Exploring Value Change in Sustainable Energy Systems

An Agent-Based Exploratory Modelling Approach

Master Thesis

Syed Mujtaba Fardeen

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An Agent-Based Exploratory Modelling Approach to Study the Change in Importance of Values

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Master Thesis

in partial fulfilment of the requirements for the degree of
Master of Science
in Engineering and Policy Analysis

by

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Date:	August 15, 2021	

Keywords: Values, Value change, Social acceptance, Responsible Innovation, Energy Transition, Energy Justice, Energy systems, Agent-Based Modelling, Exploratory Modelling

Printed by: Delft University of Technology

An electronic version of this dissertation is available at
http://repository.tudelft.nl/.

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Executive Summary

The climate change around the globe driven by Greenhouse Gas emissions (GHG) is fuelling the growth of Sustainable Energy Systems (SES) at a faster pace. However, the lack of acceptance of these systems by society has stifled its successful deployment. Societal values play a key role in evaluating the social acceptance and the broader consequences of SES.

However, there exists a complexity of change in the values of people. Alternatively known as value change, although SES may embody values permanently during its design, the values that people hold important may change during the lifetime of SES. Value change may often be driven by various exogenous factors as well as due to the complex, emergent, and dynamic characteristics of SES. Consequently, this has led to high uncertainty in the future acceptance of SES.

Exploring the uncertain scenarios of value change is crucial for social acceptance of SES as it can facilitate better consideration of values in evaluating social acceptance of SES, ultimately contributing to the future acceptability of SES by society. However, current approaches to explore value change in ethics of technology literature are scarce. Few have proposed to explore value change, but lack in dealing with value change after it has occurred, or they consider values in a static manner.

Alternatively, simulation models show better prospects in exploring complex societal dynamics of which a human mind cannot picture. Simulation models such as Agent-Based Models are seen as a suitable solution to capture the underlying mechanisms that drive the value change considering the complex and dynamic characteristics of SES. Based on this, it is found that there is a lack of knowledge on how values change in SES and no research has used Agent-Based Models to explore value change on a normative scale.

Building on this knowledge gap, the objective of this research is to gain an understanding of the mechanisms that drive the value change in SES, by formulating a modelling approach that integrates agent heterogeneity, individual decision-making, bounded rationality, and social interaction, to explore value change under various policy and uncertainty scenarios of SES. Based on this, the research question answered in this study is as follows:

How can we explore the value change in sustainable energy systems?

To achieve this objective, this study combined Agent-Based Modelling and Exploratory Modelling approaches to explore the change in importance of values. First, the model is conceptualized based on the case study of a community microgrid that resembles complex and emergent characteristics of an SES. The community microgrid consists of agents: businesses, surfclubs, restaurants, and industries that represent the actual case study of a microgrid in the Scheveningen district. Further, four values are assumed in this study: reliability, sustainability, affordability, and inclusiveness. The importance of these values varies from -1 to 1 or very low to very high, depending on agents' satisfaction with that value. The value importance— an opposite of value satisfaction—is the importance that an agent gives to a certain value depending on their satisfaction with that value. Subsequently, using this case study as a base and the characteristics of a complex system, certain concepts and the-

ories are selected and formulated. These concepts/theories include agent-heterogeneity, common-pool resource & dynamic behaviour, bounded rationality & transformative experience, and social interaction. The agent heterogeneity concerned the heterogeneity of the agents based on their (1) preference to satisfy a value, (2) individual preference for a decision (to increase or decrease energy consumption), and (3) preference to link with others in the community. The common pool resource & dynamic behaviour represents the dynamic and rivalrous action and interaction among the agents for a common good (energy) that ultimately influences their satisfaction or importance for a value. The bounded rationality & transformative experience together are used to represent the limited rationality of agents in perceiving the consequence of their decision and decision of others in the community ahead of time, due to which, they may experience unwanted consequences for their value satisfaction or value importance. The social interaction concept is represented in the scenarios: (1) social conformity—representing the behaviour of agents to conform their consumption decision to other agent(s) among their links who are in need, and 2) modes of control—where agent's energy consumption is controlled by the community microgrid in three different levels: no control, partial control, and full control.

Based on the aforementioned concepts the model is formalized and specified. The key performance indicators are the value importance levels of each value type. The model environment consists of agents located on a spatial map of the Scheveningen district. The uncertain external variables are: community formation, smart-meter control, link preference, and energy consumption rate. Each of these variables is a formulation of concepts as described earlier. The policy external variables include: 'increase capacity micro-grid', 'subsidize consumers', and 'dynamic pricing'. These policies are used to increase value satisfaction or lower value importance in the community for different values. The policy 'increase capacity' microgrid is formulated to improve the reliability satisfaction of the community. While the 'subsidize consumer' policy is formulated to improve the affordability satisfaction of the community. Lastly, the 'dynamic pricing' policy is formulated to improve the reliability satisfaction of the community.

The experiments are designed in different categories: (1) base case, (2) single policy, (3) combination of single policy and uncertainties, and (4) combination of policies and uncertainties. The base case dynamic patterns observed were: a rivalrous consumption of energy in a common pool resource is observed among agents. Dynamic conflict at the community level was observed, where value conflicts were created and solved over time. Value change is path-dependent, in that the initial value preferences, decisions and link preferences influence agents' end state of value importance. The single policy experiments dynamic patterns observed were: increase in capacity microgrid helped delay the increase of reliability and sustainability importance of community and significantly reduced the importance below the base case. Subsidize consumer policy reduced the affordability importance of the community but may have unintended consequences of inequality with respect to providing the same subsidy amount to all agents, which led to a different impact on agents based on their income. Dynamic pricing policy mainly revealed a value conflict between values reliability and affordability on a community level. Further, it showed the self-organization of surfclubs and restaurants to lower affordability importance after the negative impact of policy.

The combination of single policy and uncertainties revealed varying insights. (1) The 'increase capacity and uncertainty' scenario, shows added benefits compared to the single policy 'increase capacity' through a stable decrease in inclusiveness importance is observed, which is mainly influenced by the 'community formation' uncertainty. (2) The 'dynamic pricing and uncertainty' showed value trade-off between reliability, sustainability, inclusiveness versus affordability. In addition to value, inclusiveness is observed from a single policy due to the 'community formation' uncertainty.

Lastly, the combination of policies and uncertainties—consisting of 'increase capacity, 'subsidize consumers', 'smart-meter control', 'community formation' and 'energy consumption increase/decrease rates' reduced all value importance levels without observing a value trade-off or value conflict among them. However, on the agent level, despite the effectiveness of this policy for other agents, businesses had low reliability and affordability importance, it may be due to continuous increase in consumption by the businesses, due to which they are unaffected by the policy and uncertainty scenario. Nonetheless, this policy has revealed no conflicting results in terms of value conflict both at the community and agent level.

Next, the scenario discovery tool is used to perform further analysis on the 'combination of policies and uncertainties' scenario, to investigate the specific conditions of the scenario under which the value importance decreases (success) or value importance increase (failure). Here, the success of the policy scenario means value importance is lower than 0 or becomes less important, whereas the failure of policy scenario means value importance is greater than 0 or is highly important. These conditions of success and failure form the outcome of interest for this analysis. Subsequently, the scenario discovery maps these outcomes of interest to the uncertainty space of the policy scenario. This analysis allowed for detailed insight on the path dependencies of each parameter condition of the scenario, which leads to increasing or decreasing value importance. Based on this, the results revealed that there should be no 'smart-meter control' that blocks consumers from their freedom to increase or decrease their consumption, and 'community formation' should be promoted, to bring agents together and contribute to lesser inclusiveness importance or higher inclusiveness satisfaction. Subsequently, policies 'increase in capacity' and 'smart-meter control' are crucial for lesser reliability and sustainability importance in the community. Lastly, to maintain low affordability importance or high affordability satisfaction in the community, it is required that smart-meter control and subsidize consumer policy be implemented, and that there should be no energy consumption increase rate from businesses agent.

The outcome of the analysis reveals several implications. First, the outcome confirms the dynamic and rivalrous behaviour of agents in common pool resources, and further research in integrating value change and common pool resource theory is recommended. Second, the outcomes also confirmed the value conflicts occurring as values change and show a possibility for conflicts to be created and solved over time (dynamic conflict). Subsequently, further research can look into how dynamic value conflicts occur over time as values change. Third, the end-state of value importance of each agent implied that value change has a path-dependent property, which depends on the initial heterogeneous characteristics of agents. Fourth, the influence of 'community formation' on value change, implied that some agents are more sensitive to value change when linked to an agent of their preference than others. Further research can be done in terms of manipulating the configuration of links and networks formed and finding its influence on value change. Fifth, the smart-meter control mode which works on the principle of 'modes of control' or governance can be modeled better in terms of including its implication on relevant values such as security, privacy, or trust. Lastly, further research can improve the conceptualization of transformative experience by including more intricate decision-making by agents for energy systems such as buying a solar panel or willingness to share private data and so on.

Based on this, several recommendations regarding the topic and method developed in this research. The main ones include: (1) an increase in research for value change, (2) development of more simulation models to understand the dynamics of value change not just in energy systems but other domains, (3) manipulating the fuel-mix capacity or configuration of networks to see how values change, (4) including more scenarios of seasonal change that could more accurately give rise to value change in energy systems and (5) carrying out surveys/ empirical research to collect and form opinions on value change in different domains.

ACKNOWLEDGEMENTS

This journey has been one of the toughest yet lightning-speed journeys for me ever. As I look back to those 7-months, my enthusiasm for this research taught me to be self-reliant, disciplined, and restraint against all desires. Feeling like being pressured beneath the mountains or being stranded in an ocean, often anxiety and fear overtook my thoughts of completing this research on time. However, today I am ashore, and it would not have been possible without the Almighty, prayers, and people who have helped me on this journey.

I would like to thank my graduation committee for their immense help. This research wouldn't have gone forward without their support and valuable feedback. First of all, I would like to thank Ir. Tristan de Wildt for being a great support and for always being enthusiastic to brainstorm and give critical feedback. Thank you for believing in me. I would like to also thank Dr.ir. Jan Kwakkel for providing me with useful modelling ideas and critical feedback on my model and experiments. And Prof.dr.ir. Ibo van de Poel for providing me with relevant conceptual ideas as well as useful feedback on my report.

I am also very thankful for Ir. Yvo Hunink for believing in me and accepting me in the municipality of the Hague. Your critical and constructive comments were timely. I am also thankful to Job Swens for taking out time to be interviewed for this research.

I would also like to thank Aarthi for helping with brainstorming ideas for my model and Elvira for always being ready to help. And all my EPA friends for the good times in the Netherlands. I am also thankful for my friend Pratheep who has been very supportive and encouraging throughout these two years in EPA.

To Safwan and Tariq, for their immense support in the Netherlands since day one. Special thanks to Safwan for always believing in me and supporting my growth through EPA. I am also grateful for Yusha, Farroque, Abrar, and Muneeb.

To my family who has been through my thick and thin, I am grateful for you all. Special thanks to my two sweet sisters Afsheen and Nausheen for their love and help with my cover page and to my brother Zain for lending his ears always. Finally, I am profoundly grateful to my father Syed Fareeduddin and to my mother Samar Parveen, for always believing in me and supporting me with love, emotionally and financially. You both are my greatest inspirations. I wouldn't have made it without both of you. This is for you both.

Syed Mujtaba Fardeen
The Hague, August 2021

I

THESIS DEFINITION

1

Introduction

1.1. Sustainable Energy Systems to Combat Climate Change

The world today is in a state of climate emergency. The rampant increase in Greenhouse Gas emissions (GHG) and its subsequent impact on global temperatures have caused havoc to the global climate. Among other factors, excessive consumption of fossil fuel resources has contributed enormously to GHG emissions and, hence to the rise in global temperatures. (Bouffard and Kirschen, 2008; Ripple et al., 2021). Consequently, the warmer temperatures have fuelled forest fires, floods, droughts, and various other climate change impacts over the globe (Bazrkar et al., 2015; Ripple et al., 2021).

Among other solutions, the deployment of state-of-the-art Sustainable Energy Systems (SES) is essential to envision a low carbon economy to combat climate change as well as secure the energy supply (Adil and Ko, 2016; Bale et al., 2015; Dorian et al., 2006; Wolsink, 2012). Consequently, many countries have increasingly invested in the deployment of SES. In Europe, the Netherlands has set its goal of reducing GHG emissions by 49% by the year 2030, and in doing so, it plans to increase the total share of SES to 25% by 2030 (Netherlands Ministry of Economic Affairs, 2019). Clearly, the government, educational institutions, and niche organizations will demand a rapid increase in research and development for better uptake of SES.

1.2. Social Acceptance of Sustainable Energy Systems

As the uptake of SES with innovative research practices increases, the social acceptance of these systems is often overlooked (Wolsink, 2012; Wüstenhagen et al., 2007). According to Wüstenhagen et al., social acceptance is an amalgamation of acceptance by the socio-political, community, and market dimensions of a technology (Wüstenhagen et al., 2007). The socio-political acceptance dimension relates to the acceptance of technology by the public, law, and institutions through implementing suitable policies and regulations. Community acceptance refers to the acceptance of technology by the local society based on geographic location, identity, fairness, and trust in deploying the technology. Market acceptance relates to the market adoption of technology, or in other words, whether investors, firms and consumers are willing to pay for the technology (Wolsink, 2012; Wüstenhagen et al., 2007).

An imbalance in any of the above dimensions can stifle the successful deployment of SES (Bolwig et al., 2020; Friedl and Reichl, 2016; Wolsink, 2012). For example, although the deployment of a niche energy system may be advantageous for a part of society, it may come at the expense of indirect effects on other parts of society (Bale et al., 2015). In other words, the operation of an energy system may raise energy communities among the elites or middle-class income groups, allowing them to collaborate their costs effectively (Bouffard and Kirschen, 2008; Lowitzsch et al., 2020). However, people who cannot afford such collaboration and expensive systems may feel left out and raise complaints, leading to community acceptance issues concerning affordability and inclusiveness. Such social acceptance issues form a barrier to successfully deploy SES and ultimately slow down energy transition (Wolsink, 2012). Therefore, the inclusion of principles of social acceptance in SES is necessary for its successful deployment.

1.3. SIGNIFICANCE OF VALUES IN SOCIAL ACCEPTANCE

Values play a significant role in evaluating the social acceptance of SES. Typically, values denote something that "a person or group of people consider important in life" (Friedman et al., 2013). In other words, values are a characteristic preference or motivation of an individual to achieve a goal (Rokeach, 1979; Schwartz, 2012). However, values are not just limited to self-satisfaction or achieving personal goals and important desires (de Wildt et al., 2019; van de Poel, 2018, 2021).

In more general sense, values are addressed on broader societal scale (de Wildt et al., 2019; Demski et al., 2015; Künneke et al., 2015). According to van de Poel and Royakkers (2011), values are "lasting convictions or matters that people feel should be strived for in general and not just for themselves to be able to lead a good life or realize a good society". Rokeach (1973) highlights that values can be used to distinguish between a "socially preferable" option from a worse or opposite option.

Consequently, values form a significant criterion to address various social acceptance issues, moral issues and inequalities (de Wildt et al., 2019; Demski et al., 2015; Grunwald, 2015), and hence increase social acceptance of SES (Künneke et al., 2015; Milchram et al., 2018; Mouter et al., 2018). Values guide people to judge whether the energy system performs as per their cultural principles, expectations and perceptions (de Wildt et al., 2019; Demski et al., 2015; Grunwald, 2015).

Subsequently, social acceptance issues arise when the expectations of people have not been met or there exists a mismatch between societal values and technical and economic values of SES (de Wildt et al., 2019). Take, for instance, value *reliability* which can be defined as the measurement of the ability of the system to perform efficiently without undergoing power shortage or other severe conditions (Adefarati and Bansal, 2019; de Wildt et al., 2019). There can be plenty of ways to realize this value. A technical way of realization could be using state-of-the-art technologies such as smart meters to improve efficiency (Hess, 2014), and the societal way could be to consider the values in society, how they interact with the technology, the expectations they have, and the issues they face with the technology (Bouffard and Kirschen, 2008; de Wildt et al., 2019; Lowitzsch et al., 2020). Consequently, when the technical values take precedence or undergo a mismatch with societal values through various technical designs and policies in the deployment of SES (Wolsink, 2012), this may lead to various social acceptance issues (de Wildt et al., 2019, 2021; Künneke et al., 2015).

Further, as multiple values can exist in society and technology, the inability to realize all values at a time, or in short value conflicts, are inevitable, which again leads to various social acceptance issues (de Wildt et al., 2019; van de Poel, 2009, 2015). Value conflict occurs when "two or more values conflict in a specific situation if, when considered in isolation, they evaluate different options as best" van de Poel (2009). In other words, "a value can only be practically realized in a specific context at the expense of another value" de Wildt et al. (2019). For example, in a smart-grid community, a household may use solar panels to satisfy the value *sustainability* while facing a trade-off related to the unsafe *security & privacy* regulations inherent to smart-grids or smart meters Hess (2014). In short, value conflicts can occur both within an individual between multiple values— where a person makes a trade-off between two or more values— or differing values among two or more individuals (Demski et al., 2015; van de Kaa et al., 2020; van de Poel, 2015, 2021; van der Waal et al., 2020).

In conclusion, values form a significant criterion with which one can better evaluate the broader consequences of implementing the SES and contribute to increasing its social acceptance.

1.4. VALUE CHANGE AND SUSTAINABLE ENERGY SYSTEMS

1.4.1. VALUE CHANGE: THE CONCEPT

There exists a great complexity in the just and timely embedding of values in technology. Although technology may embody values permanently, the values that people hold important may change during the lifetime of the technology (Taebi et al., 2014; van de Poel, 2018, 2021). In other words, the emergence of a new moral problem or a new experience with the technology (van de Poel, 2021; van der Duin, 2019) may cause the values that were permanently embedded in the technology during its design phase to mismatch with the values that the society currently holds significant (van de Poel, 2021). For instance, an economic crisis may lead to a change in the importance of value *environmental sustainability*—which may have been embedded in the design phase of SES along with other social, technical and economic values— to value *affordability*, hence causing a mismatch between societal values and values embedded in SES (de Wildt et al., 2021).
Value change may occur in four different ways (van de Poel, 2021):

- Change based on a *new consequence of the technology*, leading to the emergence of new values to evaluate the technology.
- Change based on *new opportunities provided by the technology*, which again leads to the emergence of new values to evaluate the technology.
- Change based on *new choices and dilemmas emerging over time*, leading to the formation of new values.
- Change based on *new experiences with technology*, leading to the formation of new values or current values change

Value change is not just constrained to *emergence of new value* but may also exist in other forms. van de Poel (2018) provides a more specific classification of value change: 1) emergence of new values, 2) change in the relevance of values, 3) change in the importance of values , 4) change in the conceptualization of values, and 5) change in the specification of values (see chapter 2).

1.4.2. THE NEED FOR EXPLORING VALUE CHANGE IN SUSTAINABLE ENERGY SYSTEMS

There are various mechanisms that drive the value change in SES (see table 3.1). SES as a Complex Adaptive System (CAS), consists of various complex, emergent, and co-evolutionary dynamic mechanisms that contribute to the value change in SES. (Bale et al., 2015; Demski et al., 2015; Grübler, 1998; Siebert et al., 2017; Warneryd et al., 2020). The SES are characterized by long life-cycles, a constant state of transition due to the emergence of new technologies, regulations governing heterogeneous actors and their interaction with each other, and complex interaction among multiple subsystems, hence contributing to an emergent change (Adil and Ko, 2016; Bale et al., 2015; Bento et al., 2018; Naus et al., 2015; Siebert et al., 2017). First, the technical side is constantly dealing with supply and demand of consumers, updating with state-of-the-art infrastructure, and dealing with different types of data generated (Siebert et al., 2017; Warneryd et al., 2020). Second, the financial aspect deals with ever-emerging business models sparked by prosumers and private firms Adil and Ko (2016). Lastly, the society is simply acting and interacting, leading to emergent consequences for each other (Siebert et al., 2017).

Consequently, the complex, emergent, and dynamic characteristics of SES entail high uncertainty in its future use as well as the values people deem important, leading to uncertainty in future acceptance of SES (Bale et al., 2015; Castrejon-Campos et al., 2020; de Wildt et al., 2021; Demski et al., 2015). The uncertain characteristics of SES can cause different values to be traded-off or prioritized in different situations (de Wildt et al., 2019; Demski et al., 2015; van de Poel et al., 2020). Or as mentioned earlier, the uncertain consequences or problems from an SES can lead to a discrepancy between societal values and values embedded in SES (van de Poel, 2021). In short, values change due to which value conflicts emerge (de Wildt et al., 2021; von Wirth et al., 2018), leading to a lack of social acceptance of SES in the future.

To better evaluate the future acceptance of SES, one needs to explore the value change. Exploring the various uncertain future scenarios in which values change can help identify the unintended consequences and risks related to the SES implementation, as well as form accurate strategies or design requirements to facilitate better acceptance, hence contributing to better prospects for the future acceptance of SES (de Wildt et al., 2019, 2021; Nikas et al., 2020; van der Duin, 2019; von Wirth et al., 2018).

The following chapters will review approaches that have dealt with or explored value change, and subsequently use the knowledge gaps to formulate research objective and research questions.

1.5. RESEARCH OBJECTIVE

As will be explained further in the literature review, there is a lack of understanding on how values change in SES and no research has formulated a simulation model to explore value change on a normative scale. The objective of this research is to gain an understanding of mechanisms that drive value change in SES by formulating a value change model that integrates actor heterogeneity, individual decision-making, bounded rationality and social interaction, and explores the value change under various policy and uncertainty scenarios. To this end, this study aims to develop a modelling approach to explore value change in SES by making use of agent-based modelling and exploratory modelling approach.

1.6. OUTLINE OF THIS RESEARCH

The thesis is distributed into four parts: (I) Thesis Definition, (II) Model Formulation, (III) Results and Discussion, (IV) Conclusion. In chapter 2, the existing literature on value change is discussed and the knowledge gaps are identified. Using the identified knowledge gaps, a research objective and main research question are then formulated in chapter 3. In chapter 4, the conceptual framework to explore value change is delineated, which is used as an input for model formalization and specification in chapter 5. Following this, 6 verifies and validates the model to make it ready for experimentation and results in 7. Chapter 8 discusses the implication of results and analysis and the limitation of the model. Lastly, chapter 8 concludes this research by bringing together outputs from various sub-research questions to answer the main research question.

2

Literature Review

The literature in the domain of value change is very scarce. Only a handful of studies have conceptualized the idea of value change. The existing literature proposes few approaches to explore or anticipate value change. This chapter aims to review these studies and find potential approaches that have dealt with or explored value change. Thus, we review both conceptual approaches and simulation models that explore value change. Based on this review, the knowledge gap is then found and further formulated into research objective in the following chapter.

First, the limitation of contemporary approaches to consider value change is discussed. After this, the existing literature on value change is reviewed. Lastly, the current studies that have applied simulation models to explore value change are examined.

2.1. Limitation in contemporary approaches to consider value change

Currently, various contemporary approaches such as Value Sensitive Design (VSD), Design for Values (DfV) and technological assessments (Friedman et al., 2013; Van den Hoven, 2013; van den Hoven et al., 2015), are used to embed values in the design of technology. Although these approaches are slightly different from each other, they can be grouped under the same fundamental idea as VSD (Jenkins et al., 2020). VSD *"is a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process"* (Friedman et al., 2013). A VSD approach is a 'tripartite' method consisting of three phases: 1) conceptual: to identify relevant stakeholders and values, 2) empirical: evaluating stakeholder perspectives in embedding values in technology, and 3) technological investigations: identifying the impact of technology on values considered (Friedman et al., 2013). Thus, the three phases of VSD are key in embedding values for the design of SES. But is VSD able to consider value change?

VSD is limited in terms of just and timely embedding of values in SES. One limitation of the VSD approach is its inability to appropriately capture and explore value change. First, VSD assumes that societal values and opinions remain stable (Manders-Huits, 2011; van de Poel, 2018). This is because the conceptual phase of VSD considers the values of stakeholders to be static for a particular context and time. In other words, it does not consider the fact that stakeholders are able to change their future preference for values concerning the technological development (Smits et al., 2019). Second, VSD does not promote an iterative process that could regularly monitor value changes through the whole life cycle of technology and hence include the changes back into the design (Jenkins et al., 2020). Lastly, VSD does not consider any continuous chain of interaction and consequences between users and technology, to regularly update the values of society over the lifetime of technology (Manders-Huits, 2011; Nurock et al., 2021; Smits et al., 2019). In short, VSD not only lacks a dynamic exploratory and iterative characteristic but also struggles to consider the interaction between the users and technology. Based on this multiple pathways are carried out to adapt the VSD approach such that it is able to deal with or explore value change.

2.2. Existing Literature on Value Change

2.2.1. The ex-ante consideration of value change

The most recent researches have looked in ex-ante consideration of value change by adapting the contemporary approaches such as VSD

Adaptation of Contemporary Approaches

Smits et al. (2019) adds on the VSD approach by giving a touch of anticipatory and iterative characteristics using the mediation approach, to propose "Values that Matter" or VtM approach. The conceptual phase of the VSD approach is similar to the first two phases of VtM i.e: 'explore' and 'conceptualize'. However, the main difference lies in the 'anticipate' phase, which looks for values beyond the current context and reflects on the what-ifs of the future by exploring consequences of technology on the relations between actors and their values. Further, this process is iterative in the sense that after different values and relations have been explored, stakeholders are called upon to approve for redefining the values in the design of technology in the 'test' phase (Smits et al., 2019).

However, one limitation of this approach may be 'information overload' and the difficulty in processing this information. As VtM combines multiple stakeholders, their values and their relations with technology or other stakeholders, there may be discrepancies in the process produced by the designers due to their bounded rationality or incapability to process multiple information correctly in suitable time when compared to computer simulations.

Similarly, another adaption of the VSD approach is done by Umbrello and van de Poel (2021), who propose to deal with value change in unpredictable AI algorithms over its whole life cycle. The authors argue that, due to the black-box nature of AI systems, they can 'disembody' values that were embedded in them initially, which again leads to value change and value conflicts as we know.

This approach consists of four phases: 1) context analysis; 2) value identification; 3) design requirements; 4) prototyping. Apart from the generic VSD approach, the main difference lies in the anticipatory characteristic of the 'value identification' phase and both anticipatory and iterative characteristics of the 'prototyping' phase. These two phases may give rise to unknown values or values that have more priority by the stakeholders, which can be then integrated into the design through various iteration cycles (Umbrello and van de Poel, 2021). However, the approach is very context-dependent on AI and Sustainable Development Goals (SDG), which makes it uncertain as to whether this approach might apply to other technologies or energy systems in general.

Jenkins et al. (2020) compares the critique on VSD for its insufficient consideration of value change during the use of technology, and proposes to couple Energy justice (EJ) concepts with the concepts of VSD. The author identifies in their review of comparing other approaches to VSD, that VSD is limited in terms of capturing temporal change in values, whereas, EJ can very well capture this limitation of VSD due to its concept of realizing inter-generational impacts of technology in the future. Therefore, the author suggests combining EJ with VSD to get a whole picture of energy system development. Through this, the author argues that researchers can gain better insights.

Types of value change

There exists no consensus among literature regarding the types of value change. Smits et al. (2019) suggests value change occurs in the interaction between end-users and technology due to: "dynamics in value expression"— which denotes the different perceptions that end-users have with technology affecting their values— and "value definition" referring to the effect of technology on the definition or conceptualization of values. While, Hellberg and Grönlund (2013) argues that only specification of values or the design requirements of a new technology changes over time. Likewise, van de Poel (2018) provides a more specific classification of value change: 1) emergence of new values, 2) change in the relevance of values, 3) change in the importance of values , 4) change in the conceptualization of values, and 5) change in the specification of values.

As the classification provided by van de Poel (2018) is more intricate and specific, we choose to discuss further on this. All the types of value change suggested by van de Poel are suitable to study future acceptance of energy systems, however, three are most interesting to review further: emergence of new values, change in relevance of values and change in relative importance of values.

First, the author relates 'emergence of new values' to how a particular value emerges and gains prominence due to an unseen consequence or impact of technology. To give an example of how this type of value change constrains future acceptance of energy system, van de Poel (2021) exemplifies this by relating to energy systems that were developed in the past without any intention or goal to consider value sustainability which has gained prominence today. This shows that unknown consequences of energy systems in future, may need "new evaluative dimensions" that form a basis for emergence of new values (van de Poel, 2021).

Next, for the type 'change in relevance of values', the author relates to how certain values become more relevant than others in an energy system while it was not previously considered relevant. This can be related to the secondary effects of implementation of energy system, which could lead to impact on other evaluative dimensions such as safety or privacy which were not considered relevant earlier (van de Poel, 2018).

For the type 'change in relative importance of values' or prioritization of values relates to how people prioritize one value over the other due to uncertain developments of energy system. This type of value change is significant to determine the future acceptance of energy systems (van de Poel, 2018).

Finally, in order to narrow down the scope for this research, a selection among these three types of value change is made. Here, the change in relative importance or prioritization of values is considered among the other two aforementioned value change types. The reasons are two-fold. First, the emergence of new value relates directly to evolutionary uncertainty or prediction of emergence of a new value, which is out of scope of this research. Second, the change in relevance of values requires consideration of multiple values which implies much difficulty in including and exploring both relevant and (currently) irrelevant values, and hence is also out of scope of this research. Lastly, this 'change in relative importance of values' type is a generic representation of value change and may be to explore value change and future acceptance of energy systems in this research.

Other conceptual approaches

Some researches suggest for an ex-ante evaluation of consequences of actions or uncertain situations in future (Taebi et al., 2020; Van den Hoven, 2013; van der Duin, 2019). Van den Hoven (2013) and van der Duin (2019) suggest that to deal with multiple values and their underlying dynamics one ought to: *"1) collect as much knowledge as possible about the potential consequences of decisions*

2

and actions in the innovation process and 2) evaluate the moral values of the options and results of the innovation process" (Van den Hoven, 2013; van der Duin, 2019).

Taebi et al. (2020) suggests adaptive planning as a method to deal with uncertainty in evolutionary processes. According to the author, adaptive planning entails pre-planning or anticipating the uncertain situations to adapt the technology beforehand during planning phase, rather than planning after the issues emerge. The author claims that this method can make policies more robust in the face of uncertain future (Taebi et al., 2020). Similarly, to adapt the technology ex-ante van de Poel (2018) suggests designing the technology by adding adaptability, flexibility, and robustness to it such that it is easier to deal with value change beforehand.

Others propose techno-moral scenarios to deal with value change (Boenink et al., 2010; Kudina and Verbeek, 2019; Wright et al., 2014). Techno-moral scenarios can help explore and anticipate the impact of emerging technology on society. Hence, through this the design of technology may be appropriated accordingly (Kudina and Verbeek, 2019; van de Poel, 2021). However, there are several limitation of this approach. One is that it does not offer an outlook on the interaction between moral values, and Another, is that it does not accurately anticipate the consequences of technology on the users (Kudina and Verbeek, 2019; van de Poel, 2016).

In conclusion, above studies have proposed numerous methods and approaches for ex-ante consideration of value change. However, exploring scenarios of value change and only anticipating it, leaves out other questions related to dealing with value change or appropriation of technology after it has occurred. The following section looks into the studies which have considered this issue.

2.2.2. THE EX-POST APPROPRIATION OF TECHNOLOGY TO CONSIDER VALUE CHANGE

Exploring uncertain scenarios is useful to anticipate or consider value change, however, it is not known how the technology can be appropriate after they have occurred. There is a huge difficulty in appropriating technology to accommodate the value change. This difficulty is noted by some authors as the 'collingridge dilemma', where certain societal changes cannot be embedded in the technology after it has been launched and subsequently, after its consequences become evident (de Reuver et al., 2020; Hellberg and Grönlund, 2013; Kudina and Verbeek, 2019; van der Duin, 2019).

Hellberg and Grönlund (2013) and van der Duin (2019) conclude from their research that values that have changed over time can be "re-operationalized", however, this is a time-intensive process in the case of governance. This could also be true for any technological development that involves society especially in the case of SES.

Similarly, de Reuver et al. (2020) points out that it can be hard to embed values reliably and change fundamental components in systems after they are launched. However, certain incremental changes can be done. In other words, the author denotes that the "incremental changes are largely related to the boundary of the platform rather than its core, which is to remain stable as much as possible".

A method called 'social experiments' is said to potentially deal with the 'collingridge dilemma'. This method evaluates the positive and negative impact of technology through experimenting with it in society (Kudina and Verbeek, 2019; van de Poel, 2016). Although, social experiments are able to solve the 'collingridge dilemma', they totally disregard anticipating the consequences of technology.

2.2.3. CONCLUSION

The above literature review has provided various methods and approaches that potentially consider value change. Some authors have looked into ex-ante consideration of value change by exploring and anticipating it, while, others have contributed to ex-post appropriation of technology to deal with value change.

However, these approaches have serious limitations. The ex-ante side of dealing with value change, requires for example, processing of large information loads to evaluate the interactive dynamics between users and technology, or the uncertain scenarios of change. Or the approaches may be too context-dependent and lack an empirical base. Lastly, the anticipatory approaches lack in providing solutions to deal with the change or assist in appropriation of technology after the change has occurred (called as the collingridge dilemma).

On the other hand, although, the ex-post side of dealing with value change has provided solutions to deal with the change after it has occurred, they do not consider extensive exploration and anticipation of value change.

Consequently, simulation models may help overcome these limitations by using its both anticipatory as well as experimental characteristics to deal with or explore value change. The following section discusses this.

