational time. Latin Hypercube Sampling (LHS) is a possible method to deal with large input parameter sets (Nikolic and Ghorbani, 2011). LHS reduces the number of simulation runs needed by combining the possible varying input values in such a way, it substantially needs fewer samples and is able to produce similar results than a full factorial sensitivity analysis. Table 5.2 shows the input range of the LHS. Three samples are done for the three batteries. The LHS is done for the *Self Sufficiency Battery* with the *Self-Protection* value orientation scenario. The *Network Battery* is run with the *Growth* scenario and the *Market Battery* is done with th *Personal Focus* scenario. The four measured outputs are $Self - sufficiency - Rate$, $Self - Consumption - Rate$, $Total - Costs$ and $Technology - Support$, the $Total - Profit$ is included for the *Market* and *Network battery*.

Parameter	Minimum Value	Maximum Value
value-std-dev	5	50
value-mean	75	75
PV-Households	0	100
PV-influence	0	100
Community-size	0	100
social-network-size-mean	0.0	1
friends-mean	0.0	1
amount-households	50	250
interaction-change	0	100
Battery-sizing	0.5	3

Table 5.2: Parameters range for LHS

The results of the LHS are used for the sensitivity analysis. The Partial Rank Correlation coefficient (PCC) is used for the analysis of the sampling. PCC is used to show the independent relation between the parameter and the output. Figure 5.1a shows the PCC of each input parameter for all output metrics. This is the *Self-Sufficiency Battery* with *Self-Protection* scenario. Battery-sizing and PV-HOUSEHOLDS have a relatively large influence on the SSR outputs. This can be expected, as with more PV production and a larger battery more of its own demand can be covered. It also show battery size can be a limitation for the SSR. This influence can also be seen at the total costs metrics. More PV and a larger battery decreases the households costs. Amount of Households is very high as the total costs are the aggregated costs of all households, thus it has a direct influence by definition. The Technology Support output metric has more influences from the input metrics. The two largest influences are the influence of interaction between households and the Community size. Interaction-change can have a large impact if the parameter is set very high. This determines how much it will change the value importance after an interaction between households. The results show this should carefully be set and high values have a relatively high impact. This can have impact on other parameters such as social network or amount of friends. Most input parameters have a negative influence due to the *Self-Protection* scenario. Interestingly, more people within the neighborhood assures higher technology support on average.



(a) Partial Rank Correlation coefficients for Self-Sufficiency Battery LHS

(b) Partial Rank Correlation coefficients for Network Battery Growth scenario

Figure 5.1: LHS results

Figure 5.1b shows the PCC from the LHS done for the *Network Battery* with the *Growth Scenario*. The same effects can be seen for the input parameters for the SSR, SCR and total costs. Some difference can be seen compared to the LHS with the *Self-Sufficiency Battery*. Battery size does not have many variations in the LHS results for the *Network Battery*, while this was visible in the results of the *Self-Sufficiency Battery*. Moreover, the effects on Technology support in this scenario are equal to the case in figure 5.1a. Total profit is influence by the size of the battery and amount of households. The latter is interesting as more PV on households does not influence profit, but still has influence to decrease total costs. The amount of households determines the initial size of the battery and therefore it the effect can be seen here.

Lastly, the results of the LHS from the *Market Battery* are shown in figure 5.2. There are differences with the other two scenarios. Battery sizing has an unexpected negative influence on the SSR, while it has no influence in the total costs. The *Market Battery* increases the amount of trading with a larger battery. The amount of households has a larger effect on the technology support than the other scenarios. Due to the low support for the battery within this scenario, combined with high values of Self-Enhancement, the influence of owning PV has more influence on the total neighborhood.

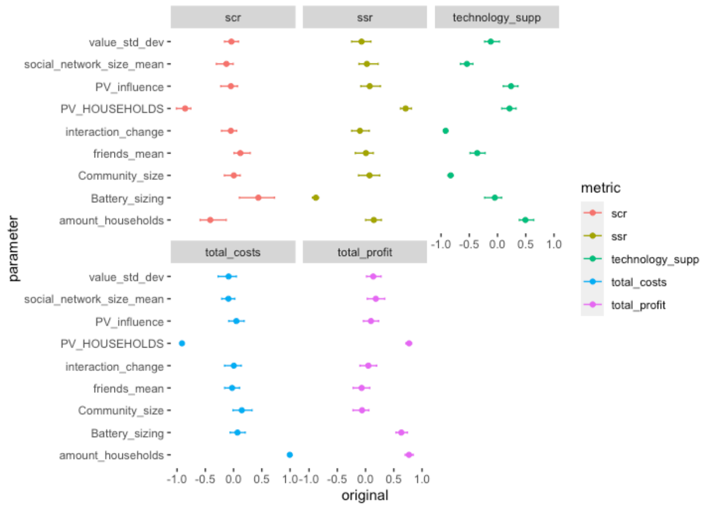


Figure 5.2: Partial Rank Correlation coefficients for Market Battery Personal Focus scenario

In conclusion, results for the three scenarios are relatively constant. The influence of interaction-change can have high impact and is therefore set to a lower end of the range. This ensures the influence is comparable to other influences within the model. Battery-sizing is kept constant within the model. Only the neighborhood size changes the battery size according equation 4.2 and 4.3. In the next paragraph the experiment setup is presented and explained.

5.4. EXPERIMENT SETUP

Three model experiments are setup to explore the influence of the different battery configuration on the neighborhood. All experiments and scenarios are run for 35040 ticks, where one tick is 15 minutes. This simulates one full year of the battery in use. By running one year, seasonal and daily variations are considered in the experiments. 15 minutes per tick is chosen since the data input is also given per quarter hour. As each model scenario has random numbers implemented, the experiment run is replicated 10 times. Although more replications would give better outputs, time limitations and model run time limit running the experiments. The model experiments are the following:

- The first experiment investigates the influence of PV penetration in the neighborhood on the economical and technical performance of the battery configurations. In table 5.3 the inputs for all parameters can be found. The parameters highlighted in red are changed with multiple scenarios.

- The second experiment analyses the influence of energy cooperatives in the neighborhood. This is done by increasing the community ratio in the neighborhood. This is done for all battery-

Parameter	Input
Value-configuration	Self-Protection
value-std-dev	20
value-mean	75
PV-Households	0-100 with steps of 10
PV-influence	30%
Community-size	40%
social-network-size-mean	0.8
friends-mean	0.15
Battery-configuration	No Battery, Self-Sufficiency, Market Battery, Network Battery
amount-households	50-250 with steps of 50
interaction-change	10%
Battery-sizing	1

Table 5.3: Parameters inputs first experiment

configurations. Also, the PV-Household parameter is varied between 10, 60 and 100% to test different kind of neighborhoods. In table 5.4 the inputs for all parameters can be found.

Parameter	Input
Value-configuration	Self-Protection
value-std-dev	20
value-mean	75
PV-Households	10, 60, 100
PV-influence	30%
Community-size	0-100% with steps of 20%
social-network-size-mean	0.8
friends-mean	0.15
Battery-configuration	Self-Sufficiency, Market Battery, Network Battery
amount-households	200
interaction-change	10%
Battery-sizing	1

Table 5.4: Parameters inputs second experiment

- The third experiment focuses on the effect of varying value orientations and distribution in the neighborhood. The value standard deviation parameter is adjusted such that more heterogeneous or homogeneous neighborhoods can be created. While the value standard deviation parameter is adjusted, the battery configuration are varied as well. As in previous experiment, the $PVHouseholds$ parameter is varied between 10, 60 and 100%. In table 5.5 the inputs for all parameters can be found.

Parameter	Input
Value-configuration	Personal Focus, Social Focus, Self-Protection, Growth
value-std-dev	5-45 with steps of 10
value-mean	75
PV-Households	10, 60, 100
PV-influence	30%
Community-size	40%
social-network-size-mean	0.8
friends-mean	0.15
Battery-configuration	Self-Sufficiency, Market Battery, Network Battery
amount-households	200
interaction-change	10%
Battery-sizing	1

Table 5.5: Parameters inputs third experiment

6
RESULTS

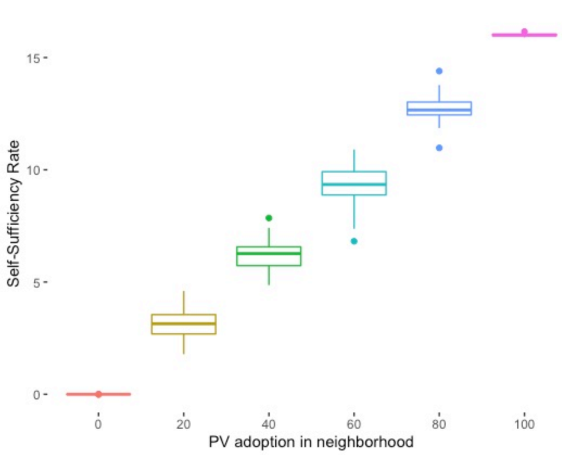
This chapter presents the results of the three executed experiments. The three experiments are done to answer the following sub-questions: *What neighborhood characteristics (values, social network, PV ownership) influence technology adoption and value satisfaction?* and *How do the various battery configuration perform technically and economically?* First, experiment 1 is shown without battery and with the various batter configurations, then experiment 2 and 3 are presented both with different neighborhood battery configurations.

6.1. EXPERIMENT 1: INCREASING PV IN THE NEIGHBORHOOD

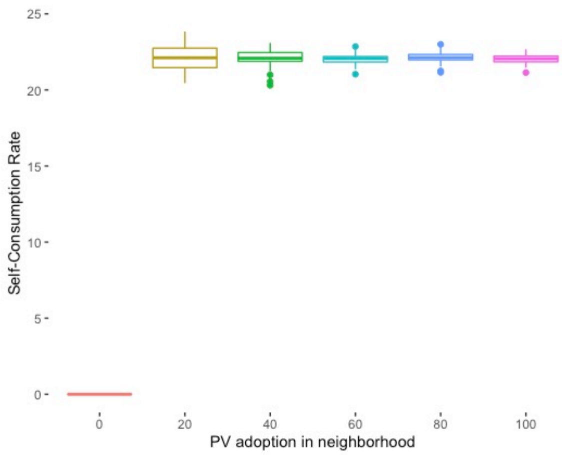
As explained in previous chapter, the first experiment focuses on the technological and economical performance of the battery configurations when PV penetration is increased in the neighborhood. First, the results without a battery in the neighborhood are presented, then the results with the battery are shown. In all battery configuration scenarios, the simulation has been repeated ten times, where the PV adoption in the neighborhood is increased from 0 to 100 in steps of 10, and the neighborhood size is varied from 50 to 250 in steps of 50. This gives a total of 550 runs for each scenario.

No Battery

Figure 6.1 shows the Self-Sufficiency rate (SSR) and Self Consumption rate (SCR) when increasing the PV penetration in the neighborhood from 0 to 100%. The experiments have been done with 50, 100, 150, 200 and 250 households. This shows the base scenario when no battery is installed in the neighborhood. When the PV penetration is increased, the SSR is linearly increasing as less electricity is needed from the grid. However, the SCR is constant when PV is increased. This confirms the mismatch between supply and demand with solar electricity, as PV electricity is required to be exported during the peak supply of PV. In the figure, more variation is seen between 0 and 100% than at 0 and 100%, due to the random distribution of PV in the neighborhood over low and high energy consumers at each run.