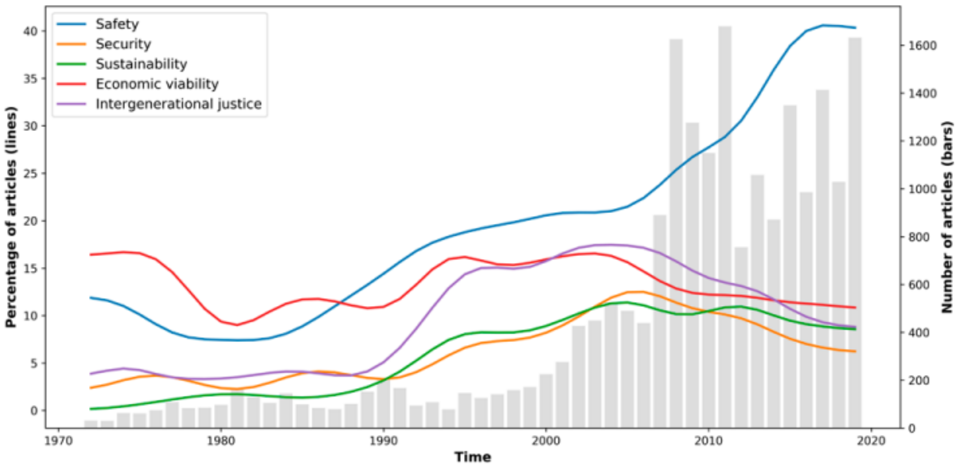

Figure 2.1: Value change over time as seen from percentage scientific articles (van de Poel et al., 2020)

2.3. SIMULATION MODELS TO EXPLORE VALUE CHANGE

Very few researches have utilized simulation models to explore value change and anticipate the future acceptance of a technology or energy system. But before we discuss what researches have simulated to explore value change, we ask: why simulate to explore value change?

Humans are limited in terms of their inherent bounded rationality. According to (Siebert et al., 2017), bounded rationality can be distinguished into three types: *"(i) the computational capacity of human beings is restricted; (ii) the information in which people rely on to make decisions is typically incomplete; and (iii) the decision-making on how to adapt to perceived situations can be conscious or unconscious, as people use simple procedures, called rules of thumb or heuristics, to guide their actions."* (Siebert et al., 2017). This is where simulation models have proved to be useful.

Simulation models have long been used in practices to process complex relations that a human mind is unable to process (Holtz et al., 2015; Kwakkel and Haasnoot, 2019). The simulation model can capture heterogeneous or multiple information sets, dynamic relation, and foresight of how dynamics play out in the future, as opposed to the human mental models, which ignore underlying feedbacks and non-linearities in the system (Holtz et al., 2015; Sterman, 1994). For instance, figure 2.1 shows the trends of values changing through the number of scientific articles parsed simultaneously through computation power. Therefore, to have a better insight of value change and value conflicts that occur due to the deployment of the SES, it is reasonable to utilize the power of simulation models such as Agent-Based Modelling (ABM), System Dynamics and other exploratory modelling methods (see chapter 3).

Both agent-based modelling and system dynamics have potential in modelling value change. Ulli-Beer et al. (2010) have proposed a system dynamics approach to study the dynamic acceptance of technologies on a subjective scale, however, they do so without considering values. On the other hand, ABM is suitable in modelling values and value conflicts for social acceptance of energy systems (de Wildt et al., 2020, 2021), however, no research has used ABM to explore value change in SES on a normative scale. Articles such as (de Wildt et al., 2020, 2021) have used ABM to conceptualize values and identify value conflicts in energy systems, but in a static manner. In other words, values remain concretely embedded in a simulation run rather than dynamically changing. Kreulen (2019) uses ABM to conceptualize and explore value change in energy systems, but assumes values on a subjective scale (Schwartz, 2012), rather than values on normative scale (de Wildt et al., 2019; Demski et al., 2015). Nonetheless, (Kreulen, 2019) and other energy transition studies (Barazza and Strachan, 2020; Bergman et al., 2008) have shown that ABM can be used to explore value change and other patterns of change in energy systems (the rationale behind the selection of ABM for this research is further elaborated in chapter 3).

2.4. CONCLUSION

This literature review showed that various conceptual approaches are incapable of exploring value change, either due to their lack in dealing with value change after it has occurred or their static characteristics to consider values. Alternatively, few simulation studies that use ABM to consider values in energy systems either statically consider values or have explored value change on a subjective level. Therefore, it is found that: (1) there is a lack of understanding of how values change in SES, as a result, there is a lot of uncertainty in value change, and (2) no research has used agent-based modelling approach or simulation models to explore value change on a normative scale. Based on these knowledge gaps, the research objective and research question are formulated in the following chapter.

3

Research Formulation

This chapter formulates the research based on the knowledge gaps identified in previous chapter: (1) a lack of understanding on how values change in SES under different uncertain scenarios, (2) no research has used a simulation model to explore value change in SES on a normative level. Based on these gaps, first, the research objective and the main research question is formulated, followed by the sub-research questions. After this, the suitable research methods are defined, and a research flow diagram is presented.

3.1. Research Objective and Scope

The objective of this research is to gain an understanding of mechanisms that drive value change in SES by formulating a value change model that integrates actor heterogeneity, individual decision-making, bounded rationality and social interaction, and explores the value change under various policy and uncertainty scenarios. To this end, this study aims to develop a modelling approach to explore value change in SES by making use of agent-based modelling and exploratory modelling approach.

Based on this objective, we identify few elements that limit the scope of this research. This research focuses on the change in the importance of values (from here referred to as value change), among other types of value change (van de Poel, 2018) (see chapter 4). Subsequently, the research focuses on value change resulting from certain mechanisms such as agent heterogeneity, individual decision-making, bounded rationality, and social interaction. Second, this research limits the modelling approach to Agent-Based Modelling and Exploratory Modelling methods (discussed in section 3.3). Third, this research derives data from the case study of micro-grid in the city district of Scheveningen—representing the SES— and hence is limited to only certain actors, values, and spatial constraints (see chapter 4). Here three points are noted: (1) this research considers only values held by direct stakeholders and not of those held by indirect stakeholders (the implication of this choice is discussed in chapter 7), (2) this research considers only four values: reliability, affordability, sustainability and inclusiveness and (3) this research does not deal with epistemic variation in the conceptualization of values, or in other words, multiple definitions of values in a different context. Lastly, we note that by exploring the impact of 'policy scenarios' on value change, we do not deem these scenarios to have direct implications for real-world policies. However, they can help understand the impact of certain technology-driven interventions (e.g.: increase in energy storage capacity of SES) on the value change in SES.

3.2. RESEARCH QUESTIONS

The aforementioned research objective and scope are used to formulate a crisp main research question:

How can we explore the value change in sustainable energy systems?

The supporting sub-research questions are demarcated as follows:

1. **What theories can be used to support the conceptualization of the model of value change in sustainable energy systems?**

   (1) How can the value change be conceptualized for the case of microgrid?
   (2) What potential theories and assumption can support this conceptualization?

   The objective of the first sub-research question is to conceptualize the model of value change in SES using relevant theories and concepts. To achieve this objective, first, a community microgrid design of the model is used as a base for the conceptualization of value change. Two research methods are used: a case study of a microgrid in the Scheveningen district and a literature review for other microgrid assumptions. Second, a literature review is used to search for potential theories and concepts relevant to microgrids and value change, to support the conceptualization of value change.

2. **How can the model of value change in sustainable energy systems be formalized and specified?**
   To answer the second sub-research question, the theories and case study used in conceptualization of the value change in previous sub-research question, are used to formalize and specify the model of value change using Agent-Based Modelling approach (see section 3.3.1) in Netlogo (Wilensky, 1999). This model is then verified and validated using the 'Evaludation' method (Augusiak et al., 2014), to be prepared for experimentation and analysis for the next sub-research question.

3. **What dynamic patterns does the model of value change generate under different policy and uncertainty scenarios?**
   The objective of the third sub-research question is to explore and analyze the model of value change under various policy and uncertainty scenarios. In this process, the exploratory modelling and analysis (EMA) (see section 3.3.2) and the scenario discovery analysis is used to analyze the impact of various policy and uncertainty scenarios on the value change. The feature scoring and scenario discovery analysis are implemented using EMA workbench, which is an open-source tool available in Python library to perform exploratory modelling and analysis (Kwakkel, 2017).

3.3. RESEARCH METHODS

This section defines the suitable research methods that are selected to answer the research questions. First, the choice of agent-based modelling is argued by comparing it with System Dynamics Modelling approach. Next, the method to help explore value change under different policy and uncertainty settings is described. Lastly, this section ends with description of an approach to verify and validate the formalized agent-based model.

Table 3.1: SES as a complex system and examples of value change in SES

Property	**SES example**	**Value change example**
Agent heterogeneity	Energy systems with heterogenous subsystems: households, commercial buildings, large industries, and utility (Bale et al., 2015)	People have heterogeneous preference to satisfy a value. Based on this preference, they set their preference to increase or decrease energy consumption, and their outcomes are influenced by those whom they prefer to link with initially (Demski et al., 2015; Siebert et al., 2017).
Emergence	consumers in SES may choose to invest in green technology or reduce consumption or any other action that helps satisfy their values (Siebert et al., 2017)	People can have heterogenous preference for a value and on a decision. The cumulative of all the decisions, will bring about an emergent pattern of value change on the community level.
Social interaction	Utilities manage supply and demand of agents, agents give feedback to utility regarding their experience. Or agents conform to the social norm regarding their decision (Hoffmann et al., 2020).	Multiple and complex interactions exists between subsystems and individuals or between two or more individuals (Siebert et al., 2017). Therefore, values can be influenced by the unpredictable social interactions in the community.
Co-evolution	Multiple sub-systems of SES are co-evolving and interdependent on each other. Hence, potentially bringing in new policies and regulations (Bale et al., 2015)	A SES is interdependent on the consumers for their consumption and agents depend on the SES to satisfy their expectations or values (Hoffmann et al., 2020). Due to a mismatch between SES and agents, issues may flare up leading to value change (van de Poel, 2021).
Dynamic	SES are changing over time with respect to technologies, institutions, costs, consumers and their demands (Bale et al., 2015)	The continuous feedback of agents acting, experiencing and then evaluating their preference for a value, gives an indication that values may change dynamically over time rather than being static.

3

3.3.1. AGENT-BASED MODELLING

The system of interest considered in this research is SES. As discussed earlier, SES being Complex Adaptive System (CAS), have properties such as agent-heterogeneity, individual decision-making, social interaction, co-evolution, and dynamic (see table 3.1). These properties or underlying mechanisms of SES are the main drivers of value change. Based on this, we identify two relevant modelling and simulation methods— System Dynamics and Agent-Based Modelling, which can model the value change in SES. These approaches are compared as shown in the table 3.2.

Agent-Based Models are most suitable in modelling SES and the complex value change occurring in it. Agent-based models appropriately capture the heterogeneity of each agent in the system of interest. Subsequently, agents act and interact autonomously, leading to a pattern of evolution or emergent change on the macro-level over time (Bonabeau, 2002).

In the context of values and value change, Agent-based modelling can be used to model the heterogeneous preferences of agents for a value, where they prefer to satisfy one value over another (Demski et al., 2015; Schwartz, 2012). Based on these value preferences, agents have preferences for certain decisions, through which they decide and influence the value change for self and others in the community (see chapter 4).

On the other hand, System Dynamics can inaccurately represent value change. Although System Dynamics can take heterogeneity, it can do so only at a certain level such that it will aggregate the characteristics, value, or behaviour of agents (Bonabeau, 2002). This obscures the intricate decisions made and the interaction among different agents that influences value satisfaction at a societal scale.

Therefore, the appropriateness of selecting an agent-based model is in its property of capturing the heterogeneity of societal values as well as the action and interaction among individuals (Rahmandad and Sterman, 2008) in society that may lead to value change. Nevertheless, there are few limitations while using agent-based models. Although Agent-Based models are most suitable for modelling social complex behaviour, it may be hard to conceptualize and formulate this behaviour in the model (Bonabeau, 2002). Further, adding too much complexity in the agent-based model can obscure the purpose of the model and interpretation of its emergent pattern (Epstein, 2011). Such as by adding too many elements of the SES or representing multiple values, it can be hard to interpret the complex effects of different factors towards value change.

Table 3.2: Comparison of simulation approaches

Method	**Advantages**	**Disadvantages**	**Level of representation**
System Dynamics	-Can capture non-linear dynamics; -Easy formulation of differential equations	-Difficult to model on a small scale level	Aggregate and high level representation of dynamics between systems
Agent-Based Model	-Is able to model complexity; -Considers heterogeneous characteristics of individual; -Is able to simulate interactions of individuals	-Can obscure the purpose of model; -Can pose difficulty to interpret emergent patterns; -Difficult to formalize complex behaviour	Bottom-up and micro level of representation

3.3.2. EXPLORATORY MODELLING AND ANALYSIS

While Agent-Based Models formulate the mechanisms of SES, exploratory modelling techniques are used to explore and analyze the value change under different uncertain scenarios, and ultimately delineate possible strategies to deal with these scenarios of value change.
Exploratory Modelling and Analysis (EMA) is "a research method that uses computational experimentation for analyzing complex and uncertain systems" Bankes (1993); Kwakkel and Haasnoot (2019). In other words, it is a "computational whatif experiment" that anticipates various uncertain situations that can occur in system of interest (Kwakkel and Haasnoot, 2019). Unlike other scenario exploratory approaches (Carter et al., 2007), EM uses different computational tools to explore through numerous sets of uncertain scenarios, and possibly test suitable strategies or policies to deal with such scenarios. This approach can utilize tools such as Scenario Discovery or Many Objective Robust Optimization (MORO) to search and sample through sets of diverse scenarios of dynamic conceptualization of values (Kwakkel and Haasnoot, 2019).

3.3.3. EVALUDATION METHOD

Verification and validation is done in order to find whether the model has correctly conceptualized and is able to simulate the concepts as expected. Over the past, verification and validation has been used loosely, where no general criteria or consensus in terminology of verification and validation was found in order to assess the model (Augusiak et al., 2014; Oreskes et al., 1994; Rykiel J. Jr., 1996). In response, Augusiak et al. (2014) has proposed 'Evaludation' method which generalizes and combines various steps of evaluation and validation. The author defines Evaludation as "the entire process of assessing model quality and establishing model credibility throughout all stages of model development, analysis, and application" (Augusiak et al., 2014).
Consequently, Augusiak et al. (2014) proposes six steps in the evaludation process. Each of this step is formulated in such as way that it closely follows each iterative aspect of modelling cycle (Grimm and Railsback, 2005). These six steps are: 1) data evaluation, 2) conceptual model evaluation, 3) implementation verification, 4) model output verification 5) model analysis 6) model output corroboration (Augusiak et al., 2014). Following this, each step of Evaludation method is performed to verify and validate the agent-based model. Using this six step verification and validation process not just allows us to see caveats in various aspects of the model and correct them where required, but also helps understand and build confidence regarding the underlying behaviour of different concepts of the model. Further, in the context of policy making, it is a means to build confidence in decision makers regarding the model's correctness.

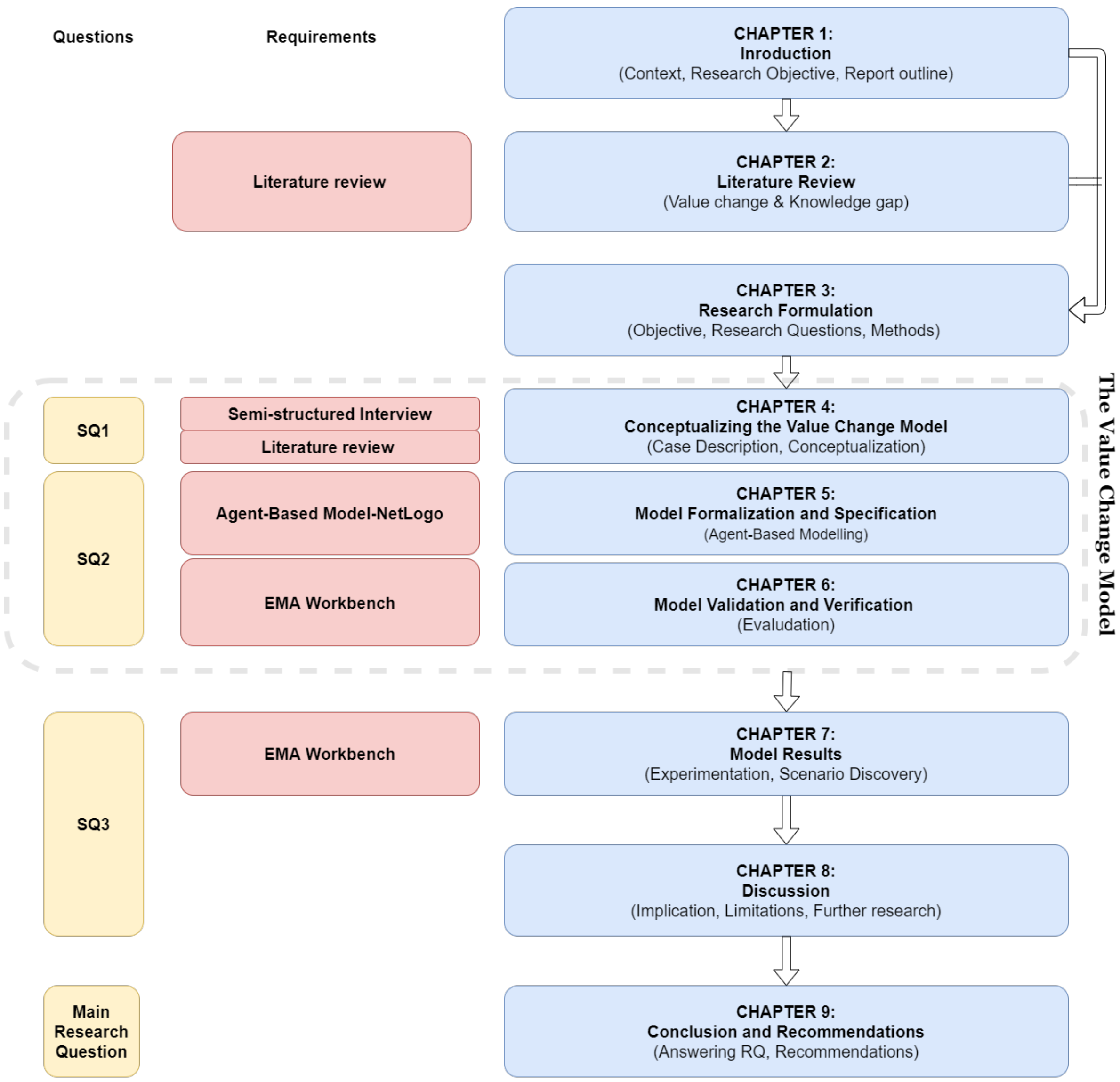

Figure 3.1: Research Flow Diagram

II

THE VALUE CHANGE MODEL

4

Conceptualizing the Value Change Model

The aim of this chapter is to form a conceptual model of value change in SES based on the case of microgrid and potential theories identified in the literature review. In doing so, this chapter answers the first sub-research question : *What theories can be used to support the conceptualization of the model of value change in sustainable energy systems?*

Here, two aspects of this question are identified:

1. How can the value change be conceptualized for the case of microgrid?
2. What potential theories and assumption can support this conceptualization?

First, the section 4.1 demarcates the boundary of the model by defining the microgrid design based on the case study of microgrid in Scheveningen district as well as other simplifying assumptions. Later, the section 4.2 defines all the suitable concepts and theories found in literature that can be used to conceptualize the value change model. The core conceptual & model assumptions of the value change model are listed in appendix B.

4.1. Case Description

4.1.1. Defining microgrid and community microgrid

The current electricity grid is less capable of accommodating large share of renewable energy. According to Lowitzsch et al. (2020), the current grid can accommodate upto 20%-40% of renewable energy. This is because of the intermittent nature of renewable energy technologies, which make it difficult to reliably balance and supply energy (Adil and Ko, 2016; Lowitzsch et al., 2020). To counter these problems, microgrids are employed as an effective solution to increase the share of renewables as well as form a resilient energy system, because of their ability to operate in isolation from the grid (Warneryd et al., 2020).

The US Department of Energy (Ton and Smith, 2012) define microgrid as:
"a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode. A remote microgrid is a variation of a microgrid that operates in islanded conditions"

As this research focuses on the community social acceptance (see chapter 1), it is assumed that microgrid is a community microgrid. A community microgrid can be defined in two different ways. Warneryd et al. (2020) adds on to the definition of US Department of Energy: *"a community microgrid is connected with its community through physical placement and can be owned by said community or other part."*. While, according to Gui et al. (2017) community microgrids are:

"self-contained and self-sufficient local electricity supply system, either standalone or connected to a centralized grid of regional or national scale, comprising residential and other electric loads, and can be supported by high penetrations of local distributed renewables, other distributed energy and demand-side resources". This research follows the definition of community microgrid provided by Gui et al..

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4.1.2. THE COMMUNITY MICROGRID DESIGN

There are several assumptions of community microgrid considered in the conceptual model. Before we explicate these assumptions, it should be noted that the data taken here for the community microgrid does not resemble the actual case study of a microgrid in the Scheveningen district. However, this case is selectively used for other data input such as model agents and spatial location (see section 5.3.1,4.1.3, and 5.5).

First, it is assumed that the key variables in the community microgrid are related to energy consumption and demand. It is advocated in literature that community microgrid design requires a proper energy management system. Authors such as Gui et al. (2017); Hoffmann et al. (2020); Siebert et al. (2017) recommend that the community microgrids need to have proper energy management resources. According to (Hoffmann et al., 2020), "maintaining system stability in future RES-based power distribution grids is the main issue". Gui et al. (2017) argues that "generation and distribution assets in a community microgrid require effective management". Therefore, it is assumed that the key variables of a conceptual model should include energy consumption and supply of community microgrid.

Second, from the definition provided by Gui et al. (2017), it is assumed that the microgrid does not generate 100% renewable energy, but it consists of a combination of renewable energy and grey electricity, such that it is self-sufficient or islanded (Platt et al., 2012). The renewable energy consists of 1.875 kW solar panels and 5 kW wind turbines, together contributing a share of about 60% to the total energy generated in the community microgrid. Whereas, the grey electricity is powered by a 5 kW diesel generator, contributing a share of 40% to the total energy generated in the community microgrid, which is to be used only in the exceptional case of a severe shortage of energy or due to the intermittent renewable energy supply.

Third, the combination of both renewable and grey energy forms the capacity or energy supply of the community microgrid, which is initially assumed to precisely match the energy consumption demand of the community. In other words, the community microgrid does not employ extra supply more than what it requires and certainly does not lack any supply. However, this does not mean that the demand cannot exceed the supply of the community microgrid.

Lastly, in the case when demand exceeds the capacity of the community microgrid, it is assumed that grey energy is used, as a result, there are GHG emissions emitted from it.

4.1.3. MODEL AGENTS

The agent considered in the conceptual model is a consumer. The agents are classified into four different types of consumers: businesses, surfclubs, restaurants and industries. These agents resemble the different categories of agents involved in the microgrid development in the Scheveningen district. However, it should be noted that where necessary the characteristics of agents are implied for simplification purposes and do not represent the actual stakeholders in the microgrid development in the Scheveningen.

The businesses are large scale consumers of energy and resemble the hotels and the stadiums in Scheveningen. The surfclubs and restaurants are assumed to be small scale consumers. Lastly, the industries are a distinct agent, in that they have higher consumption than businesses. The number of each type of agents is assumed as per the case study of micro-grid energy deployment in Scheveningen, The Hague (i.e: 4 surfclubs, 3 restaurants, 3 businesses and 1 industry)

4

All agents have annual income, annual energy consumption, allocated energy supply, willingness to invest (see appendix D for detailed data specification). First, the willingness to invest is simply certain percentage of income of the agent. Second, the annual income differs for different agents. In this case, the businesses have medium income and have high annual energy consumption. The surfclubs on the other hand have low income and low annual energy consumption. The restaurants have same income and consumption as that of surfclubs. Lastly, the industries are high income earners and have high annual energy consumption (see section 4.2.2 for other heterogeneous characteristics of agents)

Further, as mentioned earlier, the capacity of microgrid matches the consumption demand of all agents in community, so the allocated supply of each agent is same as their energy consumption.

Although, it is reasonable to assume different demographic indicators of an agent such as age, gender, education and household size on individual level of a micro-grid community, however, they have very less impact on the consumption decisions that a consumer makes (Siebert et al., 2020; Sütterlin et al., 2011).

Lastly, based on the heterogenous income and energy consumption of agents, it is assumed that agent's income and energy consumption varies over time. This assumption was based from agent-based model of Siebert et al. (2017), who assume the influence of various consumer types on the emergent energy consumption behaviour in society.

4.1.4. COMMUNITY MICROGRID DESIGN VARIABLES

Based on the above assumptions, the key variables of the community microgrid design can be defined and formulated as follows:

Total annual energy consumption and supply

$$C_{total} = \sum c_{annual}$$

$$S_{fixed} = \sum s_{allocated}$$

Where C_{total} is the total annual energy consumption of microgrid calculated as a sum of annual energy consumption of each consumer c_{annual} in the model. Whereas, S_{fixed} is the fixed total annual energy supply calculated as a sum of allocated energy supply to each consumer $s_{allocated}$ in the model.

Initially, both C_{total} and S_{fixed} are assumed to be equal. Consequently, in each iterations the C_{total} changes based on the consumption decisions made by the consumer. Both these indicators are significant in calculations of variety of values on community level such as reliability, sustainability and affordability (see section 5.2.2)

Total electricity emission

$$e_{total} = (S_{total} * r_{grey})/1000$$

Where e_{total} is the total annual electricity emission, S_{total} is the total annual electricity supply and r_{grey} is the grey electricity emission rate (constant).

The total electricity emissions e_{total} is the product of total annual electricity supply S_{total} and the grey electricity emission rate r_{grey}. Although, it is clear that the only source of electricity emissions in the community microgrid would be a gas/diesel generator, however, it is also assumed that when gas/diesel generator is not being used, the electricity emissions e_{total} are decreased by green electricity supplied from solar PV and wind. This electricity emission is reasonably used to calculate sustainability indices (Jha et al., 2020) or avoided emissions (IRENA, 2016) in comparison to grey electricity emission producing sources. This variable is mainly used in calculation of community value sustainability (see section 5.2.2).

Maximum grey electricty emission

$$e_{max} = (S_{grey} * r_{grey})$$

Where e_{max} is the maximum electricity emission of community microgrid calculated as the product of capacity of gas/diesel generator or the annual grey electricity supply S_{grey} in the community microgrid and the grey electricity emission rate r_{grey}. This variable is used as a threshold in the evaluation of community value sustainability (see section 5.2.2).

Electricity price

The electricity price is a constant that influences the electricity expenses at agent level. It is used in calculation of agent and community value affordability. Although, this value is always varying in real life, in the conceptual base model we assume it to be constant of 0.5 euro/kWh to avoid further complexity in calculating the value importance.

However, the electricity price is adjusted and varied in the experiment phase accordingly (see chapter 7. Consequently, it influences the value affordability both on agent as well as on community level. This is because it is assumed that people prefer for stable prices over unstable prices when evaluating the value affordability of the community microgrid (Perlaviciute and Steg, 2014).

4.1.5. VALUE CHANGE IN THE COMMUNITY MICROGRID

The community microgrid design as shown above is a complex and co-evolutionary system that can drive value change. Community microgrids are complex and co-evolve around various technical, economic and social aspects (Adil and Ko, 2016; Guérard et al., 2012; Kremers, 2012; Siebert et al., 2017). For instance, they are governed by multiple policies and regulations, inducted with new technologies, and consists of continuous interactions between the stakeholders, which contribute to its dynamic change over time (Siebert et al., 2017). First, the technical side is constantly matching outflows and inflows as well as updating with state-of-the-art infrastructure and dealing with different types of data generated (Siebert et al., 2017; Warneryd et al., 2020). Second, the financial aspect deals with ever emerging business models sparked by upcoming prosumers (Adil and Ko, 2016). Lastly, the societal side deal with the consequences of others consumers/prosumers as well as the consequences from utility (Siebert et al., 2017).

As discussed in the chapter 1, complex systems go through value change due to the their co-evolutionary characteristics. Due to the aforementioned social, technical and economic changes emerging in a community microgrid, it is inevitable that values may change in the process. Hence,

Table 4.1: Values in community microgrid.

Value	Description
Reliability	On community level, it is the ability of the microgrid to satisfy the demand of consumers without undergoing issues of shortage. On agent level, it is the extent to which an agent keeps their consumption level below their required demand.
Affordability	On community level, it is the ability of the community to attain affordable energy cost of microgrid. On agent level, it is the ability or willingness of an agent to invest from their income for their consumption from the energy system
Environmental Sustainability	The extent of emissions contributed by the agents in the community to the environment.
Inclusiveness	It is the willingness of the agents to conform their consumption action with critical agent's actions and values in the community

as the community microgrid represents the complexity possessed in a typical SES, a community microgrid can be taken as good example to model value change.

To conceptualize the value change in the microgrid, certain values that support the objectives of community microgrid are selected. The key objectives behind developing a community microgrid are: to foster affordable electricity access for all, to maintain a reliable supply of electricity, and to contribute to sustainability in the community (Gui et al., 2017). Based on these objectives, the suitable values that are assumed in this conceptual model are: *reliability, affordability, environmental sustainability, inclusiveness*. The definition of these values is shown in the table 4.1.

Further, it should be noted that, as searching for suitable values specifically for the case of microgrid is out of scope of this research, these values are just an assumption through the literature about the community microgrid for the conceptual model, and may not apply for the actual case of microgrid in Scheveningen. However, it is recommended to sufficiently consider all the values concerning the real world case, to be able to accurately model value change.

4.2. CONCEPTUALIZING THE VALUE CHANGE

This section describes the important concepts and assumptions that are used to develop a conceptual model of value change. Some of these concepts are based in theories from literature. Whereas, wherever necessary, certain simplified assumption had to be considered to model the complexity of value change. Although, these assumption may not be realistic, it should be noted that these assumption do not aim to accurately model the value change in the real world, and that they should be considered just as tools that can help understand the value change better.

The important concepts include varying levels of value satisfaction or value importance, individual decision-making, bounded rationality, social interaction and agent heterogeneity (see table 4.2). These concepts potentially form the underlying mechanisms that drive value change. To allow for a better understanding, these concepts and other assumptions are discussed in light of their associated theories.

Table 4.2: Conceptual Framework

Theories/Concepts	Application in the value change model
Value importance and value satisfaction	Value importance - importance that an agent gives to a certain value depending on their satisfaction with that value. Value satisfaction - the satisfaction of an agent or a community when they realize a certain value, and attain a certain preferred status with regards to that value. Value importance is the opposite of value satisfaction. The value importance varies from -1 to 1 or very low to very high, depending on value satisfaction of agents
Agent heterogeneity	The agent heterogeneity concerns the heterogeneity of the agents based on their (1) preference to satisfy a value, (2) individual preference for a decision (to increase or decrease energy consumption), and (3) preference to link with others in the community.
Common pool resource and dynamic behaviour	The common pool resource & dynamic behaviour represents the dynamic and rivalrous action and interaction among the agents for a common good (energy) that ultimately influences their satisfaction or importance for a value.
Bounded rationality and transformative experience	The bounded rationality & transformative experience together are used to represent the limited rationality of agents in perceiving the consequence of their decision and decision of others in the community ahead of time, due to which, they may experience unwanted consequences or do not make right decisions for their value importance or satisfaction
Social interaction	(1) Social conformity—representing the behaviour of agents to conform their consumption decision to other agent(s) among their links who are in need, and 2) Modes of control—where agent's energy consumption is controlled by the community microgrid in three different levels: no control, partial control, and full control.

4

4.2.1. VALUE IMPORTANCE AND VALUE SATISFACTION

As mentioned earlier, the scope of this research is limited to conceptualizing value change as the change in importance of values, among other types of value change (van de Poel, 2018). Therefore, the conceptual model assumes value change in terms of value importance and value satisfaction.

The conceptual model assumes value satisfaction as: when an agent or a community realizes a certain value, and attains a certain preferred status or satisfaction with regards to that value, it is said that the agent or the community are satisfied with the value.

In contrast, it is assumed that the value importance [1] is the importance that an agent or a community gives to a certain value depending on the satisfaction they have with that value. For instance, when value is fully satisfied, the importance for that value is low and vice versa (see table 4.3).

Table 4.3: Value importance level based on value importance and value satisfaction

Value Importance Level	Value Importance	Value satisfaction
1	very high	very low
0.5	high	low
0	indifferent	indifferent
-0.5	low	high
-1	very low	very high

[1] This study uses value importance and value satisfaction interchangeably to compare and contrast, and make it easier for the reader to understand. Value satisfaction is the opposite of value importance.

VALUE IMPORTANCE LEVELS

The value importance levels have been conceptualized for better evaluation and measurement of value importance or value satisfaction of the agent. Understanding these levels helps understand the consequence of agent's decision on their value satisfaction or value importance.

Different value importance are evaluated differently based on the decision of the agent, however, every value importance is measured on a same scale of -1 to 1 with steps of 0.5 as shown in table 4.3. It is assumed that, initially the value importance for all agents for all values is assumed to be 0 or indifferent. Later, due to the decisions of agents, the value importance and satisfaction varies.

4.2.2. AGENT HETEROGENEITY

Table 4.4: Agent heterogeneity

Category	**Link preference**	**Value satisfaction preference**
Businesses	Surfclubs	Increase reliability satisfaction
Surfclubs	Restaurants	Increase reliability satisfaction
Restaurants	Industries	Increase affordability satisfaction
Industries	Businesses	Increase reliability satisfaction

As mentioned earlier, the community microgrid consists of businesses, surfclubs, restaurants, industries. These agents have various value satisfaction and link preferences (see table 4.4) apart from their distinct characteristics of income and energy consumption as mentioned earlier. These preferences define the heterogeneity of agents in the conceptual model, however, it should be noted that these characteristics are merely an assumption and in no way conform to the characteristics of consumers in real case study. These distinct preferences are discussed in the following sections.

VALUE SATISFACTION PREFERENCE

The agents in the model have specific preference to satisfy or realize a value or lower its importance. This assumption is based on 'consumer satisfaction' as proposed by Siebert et al. (2017), who assume in their energy consumption agent-based model, that consumers have certain preferences to satisfy their values relative to sustainability and affordability.

Further, this assumption can also be supported through the claim that that agents have preferences for certain values over other another (Demski et al., 2015; Schwartz, 2012).