(a) SSR with increasing PV in neighborhood No Battery



(b) SCR with increasing PV in neighborhood No Battery

Figure 6.1: Self-sufficiency and -consumption rate with neighborhood size of 200 and different batteries

Figure 6.2 shows the total electricity costs for a neighborhood of 200 Households. The total electricity costs are the aggregated cost of each household and therefore shows if the neighborhood costs are improving or not. If PV penetration increases in the neighborhood, total electricity costs go down as expected. This is at aggregated level, as households without PV will have the same electricity costs.

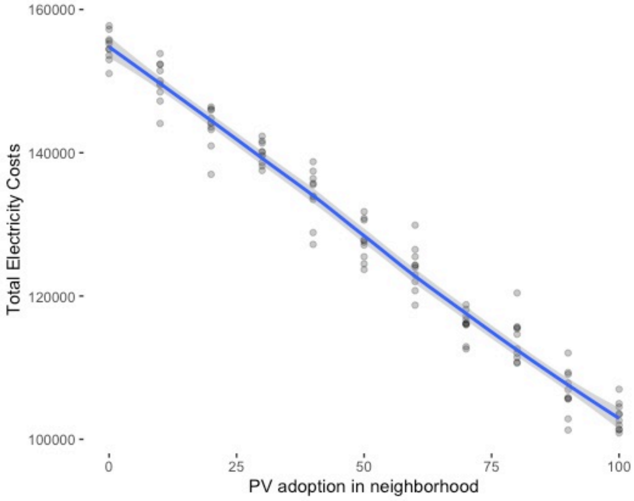


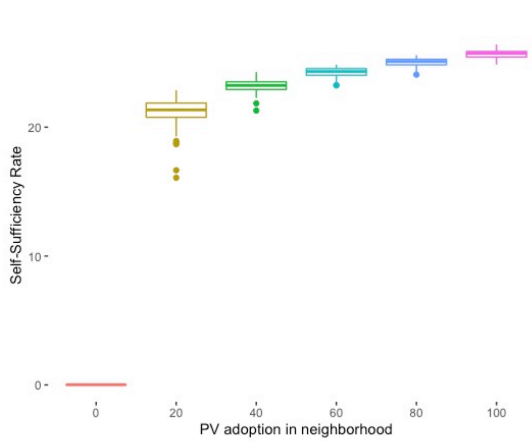
Figure 6.2: Total Electricity Costs with 200 Households and increasing PV penetration

Neighborhood with the Battery

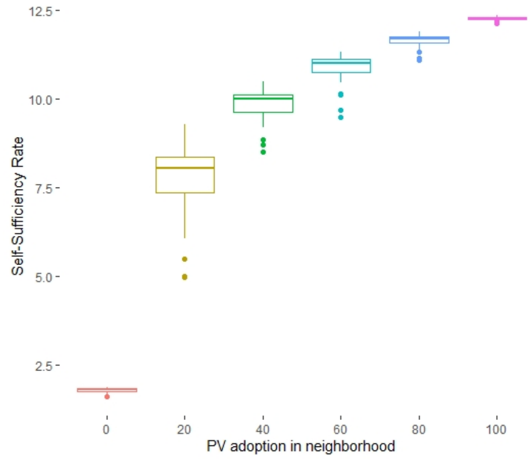
Figure 6.3 shows the SSR with the three various battery configurations. Again, the SSR expresses how much of the demand is covered by the PV production, while SCR expresses how much of the produced electricity is self-consumed. In the case of the Self Sufficiency Battery (figure 6.3a), the SSR is high at low PV penetration (20%), and increases gradually to approximately 25 % when PV penetration is increased to 100%. This is a large improvement compared to the *No Battery* scenario. The battery capacity is the limiting factor to an increasing SSR. At 20% PV penetration in the neighborhood, the Self-Sufficiency battery has multiple outliers lower than 20%. Due to the random distribution of PV and different demand profiles, a smaller neighborhood (50 Households) can have more variations in its output.

Figure 6.3b shows the SSR of the market battery. The SSR increase is steeper when PV penetration in the neighborhood is increased compared to the self-sufficiency battery. However, the overall SSR value is low and just a bit higher than the base case with no battery installed (see figure 6.1a). Neighborhoods with few solar panels show more variations than higher PV penetration. This is similar to the other battery configurations.

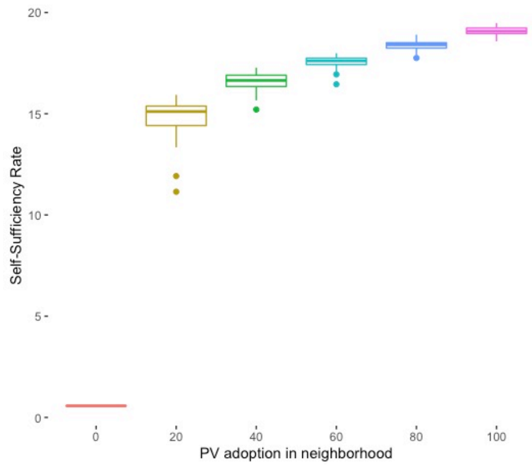
Both scenarios for the network battery are run, the part time and full time. The part time network battery places bids in the morning and evening, while the full time network battery places bids all day. Figure 6.3c and 6.3d shows the SSR results for both Network Batteries. The figures show a lower SSR than the self-sufficiency battery, but a comparable increase of the rate. While at lower PV penetrations in the neighborhood the network battery shows SSR results of 15%, higher PV penetrations show a SSR of just below 20%. Due to less capacity available in this battery, the SSR is understandably lower.
The Self-Consumption Rate (SCR) for all three battery configuration is also measured. Figure 6.4 shows the SCR of the three battery configurations. The self-sufficiency battery (figure 6.4a) shows a constant SCR over all PV penetration scenarios, except for the 20% PV penetration. This scenario shows a lot of variation and a higher SCR value. Due to randomly assigning which households have PV, households with low demand can be assigned PV and increase the SCR. Moreover, some interesting outliers can be found in these results. Compared to the results from the SSR, higher variability can be seen with the SCR values. Figure 6.4b shows the SCR of the market battery. The SCR decreases quickly to 35% when PV penetration is increased. Also less variations is seen at higher PV penetration. The PArt time Network battery shows very constant SCR outputs with little variability (6.4c). The overall SCR is very low, thus a lot of the produced PV is exported to the grid. Lower PV penetrations show more



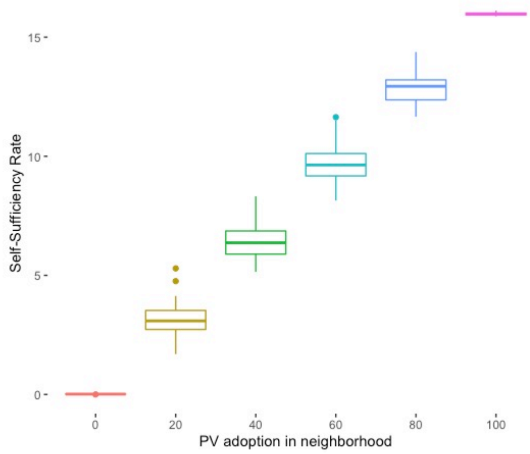
(a) SSR with increasing PV in neighborhood Self Sufficiency Battery



(b) SSR with increasing PV in neighborhood Market Battery



(c) SSR with increasing PV in neighborhood Network Battery Part Time



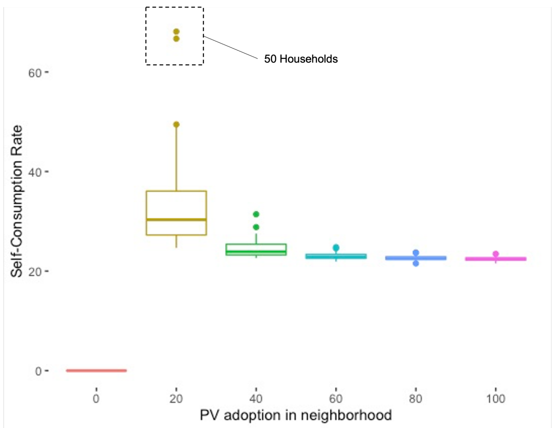
(d) SSR with increasing PV in neighborhood Network Battery Full Time

Figure 6.3: Self-sufficiency rate with various neighborhood sizes and different batteries

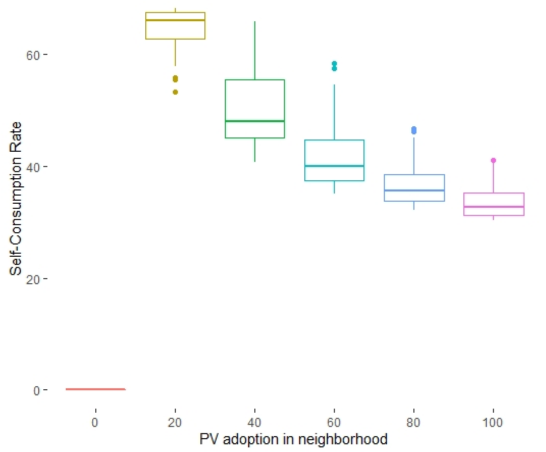
variations similar to the market and self-sufficiency battery. The Full Time Network Battery shows the same trend as the No Battery scenario. This confirms the battery has no effect on more consumption of renewable energy within the neighborhood.

Figure 6.5a show the electricity costs of the households after implementing the *Self-Sufficiency Battery*, *Market Battery* and *Network Battery*. These results are with a neighborhood of 200 Households and battery of 379 kW / kWh. The scenario with *No Battery* is also included to show the difference with the battery scenarios. The *Self-Sufficiency battery* only charges when too much electricity is produced by the neighborhood and thus costs only start to go down when PV is available in the neighborhood. When PV penetration is increased in the neighborhood, the *Self-sufficiency battery* shows decreasing total electricity costs. However, the electricity costs of the *No Battery* scenario decrease with a steeper rate when PV is increased, due to the available feed-in tariff. This decreases the gap in costs between the *self-sufficiency* and *no battery* scenario's and a small gap in costs can be seen when 100% of PV penetration is reached.