Based on this preference, the agent can in turn evaluate whether a value is important to them when experiencing consequences of different situations. Subsequently, it is assumed that each agent would like to achieve higher value satisfaction for the value they have preferred, and would do some action/decision (in this case increase or decrease energy consumption) to accomplish that goal. In short, this concept is a starting point for value change that an agent undergoes.

INDIVIDUAL DECISION-MAKING

The agents in the model have individual decision-making—related to their energy consumption (to increase or decrease energy consumption)—based on their preference to achieve high satisfaction for a particular value. This assumption is based on the agent-based model of Siebert et al. (2017), who assume in their model that agents not just have preference to satisfy their sustainability or affordability concerns, but also do some actions to accomplish their satisfaction. For example, through readily investing in green technology to their satisfy sustainability concerns or reducing consumption costs to satisfy their affordability concern.

Additionally, according to Hoffmann et al. (2020), based on the preference for attitudes or values, agents perform "different actions, such as reducing their electricity consumption or switching devices' modes of operation."

Further, this assumption can be based from other values literature, relating to how an importance for a value or preference for one value over other, forms a guiding rule in the person's action (Ajzen, 1991; Jafino et al., 2021; Schwartz, 2012).
The preference to do certain actions could be in the form of weightage for a consumption decision that a person has based on their preference for a value (Timmermans, 1980; van de Kaa et al., 2020). However, this research assumes a pre-defined preference for values rather than a numerical weightage.

In short, it is assumed that the agents prefer to take certain consumption related decision, to accomplish high satisfaction for a value they prefer, ultimately contributing to the change in importance of values.

Link preference

The agents in the model are linked to each other depending on their heterogeneous preferences to link with other agents, and based on this linkage, agents experience consequences of other agent's consumption decisions, which ultimately leads to change in importance of values.

The preference of linkage captures the consequences emerging between two or more agents who are linked, rather than depicting resource dependency among agents. Usually a linkage is used to depict directional dependency among agents. However, the assumption in this model focuses mainly on the consequences that an agent may face due to a link they have with other agent under different scenarios of social interaction (see 4.2.5).

This assumption is adapted from agent-based model of Siebert et al. (2017), that shows that people are sensitive to decisions taken by certain agents more than any other agent. Although, the author does not take physical links/indirect interaction among agents to signify this behaviour, and rather assumes physical/direct interaction among agents, we contradict due to the spatial limitation of the case study (see 5.3.1), and instead prefer to use linkages as a means to signify the consequences occurring among agents.

Lastly, it should be noted that this research does not focus on a specific configuration of social network such as a small-world network (Watts and Strogatz, 1998), but focuses on the consequences resulting from this linkage among the agents in community. This is why it is denoted as link preference instead of network preference.

In conclusion, the agents have heterogeneous preferences to satisfy a value, based on which they have preference to perform an action, and lastly they have a preference to link to others. This adequately represents the heterogeneity dispersed in the community microgrid that could resemble the real-life heterogeneous agents in an energy system.

4.2.3. Common pool resource & dynamic behaviour

A Common Pool Resource (CPR) is "a natural or man-made resource in which it is difficult to exclude or limit users once a resource is provided, and one person's consumption of the resource units makes those units unavailable to others" (Ostrom, 1999). Two main properties that define a common pool resource are its *non-excludability*, which means no one entity can be intentionally barred from accessing this type of resource, and *subtractability or rivalness*, meaning the rivalrous usage of a common resource by one agent constricts the usage by other agent.

In the context community microgrid, various authors consider it as a common resource. According to Gui et al. (2017), the microgrid consists of a common resource: the electricity, whose consumption "is rivalrous, in that, their consumption by one consumer prevents or reduces simultaneous consumption by other consumers". Similarly, according to Wolsink (2012), "microgrids [...] should be considered as common property (owned and managed by the members of the microgrid community) that is generating a common good".

Further, it is known that CPR is usually used in institutional theories and concepts (Ghorbani et al., 2017), however, Wolsink (2012) advocates that CPR is also aligned with the social acceptance concept.

Another argument is that, in CPR *"boundedly rational, local users are potentially capable of changing their own rules, enforcing the rules they agree upon, and learning from experience to design better rules."* (Ostrom, 1999). Based on this, this study assumes the rules as values, where each individual is capable changing their values.

Consequently, to model value change, it is seen that the general idea CPR propagates is regarding the self-organizing and dynamic behavior of agents among the community concerning a common resource. For example, the model considers the change in the importance of values influenced by the consumption decisions made by other agents, assuming that the resources in the community microgrid are limited, hence causing a dynamic change in the value satisfaction of agents. Therefore, the conceptual model assumes that the microgrid is a CPR, with its main resource being energy.

Based on this, the individual decision-making of the agents implies that the decisions made by the agents have an equal and opposite consequence for the other agents they are linked with. For example, an increase in consumption by one agent causes an equal and opposite decrease in the supply of another agent.

Based on this dynamic, it is evident that not only do the consumption decision of agents directly influences their value importance, but also indirectly influence other's value importance (The relation between the energy consumption and value importance has been formulated in the section 5.2). Therefore, the common pool resource can be used as an example for continuous dynamic interaction through the decision making and consequence among the agents, resulting in emergent behavior of value change on the community scale in the conceptual model.

4.2.4. Transformative experience & bounded rationality

A transformative experience is an experience that a person goes through that leads them to a severe change in their characteristics and values, such that, it would not have been anticipated by the person experiencing it. (Paul, 2014). The author relates to the fact that decisions taken by people based on their preferences are somehow always limited to the extent that a person taking a decision would not know— how and when this experience would have occurred and what would be its consequences— until they have taken the decision.

However, a person does not go through transformative experiences frequently. The author restricts this type of experience to only major life decisions that a person takes and not merely small decisions such as taking a walk after a long busy work day (Burkeman, 2013; Paul, 2014).

Nevertheless, this theory by Paul (2014) proves the fact that people's decisions are never purely rational. It shows that the person who actually experiences the consequence of their decision will never be able to anticipate the consequence of it unless if it was something usual that a person has previously experienced.

Based on these findings from the literature, it is assumed in our conceptual model that when people make decisions related to increasing or decreasing energy consumption, they wouldn't know the consequence of it due to the influence of not just their decision but also the decision of other agents in the community.

Further, as this theory propagates the bounded rationality agents have, it is assumed in our conceptual model that, when agents take decisions based on their value preference, it will not necessarily be to increase high satisfaction of that value but can also be the opposite. This depicts the unintended or unknown consequences that an agent can have due to their limited rationality. For example, this assumption is seen in businesses and industries, where despite having a preference to reduce consumption to achieve high satisfaction, they choose to increase their consumption. That leads them to low-reliability satisfaction.

Lastly, according to the theory, transformative experiences only happen when people take major decisions in their life. In our model, it is assumed that when agents take certain decisions and experience very high value importance as a result of the consequence of self and other's decisions, they are unable to satisfy their value again or their efforts are insufficient to change the course of the consequence for the rest of the time length of the simulation. This depicts the permanent consequences that agents may face as a result of their decision and decision of others.

4.2.5. Social interaction

The conceptual model assumes that the social interaction occurs between agents in two different scenarios or conditions: 'community formation' and 'smart meter control'. These scenarios and their related assumption from literature are stated below.

Conformity

In the social conformity scenario, the agents linked with each other, conform to each other's consumption decisions and subsequently on their value satisfaction in times of need. This scenario is also called 'community formation' in the model, and the fundamental idea that it displays is social conformity.

In this context, when community formation is activated, all agents look for those agents in their linked network that have high value importance than them or those that struggle to satisfy their value preference compared to them. When the agents find such agent, they will decrease their consumption or conform their consumption decision to the other agent's decision—to an amount of mean energy consumption of all agents in the current agent's network—such that it gives the struggling agent a surplus supply, leading them to potentially satisfy their reliability concerns, for example.

This behavior of conforming with other agents is assumed from the agent-based model assumption considered by (Hoffmann et al., 2020), that people can form collective decisions or decisions that are according to the 'social norm' to improve the overall reliability of the system.

Further, social conformity or trust among community plays a key role of consumption decisions in community which in turn drive value change and acceptance of microgrid or energy system. This assumption is based on the interview with an expert (see appendix A). The community and trust among community is emphasized by the expert.

Therefore, this scenario on value change implies that people conform to each other's consumption decisions and indirectly satisfy each other's value preferences. The collective and dynamic behavior produced on the individual scale can then show emergent value change on the community level when this scenario is activated.

Mode of control

Another scenario depicts the social interaction in our conceptual model. This scenario or assumption relative to value change is derived from the 'modes of governance' concept in the agent-based model of Hoffmann et al. (2020), which proposes that the utility or distribution operator of the microgrid, can interact with the consumers of the community in three different control/ governance strategies in the form of a feedback. First, the utility can decide to have no control over the consumer, as a result, the consumer decides their consumption decision on their own. Second, the utility may try to give a slight nudge to decrease or increase the energy consumption of the agent. Lastly, full control of utility means that consumers don't have any further role in their consumption decision and the utility takes full control in managing the consumption decision of agents to maintain stability in the system.

Based on this idea, the conceptual model assumes that the community interacts with a smart meter implemented by the utility or operator of the microgrid, which influences the communities consumption decision and ultimately influences their value satisfaction. This scenario is named 'smart meter control' and depicts three levels of control by the smart meter: 1) No control, 2) Partial control and 3) Full control (see figure 5.4 in section 5.3.1). Each of these levels has a different intensity of influence on the consumption decision of agents as a result influencing their value satisfaction differently.

The significance of this scenario is to capture the interaction between the community microgrid and the agents. Capturing this dynamic as well as the consequences agents face through other agent's decisions, can be interesting to see how values evolve under uncertainty. With that said, this scenario does not form a policy scenario, and is rather assumed as a structural uncertainty of microgrid on the value change in the community (see section 7.1.1 for more on uncertainty).

Conceptual Framework Summary

1. **Value importance and value satisfaction:** importance that an agent gives to a certain value depending on their satisfaction with that value. Value importance is the opposite of value satisfaction. The value importance varies from -1 to 1, depending on value satisfaction of agents.

2. **Agent heterogeneity:** (1) preference to satisfy a value, (2) individual preference for a decision, and (3) preference to link with others in the community.

3. **Common pool resource & dynamic behaviour:** dynamic and rivalrous action and interaction among the agents for a common good (energy) that ultimately influences value importance of agents.

4. **Bounded rationality and transformative experience:** limited rationality of agents in perceiving the consequence of their decision and decision of others, leading to experience unwanted consequences or not make right decisions satisfy values.

5. **Social interaction:**(1) Social conformity: representing conformity among agents regarding energy consumption 2) Modes of control: agent's energy consumption is controlled by community microgrid in three different levels: no control, partial control, and full control.

4.3. CONCLUSION

This chapter has proposed a conceptualization for the value change model. First, various assumption relative to the microgrid design were explicated. The main characteristics of microgrid design include: community microgrid, self-sufficient—no/limited connection to the grid, common pool resource—supply exactly matches demand of agents, energy mix—both green & grey electricity, agents—businesses, surfclubs, restaurants & industries. Second, the value change model was conceptualized using the concepts/theories: (1) value importance and value satisfaction, (2) agent heterogeneity, (3) common pool resource and dynamic behaviour , (4) bounded rationality and transformative experience, (5) Social interaction (see conceptual framework summary above). Based on these concepts and assumptions the value change model is formulated in the following chapter.

5

Model Formalization and Specification

The aim of this chapter is to formalize and specify the agent-based model based on the conceptual model from chapter 4. Subsequently, this chapter addresses the second sub-research question of this research: *How can the model of value change in sustainable energy systems be formalized and specified?*

To answer this question, first, the purpose of the model and its key performance indicators are defined. Next, the underlying concepts of the model such as the model agents, their properties and states and external variables are formalized. Subsequently, using these concepts the agent-based model is formalized. This includes the description of all the model flows and procedures that are implemented in Netlogo software (Wilensky, 1999). Lastly, the model is specified and calibrated using selected data from the literature.

5.1. Model Objective

The model objective is to reproduce the underlying mechanisms that drive value change in SES under various uncertainty and policy scenarios. In doing so, the model should be able to achieve the research objective formulated in chapter 3. To achieve the model objective, the conceptualization of the value change model is formalized based on the theories/concepts: agent heterogeneity, individual decision-making for a common pool resource, bounded rationality transformative experience, and social interaction.

5.2. Key performance indicators

The Key Performance Indicators(KPI) are defined and formulated to measure the change in importance of values in the conceptual model from the previous chapter. These indicators are appropri-

Table 5.1: The key performance indicators

Level	Key Performance Indicators
Community	Reliability importance; Affordability importance; Sustainability importance; Inclusiveness importance
Agent	Reliability importance; Affordability importance; Inclusiveness importance

ately chosen and formulated based on the values considered in the conceptual model as well as the assumptions of community microgrid design. Defining and formulating the KPIs can help identify various social acceptance issues and value conflicts during the process of value change in the community microgrid. These indicators can be classified on two main levels: agent and community.

Certain assumptions have been taken to consider KPIs on the community and agent level. As shown in the table 5.1, the KPIs on the community level consists of reliability, affordability, sustainability and inclusiveness importance. While the KPIs on agent level includes all the indicators of community level except for the sustainability importance. This is because, it is assumed that sustainability is more suitable to be measured on normative scale than subjective scale. However, this does not mean that agents in the community do not consider the importance of value sustainability. In fact, the consumption decision taken by the individual agents indirectly signifies how much importance they place towards value sustainability. In general, the sustainability importance on the community level indirectly depends on the consumption decisions taken by agents in community. Similarly, it is assumed that the inclusiveness in the community is cumulative of the individual decisions taken by agents to conform to other marginalized agents who are in critical need.

The KPIs are formulated as follows:

As discussed in previous chapter, the value importance are measured on a scale of -1 to 1. It is to be noted that each of the value importance indicators have been normalized to this scale after they are calculated using the formulations provided below. The specifications of variables used to calculate these value importance indicators, is provided in the section 5.5.

5.2.1. AGENT LEVEL INDICATORS

RELIABILITY IMPORTANCE

The agent reliability importance r can be formalized as follows:

$$r = r_{-1} + (c_{annual} - s_{allocated})$$

Where r_{-1} is the agent reliability importance in previous time step, c_{annual} is the agent annual energy consumption and $s_{allocated}$ is the agent allocated annual energy supply.

When the consumption of agent c_{annual} is higher than their allocated supply $s_{allocated}$, this means they over consuming energy, leading to lesser satisfaction in reliability, or higher reliability importance for the agent. On the other hand, when the consumption of agent is lesser than allocated supply, the agent will have surplus energy, leading to higher reliability satisfaction or lesser reliability importance. Here, the $s_{allocated}$ acts as threshold for agent reliability importance (see appendix D)

AFFORDABILITY IMPORTANCE

$$a = a_{-1} - (I_{willingness} - c_{cost})$$

Where a is the agent affordability importance, a_{-1} is the agent reliability importance in previous time step, $I_{willingness}$ is the agent's willingness to invest in microgrid energy and c_{cost} is the consumption cost incurred by the agent at each time step. The agent's willingness to invest in microgrid energy $I_{willingness}$ is defined as certain fixed percentage of agent's income, whereas, the consumption cost c_{cost} depends on the product of c_{annual} and a fixed electricity price of 0.5 euro/kWh.

5

When the $I_{willingness}$ of an agent is higher than their c_{cost}, this means they are able to invest and afford the cost of consumption, leading to higher affordability satisfaction or lower affordability importance. On the other hand, when the willingness to invest is less than the cost of consumption of the agent, this means they are not able to afford the energy consumption from microgrid, resulting in lesser affordability satisfaction or higher affordability importance.

INCLUSIVENESS IMPORTANCE

Denoted by $i_(n)$, The inclusiveness importance of an agent is formalized on the concept of bounded rationality as discussed in previous chapter (see section 4.2.4). According to this concept and the assumption of conceptual model, when one agent increases their consumption c_{annual} above their allocated supply $s_{allocated}$, they indirectly influence the other agent—whom they are linked to—with supply shortage, leading to lesser inclusiveness satisfaction or higher inclusiveness importance (level 1) for the other agent. While the agent who increases their consumption disproportionately remains with indifferent inclusiveness importance (level 0).

Further, the inclusiveness importance does not remain constant after an agent has achieved higher inclusiveness satisfaction, but it keeps changing depending on the consumption decisions of the agents.

On the other hand, in the 'community formation' scenario (see) , it is assumed that every agent conforms their consumption to the marginalized agent—whom they are linked—hence, causing high inclusiveness satisfaction or low inclusiveness importance (level -1) for the agent as well as on the community microgrid.

5.2.2. COMMUNITY LEVEL INDICATORS

RELIABILITY IMPORTANCE

The community reliability importance can be formalized as follows:

$$R = R_{-1} - (S_{fixed} - C_{total})$$

Where R is the community reliability importance and R_{-1} denotes community reliability importance in previous time step, S_{fixed} is fixed total annual energy supply and C_{total} is the total annual energy consumption.

Here, S_{fixed} acts as a threshold for community reliability importance. When the total annual energy consumption C_{total} of the community driven by the consumption by the agents increases above S_{fixed}, this leads to supply deficit in community, and in turn causes lesser community reliability satisfaction or higher community reliability importance. On the other hand, when there is reduction in C_{total} due to agents lowering down their consumption below their allocated supply, there is a supply surplus on community level, leading to higher community reliability satisfaction or lower community reliability importance.

Sustainability importance

The community sustainability importance can be formalized as follows:

$$S = S_{-1} + ((e_{total} - e_{max})/e_{max})$$

Where S is community sustainability importance, S_{-1} is the community sustainability importance in previous time step e_{total} is total electricity emission and e_{max} is the maximum electricity emission threshold of community microgrid calculated based on its capacity of gas/diesel generator.

As stated earlier in the formulation of total electricity emission e_{total} (see chapter 4) and community reliability importance indicator, when total annual energy consumption C_{total} increases due to increase in consumption levels of agents, above the fixed levels of total annual electricity supply S_{fixed}, there is supply deficit. As we know when there is a supply deficit in community, there is a compensation from the grey electricity supply, as a result, there is an increase in total electricity emissions e_{total} in the community.

When the e_{total} in the community crosses the fixed maximum threshold for electricity emission e_{max}— calculated as the product of the capacity of gas/diesel generator in the community and grey electricity emission rate r_{grey}—there is lesser sustainability satisfaction or higher community sustainability importance in the community and vice versa.

Affordability importance

The community affordability importance can be calculated as the mean of affordability importance of agents.

$$A = \mu(a_n)$$

Where A is the community affordability importance and a_n is the normalized agent affordability importance.
Here, the community affordability importance depends on the agent affordability importance. It means that, if average of agent affordability importance is high or above the level 0, there is lesser community affordability satisfaction or higher community affordability importance and vice versa.

Inclusiveness importance

The community inclusiveness importance can be calculated as the mean of inclusiveness importance of agents.

$$I = \mu(i_n)$$

Where I is the community inclusiveness importance and i_n is the normalized agent inclusiveness importance. This means that if the average of agent inclusiveness importance takes the value 1, there is lesser community affordability satisfaction or higher community affordability importance and vice versa. In short, the community inclusiveness importance is formulated similarly as the agent inclusiveness importance, the only difference being the average of agent inclusiveness importance.

5.3. CONCEPT FORMALIZATION

The objective of this section is to formalize concepts that were defined in the previous chapter. Identifying and formalizing the concepts such as the model agents, their states, the model environment, can help distinguish the boundaries of the model as well as form a basis for the formulation of the model (van Dam et al., 2013).

An overview of important aforementioned concepts are shown in the figure 5.1. First, the agent consists of states which include internal characteristics, but most importantly the preference they have for certain value, their value importance level, and the preference to link with other agents .rules that influences their decisions as well as overall behaviour through the model time step (van Dam et al., 2013). These states are nothing but Whereas a rule specifies what the agent will do through the time step of the model. Second, the figure also explains the type of relation a consumer has over other consumers. The relation of consumers depends mainly on the linkages they have with particular consumer as well as on community formation which questions whether the consumers conform to each other's actions and values or not. This is explained further in the next section.

First, an overview of the concepts and their relations in the model is discussed. Then, the important concepts are listed and briefly described.

5.3.1. MODEL ENVIRONMENT

The model environment is the world as seen through the lens of an agent. An agent cannot directly influence the components of the model environment such as the microgrid design, but may themselves be influenced by those components. The model environment can be static or dynamic in nature (van Dam et al., 2013). The current model consists of three parts that constitute the model environment: temporal spatial characteristics, microgrid design variables, and external variables. agents placed in specified locations on the map of city district Scheveningen. can be divided into three parts:

TEMPORAL & SPATIAL CHARACTERISTICS

The model runs over a time step measured in years, as the microgrid design variables are calculated on annual basis. The limit of time step is dependent on the dynamics and emergence of each value importance change. In other words, the end of time step may vary differently for different situations of value change. Therefore, it is should be noted that the time step does not measure the lifetime of the microgrid, instead, it is reflective of the time taken for values to change by undergoing multiple dynamics. Although, as it is not the scope of this research, it is recommended to measure the duration of value change and compare it with the lifetime of the microgrid in Scheveningen for future study.

The agents are placed on a map of city district Scheveningen spread over the Netlogo world (see figure 5.2). Each agent has a a fixed predefined location on the map, same as the locations of the agents in the real world. Based on this, the model spatial characteristics constraints the number of agents in the model.

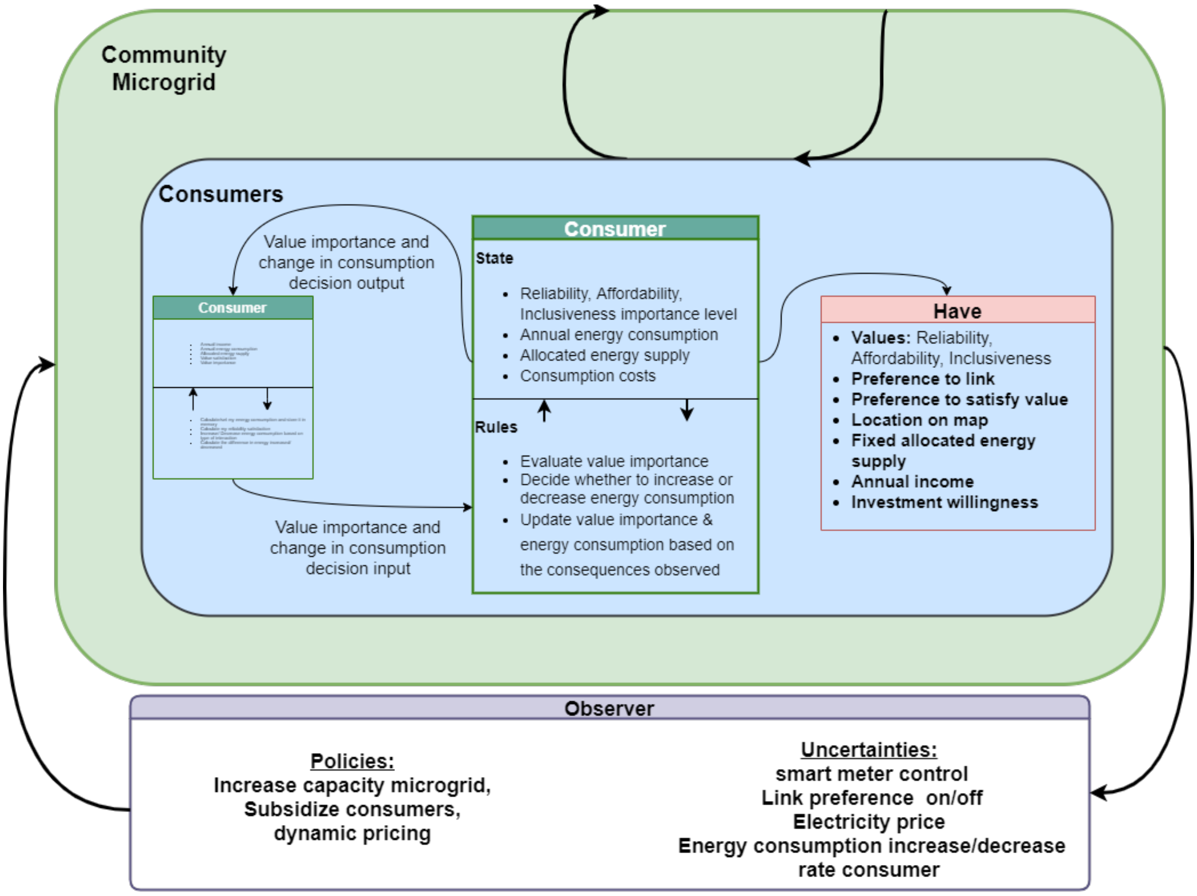

Figure 5.1: Overview of agent states, rules and relations with community and external environment

5.3.2. EXTERNAL VARIABLES

The external variables in this model are of two types: policies and uncertain variables. These two external variables influences the decision-making of agents in terms of increasing or decreasing their energy consumption. The description of each external variable is discussed below:

Figure 5.2: Model spatial interface

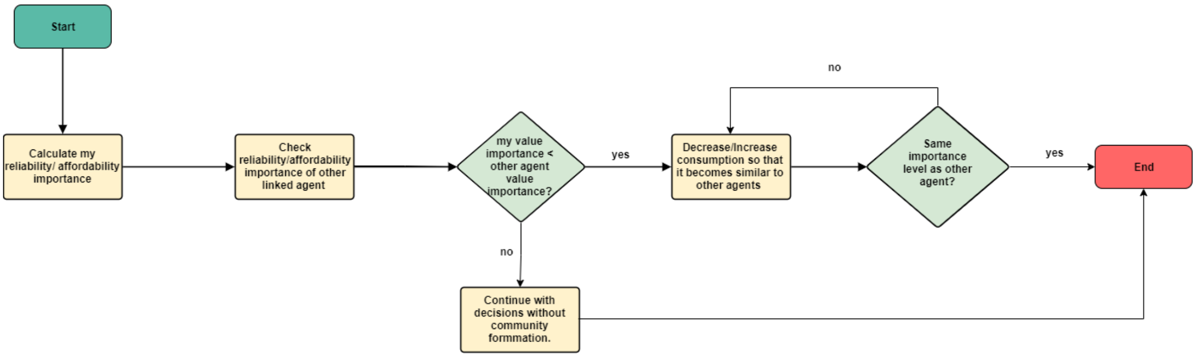

Figure 5.3: Conceptual flow of consumer decision-making during community formation mode

Community formation

The community formation is an uncertainty external variable (see section 7.1.1 for detailed specification of this uncertainty) that considers the conformity concept of social interaction (see section 4.2.5). This external variable can take binary value: True or False. A conceptual flow of decision-making of agents under community formation is shown in the figure 5.3

It is assumed that when community formation is activated or true, the agents conform to societal needs rather than their own. First, the agents check whether their own value importance is lower than value importance of others whom they are linked with, or in other words, whether they are more satisfied with their value than others in their network. The agent searches for other agents irrespective of the type of value.

When this is true, they will reduce their consumption to the mean of consumption of agents they are linked with, hence matching both their energy consumption as well as value importance level with their peers. This shows that the decisions of agents is highly dependent on the agents they are linked with and their value importance levels.

On the other hand, when the agent does not find anyone whom they can conform with—in case when the agent themselves have higher value importance than others—then they will continue to increase or decrease their consumption as they normally do without community formation. However, this is highly unlikely as agents consumption change every time step.

Therefore, the decisions of agents to conform with those who have high value importance or low value satisfaction than them, shows the conformity concept in action through this variable.

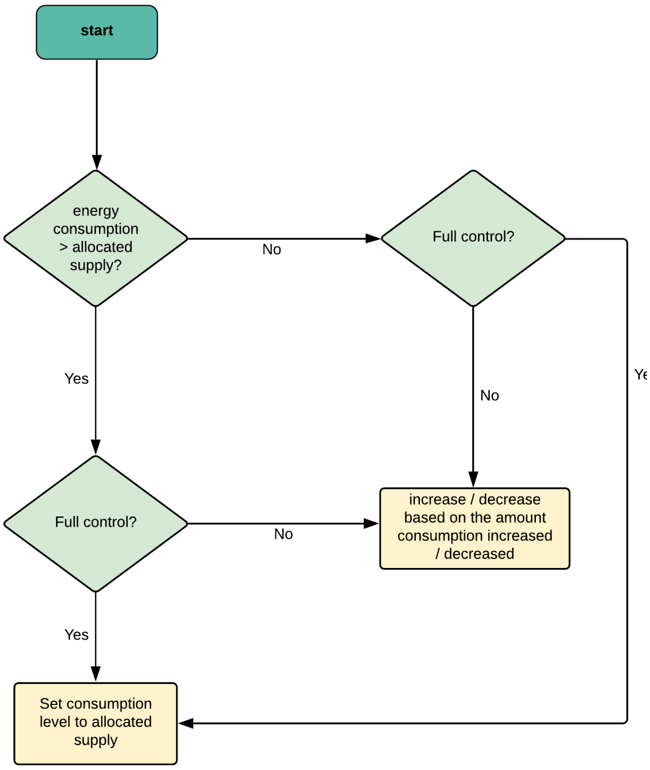

Figure 5.4: Conceptual flow of smart-meter control

5

Smart meter control

The smart meter control is an uncertainty external variable (see section 7.1.1) that is a part of technological uncertainty for its impact on the consumption decision of agents as well as their value importance. A conceptual flow of smart meter control is shown in the figure 5.4.

This external variable influences all type of value importance. It takes in values 0,1 and 2, each of them representing no control, partial control and full control respectively. When a partial control of smart-meter is activated, the decision to increase or decrease consumption of agents in community is slightly restricted, which leads to a slight influence on the value importance of the agents. Here, only the amount of energy consumption increased or decreased by the agent above or below their fixed energy supply, is deducted from or added to the energy consumption of agent at each time step.

Whereas, when the full control is active, the consumption increase or decrease is fully restricted such that there is full influence on the value importance levels of agents. So when an agent increases or decreases their consumption above or below their fixed energy supply, their consumption is returned back to their initial or fixed energy supply.

On the other hand, when smart-meter control is 0, agents have full control to increase or decrease their energy consumption as they like.

Lastly, this external variable has major influence not just on individual level but also community level. Specifically, it has implications for the value inclusiveness importance of agents, where agents may feel less included in the community when they are not able to freely increase or decrease their energy consumption. This uncertainty variable is used in combination with a policy variable (see chapter 7) only.

Link preference

The link preference is an uncertainty external variable that influences the social interaction in the community (see section 4.2.5). It can take values of True or False. As mentioned earlier, the heterogeneity of agents is captured in their specific preferences to link to other agents (see table 4.4). In doing so, they form a single link randomly with any of other consumer type of their preference. However, this only occurs when the link preference variable is True, otherwise the agents would form link randomly with any of the agents in the community irrespective of their preference.

This uncertain variable is meant to capture the uncertain interaction dynamics of the real-world. A long term network is difficult to maintain, due to the occurrence of various uncertainties. Nonetheless, this model assumes that the link preference is True for the base case, in order to simplify assumptions related to the dynamics of value change and for easy interpretability of the results.

Energy consumption increase/decrease rate

This variable is a constant specific to a consumer and is fixed in the base case. Only industries and businesses have a preference to increase their consumption, while surfclubs and restaurants have a preference to decrease their consumption. These preferences of consumer is based on their initial importance for a value such as reliability or affordability.

Increase capacity microgrid

This policy is directed towards improving the reliability concern both for consumers and community. When True, this has an influence in decreasing the reliability importance or increasing the reliability satisfaction for the community and consumers.

This policy variable has been assumed to consider the action that DSO or utility do for the community to accommodate for their reliability needs. This is based on the response of interview with an expert (see appendix A)

Subsidize consumers

This policy is directed towards improving the affordability concern both for consumers and community. When True, this has an influence in decreasing the affordability importance or increasing the affordability satisfaction for the community and consumers.

Dynamic pricing

This policy is directed towards improving the reliability concern both for consumers and community. When True, this has an influence in decreasing the reliability importance or increasing the reliability satisfaction for the community and consumers. However, this can also have a indirect effect and increase the affordability concern in society.

5.4. MODEL FORMALIZATION

Just as in a puzzle, its pieces are not randomly put together to view a bigger picture but are appropriately selected to fit in a specific juncture of the whole story. Similarly, the concepts defined in the previous section are a starting point to describe a story line of "which agent does what with whom and when" (van Dam et al., 2013). To understand this story line better, this section describes in detail a model narrative that an agent executes at every time step of the model. Then a pseudo-code is used to understand and verify the narrative with the logic of algorithms executed in the model.

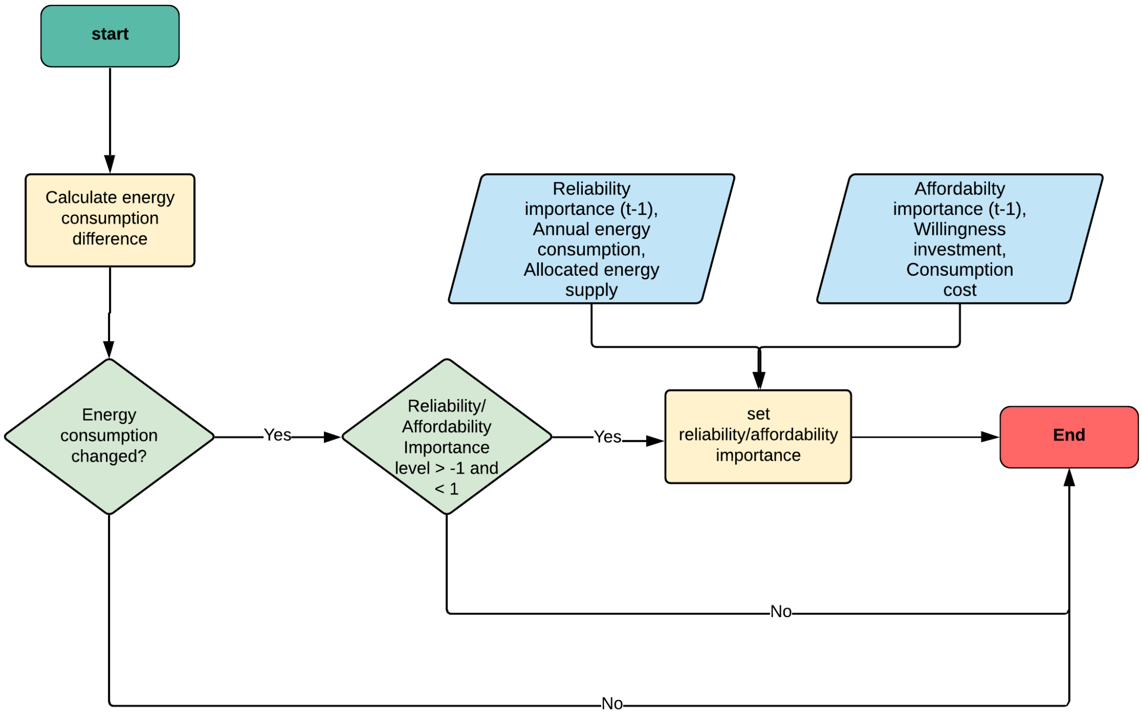

Figure 5.5: Agents evaluate the value importance by checking if their energy consumption changed, if yes, they proceed. Then, they check whether value is already fully satisfied or fully unsatisfied, if not, they proceed to calculate and set their value importance. Different agents have different preferences for value. The figure shows the input in blue boxes that agents use to evaluate their value importance.