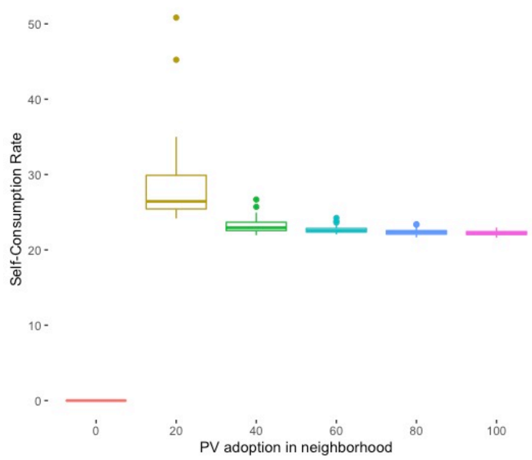
The *Market Battery* can already operate at 0% PV by buying cheap electricity from the grid and using the electricity for households or selling it to the grid. Experiments show the market battery needs to make a trade-off between supplying the households or selling its electricity to the grid. Battery decision was based on profitability for the battery. This means it was sometimes more profitable for the neighborhood to use the electricity from the battery due to high electricity prices. The PV penetration has



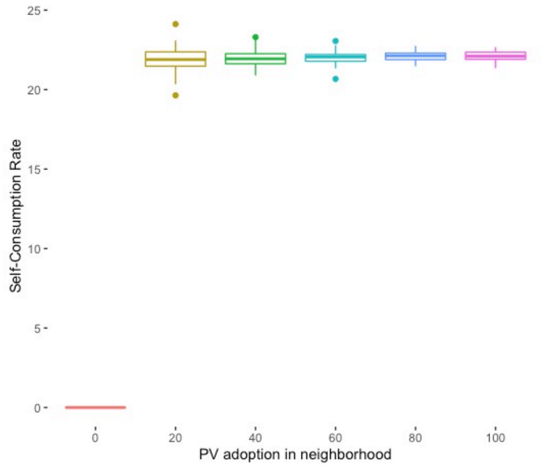
(a) SCR with increasing PV in neighborhood Self Sufficiency Battery



(b) SCR with increasing PV in neighborhood Market Battery



(c) SCR with increasing PV in neighborhood Network Battery

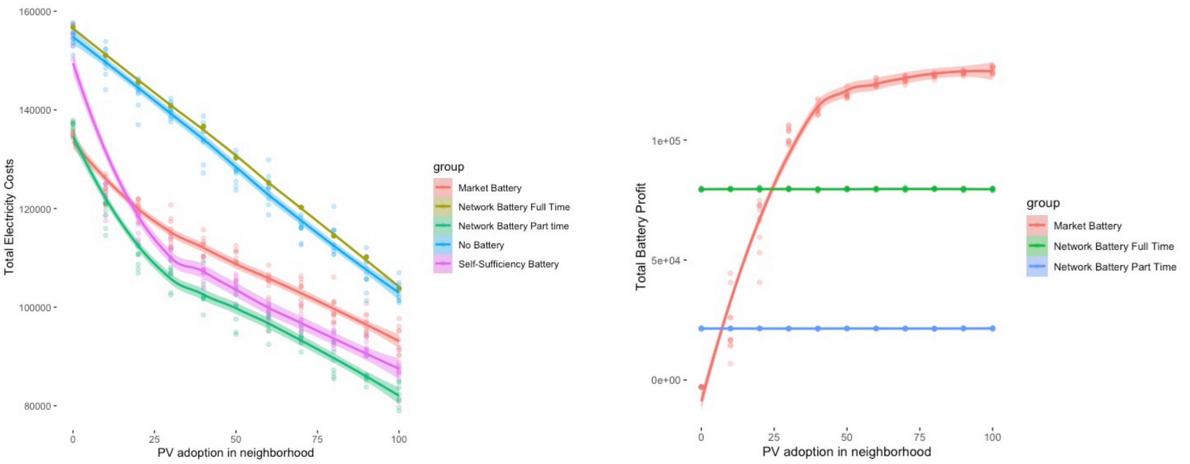


(d) SCR with increasing PV in neighborhood Network Battery Full Time

Figure 6.4: Self-consumption rate with various neighborhood sizes and different batteries

less effect on the total households costs, than it has on the performance of the *Self-sufficiency* and *Part time Network battery* on total costs. However, the *Market Battery* is having significant more profit in a neighborhood with more PV. This prevents the battery to buy expensive electricity on the market and sell it for a bit more. The margins created are significantly larger with more PV production.

The Part time *Network Battery* shows the lowest electricity costs. This corresponds with the high SSR values that was seen for this battery. The relative performance of the battery on this metric is better with low PV penetration. By using the battery on the FCR market, the battery will be empty more often and can than be used for the households during the day. This decreases the total costs. The Full time *Network Battery* shows no difference in household costs, as the households can not use the battery. However, an increase profit can be seen if compared to the part time scenario. The *Network Battery* has more revenue in a neighborhood with low PV production, but will be caught up when PV penetration is increased.



(a) Total Electricity Costs with 200 Households and increasing PV penetration

(b) Total Battery Profit with 200 Households and increasing PV penetration

Figure 6.5: Electricity Costs and Battery Profit for the three different battery configurations

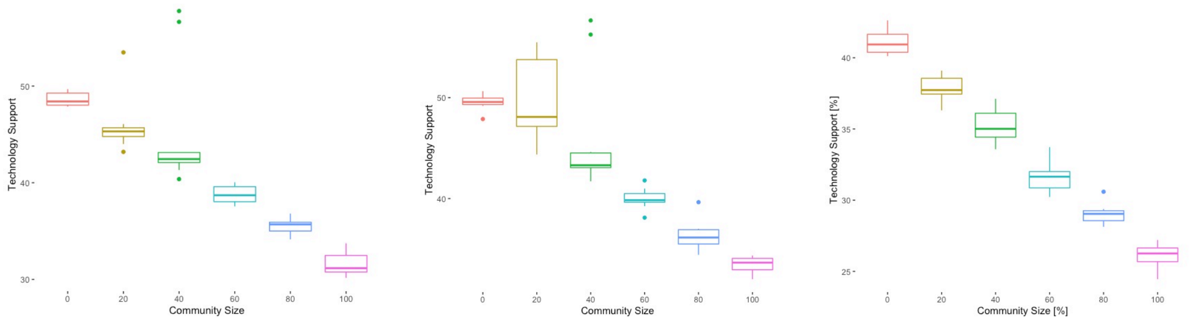
6.2. EXPERIMENT 2: INCREASING COMMUNITY RATIO IN THE NEIGHBORHOOD

The second experiment increases the community size in the neighborhood. As explained before, being part of an energy cooperative (”community”) can influence the technology support within the neighborhood. The size of the community is increased from 0% to 100% with steps of 20%. These steps are all tested with neighborhoods with PV penetrations of 10, 60 and 100%. The experiment is done with all three battery configurations. The value configurations chosen for all runs are *Self-Protection* and *Growth*. All runs have been repeated 10 times, which gives a total of 180 runs for each battery configuration.

Self-Protection

Figure 6.6 shows the technology support for increasing community size. All the batteries show a decreasing trend in support when community size is increased. Due to the support being initially around 50% for the batteries with this value configuration, the community is more easily moved towards a downward trend to decrease the support, than the opposite. This is due to the combination of social and friend interactions within the neighborhood which influence the technology support negatively (see the sensitivity analysis in chapter 5). However, some interesting outliers are visible in the figure. At 60%, 40% community sizes have high outliers towards the 60% technology support. Yet, these outliers are not visible anymore in larger community sizes and the sensitivity analyses showed outliers can be expected. These positive outliers are possible if the community is by chance all above 50% supportive for the battery.

Figure 6.6b shows the results for the Market Battery. The increased community size decreases the support for the battery. The overall variety is never more than 5% within the different runs. Figure 6.6c shows the results with the Network Battery. The graphs show the same trend as the two other batteries. When the community size is increased, the $TECHNOLOGY - SUPPORT$ decreases. In this scenario, the $TECHNOLOGY - SUPPORT$ is already below 50% when the community size is small. Thus, without community influence, the neighborhood does not support this battery very much. This could also explain why there are no positive outliers visible in this scenario. With the other two batteries, outliers to positive $TECHNOLOGY - SUPPORT$ could be seen when the neighborhood was increased. Yet, the Network battery does not show any outliers, but a strong decreasing trend.



(a) Self-Sufficiency Battery with increasing community size at 60% PV penetration

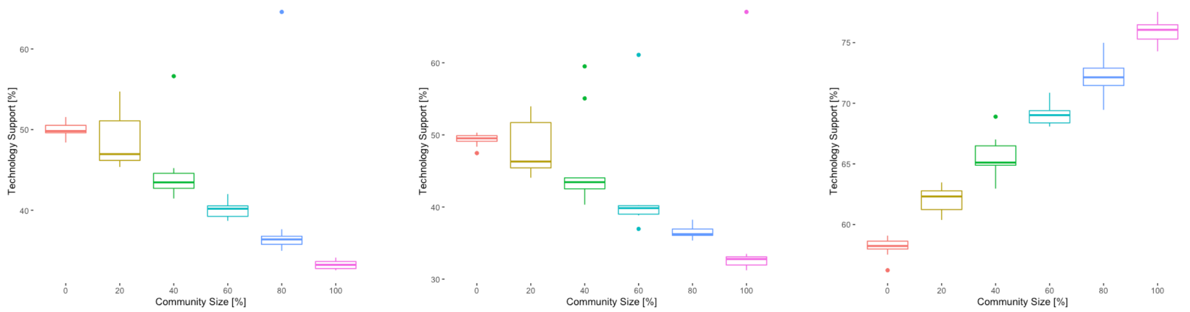
(b) Market Battery with increasing community size at 60% PV penetration

(c) Network Battery with increasing community size at 60% PV penetration

Figure 6.6: Self-sufficiency Battery with increasing community size

Growth

The *Growth* scenario shows similar results for two of the three batteries compared to the *Self-Protection* scenario. The Market and Self-Sufficiency battery both have an initial support around 50% and will more easily decrease in support than increase support for the battery. However, the *Network Battery* shows an increase in support when the community size is increased, see figure 6.7c. The results show an increase from 55-60% to approximately 75% in technology support when increasing the community size from 0 to 100% in the neighborhood. There are no outliers visible. Due to a larger community which is supporting the battery, the community is able to emphasize the neighborhood support for the battery and become more united. This ensures more value satisfaction for the households and therefore the technology support is higher.



(a) Self-sufficiency Battery with increasing community size at 60% PV penetration

(b) Market Battery with increasing community size at 60% PV penetration

(c) Network Battery with increasing community size at 100% PV penetration

Figure 6.7: Market Battery with increasing community size

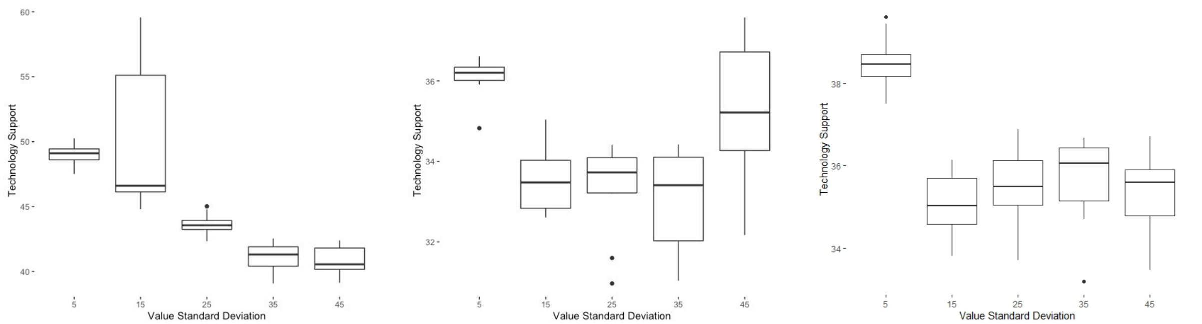
6.3. EXPERIMENT 3: VARYING VALUE SIMILARITY IN THE NEIGHBORHOOD

Final experiment varies the value standard deviation of the various value orientations. This allows to simulate neighborhoods which are more heterogeneous or more homogeneous. The value standard deviation is increased from 5 to 45 in steps of 10. Lower values create a more homogeneous neighborhood, while higher standard deviations ensure heterogeneous value distribution in the neighborhood. The four different value orientations are simulated, *Growth*, *Self-Protection*, *Personal Focus* and *Social Focus*. Likewise last experiment, this experiment is run with 10%, 60% and 100% PV penetration. *Personal Focus* orientation has the households prioritize their *Self-Enhancement* and *Openness-to-change* values. *Social Focus* focuses on *Self-Transcendence* and *Conservation* values. *Growth* prioritizes the *Self-Transcendence* and *Openness-to-change* values. Finally, *Self-Protection* orientation focuses on *Self-Enhancement* and *Conservation* values.

Personal Focus

Figure 6.8 show the results with the *Personal Focus* value orientation. The results for the *Self-sufficiency battery* can been seen in 6.8a. At the lowest value standard deviation, the $TECHNOLOGY-SUPPORT$ varies around 50%, which shows the support of *Self-sufficiency* battery is very neutral. However, the results show more heterogeneous neighborhoods support the *Self-sufficiency battery* less. A decreasing trend can be seen for the $TECHNOLOGY - SUPPORT$ when the value standard deviation is increased. However, some interesting outcomes do occur in the repetitions with higher value standard deviations. In some runs, higher $TECHNOLOGY - SUPPORT$ can be found. Larger value standard deviations gives more heterogeneous neighborhood and increases the chance for communities to have positive interactions and increase the $TECHNOLOGY - SUPPORT$.

Figure 6.8b shows the results of the *Personal Focus* value orientation for the *Market Battery*. This value orientations shows very low $TECHNOLOGY - SUPPORT$ by the neighborhood for this battery configuration. The highest $TECHNOLOGY - SUPPORT$ can be seen in figure 6.8b, with 38% support. The lowest value is around 30%, which means there is not a lot of variation in the $TECHNOLOGY - SUPPORT$ with this battery for a *Personal Focus* scenario. The *Personal Focus* scenario show very low $TECHNOLOGY - SUPPORT$ of *Network Battery* (see figure 6.8c). This scenarios has high values of Self-Enhancement and Openness-to-Change. Decreasing the value similarity in the neighborhood does not vary the outcomes. Yet, very low value standard deviation show the highest support.



(a) Self sufficiency battery with increasing value std dev. at 60% PV penetration

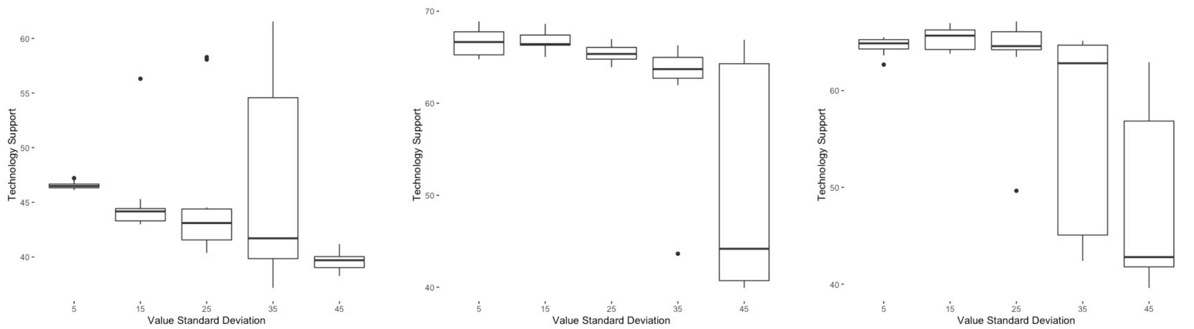
(b) Market Battery with increasing value std dev. at 60% PV penetration

(c) Network Battery with increasing value std dev. at 60% PV penetration

Figure 6.8: Neighborhood Batteries with Personal Focus Value Orientation

Social Focus

Figure 6.9 shows the results of *Social Focus* value orientation. The results of the *Self-Sufficiency Battery* can be seen in 6.9a. Same as previous results, a decreasing trend is seen when the standard deviation is increased. However, more outliers are observed in the 60% PV penetration scenario. Figure 6.9a shows the outliers increase in value. Implementing heterogeneous neighborhoods also increases the chance of communities supporting the battery more. Yet, these are still outliers and occur rarely. For the *Market Battery*, the $TECHNOLOGY - SUPPORT$ is high.. The results show high values for almost all value standard deviations, but with the highest standard deviation the $TECHNOLOGY - SUPPORT$ drops to below 50%. Due to a more heterogeneous neighborhood the support per household will differ more. The default community size set for this experiment is 40%. With a large variation in values, the community within the neighborhood can have a stronger influence on the $TECHNOLOGY-SUPPORT$. This is what can be seen at higher value standard deviations. Figure 6.9c show the results of the *Social Network* value orientation scenario. The *Network Battery* shows high support. However, with increasing value standard deviation the $TECHNOLOGY-SUPPORT$ drops significantly. More dissimilarity in the neighborhood shows again less support.



(a) Self sufficiency battery with increasing value std dev. at 60% PV penetration

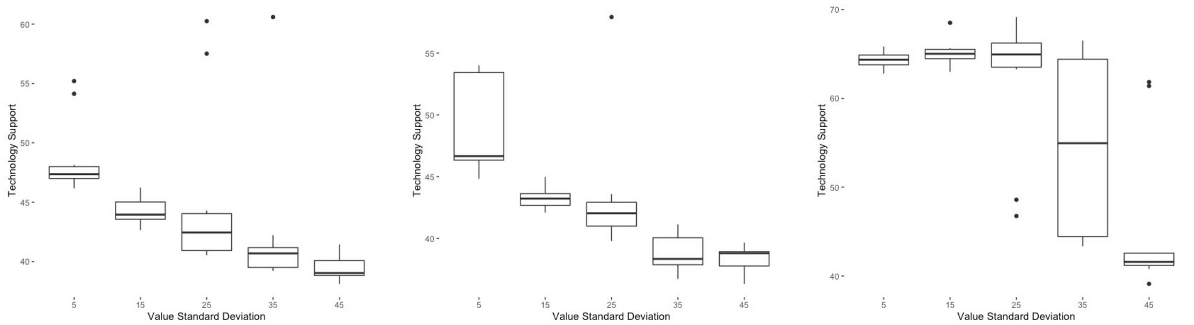
(b) Market Battery with increasing value std dev. at 60% PV penetration

(c) Network Battery with increasing value std dev. at 60% PV penetration

Figure 6.9: Neighborhood Batteries with Social Focus Value Orientation

Growth

The *Growth* value orientation outputs can be found in figure 6.10. Figure 6.10a shows similar results for the *Self-Sufficiency Battery* as previous scenario. The $TECHNOLOGY-SUPPORT$ is around 50% at low value standard deviation and the $TECHNOLOGY-SUPPORT$ decreases when the standard deviation is increased. In all three PV penetration scenarios high outliers can be found. At a more heterogeneous neighborhood (standard deviation of 35) occasional increases of $TECHNOLOGY-SUPPORT$ can be seen. Figure 6.11b shows the results for the *Market Battery*. As the neighborhood has high value similarity (std. dev = 5) the results are around 50% $TECHNOLOGY-SUPPORT$. However, the support decreases when the neighborhood becomes more dissimilar. This becomes constant at high std. dev. (35% and 45%). The *Growth value* value orientation scenario shows similar results as previous scenario for the *Network Battery*. There is high support for the *Network Battery*, but this decreases quickly when the value standard deviation is very high.



(a) Self sufficiency battery with increasing value std dev. at 60% PV penetration

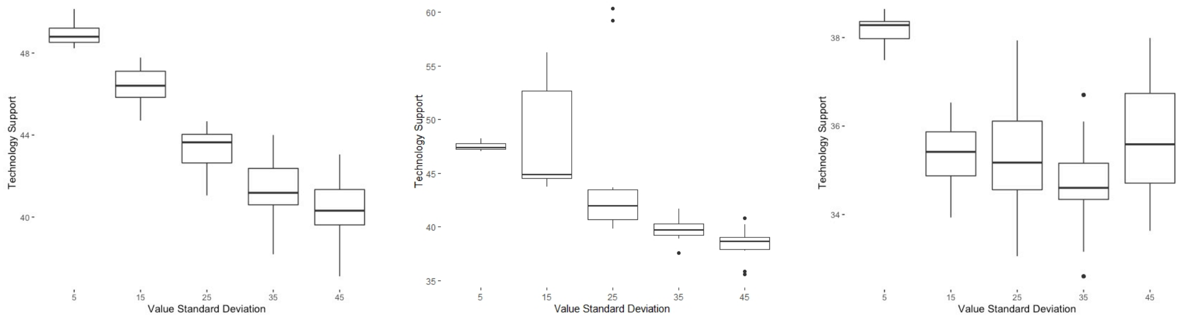
(b) Market Battery with increasing value std dev. at 60% PV penetration

(c) Network Battery with increasing value std dev. at 60% PV penetration

Figure 6.10: Neighborhood Batteries with Growth Value Orientation

Self-Protection

Lastly, figure 6.11 shows the results of the *Self-Protection* value orientation. Also, the decrease in $TECHNOLOGY-SUPPORT$ is constant. The spread in output in the 60% PV scenario is not very large, as all results are between 50% and 40%. Other scenarios show some outliers, but are also fairly constant. Compared to the *Growth* and *Social Focus*, this scenario has less outliers. The results of the *Self-Protection* value orientation can be seen in figure **??**. These show a very similar trend as the Growth value orientation. As both orientation scenarios include one value which support the *Market Battery*, (*Conservation* and *Self-Transcendence)*, figure **??** show similar results. Figure 6.11c, shows very low $TECHNOLOGY-SUPPORT$ for the Network Battery. There is few variation and the results are similar to the *Personal Focus* scenario.