EVALUATE THE VALUE IMPORTANCE

Every agent begins by first checking how satisfied they are with their preferred value. To do this, they first check if their energy consumption has changed, if yes, they proceed (as shown in the figure 5.5). Then, they check whether the value is fully satisfied or fully unsatisfied, if not, they proceed. Now, they check if they have enough energy supply or willingness to invest. In this case, the businesses check if they have enough supply from the community microgrid to evaluate their importance for value reliability. Simultaneously, the surfclubs and the industry do the same. On the other hand, the restaurants prefer to check if they have enough willingness to invest in the consumption costs of the community microgrid to evaluate their importance for value affordability. Nonetheless, all agents are initially indifferent regarding their satisfaction or importance with their preferred values. So they begin with a desire to achieve a higher satisfaction or lower importance for this value. But before the agents start to satisfy their values or lower their importance, they first register the importance level of their preferred values and energy consumption level in their memory.

INDIVIDUAL DECISION-MAKING

Now, each agent channels their desire of achieving higher satisfaction for their preferred values into a preferred action (see figure 5.6). Each agent has a decision to make at every time step: whether to increase or decrease their energy consumption by 2.5%. Despite their desire to achieve higher reliability satisfaction, the businesses prefer to increase their energy consumption to satisfy their bulky needs. Simultaneously, industries follow the same pathway as businesses. On the other hand, the restaurants and surfclubs are adamant about their values of affordability and reliability and therefore choose to decrease their energy consumption. They do this until they achieve a higher satisfaction for the value they preferred. However, they experience various consequences in satisfying their values.

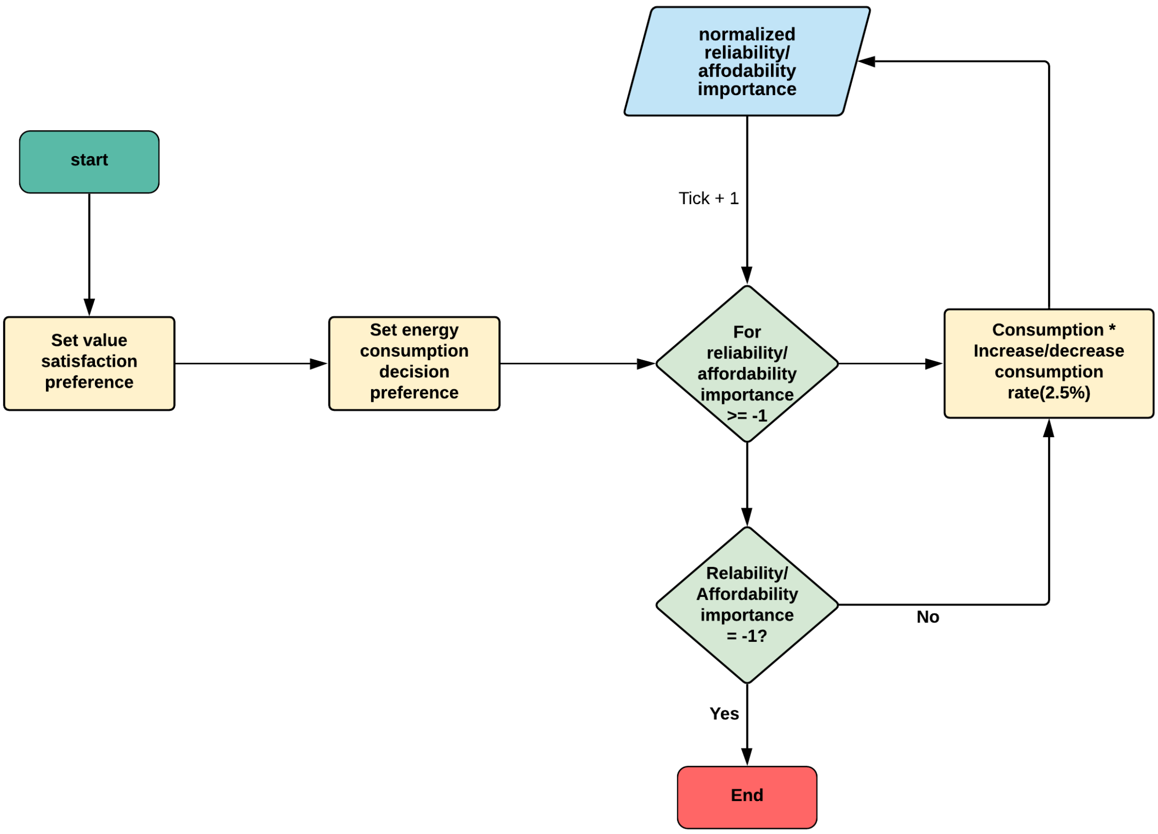

Figure 5.6: Agents make energy consumption decision. Figure shows a continuous loop of decision at each time step, that an agent undertakes to either increase or decrease their consumption, and if possible reach to the highest satisfaction level for the values they preferred.

EXPERIENCING THE CONSEQUENCES OF DECISION OF SELF AND OTHERS

After their decisions, each agent experiences consequences of their decision and then evaluates their satisfaction or importance for their preferred value again. Consequently, the businesses and industries plunge into despair, as they become less satisfied with their decision, and subsequently, their importance for value reliability rises. But it is already too late, and they have no option except to face the consequence of their decision.

On the other hand, the restaurants and surfclubs after making their decision, are initially satisfied with their actions, which is shown in their satisfaction with affordability and reliability respectively. However, they too eventually experience insufficient funds or insufficient energy supply due to the influence of businesses and industries increasing their energy consumption disproportionately in the community, but they are unaware of this. Due to this experience, restaurants and surfclubs attain lower satisfaction or higher importance for their preferred values rather than higher satisfaction or low importance (see figure 5.7)

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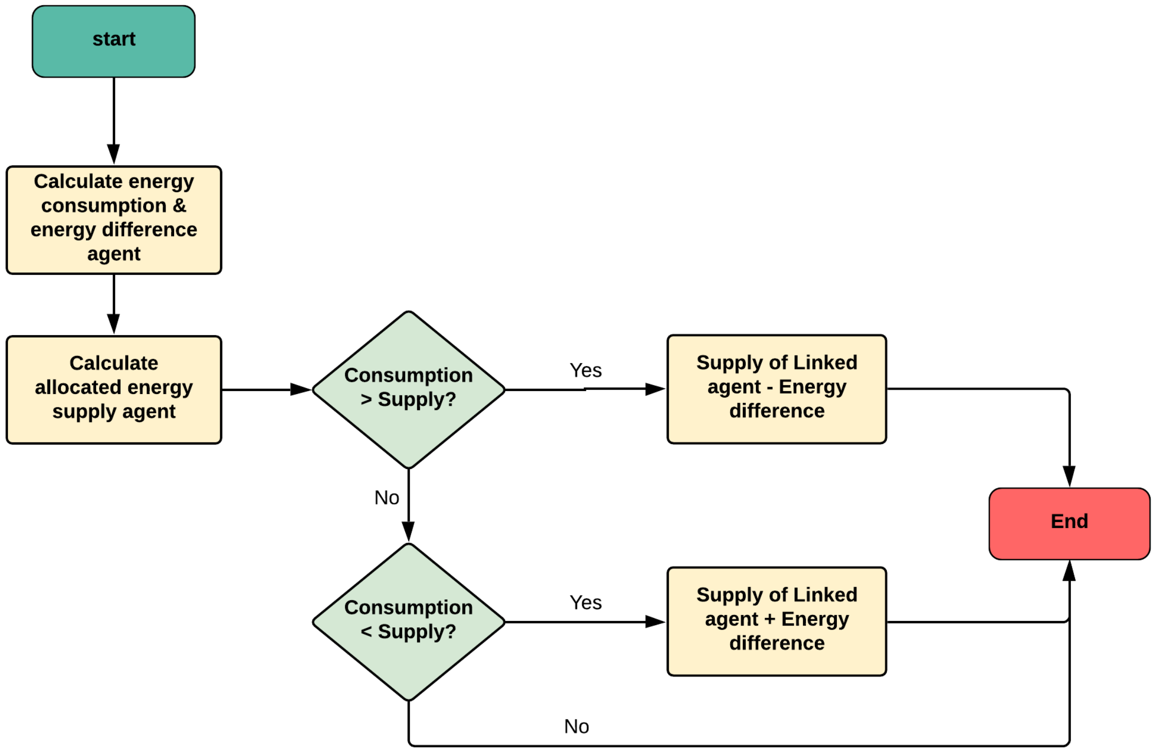


Figure 5.7: Agents experience consequences of consumption decision of one agent on others. The figure represents the observer view of how agents, after they make decision, are evaluated in terms of their consumption and supply. Based on which the community microgrid increases/decreases the supply of their linked agents with the equal and opposite amount of consumption increased by their peers.

THE OVERALL PROCESS OF VALUE CHANGE

This continuous process of agents evaluating, acting and interacting, experiencing, and then evaluating their value importance, occurs at every time step (see figure 5.8). Over time, the value importance of agents becomes stable, resulting in agents achieving their goal of lowering value importance or not depending on the consequences of self-decision and the decision of others. Hence, this results in a change in the importance of the values of agents in the community microgrid.

Additionally, the agent's importance for values may change differently in different policy and uncertainty scenarios. Such as an increase in energy capacity of the microgrid, subsidize consumers, dynamic pricing of energy costs, smart-meter control of agent's energy consumption, or social community formation. All these scenarios lead to value change taking place differently (see chapter 7).

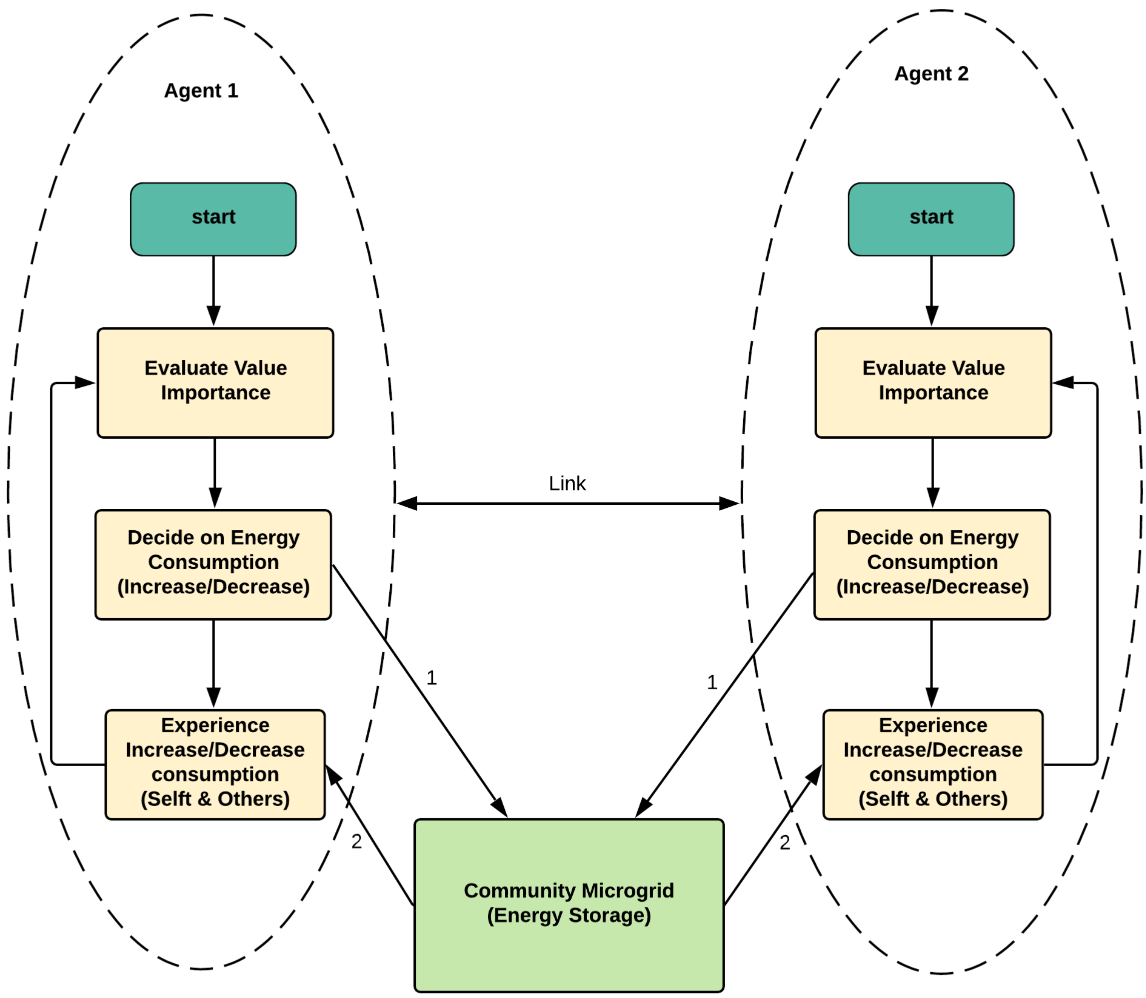


Figure 5.8: Agents evaluate, decide and interact, and experience the consequence of decision of self and others. Figure shows that agents start simultaneously. The Link 1 represents the decision of agents to increase or decrease their energy consumption. The Link 2 represents the indirect consequences agents face due to their linkage with each other and limited resources

5.5. MODEL SPECIFICATION

The model specification involves specifying the quantities of model parameters used in model formalization phase. In this study data was distinguished between three different categories: community, consumer and policies. Where derived from literature the sources of data are mentioned, however, in this study most of the data had to be assumed or adapted such as regarding the value importance indicators.

Furthermore, the normalization of value importance indicators inside the limits -1 to 1 was done by calibrating the data and checking the output.
The assumptions regarding model specification are discussed in data evaluation in the next chapter.
An overview of model specification can be referred to appendix D.

6

Model Validation and Verification

The aim of this chapter is to test whether the model created in chapter 5 is correctly conceptualized and is able to simulate the change in prioritization of values. More specifically, this chapter tests whether the model is able to properly capture various conceptual mechanisms that lead to change in prioritization of values in energy systems. In doing so, steps of verification and validation should be performed (van Dam et al., 2013). To carry out a consistent verification and validation process Evaludation method proposed by (Augusiak et al., 2014) is applied in this chapter (see section 3.3.3).

Before proceeding with the six steps, an additional step of stochastic uncertainty is performed. Considering various types of uncertainty: parameter, structure, heterogeneity and stochastic Briggs et al. (2012) in the verification and validation process leads to better validation of model concepts to real-world concepts and hence makes it ready to use in decision making process of real-world problems.

6.1. Stochastic uncertainty

Stochastic uncertainty is identified in the model when each run of the model produces varying results. This is because the model inherently uses a random seed to create random numbers. There are two reason to use random numbers while generating results in the model: 1) in order to vary results across runs to consider variation in ranges of outcomes of interests and 2) to replicate results across runs by specifying the same seed number. The stochastic uncertainties that exist within this model is shown in the table 6.1. The most important stochastic uncertainty among other uncertainties is the randomness in the linkage between consumers. Consequently, this influences the consumption behaviour of consumer depending on the consumer type they are linked with (see section 5.3.1).

In order to consider the stochastic uncertainty in the experiments, various choices regarding the run number and replications were made (see section 7.2.2).
It was observed that although the random numbers were generated for all experiments except the base case, few value importance indicators in some experiments showed no variation across run

Table 6.1: Stochastic uncertainties

Type of uncertainty	Uncertainty
Stochastic uncertainty	Consumers are randomly linked with other consumers (in the constraint of their link preference)
	Consumers are placed randomly on the map interface
	Consumers procedures are iterated randomly

numbers while other indicators did (see chapter 6). This may be due to the structure or formulation underlying these indicators.

6.2. STEP 1: DATA EVALUATION

The data evaluation step is defined by Augusiak et al. (2014) as "the assessment of the quality of numerical and qualitative data used to parameterise the model, both directly and inversely via calibration, and of the observed patterns that were used to design overall model structure, whereby not only the measurement protocols need to be evaluated but conclusions drawn from the data should be challenged as well"

The requirements to accomplish data evaluation are two: to give an overview of model specification and provide argument for those data that are assumed, and to give an overview of conceptual assumption as inputs to model. An overview of model specification is provided in appendix D. Some of the specifications are provided with sources in literature, while most data is assumed, as not much data was available specifically for changes in value importance indicators with respect to micro-grid or energy system indicators. The data used in structuring the model and giving it basis for micro-grid system was done using a simple energy consumption behaviour of a micro-grid community which is then mapped to community and consumer value importance indicators. Below the rationale behind most important assumptions of data are discussed.

6.2.1. NUMBER OF CONSUMERS

The number of consumers of each type are assumed as per the case study of micro-grid energy system in Noordelijk Havenhoofd, Scheveningen. The numbers are based on the real life spatial location. However, there is a lot of uncertainty in the future regarding the number of consumers in the area. This uncertainty is a structural uncertainty, and as consumers are influenced by their peers regarding consumption behaviour, this places a deep uncertainty in how changes in importance of values can occur in the future with changes in numbers of consumption. This is one of limitations of this model and to keep it simple, a fixed number of consumers were assumed in the base model, however, these were varied in sensitivity analysis to find their impact (see section 6.6). Future research could look into how changes in number of consumers in micro-grid energy system can lead to change in importance of reliability among community for example.

6.2.2. ENERGY CONSUMPTION AND SUPPLY DATA

For the case of energy consumption and supply data, various micro-grid data used in supporting this was assumed from (Adefarati and Bansal, 2019; Platt et al., 2012) who evaluate ideal cases of micro-grid on the basis of annual energy consumption, capacity of micro-grid and many other indicators. Initially, it is assumed that, the annual energy consumption is equal to annual energy supply. The reason is that it is crucial to understand how slight changes or mismatch between supply and demand can lead to changes in importance of values. Furthermore, this assumption hopes to mimic the operation of utility, who are constantly making both supply and demand meet. However, there is lot of scepticism in formulation of threshold regarding the supply and demand that could lead to high or low reliability importance. Following this, the limitations and assumptions of threshold data are discussed in the next section.

6.2.3. THRESHOLDS

Various thresholds such as annual energy supply, co2 emission threshold, willingness to invest, play a crucial role in deciding the change in importance levels of reliability, sustainability and affordability respectively. However, literature provides no example of the threshold data that specifically fits in measuring these value importance indicators. For instance, among different indicators of sustainability used by Jha et al. (2020) GHG emissions are a crucial indicator for sustainability, however, Jha et al. (2020) fails to base the indicators on real world consumption data but rather only bases it with qualitative data. This is similar for the cases of other value importance indicators. This difficulty in matching the technical data with qualitative value importance indices is one of the limitations of this research. Further, the uncertainty in the annual energy supply, willingness to invest, co2 emissions translate an uncertainty in changes in importance of values in future.

6.2.4. VALUE IMPORTANCE INDICATORS

Kreulen (2019) assumes in his research regarding changes in belief and value system, that importance of values can be distinguished at different levels. Although, the author distinguishes these importance levels on a subjective level, this study takes an inspiration from the importance levels and applies it for the case of normative values. However, one limitation here is that practical examples of such importance levels are rare and are merely conceptual. This limitation is related to incommensurability of values, where values measured in different units cannot be compared or scaled (Martinez-Alier et al., 1998; Munda, 2004; van de Poel, 2015). In practical sense however, there is basic notion of differentiation of changes in values or situation compared to the status quo. This study places emphasis on this differentiation rather than abstract levels of value importance.

6.2.5. LINK PREFERENCES

Maintaining relations and network is normal to see in real world cases. Consequently, they prefer to get connected or interact with people of their interests. The formulation of this uncertainty variable was inspired from Siebert et al. (2017), who assumes that specific interaction between consumers lead to changes in consumption behavior of others. These interaction can be based on resource dependency or purely local rationality. Here the link preferences are either random or structured as shown in the table D.1.

6.3. Step 2: Conceptual model evaluation

The conceptual model evaluation step is defined by Augusiak et al. (2014) as "the assessment of the simplifying assumptions underlying a model's design and forming its building blocks, including an assessment of whether the structure, essential theories, concepts, assumptions, and causal relationships are reasonable to form a logically consistent model". According to Augusiak et al., this step often needs to be carried out by testing multiple conceptual ideas, as many conceptual ideas show unfavorable behaviour later on in the modelling cycle. To carry out conceptual model evaluation in this study was a difficult process, as there is not much research done in conceptualizing value change and hence there isn't any general theory showing expected behaviour of value change. However, multiple potential conceptualization of change in importance of values were considered from different researches and tested for their resemblance with real world behaviour of consumers. First, the conceptual idea of capability approach (Nussbaum, 2011) was tested for its viability in capturing the change in importance of values. Similarly, few modelling assumptions relating to satisfaction of consumers used in energy consumption agent-based model by Siebert et al. (2017, 2020) were found suitable. Further, the conceptual ideas provided by common pool resource (Ostrom, 1999) and transformative experience (Paul, 2014), proved suitable and were selected for its resemblance in correctly modelling the dynamic mechanisms driving value change. Further, structures such as type of rational behaviour in community formation or base case was added as switches in Netlogo model. Lastly, the combination of various conceptual ideas, structures were tested and selected and its rationale and the observations of testing are presented in Step 4: Model output verification.

6.4. Step 3: Implementation verification

The implementation verification step is defined by Augusiak et al. (2014) as "the assessment of (1) whether the computerised implementation the model is correct and free of programming errors and (2) whether the implemented model performs as indicated by the model description. The aim is to ensure that the modelling formalism is accurate". To complete this step, various methods of verification as proposed by van Dam et al. (2013) are used. These steps include:

- Tracking agent behaviour
- Single-agent testing
- Interaction testing in minimal model
- Multi-agent testing

Here, first three methods are performed, as they are important in verifying the underlying behaviour of different consumer types and their output is explained in Appendix E.

6.5. Step 4: Model output verification

The model output verification step is defined by Augusiak et al. (2014) as "The assessment of (1) how well model output matches observations and (2) to what degree calibration and effects of environmental drivers were involved in obtaining good fits of model output and data. The aim is to ensure that the individuals and populations represented in the model respond to habitat features and environmental conditions in a sufficiently similar way as their real counterparts."

In this research, due to not much research performed on value change , it is hard to test conceptual ideas, when there is no particular criteria to evaluate them. However, this research assumes basic behaviour seen in a typical community regarding consumption actions. For instance, the behaviour of consumer at the conception of micro-grid technology may be supportive, however as the years pass this support may be cut down due to various endogenous changes such as income as well as exogenous factors such as economic crisis, hence leading to change in importance of values from sustainability to affordability (Dewey, 1922).

First, the capability approach (Nussbaum, 2011) was considered. This approach was able to satisfy criteria 1, 2 and 4 i.e.: person having importance for a value over others, person's action being guided by their values and the consequence of which leads to changes in score of their value importance. However, It was seen that due to many categorical variables used in the conceptual model, it produced a linear behaviour instead of expected non-linear change, which was misleading and hence this approach was rejected. Next, few assumptions from the energy consumption model (Siebert et al., 2017) were taken and tested for its viability of changes in importance of values. It was seen that,even though the results showed expected non-linear behaviour, it lacked in giving proper constraints to consumer satisfaction indicators or (in this study) opposite of value importance indicators. Further, the exponential growth of energy consumption and energy cost were misleading compared to the real world behavior. However, these assumptions were not totally discarded, but were modified and coupled with other assumptions such as common pool resource (Ostrom, 1999) and transformative experience (Paul, 2014), that led to final selection of this model.

This model does not just resemble in behaviour as expected in the defined four criteria but also the combination of structure, the assumptions and variables are valid according to real world behaviour or the behaviour expected in real world.

6.6. STEP 5: MODEL ANALYSIS

The model analysis step is defined by Augusiak et al. (2014) as "The assessment of (1) how sensitive model output is to changes in model parameters (sensitivity analysis), and (2) how well the emergence of model output has been understood. The aim is to understand the model and be able to find out why which output is being produced to avoid drawing the wrong conclusions from model output"

To perform sensitivity analysis, feature scoring technique is used to understand the sensitivity of each value importance indicators both on community as well as consumer level, to the uncertainties and policies. First, feature scoring was performed on all uncertainties both structural and parametric. Then, to go into minute details, some parameters of uncertainties were blocked to see the sensitivity of outcomes of interests that weren't seen in all uncertainties feature scoring. Lastly, two different feature scoring for different combinations of policies and uncertainties are discussed.

As shown in the figure 6.1. We see that the outcome of interest are highly sensitive to community formation as the aim of consumers in this structure is to align themselves to other's needs rather than their own.

To identify, some more details of the sensitivity of outcomes of interests on specific uncertainties, the influence of number of consumers of each type is looked into. It is seen in the figure 6.2 that the reliability of industries is highly sensitive to number of restaurants , while the reliability of restaurants is highly sensitive to number of businesses. This can be explained from the link preferences restaurants have for industries. For instance, this can be validated again by checking separately the influence of energy consumption increase/decrease rates of consumers on outcomes (see figure 6.3). On the other hand, in the case of restaurants being sensitive to number of businesses,

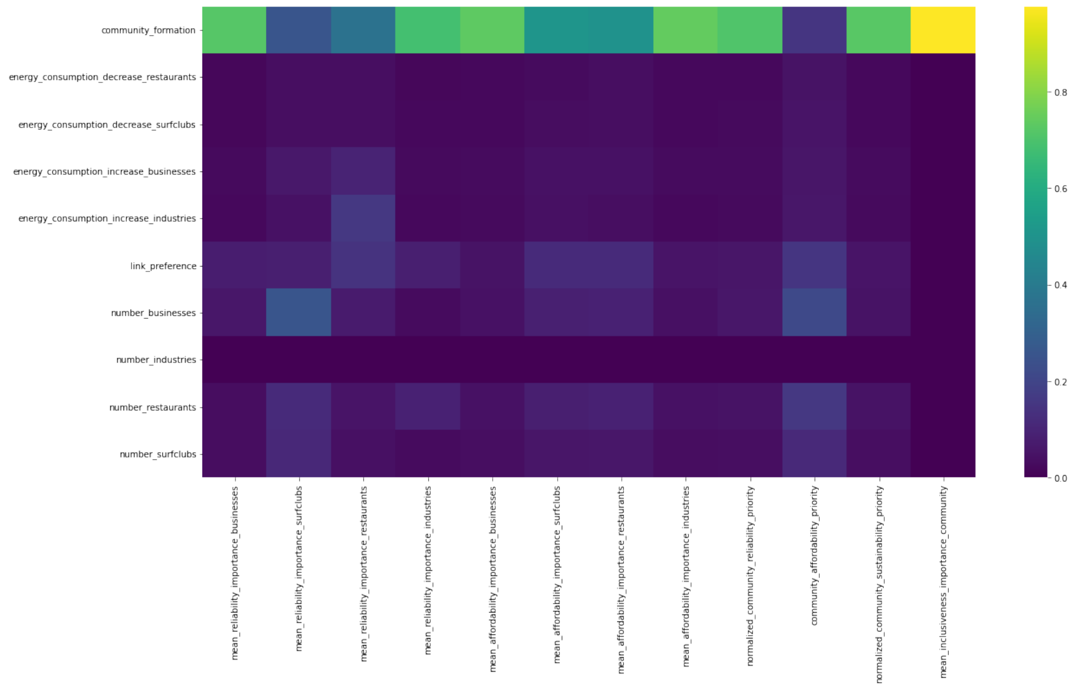


Figure 6.1: Feature scoring for all uncertain parameters

can be due to the conflicting energy consumption increase and decrease rate of businesses and restaurants respectively. In general, outcomes of interests are highly sensitive to number of businesses and restaurants.

Next, the sensitivity of outcomes on two different policy and uncertainty scenario combination was carried out. The difference between both scenarios is the policy increase capacity and policy dynamic pricing. For the case of scenario with increase in capacity policy, it is seen from the figure 6.4 that smart meter control has most influence on affordability of large consumers: businesses and industries. This can be due to smart meter's high control over the consumption increase by businesses and industries as a result their consumption cost is indirectly controlled. Whereas, for the case of policy subsidizing consumers, it is seen that the small consumers are highly sensitive to this policy. This is due to their dependency for subsidy to satisfy their preference for a low reliability importance and low affordability importance respectively. Furthermore, this has influence on community affordability importance.

Lastly, the scenario with dynamic pricing as seen in the figure 6.5, shows that dynamic pricing has main influence on consumer affordability and all community value importance indicators. More specifically the the community affordability importance is highly sensitive to this policy.

In conclusion, the feature scoring sensitivity analysis has validated the understanding of basic underlying dynamics among consumers and community in the model. The key insights that are found in this analysis are:

1. The consumers are highly sensitive to the consumers they are linked with in terms of either their total number or their conflicting energy consumption increase/decrease rate.

2. It is seen that large consumers are highly sensitive to smart meter control in terms of their affordability importance.

3. It is seen that small consumers are highly sensitive to subsidize consumers policy in terms of their affordability importance.

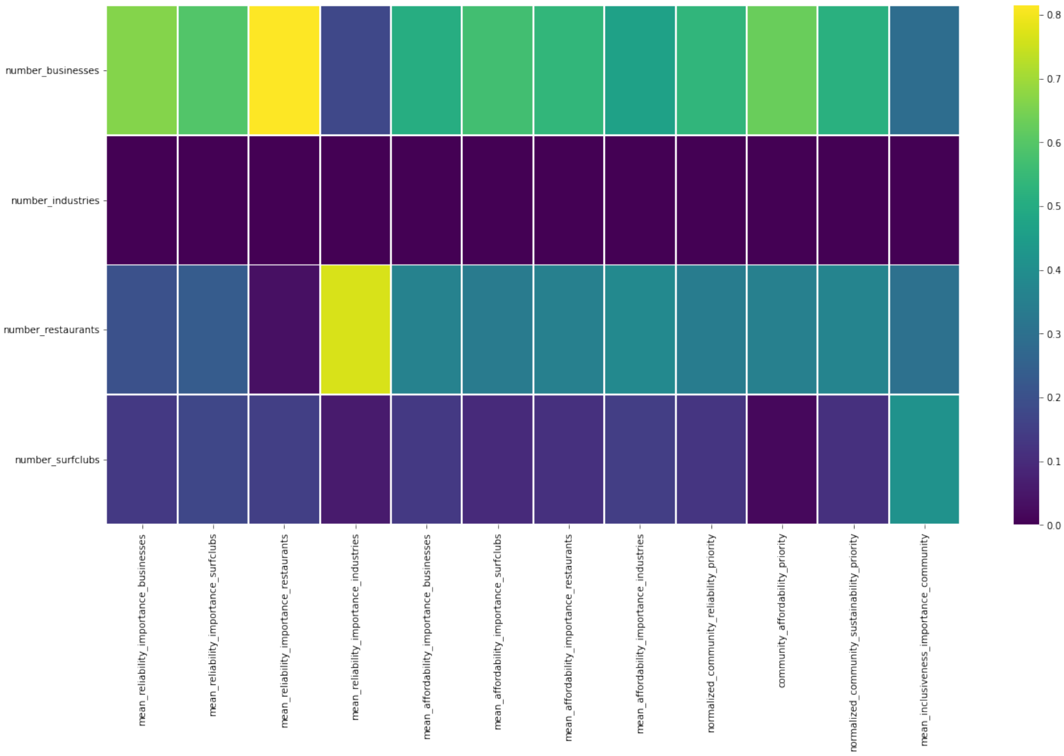


Figure 6.2: Feature scoring for number of consumer uncertainty

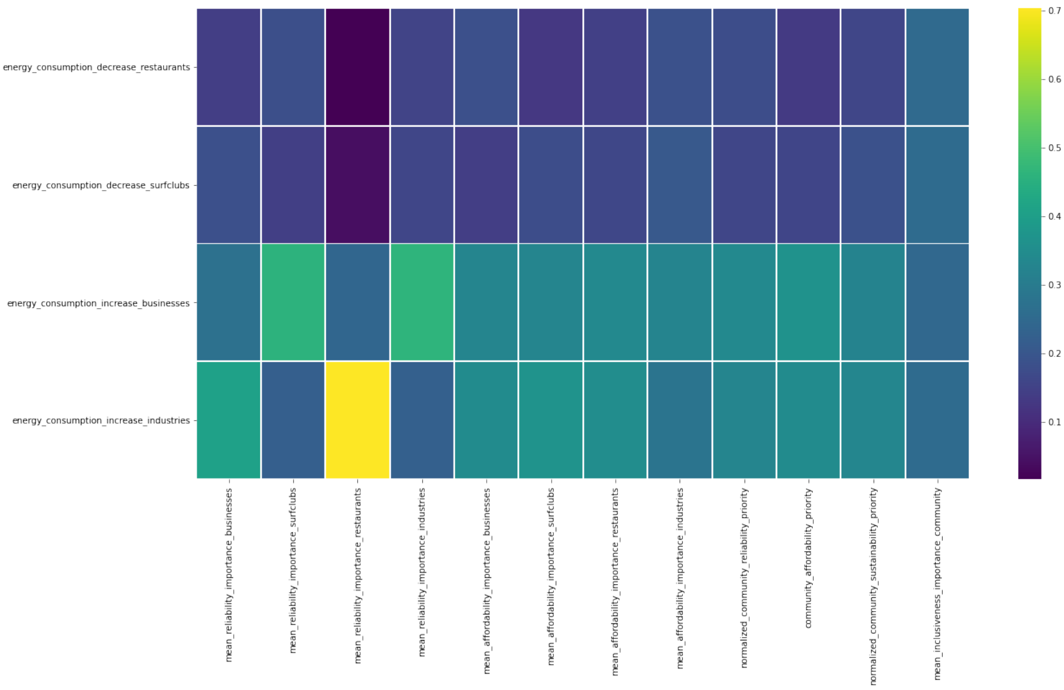


Figure 6.3: Feature scoring for energy consumption incerease/decrease rate uncertainty

4. Dynamic pricing has high influence on both consumer and community level affordability importance

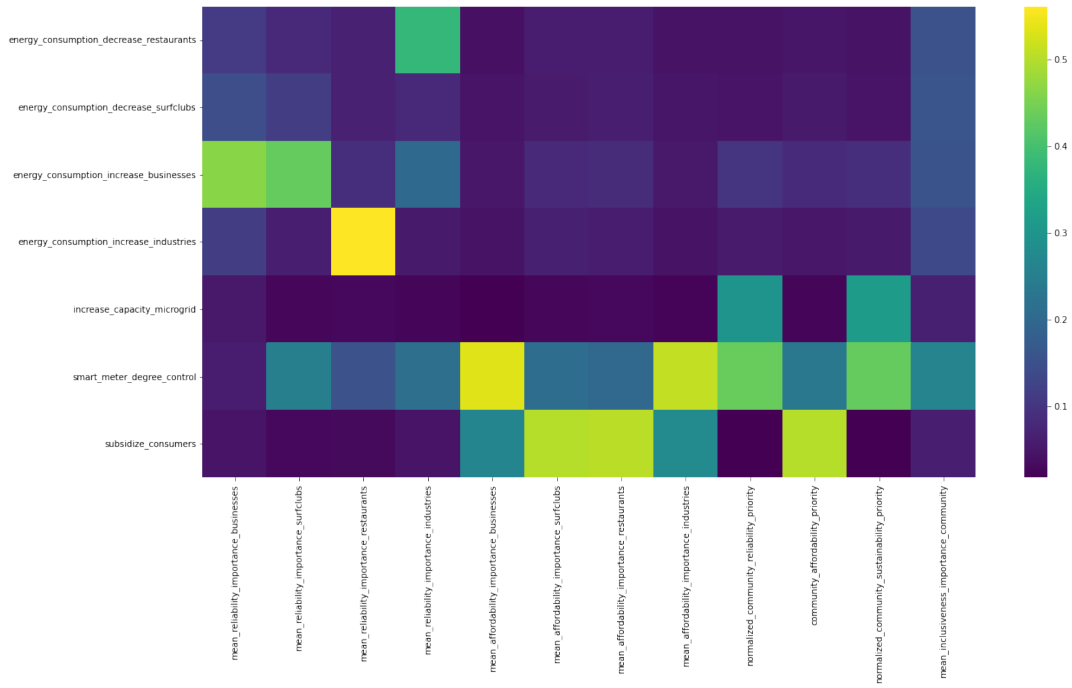


Figure 6.4: Feature scoring for policy scenario with increase capacity

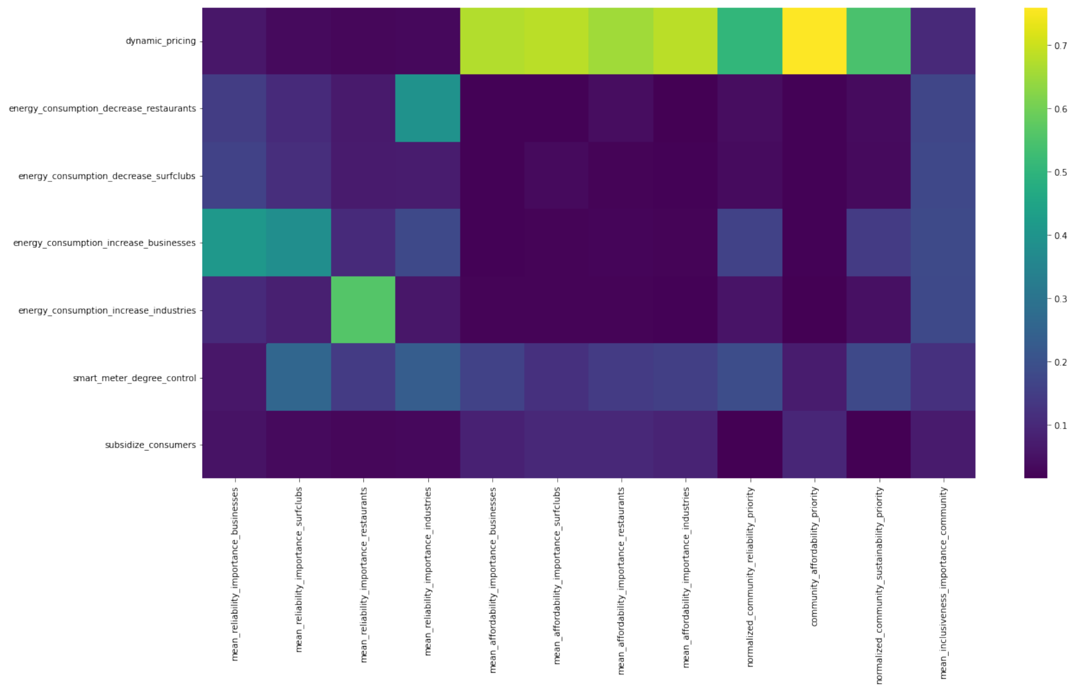


Figure 6.5: Feature scoring for policy scenario with dynamic pricing

6.7. STEP 6: MODEL OUTPUT CORROBORATION

The model output corroboration step is defined by Augusiak et al. (2014) as "The comparison of model predictions with independent data and patterns that were not used, and preferably not even known, while the model was developed, parameterised, and verified. This step strengthens a model's credibility by proving that the model is capable of predicting/reproducing pattern and data that could not have influenced the model development".

This step is not taken forward, since it does not match with the objective of this model. The objective of this model is not to predict patterns of change but rather expose and possibly anticipate the underlying potential conceptions of change in importance of values. However, in order to execute this step, further research can look into coupling the current model with real time consumption behaviour of consumers to inform changes in importance of values over the lifetime of energy system.

6.8. CONCLUSION

In this chapter, the model was validated and verified using Evaludation method (Augusiak et al., 2014). The six step process revealed various insights about the model. These insights are presented as follows:

In the data evaluation step involved critically assessing and calibrating the data (see model specification in appendix D). Thereafter, this data the rationale behind various assumptions of variables was explored both at community and consumer level and few limitations were listed out for this research. Two key insights that were discovered were limitations of formulating micro-grid energy system variables in order to measure the thresholds for specific value importance. Another key insight was limitation of incommensurability of values in terms of measuring them against some scale that practical or real world does not actually do. (Martinez-Alier et al., 1998; Munda, 2004; van de Poel, 2015).

Next, the step of model output verification revealed a suitable combination of conceptual ideas: transformative experience and common pool resource, for the agent-based model.

Lastly, the model analysis step validated the model through feature scoring sensitivity analysis. The key insights that were formed at the end of this analysis conformed to the behaviour with which the model assumptions were modelled with.

III

Results and Discussion

7

Model Results

As the value change is not just driven by endogenous mechanisms but also exogenous factors, it is important to test different policy and uncertainty scenarios, that can help us accurately understand what mechanisms or what combination of mechanisms drive the value change. Therefore, the aim of this chapter is to explore the influence of various policies and uncertainties on the value change model formalized in the chapter 5. In doing so, this chapter answers the third sub-research question: *What dynamic patterns does the model of value change generate under different policy and uncertainty scenarios?* First, the XLRM framework (Lempert et al., 2003) is used to specify

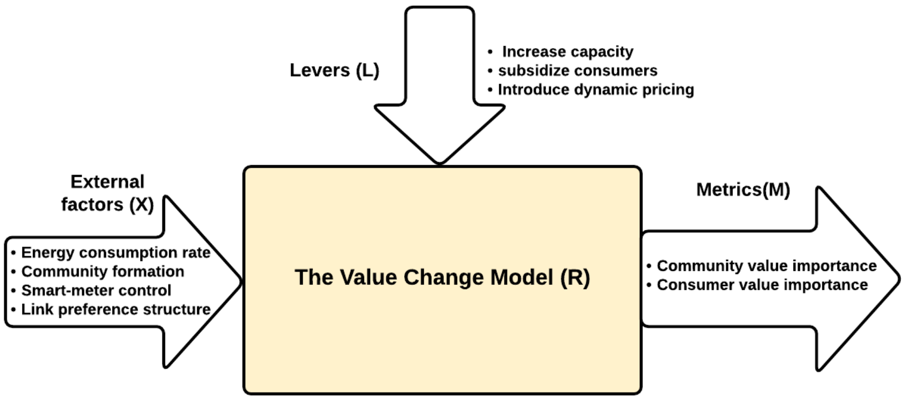


Figure 7.1: Overview of policies, uncertainties and key performance indicators using XLRM Framework (Lempert et al., 2003)

various policies and uncertainties that can influence the key performance indicators as defined in chapter 5. Consequently, the experiments are designed and the results of base case and various policy and uncertainty experiments are discussed. Lastly, scenario discovery analysis is performed on a specific policy scenario to understand the conditions that lead to value change.

7.1. Policy and Uncertainty Specification

An overview of policies, uncertainties and key performance indicators using XLRM framework in the figure 7.1. This section specifies various uncertainties identified in the model. Thereafter, the policies related to various aspects of micro-grid energy system and external influence are identified.

Table 7.1: Uncertainties

Parameters	Uncertainty type	Range	Description
Energy consumption increase businesses	Parameter	[0.5 1 3.5] (Default 2.5)	The increase in consumption of businesses causes shortage in supply for other consumers, hence not only having an affect on their reliability importance level but also reliability importance level of other consumers. This increase in consumption is solely based on the consumers preference.
Energy consumption decrease surfclubs	Parameter	[0.5 1 3.5] (Default 2.5)	The decrease in consumption of surfclubs causes their reliability importance to be lowered. This also means that other consumers get their supplies increased due to the decrease of consumption by surfclubs. However, the cumulative reliability importance level depends on both self decision and decision of others.
Energy consumption decrease restaurants	Parameter	[0.5 1 3.5] (Default 2.5)	The decrease in consumption of restaurants may or may not cause their reliability importance to be lowered as they prefer to reduce their importance for affordability / increase their affordability satisfaction by lowering their energy consumption. This can have some impact on other consumers supply and in turn affect their reliability importance.
Energy consumption increase industries	Parameter	[0.5 1 3.5] (Default 2.5)	They have a similar consequence/ affect as businesses as both of these consumers increase their consumption
Electricity price	Parameter	[0.5 1 3.5] (Default 0.5)	Electricity price mainly has an influence on the affordability importance not just of the consumers but also on a community level This only varies with dynamic pricing policy
Community formation	Structure	0: False, 1:True (Default: False)	If community formation is True, the consumers conform to each others actions, this may lead to a stable growth or stable decline in consumption depending on the network link formed between consumers. This has an influence on all the community value importance
Link preference	Structure	0: False, 1:True (Default: True)	If link preference is True, consumers connect to only those consumers they have a preference to connect with, otherwise, they connect with random consumer.
Random seed	Stochastic	[0 1000000] (Default: new random number)	Random seed can be adjusted to see how different network structure influence the consumer and community importance levels.

7

7.1.1. UNCERTAINTIES

The uncertainties identified in the model are distinguished between three types: parametric, structural and stochastic. Parametric uncertainties are defined as "uncertainty in estimation of the parameter of interest" (Briggs et al., 2012). Whereas, structural uncertainties are defined as the uncertainties in model structure or assumptions (Briggs et al., 2012). Lastly, stochastic uncertainty relates to the difference or variation in outcomes of the model based on an uncertain parameter in the system (see table 7.1).

7.1.2. POLICIES

There were three types of policies identified based on two different aspects of micro-grid energy system: technological and financial. A clear overview and explanation of each policy is provided in the table 7.2.

Table 7.2: Policies

Policy	Options	Descriptions
Increase capacity of microgrid	0: False, 1: True (default: 0)	This policy is directed towards improving the reliability concern both for consumers and community. When True, this has an influence on decreasing the reliability importance or increasing the reliability satisfaction for the community and consumers.
Subsidize consumers	0: False, 1: True (default: 0)	This policy is directed towards improving the affordability concern both for consumers and community. When True, this has an influence on decreasing the affordability importance or increasing the affordability satisfaction for the community and consumers.
Introduce dynamic pricing strategy	0: False, 1: True (default: 0)	This policy is directed towards improving the reliability concern both for consumers and community. When True, this has an influence on decreasing the reliability importance or increasing the reliability satisfaction for the community and consumers. However, this can also have an indirect effect on affordability concern in society.

7.2. EXPERIMENTATION SETTING

The results of experiments depend on various choices taken in the base case model setting and the experiments setup. First, the base case model setting is discussed. Then, the experiment setup with appropriate choices is laid out.

Table 7.3: Model settings

Model Setting	
Parameters	**Values**
Number surfclubs	4 (max)-fixed
Number restaurants	3 (max)-fixed
Number businesses	3 (max)-fixed
Number industries	1 (max)-fixed
Electricity_price	0.5 [€/kWh](can vary based on experiment)
Energy_consumption_increase_businesses	2.5% (can vary based on experiment)
Energy_consumption_decrease_surfclubs	2.5% (can vary based on experiment)
Energy_consumption_decrease_restaurants	2.5% (can vary based on experiment)
Energy_consumption_increase_industries	2.5% (can vary based on experiment)
New_seed	TRUE
Increase_capacity_microgrid	FALSE
subsidize_consumers	FALSE
dynamic_pricing	FALSE
smart_meter_control	0
Community_formation	0
Link_preference	TRUE
Run length	180 ticks

7.2.1. MODEL SETTING

The base case model is initialized and set before the experiments are performed on it. First, all policies and uncertainty parameters are set to False or 0 except link preference which is set to True for the base case so as to form fuller connecting links among preferred consumers. Next, the value importance level for each value type both for consumers and community is initialized to be 0, which means the importance of consumer or community for a value is indifferent. The number of consumers of each type is set to maximum. This is to take into consideration the actual complexity of differences between consumers and the number of consumers in the case study. Next, the energy consumption increase/ decrease of each consumer is fixed to 2.5% throughout the simulation for two reasons: such that the inherent preferences of each consumer are reflected in the model behaviour and based on calibrating the data, such that the results converge in appropriate run length of 180 ticks rather than much higher run length time which would require more simulation time for each run. The electricity price is set to 0.5 as specified in chapter 4. The random seed is set to new seed to account for stochasticity in between the model runs. This is important as, without it the the outcome space is constricted to same values, hence giving not much information of how the outcomes can vary in other situations (Bankes, 1993). Lastly, other parameter values, such as the capacity or annual supply of micro-grid and annual consumption of consumers remain fixed and as specified in chapter 4.

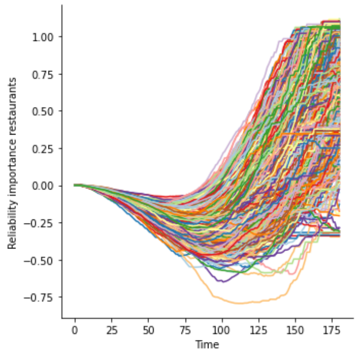
7.2.2. EXPERIMENT SETUP

For the experiments, the sampling method chosen to sample the uncertainty space is Latin Hypercube Sampling (LHS), which has its advantages in producing fuller and uniform distributions considering combination of parameters in experiments rather than single parameters in each experiments by other sampling methods (van Dam et al., 2013).

The number of runs are specified for different experiments in the table 7.4. For the base case, as the outcomes did not vary much 1000 runs were incorporated. This was done similarly for the case of experiments with single policies, as the policies did not have much variation. For the case of combination of policies and uncertainties, the replications were chosen based on the runs. In this case, 7 replications were performed since this accounted for total approximate 2000 runs. However, in case when combination of policies and uncertainties were added with one more variation, only 4 replications were performed which accounted for approximate 5000 runs. Lastly, the choice of replications and runs was mainly constrained by the time required to complete this project.

Table 7.4: Experiment setup

Experiment	Variables	Scenario runs
Base case	-	1000
	Single policy	
S1: Capacity increase	Increase capacity of Micro-grid	1000
S2: Subsidize consumers	Subsidize consumers	1000
S3: Dynamic pricing	Introduce dynamic pricing;	1000
	Combination of single policy and uncertainties	
S4: Capacity increase with uncertainty	Increase capacity of Micro-grid; Community formation; Energy consumption; increase/decrease rates	Approx. 2000
S5:Subsidize consumers with uncertainty	Subsidize consumers; community formation; Energy consumption; increase/decrease rates	Approx. 2000
S6: Dynamic pricing with uncertainty	Dynamic pricing; community formation; energy consumption increase/decrease rates	Approx. 2000
	Combination of policies and uncertainties	
S7: Increase capacity, subsidize consumers, smart meter control, community formation	increase capacity of microgrid; subsidize consumers; smart meter full control; community formation	2000
S8: S7 including other uncertainties	increase capacity microgrid, subsidize consumers; smart meter full control; community formation; energy consumption increase/ decrease rates	Approx. 5000



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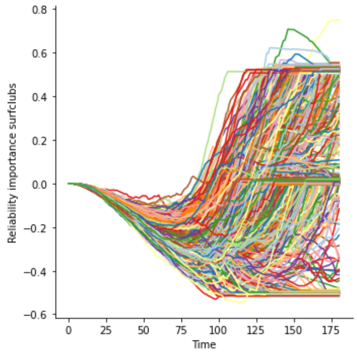

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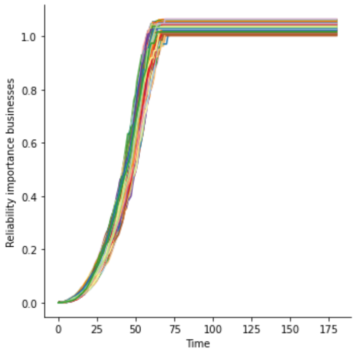

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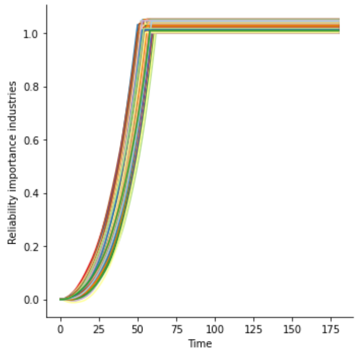

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Figure 7.2: Base case result-reliability importance of consumers. (a) reliability importance of restaurants, (b) reliability importance of surfclubs, (c) reliability importance businesses and (d) reliability importance industries. This figure shows the indirect impact of increase in consumption by businesses and industries on the surfclubs and restaurants as they achieve a high reliability importance instead of low reliability importance. Further, (a) and (b) show that restaurants experience higher impact than surfclubs due to their preference to satisfy affordability rather than reliability.

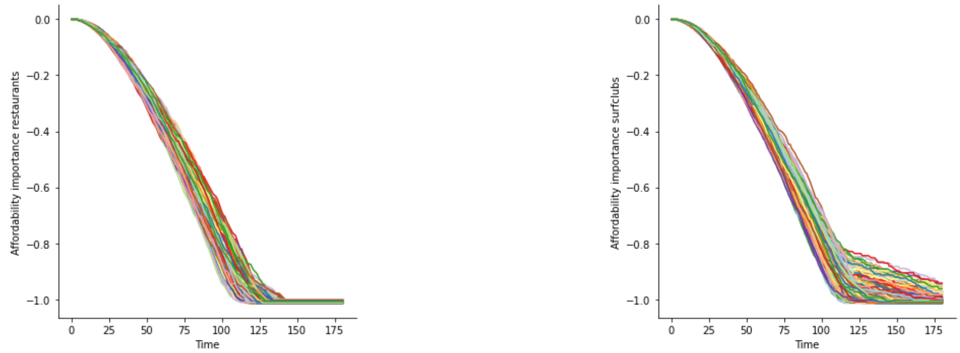
7.3. EXPERIMENTATION RESULTS AND ANALYSIS

In this section, the model behaviour generated due to the influence of policies and uncertainty on the base case is discussed. First, the base model behaviour is described with consumer and community importance level indicators. Next, the impact of various single policies as well as combination of policies and uncertainties on the base case is discussed.

7.3.1. BASE CASE RESULT

The base case model is executed without considering any policy or uncertainty variations. As formalized in chapter 4, in the base case, all stakeholders act based on their own preference to increase or decrease their energy consumption without any concern for others in the community. This has implications on value importance of both consumers and community.

Initially, businesses and industries become unsatisfied with reliability due to their decision to increase energy consumption (as show in the figures 7.2c and 7.2d). The surfclubs and restaurants—who had preferred to reduce their consumption to achieve a higher reliability or affordability satisfaction respectively—feel the consequence of actions of businesses and industries (see figures 7.2b and 7.2a). In other words, surfclubs and restaurants, in first few time steps have high reliability sat-



(a) (b)

Figure 7.3: Base case result- affordability importance of agents. (a) affordability importance of restaurants, (b) affordability importance of surfclubs. This figure shows the decreasing consumption decision taken by restaurants and surfclubs benefits them with a lower affordability importance

isfaction or low reliability importance, however, after some time steps they tend towards a lower reliability satisfaction or higher reliability importance, due to the actions of businesses and industries.

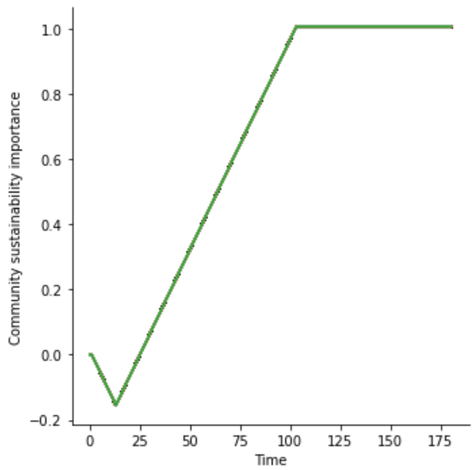
Further, the consequence felt by restaurants is much higher than the consequence felt by the surfclubs. This behaviour can be due to the preference of surfclubs to achieve high reliability satisfaction or low reliability importance, hence they are delayed in reaching high reliability importance and don't achieve maximum reliability importance. On the other hand, as restaurants prefer to achieve low affordability importance, and they don't do decisions that aim for low reliability importance, hence they experience an increase in their reliability importance to the maximum.

Consequently, restaurants and surfclubs face a value conflict. While restaurants and surfclubs have achieved a high reliability importance, they simultaneously benefit a lower affordability importance or higher affordability importance due to their actions of decreasing consumption (see figures 7.6a, 7.3b). This shows that restaurants and surfclubs face a value conflict between achieving reliability and affordability satisfaction. However, this conflict was unintentional as it was influenced by the actions of businesses and industries.

7.3.2. IMPACT OF INCREASE IN CAPACITY MICRO-GRID

When the micro-grid capacity increase policy is implemented the effects of action of consumers is evident on community level. As this policy is meant to directly influence the community reliability importance level, it is seen from the figure 7.5 that initially there is an exponential drop due to the addition of extra energy capacity in micro-grid, however, due to the persistent actions of businesses and industries, it is seen that there is steep increase in the level of community reliability importance.

Consequently, sustainability importance also undergoes a similar decrease and increase. This is because agents use less grey electricity when there is supply deficit and hence there is much lesser CO2 emissions when compared to the base case.



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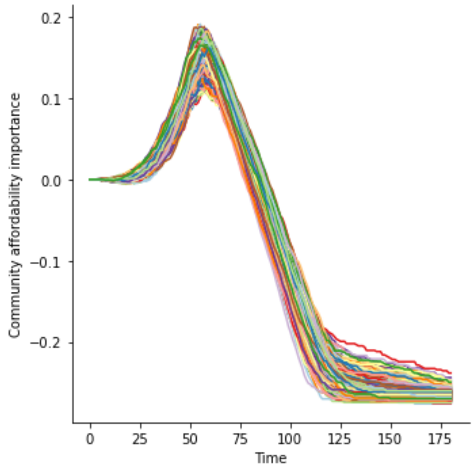

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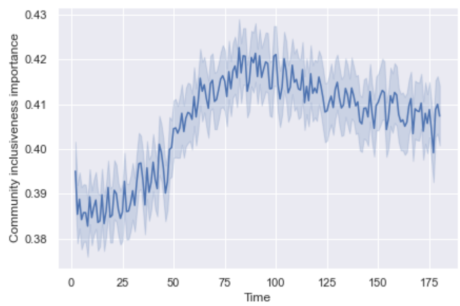
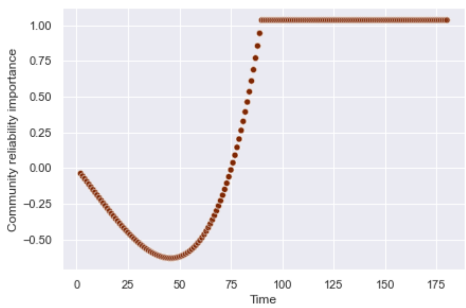


(c)

Figure 7.4: Figure shows the (a) community sustainability importance, (b) community affordability importance, and (c)community inclusiveness importance. The figures (a) and (b) shows mix of consequence of decisions taken by agents that lead to this dynamics. (c) shows a high inclusiveness importance in the community due to the rivalrous actions of agents. The envelope around it shows a high variation of changes in inclusiveness importance affected by the consumption actions of agents.



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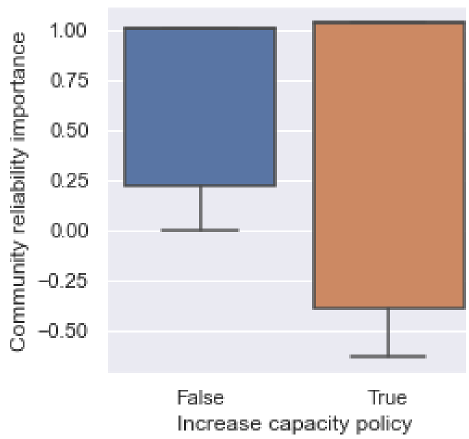

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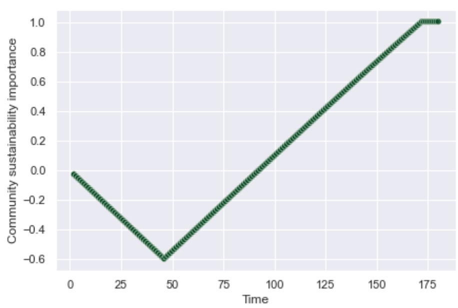

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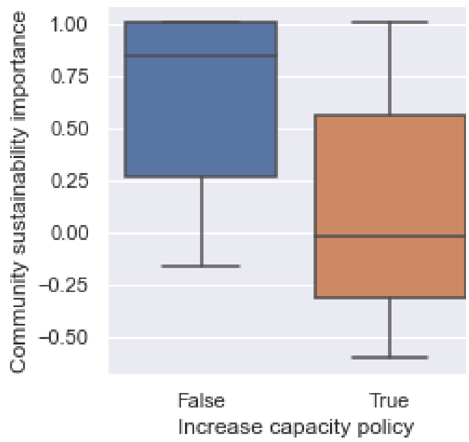

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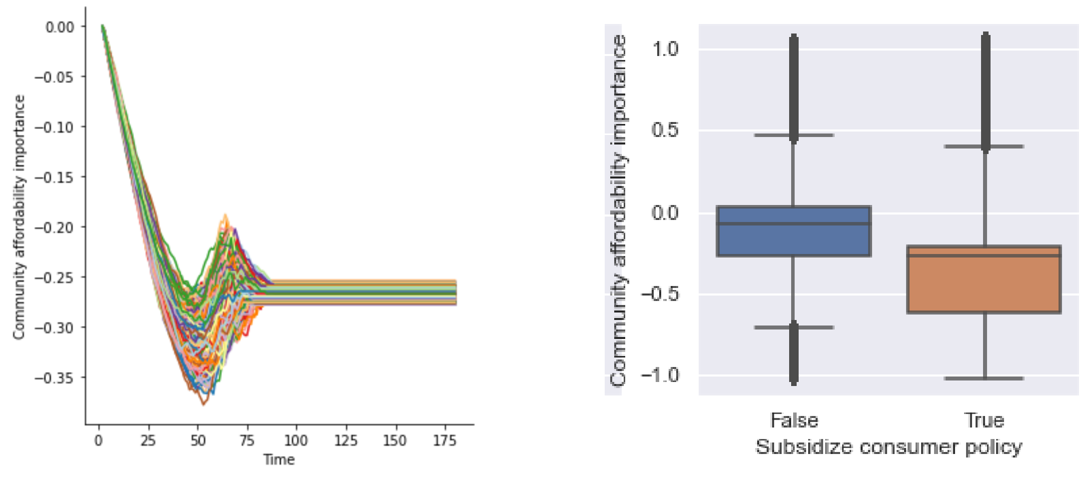
Figure 7.5: Policy increase capacity-Community reliability and sustainability importance (a) reliability importance plot (b) reliability importance box plot (c) sustainability importance plot and (d) sustainability importance box plot.



(a) (b)

Figure 7.6: Policy subsidize consumer- community affordability importance. (a) community affordability importance plot, (b) community affordability importance box plot.

7.3.3. IMPACT OF SUBSIDIZING CONSUMERS

When subsidizing consumer policy is activated, it is seen from figure C.5 the community affordability importance exponentially decreases and then remains low and constant for long time. This may be because consumer subsidy policy is not enough for some consumers such as businesses and industries in the community. Consequently, when they increase their consumption above their required consumption level, they incur high consumption costs which leads them gaining high affordability importance, despite the subsidy policy.

7.3.4. IMPACT OF DYNAMIC PRICING POLICY

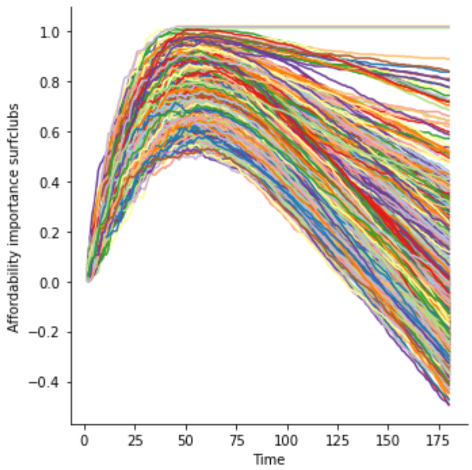
This policy is mainly intended to reduce reliability concerns of community, but has an influence on consumer affordability importance levels as well. For the case of surfclubs and restaurants, the affordability importance decreases shortly after increasing (see figures 7.7a,7.7b). This can be explained from the fact that surfclubs and restaurants have a initial preference to reduce their consumption and subsequently their consumption costs, hence most of them are able to achieve lower affordability importance after the policy is implemented. Consequently, a cumulative and similar behaviour of affordability importance is reflected on community level as shown in the figure C.1.

Lastly, this policy shows a value conflict among the community, where on one hand, the affordability importance is increasing, and on other, the reliability importance is decreased to the lowest.

7.3.5. IMPACT OF INCREASING CAPACITY AND UNCERTAINTY

First, the current experiment shows that community reliability and sustainability have more variation across runs than compared to experiment without uncertainty (C.8. This is possible due to multiple structural and parametric uncertainty.

Second, there is a faster decrease in reliability importance and sustainability importance when compared to other runs which leads to increasing both these importance levels. This shows that even though certain runs demand higher capacity of micro-grid, there will be a delay in the in-



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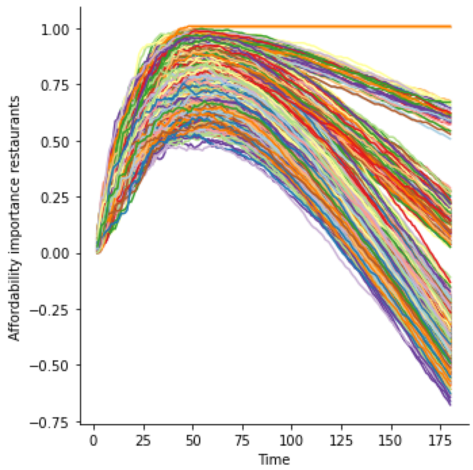


(b)

Figure 7.7: Policy dynamic pricing- Affordability importance consumers (a) affordability importance businesses (b) affordability importance surfclubs (c) affordability importance restaurants and (d) affordability importance industries.

crease of community reliability and sustainability importance levels.

Third, we see a stable decrease in inclusiveness importance, this is due to the community formation structural uncertainty, where consumers are conforming to each others consumption as well as importance levels.

Next, it is seen from the box plot figure C.18, that the community reliability importance has a importance level. This may be due to the variation in parametric uncertainties i.e: consumption increase or decrease rates of consumers. Nonetheless, the mean community reliability importance has decreased lower than 0 which means consumers are satisfied with their reliability and it is less important to them. Similarly, the sustainability importance level has decreased significantly.

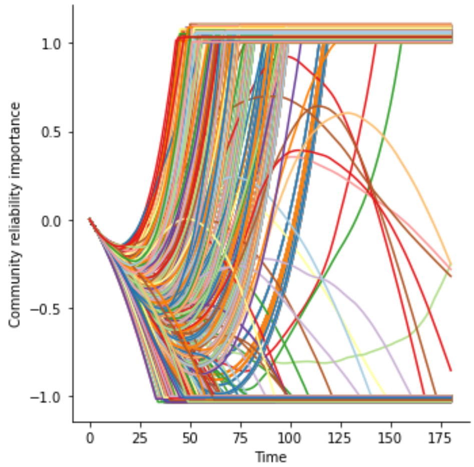
7.3.6. IMPACT OF SUBSIDIZING CONSUMERS AND UNCERTAINTY

Here, the subsidizing consumers policy is implemented in combination with uncertain parameters. compared to the policy without uncertainty variation, we see that, there is no steep exponential decrease in community affordability importance, but rather more number of runs (see figure C.9). This shows that even though the policy is implemented one-off, the consumers consumption costs requirement does not get fulfilled, hence the policy ends up with high affordability importance in the case when uncertainty is combined with this policy.