(a) Self sufficiency battery with increasing value std dev. at 60% PV penetration

(b) Market Battery with increasing value std dev. at 60% PV penetration

(c) Network sufficiency battery with increasing value std dev. at 60% PV penetration

Figure 6.11: Neighborhood Batteries with Self-Protection Value Orientation

6.4. OVERVIEW OF RESULTS

An overview of the key points found in the three experiments is given in this section. The scenario without a battery showed increasing the PV penetration in the neighborhood increases the self-sufficiency (as expected) and decreases costs (as expected), yet the self-consumption of PV electricity stayed equal. This means the highest PV production peaks are still going to the grid as these are not consumed. This is important to understand before discussing the results of the three experiments. So,three experiments were done, the first one focused on the technical and economical performance of the batteries, the second one on the community effect on the technology support, and the last experiment on the influence of value similarity in the neighborhood on technology support. The main key learning point are stated below:

- The *Self-Sufficiency Battery* shows an high increase of the SSR in the neighborhood of 15% to 22% SSR in neighborhood with few solar panels. However, the battery also shows it is limited in capacity as the SSR does not increase more when PV adoption is increased in the neighborhood. Maximum SSR is 28% at 100% PV adoption for the Self sufficiency Battery. This shows the increased mismatch between supply and demand discussed above. However, if more energy demand of the household would be electrified, a more self-sufficient grid could be achieved. The electricity from the PV and the battery could be used more during the day.
- Both the *Network Battery* and the *Market Battery* can not achieve high SSR. Only when the *Network Battery* is limited to morning and evening bids, the SSR is increased. The Network battery does not affect the SCR, however the Market Battery shows high increase of SCR. In general, lower SSR, but high SCR means the electricity is sold to the grid via the battery and is thus increasing the pressure on the grid.
- The Network Battery was tested with a planning of full day bids and part time bidding. The results showed the total Households Electricity Costs from the Network Battery Part Time is able to decrease the households costs the most. As the FCR requires reserved capacity, the *Network Battery* must return to its reserved capacity limits after FCR bids. Therefore, it discharges more often and less electricity from the grid is imported. This is interesting in comparison to the full time *Network Battery*, where electricity costs are equal to the *No Battery* scenario. The *Self-Sufficiency battery*, *Market Battery* and part time *Network battery* are able to lower costs quickly when PV adoption in the neighborhood starts, but the gap with *No Battery* is very small at high PV penetration.
- The *Network Batteries* show constant profits for all PV adoption scenarios in the Neighborhood as PV penetration in the neighborhood does not influence the operation of the FCR bidding. By

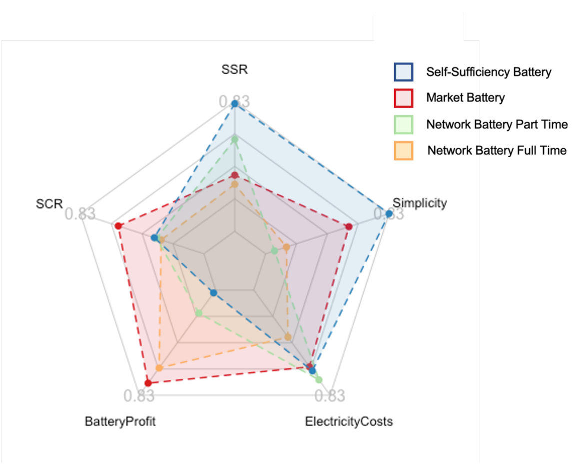
scheduling the battery for the whole day for the FCR profits are doubled compared to the part time FCR. Interestingly, the *Market Battery* can increase its profits when the neighborhood is producing more electricity. At approximately 25% PV adoption it is able to profit more than the FCR battery. Due to using the PV electricity from the households, the *Market battery* is able to profit more than when it should buy electricity from the grid to sell for higher prices.

- The second experiment where the community size was varied, showed the community can have a impactful influence on the technology support of the households. The influence can be positive or negative and depends on the initial value satisfaction from the neighborhood battery and the value scenario. The *Self-Protection* scenario, a rather conservative value scenario, showed a larger community decreases the technology support in most cases, ignoring some outliers. In the case of the *Growth* scenario, a open and self-transcending scenario, the network battery scenario showed positive increase when the community size was increased.
- Changing the value similarity of households has the highest impact when there is a positive support for the battery. This means if the battery is supported by most households in the neighborhood and the technology support shows high values, the value dissimilarity in the neighborhood can decrease the support significantly. Due to the neighborhood becoming more varied and therefore supporting the battery less, interactions within the neighborhood can have higher chance to negatively impact the technology support.
- The *Self-Sufficiency battery* shows constant results for the technology support for all four value scenarios. The *Market* battery shows higher values with the Social Focus, where values such as Self Transcendence and Conservation are supported. Consequently, the Personal Focus shows the lowest scores. If this is compared to the technical results of the *Market Battery* where SSR is very low, and the electricity costs are not decreased as much as some other batteries, it can be concluded the value orientations are matching the other results. The *Network Battery* shows highest values with the Growth and Social Focus value scenarios.

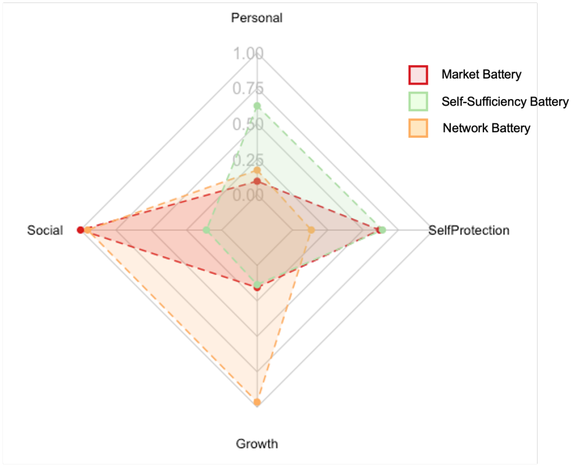
In addition to the three experiments, a comparison between all three batteries is made by setting the evaluative parameters from each battery configuration side by side. Multiple metrics are outputs from the model: Self sufficiency rate, Self Consumption rate, Total Electricity costs and Battery profit. Additionally, the metric *Simplicity* is used. The *Simplicity* metric scores each battery configuration on the (i) technical explainability to households, (ii) technical implementation into the neighborhood and energy system, and (iii) the economical or institutional difficulties to implement this battery. The *Simplicity* score of each battery was judged by a panel of experts by scoring 1-5 on these three aspects. Then, all metrics from the model were standardized such that a comparison could be made. The scoring per neighborhood battery can be found in figure 6.12a. The figure shows the relatively high scores on Simplicity and SSR for the *Self-sufficiency battery*. The *Market battery* and *Network battery* both score high in profit, but lower on SSR or Simplicity, because implementing and understanding these batteries are difficult. Interestingly, the *Market battery* scores average on other metrics and seems like a well-considered battery design.

Additionally, the *Technology support* of the three batteries are shown in respect to the four value orientations. The technology support results from the three batteries are in all four scenarios are standardized and shown in figure 6.12b. Also, this figure does not show one battery with high scores of technology support in each scenario. Since each battery has peaks in a specific scenario. The only constant technology support score is the *Self-sufficiency battery* in each scenario.

Concluding, not a single battery shows high scores on all metrics. The *Self-Sufficiency battery* is designed to increase the SSR of the neighborhood and results show it achieves to do so. However, it does not make a profit and only achieves in lowering the costs of the neighborhood. Clearly, profits are highest with the *Market Battery* and the *Network Battery*. However, both have some conditions. The *Market battery* only makes profit when enough production is available and the *Network battery* should be full time available on the FCR market for high profits. Trade-offs need to be made when a battery is placed in a neighborhood, or certain battery functions should be combined. If the support of the technology should be maximised in all conditions, it is better to stack battery functions, as figure 6.12b does not show equal support for all batteries. Depending on the neighborhood characteristics, the choice could be made to optimise a market battery with more self-sufficiency at high PV adoption



(a) Comparison of the different neighborhood batteries against the five techno-economical metrics



(b) Comparison of the technology support of neighborhood batteries in four different value orientation scenarios

Figure 6.12: Summary of the results by comparing the metrics and value orientations scenarios

neighborhoods, or to combine FCR with self-sufficiency when PV adoption is low.

7 CONCLUSION

The conclusion gives a final overview of the outcomes of the study. This chapter answers the research question and sub-questions introduced in Chapter 1. Then, the scientific contribution of this study is discussed. Lastly, this chapter ends with a section with policy recommendations.

7.1. MAIN FINDINGS

This research aimed to answer the research question *How do Neighborhood Batteries influence value satisfaction, technological performance, and economical performance?*. Through the development of a value-based agent-based model, the research question was answered. To answer the research question five sub-questions were defined. All sub-questions and their answers are discussed below. Finally, the research question is also answered.

SQ1: What institutional and technical designs of Neighborhood-scale Batteries currently exist in The Netherlands or are being developed?
Chapter 1 and 3 answer this sub-question through a literature study. In the Netherlands, multiple pilots exist who are experimenting with large (mostly Li-ion) batteries. These batteries are placed in small neighborhoods where energy cooperatives exist. In cooperation with energy cooperatives, market players, and network operators the batteries are tested. The batteries are used for self-sufficiency of the households, energy arbitrage, and network balancing. Institutions for batteries are not yet strictly developed, but network operators will not be allowed to own batteries. However, they will be allowed to operate or procure these batteries as they deliver advantages for the grid. Current business cases are not economic feasibly yet due to the transportation costs to and from the battery. Even more challenging is the allocation of the benefits and costs when the battery is implemented. As neighborhood batteries could enable shared ownerships or collaborations between different market players, it can be difficult to have clear contractual agreements about the benefits and costs. The Netherlands has an increasing amount of installed battery capacity for the balancing market. The next step would be to implement this on the community level for more services and decentralized flexibility on the grid.

SQ2: How can metrics be defined for technology support and value satisfaction?
This study introduced a value perspective to the socio-technical innovation of neighborhood batteries. When neighborhood batteries are implemented near households and households have to interact with the battery, it is important to consider values in the implementation of the batteries. Personal values influence how people interact with technology and the level of support can change depending on the values people support. For this study, the support for the neighborhood batteries from the households was measured by modeling personal values. This was done by using Schwartz, 1992 values. Also the batteries have strong or weak connection to concrete values such as *Justice*, *Fairness* or *Power*. By connecting these values to the personal values from the modeled households, a value tree is formed (Heidari et al., 2020). Households have a value-based decision to support or not support the battery configuration. It depends on how much the battery satisfies the personal values of the household. This is combined in the new evaluative parameter $TECHNOLOGY - SUPPORT$, which measures the average value satisfaction of the neighborhood. This ensures to evaluation the support of the battery from the complete neighborhood.

SQ3: How can values, neighborhood battery designs and characteristics of The Netherlands be specified in a simulation model?
Through the development of an agent-based model, it is possible to simulate the technical and economical performance of a battery in an electricity system and to also model the influence of interac-

tions and values of households. The model is divided into three parts, a technical, economical, and social sub-model. Three battery designs are considered in the ABM, a battery that operates only for the neighborhood, one which is also trading on the intraday market, and a battery that is operating on the FCR market, respectively the *Self-Sufficiency Battery*, *Market Battery* and *Network Battery*. A lot of data is needed for the modeling of the batteries: Household electricity demand, household PV supply, EPEX spot, FCR prices, FCR capacity prices, and FCR activation data. With the help of industry experts, the batteries are modeled. The economical sub-model is used to measure the profits made on the FCR market and the EPEX spot market. The social sub-model includes modeling the values, social interaction, and influences from communities. In this study, it is assumed that interactions between households can make small changes to the value orientations of these households. Also, it is assumed that communities within a neighborhood, such as Energy Cooperatives are able to influence common support for or against the batteries. Therefore, these interactions are considered in the model.

SQ4: What neighborhood characteristics (values, social network, PV ownership) influence technology support and value satisfaction?
The model results suggest technology support is influenced and changed by social interaction in the neighborhood, value dissimilarity and community size. Due to the different value scenarios, *Personal Focus*, *Social Focus*, *Growth* and *Self-Protection*, the support differs per battery. The *Self-Sufficiency battery* is constant over all scenarios. It shows support around 50%. The *Market Battery* shows high support with the *Social Focus* scenario. This consecutively results in a lower score in the *Personal Focus* scenario as these have opposite values in the Schwartz circumplex. The *Network battery* shows high support with the *Growth* and *Social Focus* scenario.

Different sizes of communities show a large influence on the technology support depending of the value scenario. The results on the *Self-Protection* scenario show a negative influence on the technological support, but with a *Growth* scenario the *Network battery* shows significant increase. This shows how the community emphasizes the technology suport within a neighborhood. More dissimilar neighborhoods decrease the support of the model in almost all scenarios in this model. Only in cases where the scenarios where the technology support is already low, the results show no difference. In scenarios with high support, the technology support drops only when the neighborhood has high dissimilarity, whereas an immediate decrease can be seen in other scenarios. Social interactions and communities within the neighborhood are able to influence the support when households all have high value satisfactions. However, if the neighborhood becomes to heterogeneous, the value satisfaction of household decreases and technology supports becomes lower.

SQ5: How do the various battery configuration perform technically and economically?
The Self-Sufficiency Rate (SSR), Self-Consumption Rate (SCR), Total Households electricity costs and Battery Profit are used to compare the technical and economical performance of the batteries. The SSR shows how much of the demand can be satisfied with the PV production and is therefore an important metric. As expected, the *Self-Sufficiency* battery shows the highest increase of SSR. Compared to the scenario without a battery, at low PV adoption the SSR increase is 15% and this extends to maximum 28% with 100% PV adoption in the neighborhood. As the *Network battery* and *Market battery* are modeled with other strategies, a limited increase in SSR can be seen when these batteries are implemented in the model. If the *Network Battery* is operated at part time, such that during the day it is able to store energy from the households, higher SSR can been achieved. Of course, this impacts the profits made by the battery. Important to consider with these results is the amount of trading or import/export the battery has from the grid. The Neighborhood battery could be placed to lower the peaks for the grid and provide some congestion relief. The SCR does not show an improvement if compared to the no battery scenario. This means the amount of electricity imported from the grid is equal. High grid peaks will still present and possibly overload the grid, even more so when a lot of trading is done on the intraday market.

The results of this study suggests neighborhoods batteries implemented in low PV penetration neighborhoods should not operate on the intraday market if they would like to maximise their profit. Using the battery on the FCR market can be a better choice in this case. The *Market battery* is operating and trading with more profit when the PV production in the neighborhood is high. The *Network battery* has a constant profit which is not affected by PV adoption in the neighborhood. However, if the battery is planned to bid more, the profits increase significantly. This has the disadvantage for the households as they can not use the battery to store their own produced electricity.

Main RQ: How do Neighborhood Batteries influence value satisfaction, technological performance, and economical performance?
In this thesis, it was considered the value embeddedness in technology is able to influence value satisfaction. Therefore, different households can vary how much they support the technology. The agent-based model built in thesis showed neighborhood batteries have more influence on value satisfaction through value similarity and community sizes. Depending on the initial technical support from the neighborhood, the community size can increase or decrease the support significantly. Value similarity showed a positive effect on the value satisfaction of the households.

Concluding, the technological and economical performance differ per battery configuration and not one neighborhood battery performs optimal on all evaluative aspects. However, the performance is quite influenced by the PV penetration in the neighborhood. The characteristics of the neighborhood should be considered if the neighborhood higher performing neighborhood batteries

7.2. SCIENTIFIC CONTRIBUTION

This research made an important step into modeling neighborhood batteries and including the scientific perspective of responsible innovation into agent based modeling. The study showed the impact of innovative energy technologies needs interdisciplinary research and a holistic view on the system. Agent-Based Modelling has been used to model the batteries in the neighborhood and study the influence of values and interactions on the technology adoption. Three promising neighborhood battery use cases have been modelled with consideration of the characteristics of a neighborhood. In literature, neighborhood batteries are compared to home batteries or other type of batteries, and the functionalities of the batteries are not varied. This thesis helps to understand the effect of different configurations when implementing the batteries in the neighborhood. Moreover, the concepts of value-based design and responsible innovation have been applied in the evaluation of the batteries. By using the concepts of value-trees and adopting them for linking household personal values to battery values, it was possible to measure 'value satisfaction'. There is no standard found in literature to evaluate the support from households towards the newly implemented technology. This thesis provided a definition for 'Technology support' and a metric to measure the support from households towards the neighborhood battery.

Two important contributions came from the results of the study. First, neighborhood batteries are able to significantly improve the technological performance of the energy system, lower costs or make a profit. However, trade-offs between these goals should be made according to the characteristics of the neighborhood and the needs of the stakeholders. Second, as the technology support differs per battery and value scenario, the most constant option can be the best option for newly implemented technology. Communities and value dissimilarities had large influences on the *Market* and *Neighborhood* battery when it was highly supported, while the *Self-Sufficiency battery* was less affected due to having an average support.

7.3. POLICY RECOMMENDATIONS

As our electricity system becomes more complex, decentralized, and unstable, research on solutions to relieve the grid is needed. Congestion is growing on the high voltage grid and is also expected to increase in the coming years on the low voltage grid. More solutions to react to the volatility of the supply are therefore needed, while demand is also changing due to the more electrical assets such as EVs and heat pumps. This study focused on one solution in particular: the neighborhood battery. The results from this study show the multi-functional usability of neighborhood batteries. The battery can be used for trading on the FCR or intraday market and can be used to increase the self-sufficiency of the neighborhood. Moreover, the congestion market is also growing and could be an interesting choice for the battery. As congestion is limiting grid connections and renewable growth, operating the battery to prevent congestion can satisfy multiple actors. This could help neighborhoods where industries are present and want a secure and flexible grid. New collaborations between industries and energy cooperatives could possibly be formed. Market and grid operators should reflect on their role for neighborhood batteries and determine how they could develop new projects.

Next to that, a neighborhood battery should be optimized for the needs of the neighborhood. The diverse functionalities of the neighborhood battery show advantageous technical capabilities in comparison to home batteries for instance. Households care about sustainability, fairness, and justice, and the priority of the battery should not only lie in its profitability. Current pilots have been done in a neighborhood where each household had solar panels and all households could participate. More projects should be encouraged where batteries are implemented in diverse neighborhoods to demonstrate how equal distribution of profits and costs can be achieved. Current rules and regulations enable battery projects, but battery models that achieve large-scale implementations are missing. Therefore it is necessary to expand the amount of neighborhood battery projects in The Netherlands that focus on equal benefits for all energy users. Within these project value-based decisions can help the process of implementing the neighborhood battery. These social dimensions should be payed attention to and responsible innovations can help to do so. If more attention will be payed to local developments and the role of all energy users, the neighborhood batery will provide a platform to store and share your power.

8
DISCUSSION

This chapter discusses and interprets the results of the three experiments shown in the previous chapter. The results are discussed from the socio-technical-economical perspective of Responsible Innovation. Also, the practicality of using values in modeling energy systems is discussed. Next, model and research limitations are presented. Finally, the discussion is closed with discussing possible further research directions.

8.1. NEIGHBORHOOD BATTERY DESIGNS

In chapter 1 the Responsible Innovation Framework was introduced (figure 1.2). This framework shows how responsible innovation can help align innovation with socio-technical, economic, and institutional aspects. This chapter discusses the results of this study with the use of this framework.

Technology

Results in this study suggest that a neighborhood battery can be a good implementation for a neighborhood with lower and high PV production. However, the right configuration should be chosen for the right neighborhood. Current installed battery energy storage systems in The Netherlands are used on the FCR market (DNV, 2021). Yet, these are not always connected to a supply source and aim to maximize profit. With the results of the three different configurations, it is suggested the Network Battery can profit independently from the characteristics of the households. However, the self-sufficiency rate will be low and households will not increase their consumption of PV electricity. The Market Battery can profit significantly when PV production in a neighborhood is high. The trade-off for more trading is less battery capacity that can be used for the neighborhood. These trade-offs are important to consider when configuring a neighborhood battery. Stacking the functions of the battery can create more value for the households and the system, but 'smart' algorithms are needed to create ideal combinations and optimizations. Battery technology (Li-ion) is decreasing in costs which makes the business case for the battery viable (Jongsma et al., 2021). However, single-use business cases are difficult to implement. The neighborhood battery is a better contender for multi-use functionality than home batteries for instance. Heterogeneous customers could join the neighborhood battery project and their use case could be considered with a larger battery (Lombardi and Schwabe, 2017).

Socio-Economics and Environment

The three different battery configurations have unique business cases. As the *Market battery* can increase its profit with more PV productions, the FCR can have certainty when bidding on the FCR market. It is important to understand how profits and costs would be shared in a neighborhood when interpreting these results. In this study, no assumption is made about who owns, operates, and invests in the battery. However, the *Network battery* and probably also the *Market battery* will need complex optimization methods and therefore collaborations with third parties are required for a community. This would make the project more complex and would also impact the allocation of profits.

Secondly, this study focused on the influence of technology on the value satisfaction of households. As the batteries represent certain values, the model shows the batteries are not equally supported in each scenario. If these should also be considered during the project development, the project would be made extremely difficult. It is important to consider multiple values in an implementation project for energy technologies and always take into account the needs of all parties involved. The *Self-Sufficiency* battery shows the most constant result in all scenarios. This can be a good starting point for a neighborhood battery. Then, by stacking other functions the business case can be extended and profits can be increased or costs decreased. By considering the technology and the values during the implementation the project can develop responsibly.

Lastly, current battery projects are provider-driven. This means households need to trust the project developer if their interests and values are considered (Kloppenburg et al., 2019). However, households can be engaged in the battery projects not only as users but can be integrated into the total energy system as participants with needs and wishes. The effect of technology support is affected by communities and close contacts. By enabling initiation of neighborhood battery projects with the community, more support can be found, if the battery supports and satisfies personal households values. This study suggests if a neighborhood has more heterogeneous values, the technology support is more likely to decrease. While more heterogeneous values in neighborhoods are able to have more constant technology support or even increase the support in some cases. For practical implications considering the neighborhood battery, this can be important. So, choosing a suitable location (neighborhood) where to initiate neighborhood batteries can affect the success of a battery project.

Institutions, Policies, and Regulation

Regulations and policies in The Netherlands are complex and form an organizational barrier for neighborhood batteries. It is unclear how to organize such a project and which fees and taxes to add when implementing a neighborhood battery on an urban level. The uncertain regulatory framework for neighborhood batteries is also mentioned in other studies, Gährs and Knoefel, 2020; Koirala, van Oost, et al., 2018; Parra, Swierczynski, et al., 2017. Currently, battery storage pay twice the transportation costs for electricity stored and have therefore a clear disadvantage compared to generation facilities (Gährs and Knoefel, 2020). Institutions do not distinguish between neighborhood batteries or other kinds of storage. The definition is the same in law and regulations. If the neighborhood battery should be more widespread, standards and a clear definition are needed to help industry actors and consumers/prosumers.

Next to that, regulators and policy-makers need to understand the added value of storage besides the technical and economical aspects. The possibility to use the neighborhood battery as a common good provides chances to decrease distributional inequality in certain communities. Even more so, the ability of the neighborhood battery to be combined with ancillary grid services can quickly aid current congestion problems in The Netherlands.