7.3.7. IMPACT OF DYNAMIC PRICING AND UNCERTAINTY

Here, the dynamic pricing policy is implemented in combination with uncertain parameters. Here, we see that the minimum and mean of community reliability importance is at the lowest possible importance level and similar is the case for sustainability as shown in the figure 7.9. Further, we also see that, the mean of community affordability is at the maximum importance level possible for affordability importance when compared to the base case which is below 0.

On the other hand, it is seen from the figure C.11, that the inclusiveness importance has decreased compared to the policy without uncertainty case, however, this symmetric change is not reflected in the box plot (see figure 7.9). This shows a clear trade-off or value conflict (van de Poel, 2015) between reliability sustainability and affordability.



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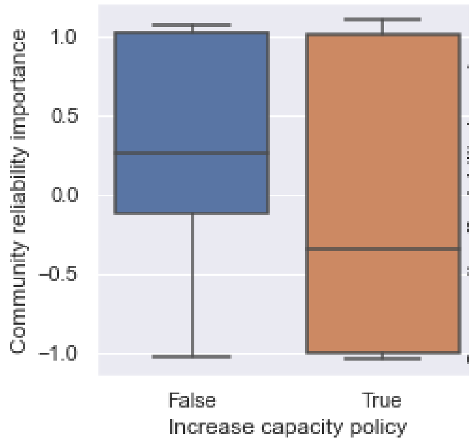

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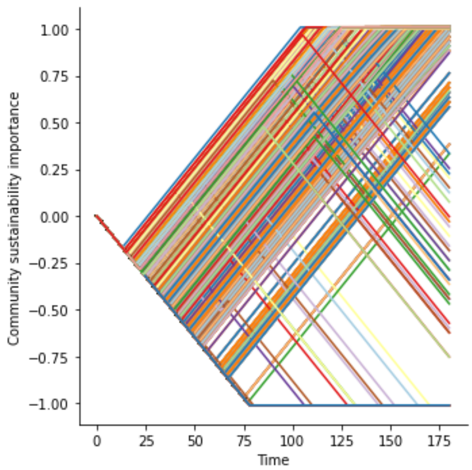

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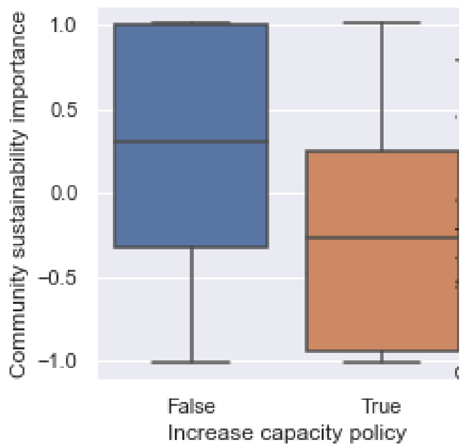

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Figure 7.8: Policy increase capacity with uncertainty-Community reliability and sustainability importance (a) reliability importance plot (b) reliability importance box plot (c) sustainability importance plot and (d) sustainability importance box plot.

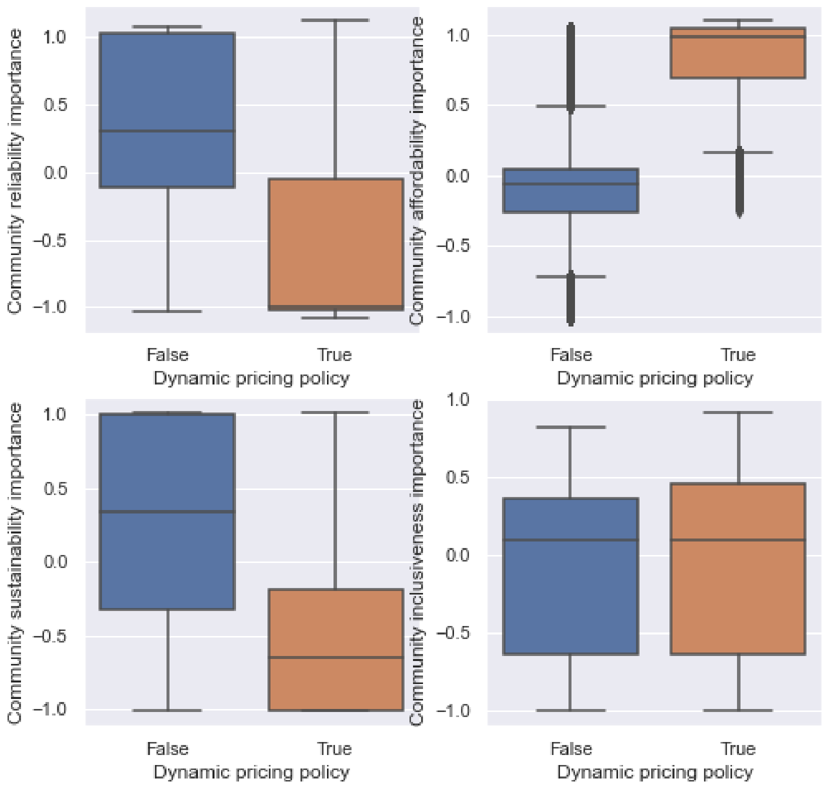


Figure 7.9: Box plot of impact of combination of dynamic pricing and uncertainty on community value importance indicators.

7.3.8. IMPACT OF COMBINATION OF POLICIES AND COMMUNITY FORMATION

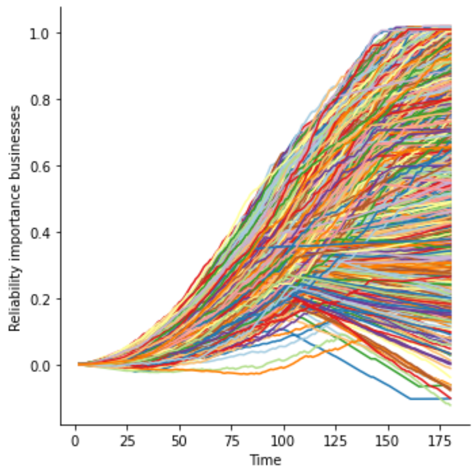
The main addition to this experiment is combination of policies and community formation. All of the indicators in general achieve a lower importance levels when compared to the base case and is deemed to be the best policy combination among other single policy experiments (see figures 7.10a,C.12,C.13,C.15).

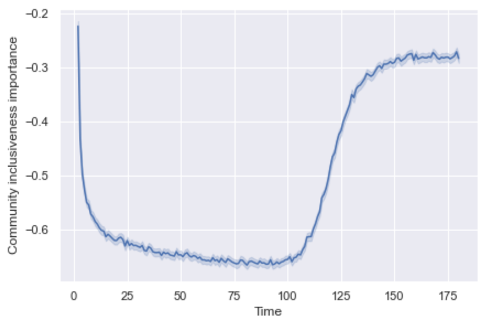
However, despite other agents percieving change in their reliability importance, the reliability importance of businesses still increases (see figure 7.10a). This shows that even the a good policy combinations can fail on consumer level due to the actions of one agent.

Further, it is seen from the figure 7.10b that the community inclusiveness importance has significantly decreased compared to other policy scenarios. This shows there is a wide consensus in behaviour of consumers regarding the influence of this policy scenario (see figure C.14).

7.3.9. IMPACT OF COMBINATION OF POLICIES AND COMBINATION OF UNCERTAINTIES

This experiment is different from previous policy scenario experiment in that it covers even larger uncertainty space. In other words, apart from the structural uncertainty, the parameter uncertainty i.e.: the consumption increase/decrease rates are included in this policy scenario as well. Com-





(b)

(a)

Figure 7.10: Combination of policies and community formation- Affordability importance consumers (a) Reliability importance of businesses has not decreased despite decreasing for other agents have (b) Community inclusiveness importance has reduced. The envelope drawn across this plot signifies the variation in inclusiveness importance

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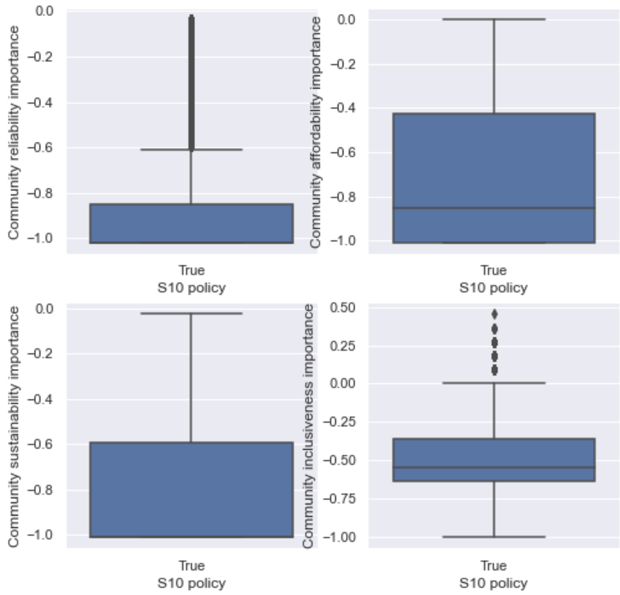

Figure 7.11: Impact of combination of policies and combination of uncertainties on community value importance indicators

pared to the previous policy scenario experiment two differences were identified. First, it is found that the community value importance indicators have much larger variance as shown in the figure C.19. Second, the inclusiveness importance achieve much more tighter and condensed data in them compared to their representation in box plot of policy scenario without uncertainty (see figures 7.11, C.14).

7.3.10. CONCLUSION

In this section, the formulated model was experimented with various single policy as well as combination of policies and uncertainties. To support these experiments, first with the help XLRM framework, a list of uncertainties and policies were formulated. Next, the base model setting as well as the experiment settings were discussed. Lastly, the experiments were analyzed for different categories as specified in experiment setting and the results were reported.

7.4. SCENARIO DISCOVERY RESULTS AND ANALYSIS

Based on the experiments performed in previous section, in scenarios that combined policies and uncertainties, it was not clear what specific parametric conditions of policies and uncertainties among the combination of policies and uncertainties had an influence on increase or decrease in the imp and ultimately contributed to failure or success of that policy scenario respectively. These questions are answered in this chapter. The aim of this section is to find the parametric conditions under which a policy scenario is able to achieve success or failure. Understanding these conditions will help in better anticipation of change in importance of values. In order to proceed with this, scenario discovery tool is used. Scenario discovery can inform us about specific conditions under which combinations of policies and uncertainties succeed or fail. The success of a policy scenario is based on decrease in relative importance of value or increase in satisfaction for that value. Whereas, the failure of a policy scenarios is based on increase in relative importance of a value or decrease in satisfaction for that value. Here, Patient Rule Induction Method (PRIM) algorithm is used in order to map the outcome space to the uncertainty space (Bryant and Lempert, 2010). The outcome space is defined by the proportion of outcomes that are of interests for this analysis.

7

To start, first outcome space is defined by specifying one of outcome of interests in this study. In this analysis, the outcomes of interests are taken as the four community importance indicators: reliability, affordability, sustainability and inclusiveness. The reason for this is that, although, a detailed analysis can be done with other outcomes of interests used in this study such as consumer importance indicators, however, the success or failure of policies does not depend solely on the increase or decrease of individual value importance indicators but also on increase or decrease of value importance of others in community as well as other uncertain factors.

The outcomes of interests for the analysis are simple. Based on the value importance scale, we know that above 0 would lead to high value importance and less than 0 would lead to low value importance. So our outcome of interest are: 1) success of a policy if a community value importance indicator is less than 0 depending on the type of community value importance and 2) Failure of a policy if the community value importance indicator is greater than 0 depending on the type of community value importance.

Consequently, the outcomes of interests for this analysis are ready to be mapped to the uncertainty space. In other words, outcomes are contained in different "boxes" having some parameter bounds for the outcome of interests i.e.: bounds defined for uncertain parameters or policies and then they are tested against a larger uncertainty space.

7.4.1. PRIM SETTINGS

The PRIM analysis is carried out by selecting the policy scenario of increase capacity, subsidize consumer, high smart meter control and community formation (Denoted as S1). This is scenario is selected for two reasons. First, it is the best case scenario found in our results where all importance levels become low, so understanding more about the conditions under which this policy can attain success or fail can help us anticipate change in importance of values from every aspect of this policy. Second, although other scenarios can be tested through PRIM analysis, this scenario is unique in that it considers combinations of policies and combination of uncertainties whose consequences are difficult to interpret without computational power, hence it is best to analyze such policy scenario.

As shown in the table 7.5, each of the outcome of interests are varied for two thresholds as mentioned earlier. The choice of density threshold and peel alpha is specific to each case, where the value is set after iterating and successfully finding a box.
[1]

Table 7.5: PRIM settings

PRIM settings				
Policy Scenario	**Outcome of interest**	**Outcome threshold**	**Density threshold**	**Peel alpha**
S1* with uncertainty	Community reliability importance level	less than 0	0.7	0.01
		greater than 0	0.7	0.01
	Community affordability importance level	less than 0	0.8	0.05
		greater than 0	0.5	0.05
	Community sustainability importance level	less than 0	0.8	0.05
		greater than 0	0.8	0.05
	Community inclusiveness importance level	less than 0	0.5	0.05
		greater than 0	0.5	0.05

7.4.2. PRIM RESULTS AND SCENARIOS

This section provides detailed outlook on each scenario that leads to success or failure of a policy scenario. First, the results are presented. Thereafter, the scenarios of success and failure are elucidated.

COMMUNITY RELIABILITY IMPORTANCE

Here, the success or failure of policy scenario is assessed with respect to community reliability importance. As shown from the figures 7.12 and 7.13, it is seen that the policy can be successful only when the two supporting policies of this policy scenario i.e.: smart-meter control and increase capacity micro-grid are implemented or in other words there values are above 1 and 0.5 respectively. As we know that increase capacity micro-grid policy is a binary value with values 0 and 1, it is assumed from the figure that, in order for the policy to achieve success in terms of reliability importance level, it would compulsorily require the implementation of increase in capacity policy among other policies.

Similarly, it is seen from 7.13, that policy can fail in terms of reliability importance, when energy consumption increase rate of businesses is greater than 2%, when energy consumption decrease rate of surfclubs is less than 3% , when there is no community formation, smart meter control or increase capacity.

[1] *Where S1 is policy scenario: increase capacity micro-grid, subsidize consumers, high smart meter control and community formation

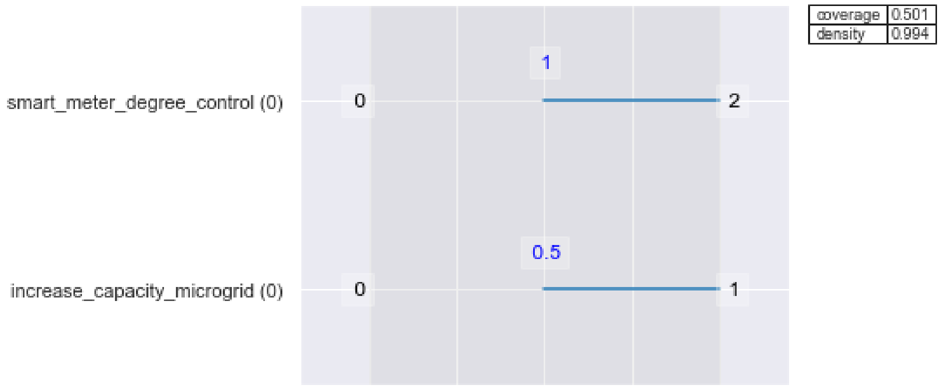

Figure 7.12: Community reliability importance less than 0

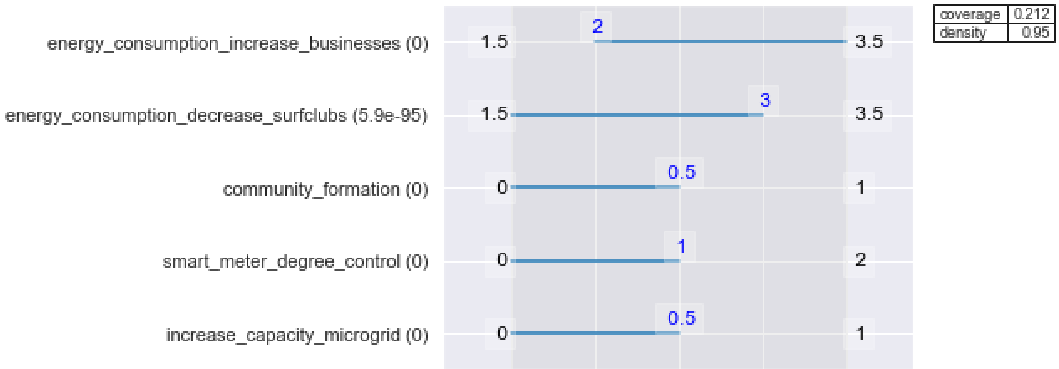

Figure 7.13: Community reliability importance more than 0

Both of these results, show the success and failure of the policy with respect to reliability importance is dependent on common policy variables that constrain them: increase capacity and smart meter control. The selection of such bounds especially for reliability importance is apt. Lastly, to better visualize the influence of major variables, dimension stacking was carried out (see Appendix C)

COMMUNITY AFFORDABILITY IMPORTANCE

Here, the success or failure of policy scenario is assessed with respect to community affordability importance. As shown from the figures 7.14 and 7.15, it is seen that the policy can be successful only when the two supporting policies of this policy scenario i.e.: smart meter degree control and subsidize consumers are implemented or in other words there values are above 1 and 0.5 respectively. As we know that increase subsidize consumers can only take a binary input, it is assumed from the figure that, in order for the policy to achieve success in terms of reliability importance level, it would compulsorily require the implementation of subsidize consumer policy among other policies.

Further, as shown in 7.15, the chances of policy failing depends on three parameters: Energy consumption increase rate businesses , smart meter control and subsidize consumer. After visualizing this better through dimensional stacking, it is seen that the most influential parameters are smart meter control and subsidize consumers, and without these parameters, the policy is bound to fail in terms of affordability importance level.

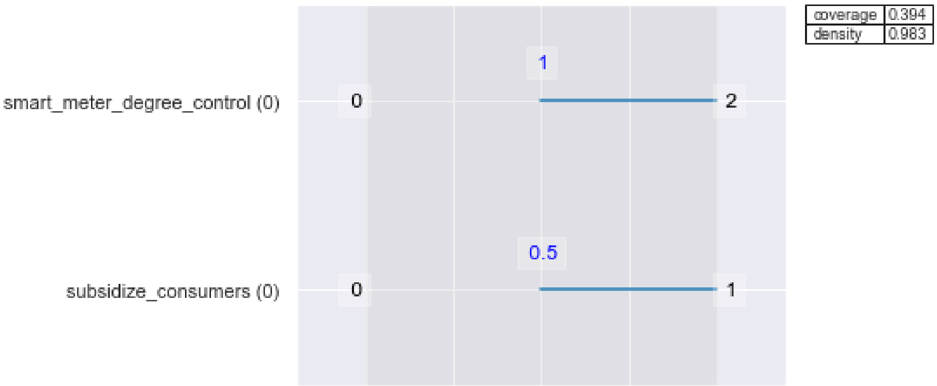

Figure 7.14: Community affordability importance less than 0

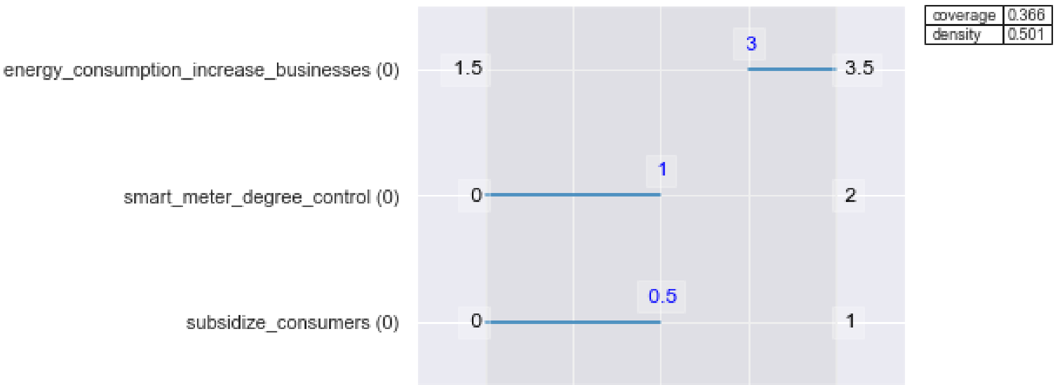

Figure 7.15: Community affordability importance more than 0

7

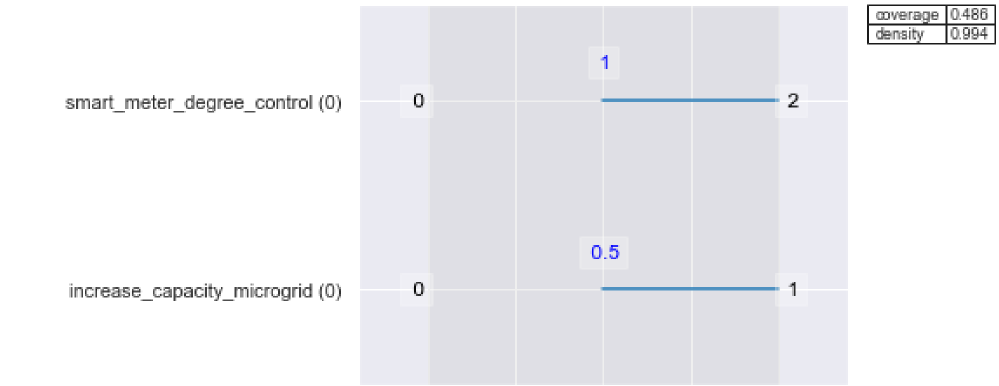

Figure 7.16: Community sustainability importance less than 0

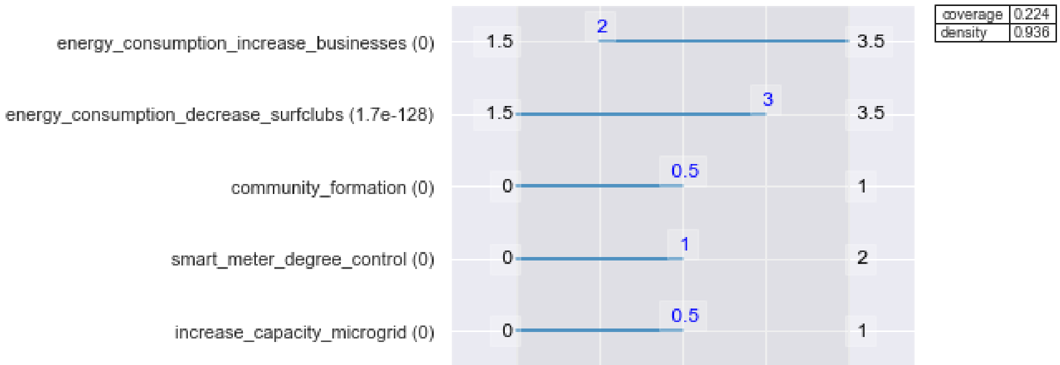

Figure 7.17: Community sustainability importance more than 0

COMMUNITY SUSTAINABILITY IMPORTANCE

Here, the success or failure of policy scenario is assessed with respect to community sustainability importance. As shown from the figures 7.16 and 7.17, it is seen that the constraints that lead to success or failure of policy is same as those in community affordability importance case. However, when looked closely, for instance, using dimensional stacking (see figure 7.18), it is seen that failure of policy with regards to sustainability importance is highly dependent on energy consumption increase rate businesses which should not be above 2% and energy consumption decrease rate surfclubs which should not be below 3%. On the other hand, the constraints for success of the policy with respect to sustainability importance remain the same as reliability importance.

COMMUNITY INCLUSIVENESS IMPORTANCE

Here, the success or failure of policy scenario is assessed with respect to community inclusiveness importance. As shown from the figures 7.19 and 7.20, an interesting trade-off to notice is that to achieve success for this policy in terms of inclusiveness importance, the smart meter control should be less than 1 or simply said there should be no smart meter control that blocks consumers in their freedom to increase or decrease their consumption over time. On the other hand, community formation is crucial in terms of bringing consumers together to contribute to lesser inclusiveness importance or higher inclusiveness satisfaction. Hence, the community formation should never be below 0.5 or simply said should never be false, to avoid failure of this policy with respect inclusiveness importance.

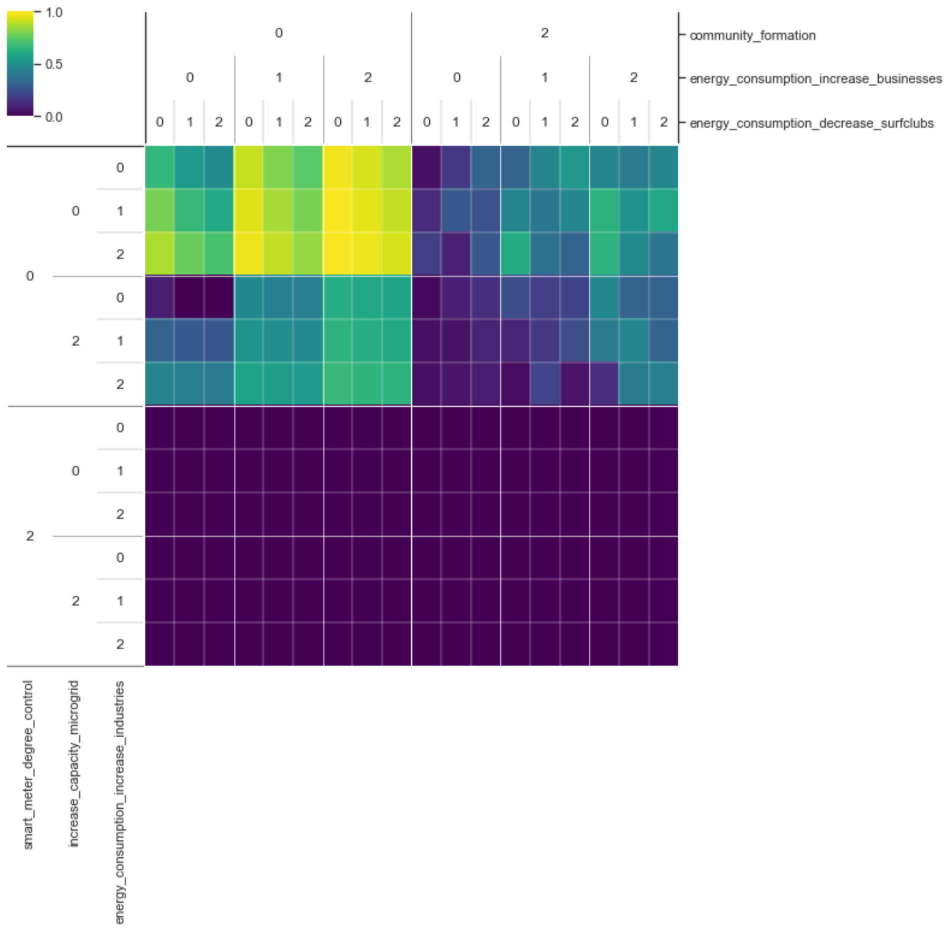

Figure 7.18: Dimensional stacking of community sustainability importance more than 0

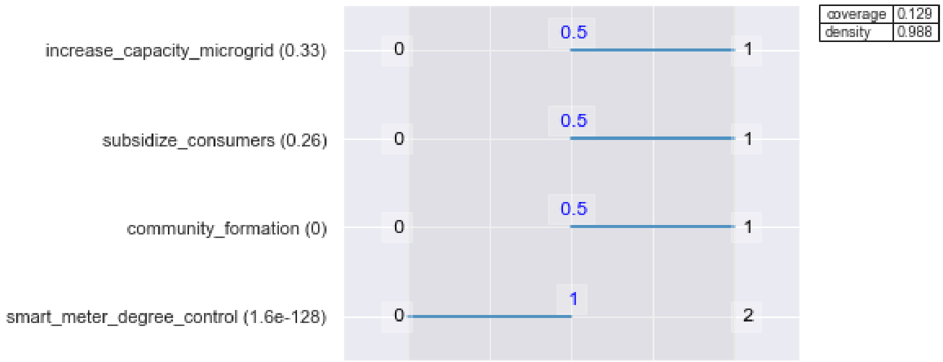

Figure 7.19: Community inclusiveness importance less than 0

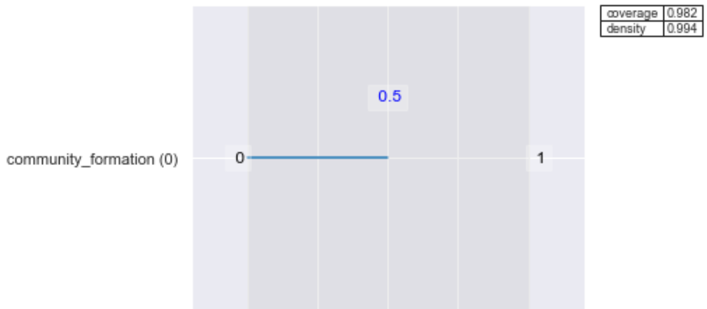

Figure 7.20: Community inclusiveness importance more than 0

7.4.3. CONCLUSION

In this section, the scenario discovery method is performed on best policy scenario or combination of policy and uncertainty. This study employed PRIM algorithm to map the space of outcome of interest to uncertainty space. The results of scenario discovery revealed various conditions that can contribute for success or failure of the policy. This in turn supports anticipation of future changes in importance of values.

7.5. CONCLUSION

In this chapter, the model was explored and analysed through experimentation and scenario discovery analysis. First, the formulated model was experimented with various single policy as well as combination of policies and uncertainties. To support these experiments, first with the help XLRM framework, a list of uncertainties and policies were formulated. Next, the base model setting as well as the experiment settings were discussed. Lastly, the experiments were analyzed for different categories as specified in experiment setting and the results were reported.

In the scenario discovery analysis is performed on best policy scenario or combination of policy and uncertainty. This study employed PRIM algorithm to map the space of outcome of interest to uncertainty space. The results of scenario discovery revealed various conditions of combination of policy and uncertainty scenario, that can contribute change in importance of values for different values. This in turn supports exploration of future value change.

8

Discussion

The aim of this chapter is to discuss the results obtained in the previous chapter and reflect on the limitations of the value change model. In the previous chapters, a modelling approach was developed to capture mechanisms such as heterogeneous value and link preferences, dynamic consumption behaviour, transformative experience, and social conformity and interaction, to explore and analyze the impact of various policy and uncertainty scenarios on value change in SES. A conceptualization of value change was formalized based on a case study of microgrid using agent-based modelling and exploratory modelling approach.

This chapter will discuss and critically reflect on this research in three-fold. First, the implication of the findings of this research are discussed. Second, a reflection on the limitations of the conceptual framework, the value change model, and the research approach are provided. Lastly, this chapter concludes with recommendations for future research.

8.1. Implications of findings

This section discusses the implications of the outcomes obtained in the previous chapter. The implications of findings are discussed in light of the conceptual framework considered in this research. This includes the on the outcomes is discussed. Later, the implications of external variables (policy and uncertainty) on the outcomes is discussed.

8.1.1. Dynamic behaviour in a common pool resource

Results discussion

Rivalry in Common Pool Resource (CPR)—energy, leads to a dynamic change in value importance among the agents. A clear dynamic behaviour in the base case (see section 7.3.1) is generated when an increase in energy consumption by businesses and industries leads to indirect consequences for surfclubs and restaurants. Initially, businesses and industries become unsatisfied with value reliability due to their decision to increase energy consumption. On the other hand, the surfclubs and restaurants—who had preferred to reduce their consumption to achieve a higher reliability or affordability satisfaction respectively—feel the consequence of actions of businesses and industries.

Further, this dynamic behaviour is reflected on the community level. For community sustainability importance, the initial slight decrease in importance level is met with an exponential increase in importance level (see figure 7.4a). This dynamic may be due to the consumption increase decision of businesses and industries overpowering the consumption decrease decision of surfclubs and restaurants. Second, for affordability importance, the initial slight increase in the importance level due to the actions of businesses and industries is overcome by an exponential decrease in importance level driven by the decrease in consumption of restaurants and surfclubs (see figure 7.4b). Lastly, The inclusiveness importance of community increases steeply due to the rivalrous actions of agents in the community (see figure 7.4c). Hence, this dynamic behaviour is observed and confirmed.

Similarly, this dynamic behaviour of CPR is projected in other policy and uncertainty situations as well. For instance, in the case of 'increase in capacity policy', initially the reliability importance experiences an exponential decrease, however, due to the continuous consumption in CPR, the reliability importance steeply increases.

Another interesting dynamic was observed when 'dynamic pricing' was activated. Here, the affordability importance of businesses and industries is high and goes unaffected as they naturally increase their energy consumption and hence energy costs increase. However, the surfclubs and restaurants undergo a significant impact on their affordability importance as they initially reduce their consumption. Nonetheless, as 'dynamic pricing' is input as a one-off policy, the surfclubs and restaurants are able to satisfy their value affordability or lower its importance again. This is due to the self-organizing and dynamic behaviour possessed by the system and the agents.

IMPLICATIONS FOR THE THEORY

The main purpose to include CPR in the value change model was to capture the interdependencies between agents and self-organizing and dynamic behaviour of agents that lead to change in the importance of values among stakeholders.

As discussed in chapter 4, although, CPR may be used in the context of managing institutions with certain rules (Ghorbani and Bravo, 2016; Ghorbani et al., 2017), it propagates a similar idea of change that values undergo. In CPR, *"boundedly rational, local users are potentially capable of changing their own rules, enforcing the rules they agree upon, and learning from experience to design better rules."* (Ostrom, 1999). Based on this definition, in this study, the rules can be implied as values. But most important to note is the self-organizing value change behaviour of agents that lead to a dynamic change in values in the community.