8.2. VALUE-BASED MODELLING

In this research, values are used to evaluate technology implementations and to simulate the value-based reasoning of households. By taking a holistic view on the modeling of batteries, the evaluation is done on technical, economic, and social aspects. This creates a model that represents the impact on the neighborhood and its needs. Simulations with values result in more strength when agent behavior or humans needs to be explained (Mercuur et al., 2019). Although this study does not try to predict human behavior, the results show the importance of value differences towards the perception and support of technology. Communities within neighborhoods, social interaction and different value orientations impact the attitudes towards technology. However, this study only modeled the tip of an iceberg, but by practising this method on a socio-technical innovation, the importance of value embeddedness is shown. Neighborhood batteries are multi-stakeholders and collaborative projects and will therefore need another approach than proposing a final project to the participants. As stated before, the households should be involved in the process. Dittrich et al., 2015 has made a business-case methodology to include values into the project development. Figure 8.1 shows the consecutive steps taken in the value case methodology. As mentioned before, by taking the *Self-Sufficiency battery* as starting point for neighborhood batteries, almost all neighborhood will have positive supporters. Next steps can be to listen to other needs and include more case-specific value into the neighborhood battery.

8.3. LIMITATIONS

Sub-model interaction

Three sub-modelled were implemented in the agent-based model, a technological, economical and value-based sub-model respectively. Between the technological and economical sub-model interactions influenced the outcomes of the batteries. For instance, a higher electricity price means higher costs, but can also mean the battery buys less electricity from the spot market. These interactions did

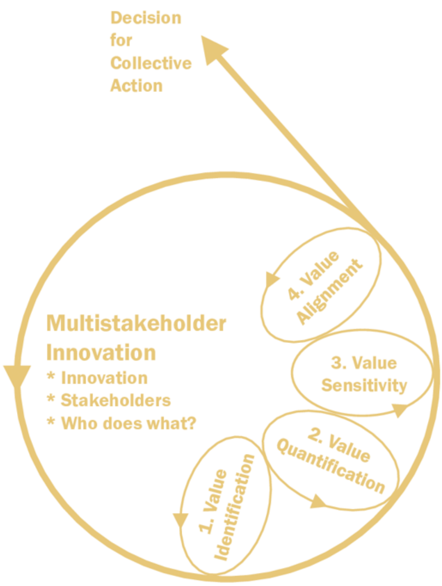


Figure 8.1: Value Case Method from Dittrich et al., 2015

not exists between the value sub-model and the other sub-models. However, one could argue if the battery performs better economically, the value of *Self-Enhancement* could be more satisfied. Including more feed-back loops would create a more integrated and holistic view of the system. Adding these interactions was not possible due to time limitations. Also, confident results were got with the combined technical and economical sub-model and the social sub-model.

Another approach would have been to consider the households as participants in the energy system who do need to make a choice how they will participate. Different modes of storage or electricity sharing are possible, for instance households can share their electricity in a smart grid, store their energy or trade it. However, as mentioned before, this study did not focus on the implementation phase of the battery as too many assumption would need to be made. There is no standard method how citizens become part of the energy systems, but more future projects will exist where citizens will need to make a choice to participate or not. As interaction with citizens in future projects will increase, it will become more important how to consider their values and behavior.

Value modelling

This research has used Schwartz values to model values. For modeling purposes, Schwartz's values are very pragmatic as he provides functional reasoning behind human values. Schwartz, 1992 sees values as motivators to cope with the human condition. Agent-Based Modelling and Schwartz values are already combined more often (Boshuijzen-van Burken et al., 2020; Ghorbani et al., 2021; Heidari et al., 2020), but other results could have been found if a different theoretical stance would have been taken. Values could also be taken as universal intuitions about what is desirable in life and for the world (Boshuijzen-van Burken et al., 2020). By using the value trees from Heidari et al., 2020 more moral values were connected to the Schwartz values which tried to overcome this limitation. This ensured a value-sensitive process of the battery evaluation method. However, there does not exist a standard method to transform Schwartz values into more concrete moral values and this requires interpreting the Schwartz values (Heidari et al., 2020). This leads to a more open interpretation of linking Schwartz to general values and varying results depending on the researcher or study.

The assumption was made in this study that values influence the support of households for technology. Although values are often linked to the attitudes and behavior of people, Ponizovskiy et al., 2019 shows the power of values toward a behavior is dependent on its social context. The link between behavior and values is therefore very dependent on the relationship within your social network. In this study, influence from social networks and friends was considered. It was modeled to influence the value importance of connected households. The 'strongness' or 'direction' of the relationship was not considered and could therefore have more influence on our beliefs than on the values of households.

Battery modeling

More commonly, optimization methods are used for the modeling of battery and electricity markets (Nitsch et al., 2021). This study has shown that Agent-Based Modelling is capable to simulate a neighborhood battery, however, optimizing the battery (dis-)charging would be beneficial for better results. Moreover, some improvements could have been made to the modeling of the batteries in the ABM. The battery modeling in the case of FCR trading had limited minimal and maximum SOC (40% and 70% respectively), to have sufficient capacity for the capacity reserve market. Ideally, these SOC limits were varied to find the best performing network battery. The bid strategy was fully planned as the battery bid twice a day, morning and evening. Using a different strategy could also have benefited the outputs. In the case of the market battery also some assumptions were made. The market battery only bought electricity when the price was lower than the feed-in tariff and sold this electricity when prices were higher to profit. Yet, basing the decision to buy on the feed-in tariff could not have been the right modeling choice. Lower or higher limit market prices could have been more optimal for the market battery. Using a market forecast could have been helpful. Trading decisions were then have been made on forecast prices, instead of a price limit.

In all battery configuration scenarios, battery degradation has not been considered. As the model only runs for one year, the effect would be insignificant. However, for long-term analysis of neighborhood batteries, battery degradation should be considered for economic and technological evaluation. This research considered the household electricity costs and battery profits in the economic evaluation. A more extensive economical comparison could give clear outcomes about the feasibility of the different business cases. In this study, a limited economic evaluation was done of the batteries. To fully compare neighborhood batteries, the investment costs, operational costs and market participation costs should be considered. With these the Levelized Cost of Storage (LCOS) could be calculated. The LCOS can be measured as the calculation is done for levelized cost of energy, it are total costs and expenditures divided by the total electricity discharged by the battery. Important parameters in the LCOS calculations are the CAPEX, discount rate and the economic lifetime of a battery (around 15 years currently).

The datasets used for the modeling of the battery have been collected from trustworthy sources (e.g. NEDU, 2021, ENTSO-E, 2022, TenneT, 2022), however the heterogeneous mix of households with their electricity supply and demand could not be fully represented. The neighborhoods are varied with Elderly, Family, and Single demand profiles, and also the number of solar panels is varied within the modeled neighborhood. Yet, households with EV chargers or heat pumps could probably change the outputs of the model. These possible variations should be acknowledged when the results are interpreted.

8.4. FUTURE RESEARCH

Multi-functional batteries

Further research should focus on the possibilities and implementations when stacking multiple functions in a battery. Many studies explain the profitability of batteries, multi-use cases are needed (Australian National University Canberra, 2020b; DNV, 2021; Jongsma et al., 2021). New markets are emerging and proving a possible use case for batteries. Congestion markets and the GOPACS platform can enable more revenue streams (GOPACS, 2022). However, as no clear regulations exist, it is unclear if combining markets are allowed and will stay so. Also, congestion relief services for the grid operator do not have clear transparent remuneration.

The energy system is becoming more decentralized and everyone can become an energy player. This creates a system with different needs and interactions in the system. Case-specific neighborhood batteries could be interesting for further research. Larger batteries can adjust to the demand of different energy actors more easily, certainly in a system with heterogeneous demand. This could be an advantage for projects where industry, households, and market operators are collaborating or near each other.

Changing energy system
Market players, grid operators, and other energy system participants could be able to initiate a neighborhood scale battery project, as these can all benefit. The ownership and management structure is unclear but is important if the wide-scale implementation of NSBs should succeed. *Net-metering* has been very favorable for the growth of PV systems but is withholding the adoption of energy storage systems. Newer models exist and can be explored for the implementation of neighborhood batteries, such as location-based net metering, community grids, and local energy market (Koirala et al., 2019). By exploring these new models and the effect on a battery, more viable strategies can be found for future policies. It is a different type of energy system that can be expected in the future. One that could create more incentives to share local energy and initiate local battery projects. The necessary conditions for a change in the energy systems should be identified, such that a clear strategy for neighborhood batteries can be made. More research into these conditions can help further the development of neighborhood batteries.

Empirical Value research
This study showed how households can consider values to assess different battery designs. Households support technology not only for economic reasons but reducing carbon emissions, increasing fairness, or renewables are all behavioral reasons for households when energy systems are evaluated. Further research should consider empirical research on the values of households towards energy storage, and neighborhood storage explicitly. Other studies have been done about Germany and Australia, however, this is difficult to compare as the countries are not the same (Hoffmann and Mohaupt, 2020; Ransan-Cooper et al., 2022). These are different in terms of values and energy systems.

REFERENCES

Acosta, C., Ortega, M., Bunsen, T., Koirala, B. P., & Ghorbani, A. (2018). Facilitating energy transition through energy commons: An application of socio-ecological systems framework for integrated community energy systems. *Sustainability (Switzerland)*, *10*. https://doi.org/10.3390/su10020366

Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, *50*(2), 179–211.

Ambrosio-Albala, P., Upham, P., Bale, C. S., & Taylor, P. G. (2020). Exploring acceptance of decentralised energy storage at household and neighbourhood scales: A uk survey. *Energy Policy*, *138*. https://doi.org/10.1016/j.enpol.2019.111194

Australian National University Canberra. (2020a). *Implementing community-scale batteries*. Australian National University Canberra.

Australian National University Canberra. (2020b). *Implementing community-scale batteries*. Australian National University Canberra.

Barbour, E., Parra, D., Awwad, Z., & González, M. C. (2018). Community energy storage: A smart choice for the smart grid? *Applied energy*, *212*, 489–497.

Bidwell, D. (2016). Thinking through participation in renewable energy decisions. *Nature Energy*, *1*. https://doi.org/10.1038/nenergy.2016.51

Boshuijzen-van Burken, C., Gore, R. J., Dignum, F., Royakkers, L., Wozny, P., & Shults, F. L. (2020). Agent-based modelling of values: The case of value sensitive design for refugee logistics. *Journal of Artificial Societies and Social Simulation*, *23*(4).