However, this might not always be true in the real life as there can be some groups who are willing to conform and understand the actions of each other, such that even if a shortage was to occur due to extra consumption by one agent, it wouldn't severely impact the value satisfaction of another agent. In this case, the value 'Trust' is more preferable by the group of agents than other values.

Further, the energy load is not the only limited resource that could lead to value change. Energy could be rivalrous among a group of people or community, however, there could be other resources such as water bodies, forests, fisheries which all consist of limited resources (Ghorbani et al., 2017). In short, factors other than energy load may also influence the value change in the community.

Lastly, it should be noted that not much has been researched regarding value change and CPR. Future research can look into this part of the discussion for better modelling or consideration of values.

8.1.2. VALUE CONFLICT

RESULTS DISCUSSION

Value conflicts occur when values change
As discussed in chapter 1, two types of value conflict are observed: (1) Within an agent and (2) between two or more agents.

First, two agents can enter value conflicts due to their heterogeneous preferences. The businesses and industries due to their unintended or indirect consequence of consumption increase may face a value conflict or backlash from restaurants and surfclubs as it increases their reliability importance. This value conflict is due to the limited common pool resource in the community (see figure 7.2).

Second, agents can enter value conflicts within themselves. The restaurants and surfclubs faced an unintentional value conflict where they were faced with two values to satisfy: reliability or affordability (see figures 7.2b, 7.2a, 7.6a, 7.3b). Since the restaurants and surfclubs already experience low affordability importance and high-reliability importance, restaurants will not face a value conflict as they initially prefer to satisfy affordability. However, there may be conflict within surfclubs to decide what to satisfy.

Dynamic value conflict
On the community level, a 'dynamic' value conflict is observed. As mentioned earlier, the sustainability importance of community increases over time and affordability importance decreases gradually (see figure 7.4c). The sustainability importance undergoes a slight decrease and then increases until it stabilizes. Similarly, the affordability importance undergoes a slight increase and then decrease. This dynamic pattern can be explained through the rivalrous actions of increase or decrease in consumption by agents. This leads to value conflicts being created and solved simultaneously and hence a 'dynamic' value conflict is observed.

Value conflict in dynamic pricing and uncertainty scenario
Value conflict is also seen on the community level for the 'dynamic pricing policy' scenario. It is shown from the graph 7.9 that reliability and sustainability importance decreases, however, the affordability importance increases. Further, as the scenario is performed under community formation, the inclusiveness importance is also low (see figure C.11). This shows a clear value trade-off between reliability, sustainability, inclusiveness versus affordability.
Value conflict with smart-meter control
It is seen from the scenario discovery analysis that while smart-meter control is necessary to ensure high reliability, affordability and sustainability satisfaction in the community, however, it comes at the expense of diminishing the inclusiveness satisfaction of the community.

ACADEMIC IMPLICATIONS

Firstly, the results have indeed confirmed the claim: value conflicts can occur when values change (see chapter 1). Here, we identify that value conflicts can occur both within an individual between multiple values— where a person makes a trade-off between two or more values— or differing values among two or more individuals (Demski et al., 2015; van de Kaa et al., 2020; van de Poel, 2015, 2021; van der Waal et al., 2020).

Further, we also find 'dynamic' value conflict, which refers to value conflicts being created and solved over time due to the dynamic behaviour of agents in the community. Unfortunately, this study does not cover much of this aspect. However, it is recommended to research dynamic conflicts occurring in different scenarios of value change on a normative scale.

8.1.3. ACTOR HETEROGENEITY & PATH DEPENDENCY IN VALUE CHANGE

HETEROGENEOUS VALUE PREFERENCES

Different consequences observed by different agents
In the base case, it is observed that the consequence on reliability importance of restaurants is much higher than the consequence for the surfclubs. This behaviour can be due to the preference of surfclubs to satisfy value reliability, hence they are delayed in reaching high-reliability importance and don't achieve extreme reliability importance. On the other hand, as restaurants prefer to satisfy affordability, and they don't make decisions that aim for low-reliability importance, hence they experience an extreme increase in their reliability importance.

Dynamic pricing scenario
Similarly, for the case of the 'dynamic pricing' policy scenario, it is observed that affordability satisfaction of surfclubs and restaurants is severely affected, however, the unintended consequences of this policy on affordability are short-lived, due to which surfclubs and restaurants achieve high affordability satisfaction again. This showed that agents can be adamant about their initial value preferences, such that, they will continue to thrive for satisfying their value or lowering its importance, even after they have experienced a severe consequence.

However, there is could be a caveat. It could also mean that influence of the 'dynamic pricing' scenario becomes ineffective as time passes and agents will naturally tend to satisfy their value preferences. Unfortunately due to the complexity capture in one behaviour, it is not possible to distinguish this.

Nonetheless, these results mainly imply that value change is path-dependent, such that it depends on the initial value preferences chosen by the agents.

8

INDIVIDUAL DECISION-MAKING

The 'combination of policies and uncertainties' scenario shows that value change is path-dependent on the initial decision preference chosen by the agents which are based on the value preferences. We see in this scenario that all other agents have their reliability importance lowered except the businesses (see figures 7.10a,7.2). The reliability importance of businesses increase despite a good combination of policy being activated, that is expected to satisfy all value preference of agents. This could be due to the continuous increase in consumption by the businesses, due to which they are unaffected by the policy and uncertainty scenario. Hence, the value change is dependent on the initial preference for a decision to satisfy one's values. However, more number or variety of experiments can be conducted to see if this claim holds true.

8.1.4. SOCIAL INTERACTION

COMMUNITY FORMATION

Results discussion-sensitivity analysis
The value change occurring in the community formation scenario depends on the initial link preferences of agents and their numbers. In chapter 4, the link preferences of each agent were conceptualized. Further, the number of agents of each type was chosen to be maximum i.e: 4 surfclubs, 3 restaurants, 3 businesses, and 1 industry. Based on this, the conceptualization of a sensitivity analysis using the feature scoring method gave a good view of the influence of community formation on value change.

Consequently, it was found that in general, all outcomes of interests are highly sensitive to community formation (see section 6.6). More specifically, it was seen that the reliability importance of industries is highly sensitive to the number of restaurants they are linked to, while the reliability importance of restaurants is highly sensitive to the number of businesses (see figure 6.2). All other value importance indicators showed slight sensitivity to the number of businesses and no sensitivity at all to the number of industries. Hence, this satisfies our assumption that people are sensitive to decisions taken by certain agents more than any other agent (Siebert et al., 2017).

Results discussion-model experiments
In the model experiments, the base case might have shown this complex dependency of link preference on value change. For instance, we know that the total number of industries in the community is 1, and the total number of businesses is 3. Subsequently, the influence businesses and industries have on surfclubs and restaurants might be different because of this reason. As shown in figures 6.2, less sensitivity of reliability of surfclubs to number of businesses, and more sensitivity of reliability of restaurants to number of businesses, could be the reason explaining the high inflation of reliability importance of restaurants than the same for surfclubs.

Hence, this could possibly indicate the path dependency of value change behaviour based on the initial link preferences.

Potential implications for the real-world
The real-world implications of this could be that values could change based on individual preference for contact with other people in the community, either through businesses or through follow-up advice. Consequently, certain people may be more sensitive to the changes done by their links or counterparts. However, a rigorous sensitivity test should be done in order to reap more details about the influence of one actor over the other throughout the simulation period for example. This could be the influence of a government on a local stakeholder.

Further research
Lastly, it should be noted that this research does not focus on a specific configuration of social network such as a small-world network (Watts and Strogatz, 1998), but focuses on the consequences resulting from this linkage among the agents in the community. This is why it is denoted as link preference instead of network preference. Based on this, further research could also look into the influence of various configurations of social networks on value change.

MODES OF CONTROL

Results discussion-model experiments
Modes of control have been considered in an uncertainty variable called smart-meter control. The influence of this variable on the value change is only visible in the combination of policy and combination of uncertainty scenarios, which have been both analyzed in experiments and through scenario discovery analysis.

Although, smart-meter control significantly contributes along with other policy and uncertainty variables to the decrease in reliability importance of the consumers (see figure C.30), the experiment results does not show how much of contribution does smart-meter control bring to the combination of policies except for the behaviour of community inclusiveness importance (see figure 7.10b).

The inclusiveness importance shows a dynamic behaviour. Initially, the lowest possible inclusiveness importance is observed when compared to other experiments. However, over time due to smart-meter control, the inclusiveness importance rises steeply and becomes stable. This shows the dynamic change in community inclusiveness importance. However, it is not yet clear whether inclusiveness importance is solely affected by smart-meter control or are there other variables involved. To understand this better scenario discovery analysis was done.

Results discussion-scenario discovery analysis

In the scenario discovery analysis, it is seen that smart-meter control is useful to reduce reliability, affordability, and sustainability importance, however, it is unwanted uncertainty for inclusiveness importance. This is because, the conceptualization of smart-meter control considers reducing the extra consumption used by any agent, which leads to lesser reliability, affordability, and sustainability satisfaction. But it also increases the inclusiveness importance of the community, which leads to a value conflict as mentioned earlier.

Further research

The implication of smart-meter control on value change seems to have clear benefits, however, it could be conceptualized more accurately by considering the more accurate feedbacks or reactions from the community. Currently, smart-meter control is conceptualized in terms of reducing consumption in different levels: none, partial and full. Further research could conceptualize smart-meter control in terms of value privacy, security or trust, as smart-meter is much more critically viewed from these values (Hess, 2014).

In addition, future research could look into more accurate conceptualization with intricate modes of control that represent the actual modes of governance that it is supposed to represent (Hoffmann et al., 2020) rather than a technical feature that this study undertakes. Understanding how different modes of governance or control by the authority or utility could be interesting to understand its influence on value change.

8.1.5. TRANSFORMATIVE EXPERIENCE & BOUNDED RATIONALITY

The base case results have proven that the agents have bounded rationality when it comes to perceiving the consequence of their decision and decision of others in the community, and hence may experience unwanted consequences. The results indicate the limited rationality of businesses and industries to make a decision to increase consumption, which has influenced themselves and surfclubs and restaurants in the community. When they do make such decisions, they themselves reach high value importance, but also influence others in the process. This may mean that they do have not much information about their consequences for others or may just compete to consume more energy, just like in a common pool resource as discussed earlier.

Further, when they reach the extreme most level of value importance, it was assumed that they are not able to satisfy this value once again, hence indicating a transformative experience. Based on this, the assumption was successfully reproduced by the results.

On the other hand, the restaurants and surfclubs also do not perceive the consequences of businesses and industries, as a result, are severely affected or undergo a transformative experience. (the limitations of this theory is discussed in section 8.2.1)

Community formation and Bounded rationality

Bounded rationality does not necessarily lead to a negative or extreme transformative experience. In the scenario of community formation, it can be seen that agents conform their actions to those with whom they are linked. This represents the limited rationality of agents in searching for only those in their network and not others in the community. However, this is positive for the community, because when agents conform to each other they are not only conforming to reduce the community reliability and other value concerns but also maintain their own value satisfaction by conforming to others in need in the community.

Further research could include different types of rationality among agents such as prospect theory to observe how agents take decisions from a behavioural or psychological perspective (Kahneman and Tversky, 1979) and find out its influence on the value change of community and the agents.

For Transformative experience, as this research considers every experience as a transformative experience and the decisions are so critical, further research could consider a more accurate conceptualization of transformative experience. For instance, from an energy system perspective, by including more intricate decision choices taken by agents like what electric vehicle to buy? how much capacity of solar panel would be suitable for me? Do I want to opt-in for a smart meter and sell my privacy? and such a question. These questions can lead to the agent making critical decisions that lead to a transformative experience.

8.2. LIMITATIONS OF THIS RESEARCH

Multiple limitations of this research exists mainly due to a lack of a similar value change model or a well formulated research approach to tackle value change, that has clearly led to building a model with many simplifying assumptions. The critical evaluation of these assumptions in concepts, model as well as the research approach is given below.

8.2.1. LIMITATIONS OF CONCEPTUAL ASSUMPTIONS

Few of the conceptual limitations were identified during the process of verification and validation (see chapter 6). While some of them were identified during the process of model formulation.

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The choice of using energy systems as a means to represent value change is also limited. Firstly, not many examples of energy systems exists that consider values itself, so conceptualizing changes in values is a underdeveloped issue which requires rigorous increase in research. Second, conceptualizing value change using energy system design or a more specific design, can limit the implication of the conceptualization for other design or energy systems.

Other limitations of conceptual assumption lies in how people evaluate their values on the basis of certain named or normative values. There are two limitations here. First, it is hard to realize that in real life, people give names to their own values. This is because, values are meant as a guide for people to judge between right and wrong compared to their cultural principles and expectations (Demski et al., 2015; Rokeach, 1979), however, it does not really mean that people name their values. and Second, values could rather be hidden and inherent and a person would never know why they would take certain actions in certain conditions. Therefore, two points to note are: (1) people often do not know why they act in certain actions or conditions, and (2) people do have values, but it is unrealistic to assume that they can give it names.

Value importance levels

People do not evaluate the level of importance of values before making a decision. People know two things, the good and the bad. The good and bad vary depending on the experiences of people (or better said 'path dependency' (van Dam et al., 2013)). However, it is hard to assume that a person evaluates their decision based on a generalized level of good and bad or generalized levels of importance of values. Rather when something has a good or bad impact on the person, they know how far-reaching or low-reaching the impact is. A question then arises: can people's behavior be evaluated in terms of their values, even if they do not accurately represent its generalized form?.

In other words, the importance of values is incommensurable in that there isn't an agreed consensus on levels of importance of values based on their impact (see for example: (Martinez-Alier et al., 1998; Munda, 2004; van de Poel, 2015)). This shows that the importance of values can never be generalized for all people, and hence has major implications on how people evaluate their decision or a potential future decision.

incommensurability of values
Further, there is a limitation in not just incommensurability of level of a single value, but also limitations of incommensurability when two values are compared. For instance, it is not known in real life whether reliability is more important than sustainability or affordability, this solely depends on the time, the exogenous, and the endogenous forces acting.

It is assumed in the model that people have a preference for increasing or decreasing their value importance through increasing or decreasing consumption. However, it is hard to imagine whether these goals can be measured or have certain limits. For instance, the extremes of a value importance level are 1 and -1. In this case, as noted earlier, the importance of values is incommensurable, and hence they can never have a limit. This assumption was merely chosen depending on simplification choices considered such that the model is easily understandable.
Another limitation of conceptual assumption as seen in the model is that people's values change every time step. However, it is unrealistic to assume that people's values change instantaneously (Boenink and Kudina, 2020; Schwartz, 2012). Boenink and Kudina (2020) puts it rightly and says "Most human actions are based on automated processes and routines" and "If we drive to work by car every day, we do not consciously decide again and again that 'comfort' is more important to us than 'sustainability; we rather continue a habit" (Boenink and Kudina, 2020). Schwartz (2012) remarks that people hardly ever consciously decide based on their values. These points prove the fact that if a person has started to do some activities such as a decrease in consumption, they will continue to do these actions regardless of minor changes.

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Some improvements can be done in how subsidy policy could be accurately modelled. First, consumer subsidy can be calibrated better to suit the actual needs of agents for the long term. Second, to maintain equitable growth in affordability satisfaction, more conditions on who is eligible for the subsidy and how much can the consumers spend from their subsidy needs to be pondered. This can lead to modelling this policy more accurately.

Lastly, this research only explored a chosen theoretical/ conceptual assumptions (see chapter 4) to support conceptualization of value change in agent based model. However, more theoretical assumptions could be collected and evaluated against some criteria in order to assess the viability of each assumption.

8.2.2. Model limitations

Among various limitation of model are the assumptions. A variety of assumptions have been taken to produce the agent-based model.

One of the limitation of model is that it is assumed that people's importance for all values are initially indifferent or neutral or the utility/community importance levels are neutral. However, this cannot be true in real life, where people have some kind of inherent preference for values. Although, this inherent preference is shown in the base model behaviour and is of not main concern, but the assumption that people's importance for a value starts off from zero or indifferent is unrealistic. This is because people/ agents have some 'history' and are 'path dependent' (van Dam et al., 2013).

Similarly, with for the case of technologies, they too are never value neutral (see (Klenk, 2020)). This model is limited in terms of considering a learning and adaptation feature of agents. It would be very insightful to see how agents react after they have achieved certain level of value importance. However, due to certain conceptual limitations, the model could not consider a learning feature. Another limitation in modelling choices is a trade-off about whether to include more values in the model or to represent a few and analyze them in-depth. Each value has some complexity attached to it, that when added to the model produces results that are hard to interpret. However, for the policy side, it is always good to consider all the different types of values that exist in society to be able to anticipate better. Further, using more values as an input in the model makes it hard to visualize which value has clear consequences on output (as seen in the feature scoring analysis section in chapter 3). This shows a clear trade-off regarding considering the number of values in the model.

A limitation in the verification and analysis was perceived. A feature scoring was performed on different structural uncertainty variables, and this showed that it is limited in terms of capturing interaction effects among different variables. Currently, the analysis was done by blocking some variables to find the influence of other variables on outcomes of interest. However, the results of this analysis depend on the initial value of the blocked variable. Hence, it avoids "true" analysis of interaction effects.

Another limitation of this model is that consumers do not take critical decision-making as done in real life by assessing the situation and then acting (see for example Hoffmann et al. (2020)). Rather, this model assumes that consumers take actions based on their preference and consequently they get influenced by the consumption actions of others.

The current model reflects changes on all values of agents irrespective of whether they prefer it or not. This shows the model is limited to consider which specific values are preferred by which specific agent in the model.

8

There exist limitations and difficulty in matching the technical data with qualitative value importance indices. In other words, the formulation of individual values is difficult in modelling value change, as there are multiple formulations of individual values. However, this research has not considered these multiple formulations. Which is one of the limitations of this research.

Similarly, the model also does not assume values of multiple agents in the arena and merely selects four values to represent the change in the importance of values easily. However, including all relevant stakeholders can accurately model the situation or help understand the points giving rise to value change.

In addition, the model does not automatically consider the value preferences of agents. For instance, if restaurants prefer value affordability, the model shows an influence on their value reliability also, when in fact they are insensitive to it.

Further, this model assumes a selected number of values, whose conceptualization may not be accurate due to less interaction with actual stakeholders. However, when more distinct values are considered there is a chance to better explore value change and the acceptance of energy system.

Lastly, a limitation in experimentation and results was perceived. Despite making the random number to change every run, some of the outputs displayed no variation across runs. This can be due to the structural uncertainty of the model.

8.3. REFLECTION ON THE MODELLING APPROACH

The objective of the agent-based model was to reproduce the underlying mechanisms that drive value change in SES under various uncertainty and policy scenarios.
Considering the similarity of mechanisms that contribute to value change in SES and characteristics of CAS. It is can be said that the Agent-Based Models are best suited to capture value change, despite there aren't other ABMs to validate this point.

First, as our research involves multiple endogenous and exogenous factors that contribute to importance of a value, Agent-Based Model have proved to be useful in exploring various combinations of these factors and exploring their impact on change in importance of values.
Second, one of the best characteristics of Agent-Based Model is that it can capture the evolutionary aspects in a macro-system driven by micro-systems. This advantage was considered in modelling agent level importance indicators whose actions ultimately contributed to the importance level at community level.

Third, making use of this combination of agent-based model exploratory modelling approach, a much more detailed insight can be obtained on the conditions in which values change using scenario discovery analysis.

Fourth, exploratory modelling proved to be a robust tool in terms of exploring change in importance of values. However, in case of performing scenario discovery, it was seen that PRIM analysis had to be done on each different outcome of interest. These experiments consisted of using binary classification of thresholds on single outcome of interest, which shows that it is a limiting version of scenario discovery. In this case, more advanced techniques of PRIM could be used (Kwakkel and Jaxa-Rozen, 2016).

Fifth, the feature scoring technique used as sensitivity analysis on different structural uncertainty variables, showed that it is limited in terms of capturing interaction effects among different variables. Currently, the analysis was done by blocking some variables to find influence of other variables on outcomes of interest. However, the results of this analysis depends on the initial value of the blocked variable. Hence, it avoids "true" analysis of the interaction effects.

Last, despite these advantages, there are also some disadvantages for using agent-based model in anticipating value change. It is to be noted that, through each step of modelling cycle there is always a some uncertainty added in the model behaviour, which would make it hard to predict in case more number of values and more complexity was added.

8.4. FURTHER RESEARCH

This research can be extended with other types of value change such as a change in the conceptualization of values (van de Poel, 2018). For instance, here the formulations used for environment sustainability were dependent solely on GHG emissions or co2 emissions, however, (Jha et al., 2020) uses two other indicators that measure a different aspect of environmental sustainability such as land use and other environmental impacts. This can be taken forward by allowing conceptualization of environment sustainability to change based upon actions of people or actions of utility/ external forces. Or if this would be hard to model, a simple deterministic model can be projected to see dynamics between different conceptualizations of values in a certain time constraint.

Based on the limitations of this model to consider transformative experience, further research could consider a more accurate conceptualization of transformative experience. For instance, from an energy system perspective, by including more intricate decision choices taken by agents like what electric vehicle to buy? how much capacity of solar panel would be suitable for me? Do I want to opt-in for a smart meter and sell my privacy? and such a question. These questions can lead to the agent making critical decisions that lead to a transformative experience.

Further, this research considered representing value change in energy systems using micro-grid energy systems. Future research could look into how values change in another niche, uncertain and emerging energy systems, or even other emergent technologies or algorithms such as Artificial Intelligence or Machine Learning models. Although the formalization of this could be tough, a simple dynamic of action and reaction among entities would be enough to show many results of the certain inputs and outputs that cause values to change.

Further, as this research does not consider the learning and adaptation element in the agents, further research can extend the current model with these concepts among agents, such that they are able to adapt to certain circumstances, rather than just experiencing and updating value importance. This way a more accurate model could be produced which considers the more precise decision-making in the agents.

Further research could conceptualize smart-meter control in terms of value privacy, security or trust, as smart-meter is much more critically viewed from these values.Also future research could look into more accurate conceptualization modes of control that represent the actual modes of governance, rather than a technical feature that this study undertakes.

Future research can look into the integration of value change and CPR as not much research has been done on this topic.

It would be interesting to see if the current model can be reproduced by some other researchers. Doing so will not only improve the validity of the current model but also helps in critically thinking about the current model and adding new perspectives.

As the objective of this research was mainly aligned towards modelling value change, many simplified assumptions were taken in the microgrid system. Future work could focus more on how we can integrate both these domains precisely to re. Although value change is not yet fully developed, various concepts from microgrids can be used as a starting point for real-world concepts of microgrid such as demand response strategies(flex capacity), extra assets, flex capacity, price boundaries selection (determining the maximum pay for energy) and many more aspects of microgrid found in the literature.

Current model reflects changes on all values of agents irrespective of whether they prefer it or not. Further research can look at how the current model could detect the change in value importance preferences or simply the initial value preferences, before reproducing any change on an irrelevant value for an agent.

Further research can include more intricate policy scenarios that could consider real-world phenomenon better. For example, a policy or policies that consider an economic crisis such that it is able to understand more precisely how values change.

Further research from transformative experience include: to consider a more accurate conceptualization of transformative experience. For instance, from an energy system perspective, by including more intricate decision choices taken by agents.

The experiments performed in this research can be extended to perform an extensive experiment and analysis. For instance, a policy scenario could consider the number of times a value importance increases or decreases depending on the external or endogenous situation acting. The number of times can be used to distinguish and rank different scenarios to find the best-case scenario. Further, as this research work on a fixed number of agents in the model, further research can experiment with changing the number of agents and checking what influence does it have on the value change? Is adding more people to the community beneficial or costly (in terms of value change)?

Future research could also focus on finding/conceptualizing the number of interactions between agents before value change occurs. This could realistically conceptualize the interaction as well as put some delay to the value change. By setting the number of interactions we could see how only after a certain number do we see values change. The interactions need not be direct but can be indirect as well.

Lastly, This research was also limited indirectly linking with the participants of the case study, as it was out of the scope of this research. However, future research can focus on direct communication with stakeholders to gain accurate information regarding their needs and problems which would show enough regarding their preference or importance for a value.

8.5. CONCLUSION

This chapter discussed the implication of the findings of this research. Second, a reflection on the limitations of the conceptual framework, the value change model, and the research approach are provided. Lastly, this chapter concludes with recommendations for future research. Few key insights obtained from the discussion are as follows:

- The dynamic and rivalrous behaviour of agents in a CPR is observed and confirmed.
- Future research can look into the integration of value change and CPR as not much research has been done on this topic.
- Value conflicts occurring due to value change was confirmed on the basis of two types of value conflict: (1) Within an agent and (2) between two or more agents.
- Dynamic conflict is also found. Which means conflicts are created and solved simultaneously on the community level. It is suggested for future studies to include or research dynamic conflict between values.
- Value change is path-dependent, such that it depends on the initial value preferences chosen by the agents
- Agents experience different consequences based on their heterogeneous preferences.
- Dynamic pricing scenario shows a conflict between reliability, inclusiveness, sustainability versus affordability

- Individual decision-making of agents play a key role in the path dependency of value change
- Agents are sensitive to decisions made by certain agents(linked) more than any other agent.
- The influence of 'community formation' on value change, implied that some agents are more sensitive to value change when linked an agent of their preference than others. Further research can be done in terms of manipulating the configuration of links and networks formed and finding its influence on value change.
- Insights from smart-meter control showed that inclusiveness importance increases due to this uncertainty.
- Further research could conceptualize smart-meter control in terms of value privacy, security or trust, as smart-meter is much more critically viewed from these values.Also future research could look into more accurate conceptualization modes of control that represent the actual modes of governance, rather than a technical feature that this study undertakes.
- Community formation and bounded rationality is found to be beneficial for the community, as it reduces the community reliability but also helps agents maintain their own value satisfaction.
- Further research from transformative experience include: to consider a more accurate conceptualization of transformative experience. For instance, from an energy system perspective, by including more intricate decision choices taken by agents.

IV

CONCLUSION

9

Conclusions and Recommendations

The deployment of Sustainable Energy Systems (SES) is necessary to combat climate change, and its social acceptance plays a vital role in its uptake. Subsequently, values play a key role in social acceptance of SES and help evaluate the consequences of SES deployment.

However, there exists a complexity of change in the values of people. Alternatively known as value change, although SES may embody values permanently during its design, the values that people hold important may change during the lifetime of SES. This change is the result of highly unpredictable complex, dynamic and emergent characteristics of SES. Consequently, this has led to high uncertainty in the future acceptance of SES.

Exploring the uncertain scenarios of value change can facilitate better consideration of values in evaluating the social acceptance of SES and form better prospects for the future acceptance of SES. However, current approaches in ethics of technology literature are incapable of exploring value change, either due to their lack in dealing with value change after it has occurred, or their static characteristics to consider values.

Alternatively, simulation models have shown better prospects in exploring complex societal dynamics of which a human mind cannot picture. Simulation models such as Agent-Based Models are seen as a suitable solution to capture the complex and dynamic characteristics of SES as well as the underlying mechanisms that drive the value change in SES. Although very few studies have modelled values using the Agent-Based Modelling approach, no research has used Agent-Based Models to explore value change on a normative scale.

Building on this knowledge gap, the objective of this research was to gain an understanding of mechanisms that drive the value change in SES, by formulating a modelling approach that integrates agent heterogeneity, individual decision-making, bounded rationality, and social interaction and explores the value change under various policy and uncertainty scenarios. To this end, this study combined Agent-Based Modelling and Exploratory Modelling approaches to explore value change in SES.

In chapters 1 to 3, the research problem was introduced and the research objective and questions were formulated. Chapters 4 to 7 answered the three sub-research questions.

This chapter will conclude this research by answering the research questions, discussing the scientific and societal contribution made by this research, and suggesting suitable recommendations for policymakers and researchers.

9.1. ANSWERING THE RESEARCH QUESTIONS

Sub-question 1: What theories can be used to support the conceptualization of the model of value change in sustainable energy systems?

The objective of the first sub-research question was to identify suitable theories and concepts that could support the conceptualization of the value change model. To answer this question, two parts were identified:

1. *How can the value change be conceptualized for the case of microgrid?*
2. *What potential theories and assumption can support this conceptualization?*

The answer to the first part forms a basis for the conceptualization of value change model. This part consists of a microgrid design, resembling the complex and emergent characteristics of an SES. The technical assumptions of the microgrid design are: 1) It is a community microgrid, self-sufficient such that it does not require any connection or requires limited connection to the main grid; 2) The energy consumption and demand are key variables that are considered in the microgrid design; 3) The microgrid has an allocated supply which exactly matches the demand of the consumers—which makes it a limited common pool resource; 4) The microgrid consists of combination of renewable energy and grey electricity, to be able to manage energy in scenarios of severe shortage of supply; 5) Lastly, the values considered in the microgrid are four: reliability, affordability, environmental sustainability, and inclusiveness. These values are interwoven with each other and hence are suitable to model value change.

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The assumptions regarding the agents or consumers in the microgrid design are: (1) The agents are categorized into four types: businesses, surfclubs, restaurants and industries based on the case study of microgrid development in the Scheveningen district; (2) The businesses and industries are both large scale consumers, whereas, the surfclubs and restaurants signify the small scale consumers; (3) Every agent in the community has an income, energy consumption, allocated supply, and willingness to invest which can vary over time. The agents have varying income and energy consumption depending on the agent type. The willingness to invest is a certain percentage of agent's income.

The answer to the second part is the conceptualization of the value change model. This part includes different theories and concepts that can support the formulation of the value change model. First, the concept of value importance and value satisfaction are introduced. This is based on the scope of this research to measure the change in importance of values among other value change types. The value importance is opposite of the value satisfaction, and it is the importance that an agent or community gives to a certain value depending on the satisfaction they have with that value. Consequently, the value importance is assumed to be measured on scale of -1 to 1, measuring the variation in value importance from low to high respectively.

Second, the concept of agent heterogeneity is assumed, which include three types of heterogeneous preferences: (1) value satisfaction preference; (2) individual decision-making (to increase or decrease energy consumption); and (3) link preference. All these preferences contributes to the agent's decision making and social interaction with their peers, which ultimately influences their value importance or value satisfaction.

Third, based on the concept of Common Pool Resource (CPR), which signifies limited energy resources, it is assumed that the decisions of agents have an equal and opposite consequence for their linked agents. For example, an increase in consumption by one agent causes a reduction in the supply of another agent. Based on the action and consequences, agents experiences varying levels of value importance or value satisfaction. This concept is considered primarily to hold the assumption of dynamic value change over time through dynamic change in energy consumption of agents.

Fourth, from the theory and concept of transformative experience and bounded rationality three assumptions are derived: (1) Agents cannot perceive a consequence of their decision in advance, due to the uncertainty in the consequence of decisions taken by other agents in community; (2) Due to the bounded rationality of agents, they may not necessarily select the right decision that contributes to their high value satisfaction or low value importance; (3) Based on the assumption of theory that transformative experience occurs only in case of major decisions of agents, it is assumed in model that when agents reach extreme levels of value importance, they are unable to satisfy their value again or there efforts are insufficient to change the course of consequence throughout the simulation period.

Lastly, the concept of social interaction is assumed to be occurring in two different scenarios of model. (1) social conformity—where agents will conform to the energy consumption levels of other agents who have high value importance and are linked with them. (2) mode of control—where agents are influenced by the community microgrid in three different levels of control on their energy consumption. Therefore, these two scenarios/concepts are meant to observe the value change resulting from social interactions.

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Sub-question 2: How can the model of value change in sustainable energy systems be formalized and specified

The objective of second sub-research question was to formalize and specify the value change model based on the theories and concepts identified in the previous sub-research question. The outcome of this sub-research question is a formalized value change model that could reproduce the underlying mechanisms that drive value change in SES under various uncertainty and policy scenarios.

First, the model objective and the Key Performance Indicators (KPI) were defined and formulated. As the scope of this research lies in measuring the change in importance of values, the key performance indicators are taken as value importance levels of each value type as conceptualized in previous sub-research question. Further, the KPIs are distinguished based on community and agent level. Subsequently, while all value importance KPIs are considered on the community level, the sustainability value importance is not measured on the agent level due to the assumption that agents indirectly influence the value sustainability on community level through their decisions. However, all other value importance indicators are still considered on the agent level. Further, the KPIs are normalized to values -1 to 1 range after they are calculated from the respective formulations.

Next, the concepts concerning the model environment and external variables are formalized. First, the model is implemented in Netlogo software (Wilensky, 1999). The user interface is constrained with a spatial map of the case study consisting of each agent placed at their defined location as in the real-world. Further, it is assumed that the time/ run length in the model environment is dependent on the dynamics and emergence of value importance over time and hence, is not limited to a specified run length.

Then, the flow of main external variables: community formation, smart-meter control, link preference, and energy consumption rate, is formulated. The community formation resembles the concept of social conformity among the agents concerning their consumption behavior and their value importance level. Whereas the smart-meter control represents the modes of control as defined in the previous sub-question. The link preference resembles the inherent preferences of the agent to connect to another type of agent, which represents the agent heterogeneity. This link preference is an external variable that is different from the concept as defined in the previous sub-question, as it assumes a binary value with regards to the preference for a link to other agent being activated or not activated.The energy consumption rate is a formulation of individual decision-making preferences agents have: to increase or decrease energy consumption. This is formulated on community scale such that it has an influence on other agent's value importance. Lastly, other external variables include policy scenarios which are discussed further in following sub-research question.

The model formalization ends with the model narrative and the model specification. The model narrative consists of three steps that an agent follows in a simulation run: (1) *Evaluate the value importance*—here the agent evaluates the importance of their preferred value based on dependent variables considered in the formulation of KPIs. (2) *Individual decision-making*— where agents put their preference for value in decision to achieve a higher value satisfaction. (3) *Experiencing the consequence of self and others*—which shows the indirect consequences agents face resulting from decisions of other agents in the community. Following this, an overview of the value change process in the model shows the iterative structure of the model narrative.

Lastly, the model is then verified and validated using the Evaludation approach (Augusiak et al., 2014) which included a six step verification and validation process.

Sub-question 3: What dynamic patterns does the model of value change generate under different policy and uncertainty scenarios?