Burken, C. B. V., Gore, R., Dignum, F., Royakkers, L., Wozny, P., & Shults, F. L. (2020). Agent-based modelling of values: The case of value sensitive design for refugee logistics. *JASSS*, *23*, 1–20. https://doi.org/10.18564/jasss.4411

CBS. (2022). Cbs open data statline. https://opendata.cbs.nl/statline/portal.html?_la=nl&_catalog=CBS

Cohen, J. J., Azarova, V., Klöckner, C. A., Kollmann, A., Löfström, E., Pellegrini-Masini, G., Polhill, J. G., Reichl, J., & Salt, D. (2021). Tackling the challenge of interdisciplinary energy research: A research toolkit. *Energy Research and Social Science*, *74*. https://doi.org/10.1016/j.erss.2021.101966

Consumentenbond. (2022). Hoeveel zonnepanelen heb ik nodig? https://www.consumentenbond.nl/zonnepanelen/hoeveel-zonnepanelen

Correljé, A., Cuppen, E., Dignum, M., Pesch, U., & Taebi, B. (2015). *Responsible innovation in energy projects: Values in the design of technologies, institutions and stakeholder interactions*. Springer International Publishing. https://doi.org/10.1007/978-3-319-17308-5_10

Danish Energy Agency. (2021). Technology data for energy storage. https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-energy-storage

Dittrich, K., Koers, W., Berkers, F., Becker, J., & Montalvo, C. (2015). A value case approach for analysing goal alignment in multi-stakeholder networks: The case of sustainable product manufacturing in the electronics industry, 15–17.

DNV. (2018). *Feasibility and scalability of the community energy storage*. DNV GL. www.dnvgl.com/energy

DNV. (2021). *Battery energy storage systems in the netherlands*. DNV.

Dong, S., Kremers, E., Brucoli, M., Rothman, R., & Brown, S. (2020). Techno-enviro-economic assessment of household and community energy storage in the uk [Agent-based model - optimisation]. *Energy Conversion and Management*, *205*. https://doi.org/10.1016/j.enconman.2019.112330

Edmonds, B., Page, C. L., Bithell, M., Chattoe-Brown, E., Grimm, V., Meyer, R., Montañola-Sales, C., Ormerod, P., Root, H., & Squazzoni, F. (2019). Diierent modelling purposes. *Journal of Artificial Societies and Social Simulation*, *22*.

EESI. (2019). Fact sheet: Energy storage. https://www.eesi.org/papers/view/energy-storage-2019

ENTSO-E. (2022). Prices of activated balancing energy. https://transparency.entsoe.eu/balancing/

EU. (2020). *The eu clean energy package*. European University Institute. https://doi.org/doi/10.2870/33236

European Commission. (2020). Energy communities: An overview of energy and social innovation. (KJ-NA-30083-EN-N (online)). https://doi.org/10.2760/180576

Gährs, S., & Knoefel, J. (2020). Stakeholder demands and regulatory framework for community energy storage with a focus on germany. *Energy Policy*, *144*. https://doi.org/10.1016/j.enpol.2020.111678

Ghorbani, A., de Bruin, B., & Kreulen, K. (2021). *Studying the influence of culture on the effective management of the covid-19 crisis*. https://doi.org/10.1007/978-3-030-76397-8_8

Ghorbani, A., Nascimento, L., & Filatova, T. (2020). Growing community energy initiatives from the bottom up: Simulating the role of behavioural attitudes and leadership in the netherlands. *Energy Research and Social Science*, *70*. https://doi.org/10.1016/j.erss.2020.101782

GOPACS. (2022). https://www.gopacs.eu/

GridFlex. (2021). Gridflex. https://gridflex.nl

GridFlex. (2022). Gridflex heeten. https://gridflex.nl/

Heidari, S., Jensen, M., & Dignum, F. (2020). Simulations with values. *Springer Proceedings in Complexity*, 201–215. https://doi.org/10.1007/978-3-030-34127-5_19

HIER Opgewekt. (2022). Lokale energie monitor. https://www.hieropgewekt.nl/lokale-energie-monitor

Hoffmann, E., & Mohaupt, F. (2020). Joint storage: A mixed-method analysis of consumer perspectives on community energy storage in germany. *Energies*, *13*. https://doi.org/10.3390/en13113025

IEA. (2021). *Renewables 2021 - analysis and forecast to 2026*. www.iea.org/t&c/

IRENA. (2017). Electricity storage and renewables: Costs and markets to 2030. https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

Jongsma, C., van Cappellen, L., & Vendrik, J. (2021). *Omslagpunt grootschalige batterijopslag*. CE Delft. www.ce.nl

Kloppenburg, S., Smale, R., & Verkade, N. (2019). Technologies of engagement: How battery storage technologies shape householder participation in energy transitions. *Energies*, *12*(22), 4384.

Koirala, B. P., Araghi, Y., Kroesen, M., Ghorbani, A., Hakvoort, R. A., & Herder, P. M. (2018). Trust, awareness, and independence: Insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems. *Energy Research and Social Science*, *38*, 33–40. https://doi.org/10.1016/j.erss.2018.01.009

Koirala, B. P., Hakvoort, R. A., Oost, E. C., & der Windt, H. J. (2019). Community energy storage: Governance and business models. *Consumer, Prosumer, Prosumager: How Service Innovations will Disrupt the Utility Business Model*, 209–234. https://doi.org/10.1016/B978-0-12-816835-6.00010-3

Koirala, B. P., van Oost, E., & van der Windt, H. (2018). Community energy storage: A responsible innovation towards a sustainable energy system? *Applied Energy*, *231*, 570–585. https://doi.org/10.1016/j.apenergy.2018.09.163

Koirala, B. P., van Oost, E., & van der Windt, H. (2020). Innovation dynamics of socio-technical alignment in community energy storage: The cases of drten and ecovat. *Energies*, *13*. https://doi.org/10.3390/en13112955

Koirala, B. P., van Oost, E. C., van der Waal, E. C., & van der Windt, H. J. (2021). New pathways for community energy and storage.

Liander. (2017). Buren slaan lokale zonnestroom op in buurtbatterij. https://www.liander.nl/nieuws/2017/11/23/buren-slaan-lokale-zonnestroom-op-buurtbatterij

Liander. (2022). Beschikbare data. https://www.liander.nl/partners/datadiensten/open-data/data

Lombardi, P., & Schwabe, F. (2017). Sharing economy as a new business model for energy storage systems. *Applied Energy*, *188*, 485–496. https://doi.org/10.1016/j.apenergy.2016.12.016

Mercuur, R., Dignum, V., & Jonker, C. M. (2019). The value of values and norms in social simulation. *Journal of Artificial Societies and Social Simulation*, *22*. http://jasss.soc.surrey.ac.uk///////.html

Milchram, C., Künneke, R., Doorn, N., van de Kaa, G., & Hillerbrand, R. (2020). Designing for justice in electricity systems: A comparison of smart grid experiments in the netherlands. *Energy Policy*, *147*. https://doi.org/10.1016/j.enpol.2020.111720

Milchram, C., Märker, C., Schlör, H., Künneke, R., & Kaa, G. V. D. (2019). Understanding the role of values in institutional change: The case of the energy transition. *Energy, Sustainability and Society*, *9*. https://doi.org/10.1186/s13705-019-0235-y

Mittal, A., Krejci, C. C., Dorneich, M. C., & Fickes, D. (2019). An agent-based approach to modeling zero energy communities. *Solar Energy*, *191*, 193–204. https://doi.org/10.1016/j.solener.2019.08.040

NEDU. (2021). Verbruiksprofielen. https://www.nedu.nl/documenten/verbruiksprofielen/

Netbeheer Nederland. (2021). *Een stabiel energiesysteem door afbouwen saldering en introduceren subsidies voor decentrale opslag*. https://www.netbeheernederland.nl/_upload/Files/Saldering_en_Opslag_-_Position_Paper_NBNL_en_Energy_Storage_NL_17-11-2021_228.pdf

Nikolic, I., & Ghorbani, A. (2011). A method for developing agent-based models of socio-technical systems. *2011 International Conference on Networking, Sensing and Control, ICNSC 2011*, 44–49. https://doi.org/10.1109/ICNSC.2011.5874914

Nitsch, F., Deissenroth-Uhrig, M., Schimeczek, C., & Bertsch, V. (2021). Economic evaluation of battery storage systems bidding on day-ahead and automatic frequency restoration reserves markets. *Applied Energy*, *298*, 117267.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419–422.

Parra, D., Norman, S. A., Walker, G. S., & Gillott, M. (2017). Optimum community energy storage for renewable energy and demand load management. *Applied Energy*, *200*, 358–369. https://doi.org/10.1016/j.apenergy.2017.05.048

Parra, D., Swierczynski, M., Stroe, D. I., Norman, S. A., Abdon, A., Worlitschek, J., O'Doherty, T., Rodrigues, L., Gillott, M., Zhang, X., Bauer, C., & Patel, M. K. (2017). An interdisciplinary review of energy storage for communities: Challenges and perspectives. *Renewable and Sustainable Energy Reviews*, *79*, 730–749. https://doi.org/10.1016/j.rser.2017.05.003

Pena-Bello, A., Parra, D., Herberz, M., Tiefenbeck, V., Patel, M. K., & Hahnel, U. J. J. (2021). Integration of prosumer peer-to-peer trading decisions into energy community modelling. *Nature Energy*. https://doi.org/10.1038/s41560-021-00950-2

Ponizovskiy, V., Grigoryan, L., Kühnen, U., & Boehnke, K. (2019). Social construction of the value–behavior relation. *Frontiers in Psychology*, *10*, 934.

Ransan-Cooper, H., Shaw, M., Sturmberg, B. C., & Blackhall, L. (2022). Neighbourhood batteries in australia: Anticipating questions of value conflict and (in)justice. *Energy Research and Social Science*, *90*. https://doi.org/10.1016/j.erss.2022.102572

Ransan-Cooper, H., Sturmberg, B. C., Shaw, M. E., & Blackhall, L. (2021). Applying responsible algorithm design to neighbourhood-scale batteries in australia. *Nature Energy*, *6*, 815–823. https://doi.org/10.1038/s41560-021-00868-9

Savelli, I., & Morstyn, T. (2021). Better together: Harnessing social relationships in smart energy communities. *Energy Research & Social Science*, *78*, 102125. https://doi.org/https://doi.org/10.1016/j.erss.2021.102125

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. *Advances in Experimental Social Psychology*, *25*, 1–65. https://doi.org/10.1016/S0065-2601(08)60281-6

Schwartz, S. H., & Bilsky, W. (1987). Toward a universal psychological structure of human values. *Journal of Personality and Social Psychology*, *53*, 550–562. https://doi.org/10.1037/0022-3514.53.3.550

SolShare. (2021). Solshare. https://me-solshare.com/what-we-do/

sonnen. (2021). https://sonnengroup.com/sonnencommunity/

Sovacool, B. K., & Dworkin, M. H. (2014). *Global energy justice*. Cambridge University Press.

Tegenstroom. (2018). Demonstratieproject buurtbatterij rijsenhout. https://tegenstroom.nl/zonnepanelen/buurtbatterij-rijsenhout

TenneT. (2022). Export data. https://www.tennet.org/english/operational_management/export_data.aspx

Van Dam, K. H., Nikolic, I., & Lukszo, Z. (2012). *Agent-based modelling of socio-technical systems* (Vol. 9). Springer Science & Business Media.

van der Stelt, S., AlSkaif, T., & van Sark, W. (2018). Techno-economic analysis of household and community energy storage for residential prosumers with smart appliances [Optimisation method]. *Applied Energy*, *209*, 266–276. https://doi.org/10.1016/j.apenergy.2017.10.096

Wilensky, U. (1999). Netlogo. evanston, il: Center for connected learning and computer-based modeling, northwestern university.