The objective of the third sub-research question was to find the dynamic patterns projected by the value change model under different policy and uncertainty scenarios. First, using the XLRM framework by (Lempert et al., 2003) various model parameters were classified under: exogenous factors (X), policy levers (L), metrics (M), and the relationships (R). The R and M have are already been defined in the answer of second sub-research question. The X and L are defined in this sub-research question based on the case study of community microgrid.

Although, the policies in this model influence all outcomes of interests directly or indirectly, they are mainly directed to improve reliability importance and affordability importance at community level. These policies include: (1) increase capacity microgrid, (2) subsidize consumers, and (3) dynamic pricing.

The uncertainties in this model are identified by three types: structural, parametric and stochastic uncertainty based on the classification provided by (Briggs et al., 2012). The structural uncertainties include: (1) community formation, (2) link preference, and (3) smart-meter control, while the parametric uncertainty include: (1) energy consumption increase/decrease rate of all agents and (2) electricity price.

Model experiments
The formulated model is used to setup experiments in different categories: (1) Base case, (2) single policy, (3) combination of single policy and uncertainties, and (4) combination of policies and combination of uncertainties.

The base case dynamic patterns observed were: (1) a rivalrous consumption of energy in a common pool resource is observed among agents. (2) at community level a dynamic conflict was observed, where value conflicts were created and solved over time. (3) value change is path dependent, in that the initial value preferences, decisions and link preferences influences agents end state of value importance.

The single policy experiments dynamic patterns observed were: (1) Increase in capacity microgrid helped delay the increase of reliability and sustainability importance of community and significantly reduced the importance below the base case. (2) Subsidize consumer policy reduced the affordability importance of community, but may have unintended consequence of inequality with respect to providing a same subsidy amount to all agents, which led to a different impact on agents based on their income. (3) Dynamic pricing policy mainly revealed a value conflict between values reliability and affordability on community level. Further, it showed the self-organization of surfclubs and restaurants to lower affordability importance after the negative impact of policy.

The combination of single policy and uncertainties revealed varying insights. (1) The 'increase capacity and uncertainty' scenario, shows added benefits compared to the single policy 'increase capacity' through a stable decrease in inclusiveness importance is observed, which is mainly influenced by the 'community formation' uncertainty. (2) The 'dynamic pricing and uncertainty' showed value trade-off between reliability, sustainability, inclusiveness versus affordability. An addition of value inclusiveness is observed from single policy due to the 'community formation' uncertainty.

Lastly, the combination of policies and uncertainties—consisting of 'increase capacity, 'subsidize consumers', 'smart-meter control', 'community formation' and 'energy consumption increase/decrease rates' reduced all value importance levels without observing a value trade-off or value conflict among them. However, on the agent level, despite the effectiveness of this policy for other agents, businesses had low reliability and affordability importance, it may be due to continuous increase in consumption by the businesses, due to which they are unaffected by the policy and uncertainty scenario. Nonetheless, this policy has revealed no conflicting results in terms of value conflict both at community and agent level.

Scenario discovery analysis:

The scenario discovery method informed us about specific conditions under which the 'combinations of policies and uncertainty' scenario, lead to high-value satisfaction/low-value importance (success), or low-value satisfaction/high-value importance (failure). Therefore, the 'success' of a policy scenario is the decrease in the importance of value or an increase in its satisfaction (measured as value importance level less than 0). Whereas, the 'failure' of policy scenario is the increase in the importance of a value or decrease in satisfaction for that value (measured as value importance level more than 0). And since, the experiments are measured against each value at community level, the outcome of interests are all the community value importance indicators.

There are several algorithms that could be used to execute the above experiments. This study employed PRIM algorithm to map the space of outcome of interest to the uncertainty space. The PRIM setup included outcome of interests for both: less than 0 and more than 0 threshold. The results of scenario discovery revealed various conditions that contribute to increase/decrease in value importance above or below the 0 threshold.

The 'combinations of policies and uncertainty' scenario can achieve a low reliability importance or high reliability satisfaction in the community when (1) increase capacity policy is implemented, (2) full smart-meter control is activated, and (3) community formation, and (4) no/less energy consumption increase or decrease by businesses and surfclubs respectively. Similarly, these are the same conditions / parameter constraints for the policy scenario to achieve a low sustainability importance or high sustainability satisfaction

Similarly, the 'combinations of policies and uncertainty' scenario can achieve a low affordability importance or high affordability satisfaction when (1) subsidize consumers policy is implemented, (2) full smart-meter control is activated, but (3) no/less energy consumption increase by businesses.

Lastly, when the policy scenario was evaluated against inclusiveness importance, results revealed interesting insights: there should be (1) no smart meter control that blocks consumers in their freedom to increase or decrease their consumption over time. On the other hand, (2) community formation is crucial in terms of bringing consumers together to contribute to lesser inclusiveness importance or higher inclusiveness satisfaction. So, in short high-inclusiveness satisfaction depends on community formation uncertainty, while the low-inclusiveness satisfaction depends on the smart-meter control uncertainty.

Based on the answers of the three sub-research question, the main research question & answer is as follows:

How can we explore the value change in sustainable energy systems?

Based on the main objective of this research, this study combined agent-based modelling with an exploratory modelling approach to explore the change in importance of values in SES. This agent-based model was formulated using a case study of community microgrid resembling the complex and emergent characteristics of an SES and utilized the concepts: agent heterogeneity, individual decision-making, bounded rationality, and social interaction. Then, an exploratory modelling approach was used to verify and validate the agent-based model for its fitness for the purpose. Later, the effects of each policy and uncertainty scenario on the change in importance of values were explored and analyzed. Subsequently, the scenario discovery method allowed for an investigation into certain parametric conditions under which the combination of policies and uncertainties scenario achieves high or low-value importance depending on the type of conditions and the value considered.

In conclusion, formulating a value change agent-based model with relevant concepts, theories, and a case study, and exploring the impact of various policies and uncertainties on this model, ultimately led to a better understanding of the underlying mechanisms that drive value change in Sustainable Energy Systems.

9.2. SCIENTIFIC CONTRIBUTION

1. Currently, there exist no particular simulation method that explores value change on a normative scale. Specifically, no research has applied Agent-Based Modelling with Exploratory Modelling approach to explore value change. This study contributes methodologically by combining the agent-based model with exploratory modelling approach to explore the underlying mechanisms of value change by analyzing the impact of various policies and uncertainties on the change in importance of values. Therefore, this study contributes mainly to three literature domains: value change in ethics of technology domain, values studied using Agent-Based Models and Exploratory Modelling approach, as well as, to the theories used in the conceptualization of value change: common pool resource (Ostrom, 1999) and transformative experience (Paul, 2014).

2. In the domain of ethics of technology, first, the current literature lacks in having better consideration of values or value change to evaluate the social acceptance of SES or any technology (de Wildt et al., 2021; Oosterlaken, 2014). This research primarily explores the complexity posed by value change in SES, and contributes to a better understanding of emerging value conflicts and social acceptance issues occurring in SES over time. Hence, this research contributes to better consideration of values or value change to evaluate the social acceptance of SES.

3. Second, we have also seen in the literature (see chapter 2), the approaches to explore value change are scarce, and specifically, no research has used agent-based models or simulation models in general to explore value change. Subsequently, this research contributes to the literature of value change in the ethics of technology domain by proposing an agent-based exploratory modelling approach, as a means to explore value change.

4. Third, it was found that the understanding of underlying mechanisms that drive value change in SES is limited in research. This research has combined concepts and theories such as agent heterogeneity, individual decision-making for a common pool resource, bounded rationality transformative experience, and social interaction, to conceptualize value change in SES, which ultimately helps understanding the underlying dynamics and mechanisms driving the value change in SES.

5. Subsequently, the usage of transformative experience and common pool resource as theories to model value change contributes to these respective domains as well.

6. In the domain of values in agent-based models, this research has improved on previous researches regarding the way in which values were included in agent-based model. For example, values were included in agent-based models in a static manner (de Wildt et al., 2020, 2021). This research contributes with a dynamic representation of values and value change in agent-based models. Therefore, it could allow for better and more accurate consideration of values for future acceptance of SES (de Wildt et al., 2021).

7. Lastly, this research adds to the exploratory modelling domain for its use with an agent-based model to explore value change. Currently, no study has utilized exploratory modelling techniques to explore value change. By applying the scenario discovery method to the agent-based model of value change, this research has explored the specific parametric conditions under which value importance increases/decreases over time, hence contributing to exploring value change using exploratory modelling techniques.

9.3. Recommendation for researchers

This section recommends academic researchers few insights and informs them of the pitfalls that I have gone through based on my reflection of the process of conceptualizing and modelling value change. They are noted as follows:

1. From a modelling perspective, it is necessary to strike a balance in the number of values to be considered and the number of value that are actually required. Not doing so will only make the model of value change, complex and hard to interpret.
2. Value change models can involve much complexity due to their consideration of different mechanism. So while explaining value change to laymen, it is recommended to use simple flow diagrams and flow charts to help them get on track with you.
3. In conceptualizing value change, do not ever use categorical variables or discrete numbers as variables and values to conceptualize values. This will only make the conceptualization deterministic, which hardly captures a more dynamic behaviour of value change.
4. With that said, I do not say that a deterministic model is not suitable to model value change. In fact, my primary conceptualization or models of value change contained a deterministic behaviour. One advantage of this method is that we can place multiple exogenous and external events happening in one timeline that could lead to change in values.
However, I deem it as an unrealistic way to model value change. First, value change concept itself is of evolving and co-evolutionary nature. It is recommended to explore this random behaviour rather than constrain it to your own construct of how values change. The juice is in the exploration. Hence, in my view a deterministic method of modelling value change is not useful.
5. Another useful point is to think before adding more complexity to the model. Do not jump easily to accept certain conceptualizations and way of thinking. Question yourself regarding the value the additional complexity adds to the model.
6. In modelling social interaction, initially, I had modelled it with simple heuristics or direct interaction among stakeholders. In other words, the model agents had to have a touch or nearness to count it as an interaction. However, it is unrealistic to assume people randomly meet each other and change values or decisions. Therefore, it is recommended to conceptualize it as indirect interaction for example through links or networks in ABM.
7. Lastly, my reflection of value change is such that it is underdeveloped and has lot of improvements can be done to bring to the light of discussion among stakeholders. To do this, it is recommended to create and conceptualize more models of value change that have been applied in different domains and not just energy systems.

9.4. Recommendation for policymakers

This section recommends policy makers on how they can improve this research further. Below are few points on what can be done to take the topic of value change forward:

1. This research considered modelling the fuel mix capacity of micro-grid, however, this fuel mix was assumed to be fixed, while other consumption related variables were varied. From a technical point of view, investigating into the changes in percentage of fuel mix and its influence

on importance of values could produce some significant insights. Hence, future research can consider a more dynamic and intricate conceptualization of value change with distinct fuel mix(es) such that they have some influence on the change in importance of values.

2. As this research considered a simplistic network/social interaction, to accurately observe the dynamics in a structured network it is recommended to try different configurations of social network and find how values change as a result of agents acting and experiencing consequences.

3. A problem that exists in modelling value change is that people have different perception of how value change occurs or what factor contributes to value change. Therefore, it is recommended to conduct an extensive survey / empirical research to collect and form opinions on value change. This then can be very useful for other researchers to use such ideas in conceptualizing value change models.

4. Further, as this research considered only energy consumption decisions and not diverse options an agent can face in real life. To enhance this, further research can look into modelling agents such that they are able to choose diverse options such as solar panels, wind, electric vehicles etc. based on a defined set of criteria. This research can help see how values change based on technology related decisions taken by stakeholders, rather than only from societal point of view.

5. Although there are limited technologies on which it is worth to explore value change on. It is recommended to apply the current model to other types of energy systems, technologies, or any other project where there is continuous action, reaction and experience among the stakeholders.

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dissertation

A

Interview

A.1. Interview protocol

Introduction

Good morning! Job, thank you for taking your time to speak with me today. I am student at TU Delft currently studying Masters Engineering and Policy Analysis. For my graduation project I am currently researching in the domain of ethics and philosophy of technology, I dive deeper into the values that are embedded in technologies and how these values change over time. I will briefly summarize the points of my research:

- So my project is about value change, in my research I consider that values are not permanently embedded into the technology as values often change, evolve and emerge due to the influence of various factors.
- There are different types of value changes that could occur: such as change in importance of values, emergence of new values, change in relevance of values, change in conceptualization of values, and change in specification of values.
- In my project I consider the changes in relative importance/ prioritization of values over time.
- The factors that influence change are either exogenous or endogenous and their influence diminishes successful deployment of technology in future.
- Exogenous factors can be any external calamity—climate change, change in regulations, energy price, economic crisis etc.
- Endogenous factors can be internal/personal factors changes such as changes in income, ownership of property, technical knowledge or energy label of house etc.
- And of course these factors as you know co-evolve with each other over the lifetime of technology.

A

- These changes cause severe impact to the technological deployment, one good example as you know is the case of Groningen.
- To consider these dynamic changes in the energy system that cause value change and possible social acceptance issues and inequalities, I use agent-based models to explore this change.

Recording Instructions
Before I begin to summarise briefly the setup and aim of this interview, would you be ok if I recorded this interview for the later stages in this project?

To note: As this was a semi-structured interview, the questions were compiled together without follow-up questions. The responses received from the interviewee were modified and paraphrased to be written. Further, this interview included discussion for values: autonomy, privacy, trust, cost-effectiveness, reliability and environmental sustainability. Lastly, this interview involved detailed discussion between multiple values and how they are related. Only few are relevant values and questions that are selected and reported here.

A.2. INTERVIEW QUESTIONS

1. Which actions could be taken by the stakeholders to enhance the reliability of the energy supply?
2. What could be the most likely scenario in the future that could change/impact the value of reliability among stakeholders relative to the microgrid?
3. Which actions could be taken by the stakeholders to enhance their environmental sustainability?

Interviewee: Job Swens, J-OB

A.3. INTERVIEW RESPONSES:

Which actions could be taken by the stakeholders to enhance the reliability of the energy supply?

Collaboration is importance. When there is no collaboration, no community batteries and whatsoever, the whole transition makes our whole system less reliant. When more flexible components are employed, the reliability goes up. When a community undergoes reliability issues, a deal is made with DSO to expand the network.
The larger the community, with different profiles the higher the probability to enhance/save energy supply.
What could be the most likely scenario in the future that could change/impact the value of reliability among stakeholders relative to the microgrid?
Price setting for different income groups can be done in future where for low income can get for example 1/3 fee. This is similar to the 3- step french fee rule.
Values are changing when people see new possibilities, see people around them change. For innovators, for every change perceived, a mutual trust is important. If things are changing- mutual trust plays an important role.
Which actions could be taken by the stakeholders to enhance their environmental sustainability?

Environmental thinking and getting together, not making extra profit due to the usage of RES are very important factors to enhance sustainability. Maximizing flexibility and Timing and location is very important.

B

MODEL ASSUMPTIONS

1. Main assumption 1: Agents have a preference to satisfy a value or lower its importance. This assumption is based mainly on the values and value conflict literature review. This assumption form a starting point for measuring the change in importance of values of agents.

2. Main assumption 2: Agents decide on whether to increase or decrease energy consumption to satisfy their values. This assumption is taken again from both microgrid and values literature review. Agents deciding on only consumption increase or decrease is taken from microgrid literature. Whereas, agents deciding to satisfy their values is taken from values literature. This assumption becomes a starting point of value change in the community.

3. Main assumption 3: Agents experience consequence of self decision and decision of others regarding their value importance levels. This is based on the assumption that people have a bounded rationality while taking decisions related to increasing or decreasing consumption, ultimately having consequence for other agents in the community. Further, this assumption is also sourced from microgrid literature and common pool resource, where energy consumption is contested among the agents in community.

4. Agents have bounded rationality and as a result undergo transformative experience. While making decisions to satisfy their value, they do not yet know if those decision are right or wrong. They would only know when they make the decision. It may happen that when they take a decision they experience unexpected change in importance of their values or unexpected satisfaction with a value.

5. Social conformity or trust among community plays a key role consumption decisions in community which in turn drive value change and acceptance of microgrid or energy system. This assumption is based on the interview with an expert. The community and trust among community is emphasized by the expert.

6. Agents have preference to interact with certain other agents in the community.

7. Initially for the base case, the link preference uncertainty variable is True, which means that the agents are linked to other agents as per their preference rather than randomly.
8. It is assumed that agents are able to evaluate the change in importance of values based on the scale of -1 to 1.
9. It is assumed that agents initially are indifferent to all values. Hence, initially, the value importance level is 0
10. The type of microgrid is a community microgrid characterized as a common pool resource.
11. Electricity consumption and supply are the key variables of the community microgrid.
12. The community microgrid consists of combination of renewable energy and grey electricity whose capacity/supply precisely matches the demand required by the community.
13. GHG emissions are emitted from the community microgrid in case when there is severe shortage of supply and the consumer starts to use the grey electricity.
14. The microgrid consists of agents who are consumers of electricity.
15. Decisions of agents are solely—increasing or decreasing energy consumption
16. Each agent is defined by their own value preference, link preference, energy consumption demand, income and location in map

C

Model Results

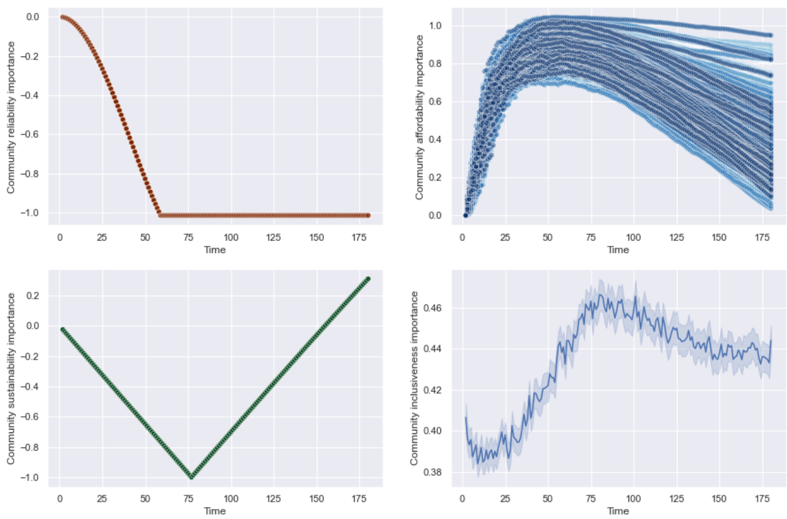

Figure C.1: Impact of dynamic pricing policy on community value importance indicators

Further, the affordability importance level and inclusiveness importance level does not get affected as this policy is directed solely towards decreasing reliability importance and consequently sustainability importance in community.

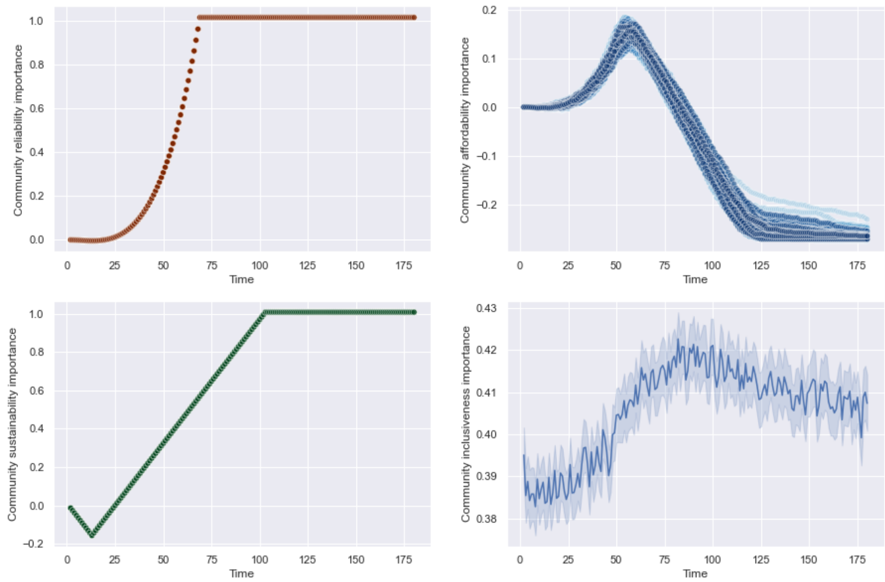

Figure C.2: Community value importance indicators

to the combination of various uncertain factors acting.

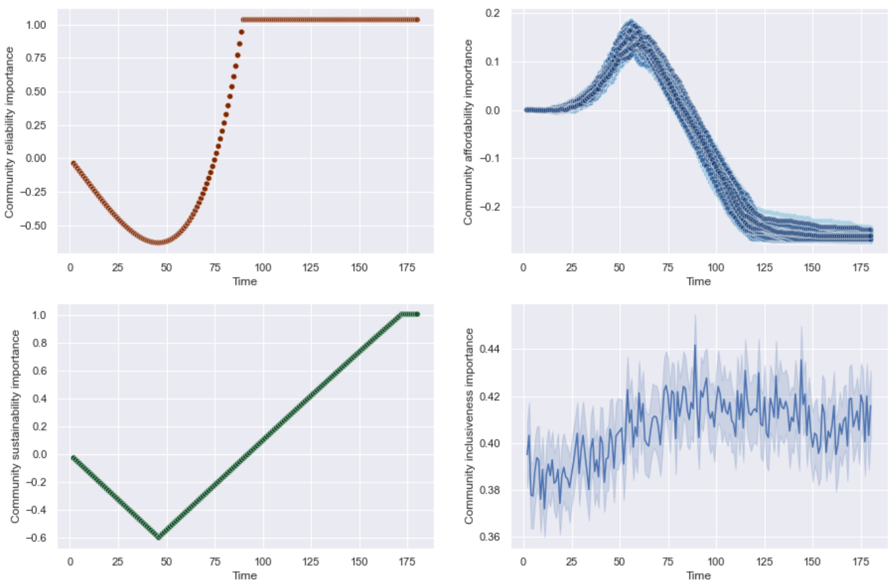

Figure C.3: Impact of increase in micro-grid capacity on community value importance indicators

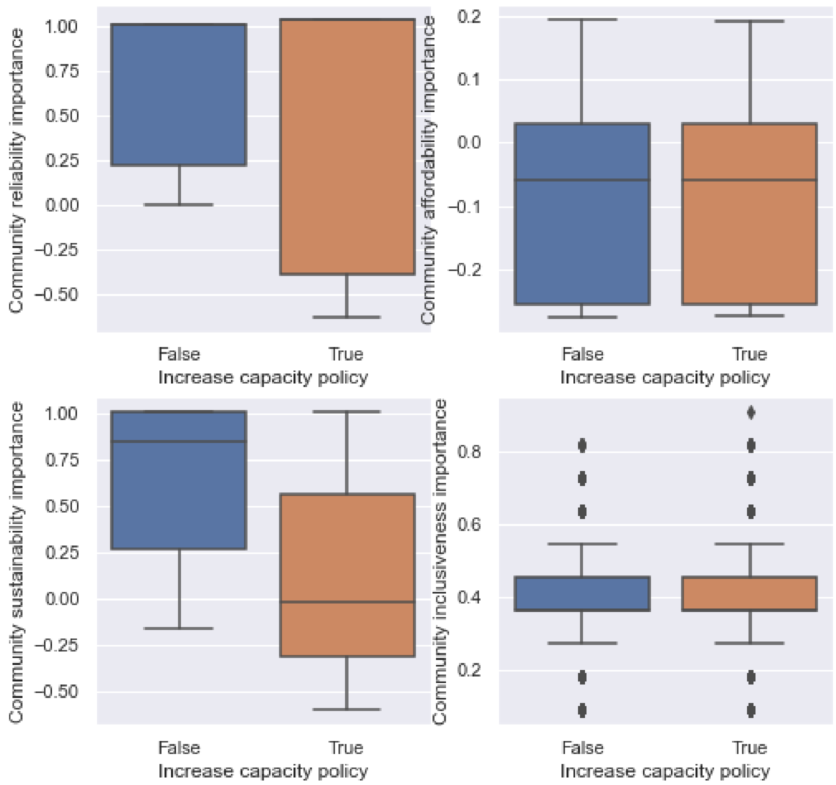

Figure C.4: Box plots comparing the impact of increasing capacity policy on community value importance indicators from the base case

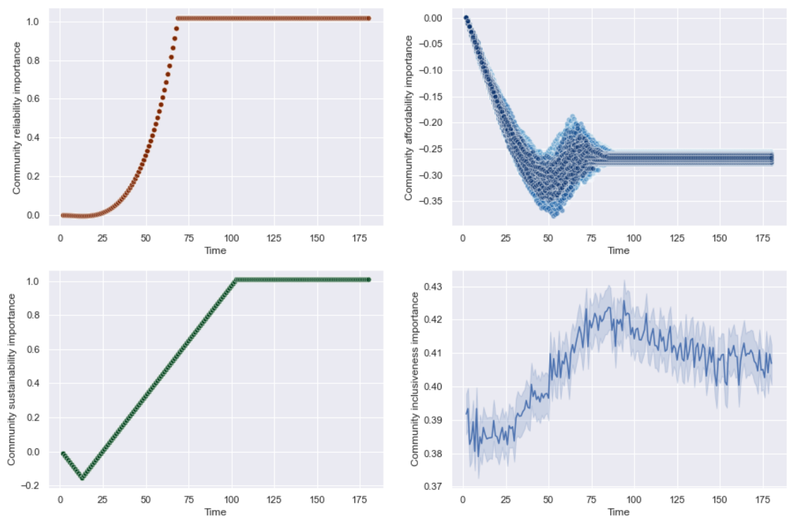

Figure C.5: Impact of subsidizing consumers on community value importance indicators

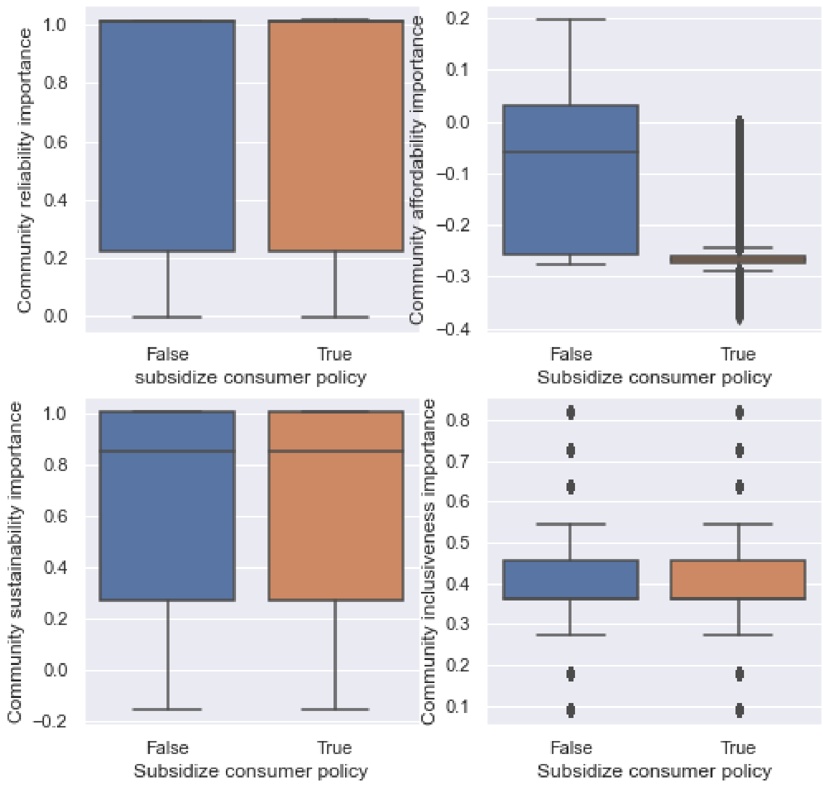

Figure C.6: Box plots comparing the impact of subsidizing consumers policy on community value importance indicators from the base case

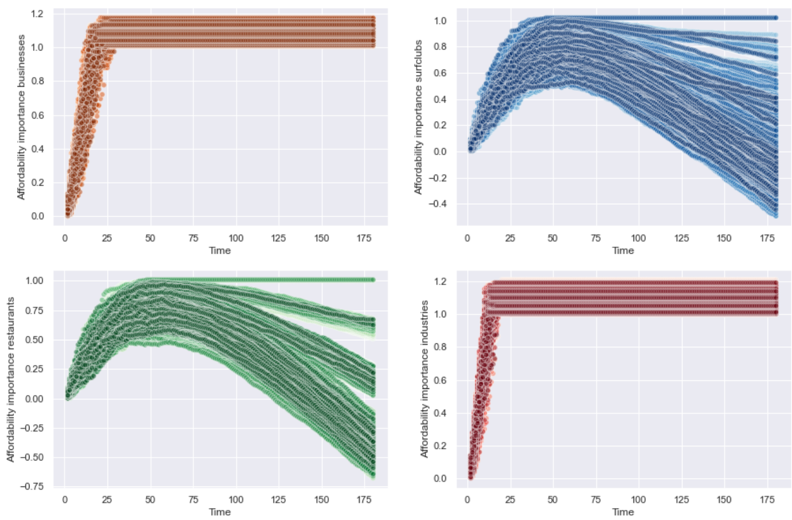

Figure C.7: Impact of dynamic pricing policy on affordability value importance indicators of consumers

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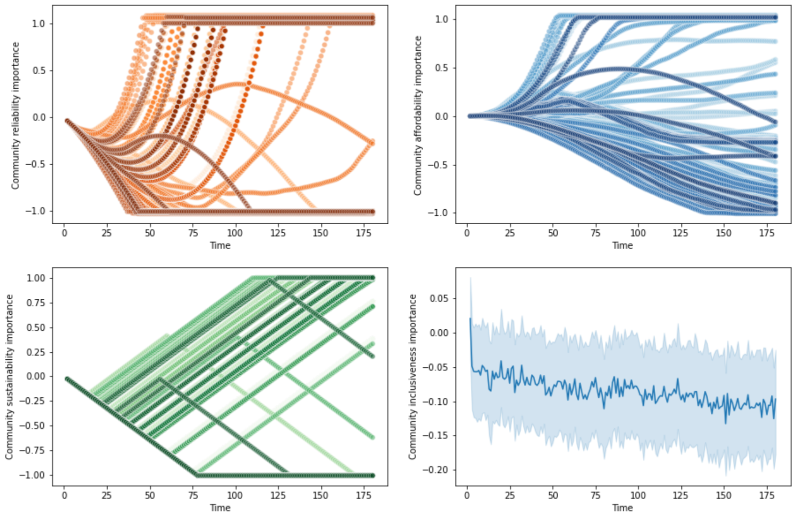

Figure C.8: Impact of combination of increasing capacity and uncertainty on community value importance indicators

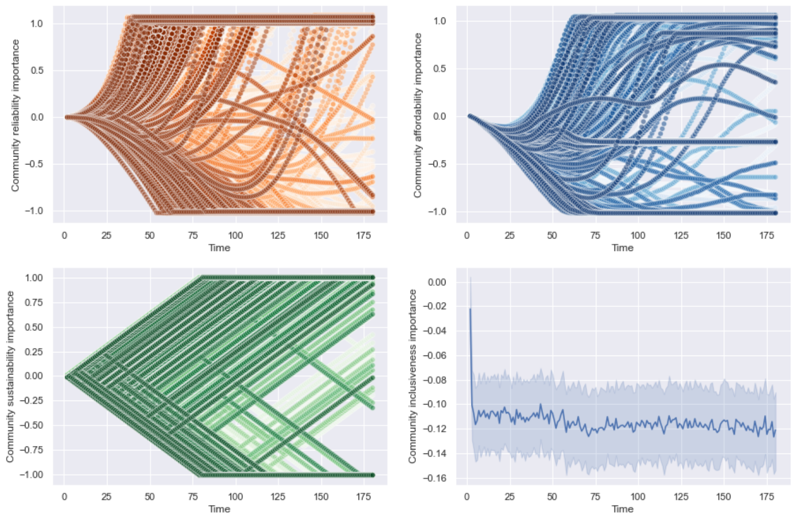

Figure C.9: Impact of combination of subsidizing consumers and uncertainty on community value importance indicators

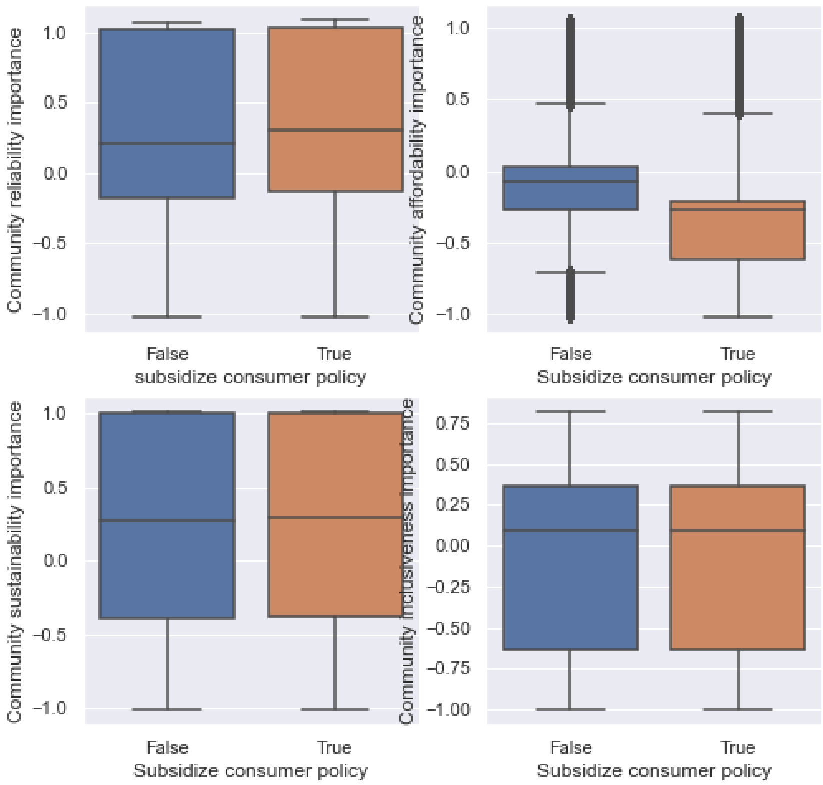

Figure C.10: Box plot of impact of combination of subsidizing consumers and uncertainty on community value importance indicators

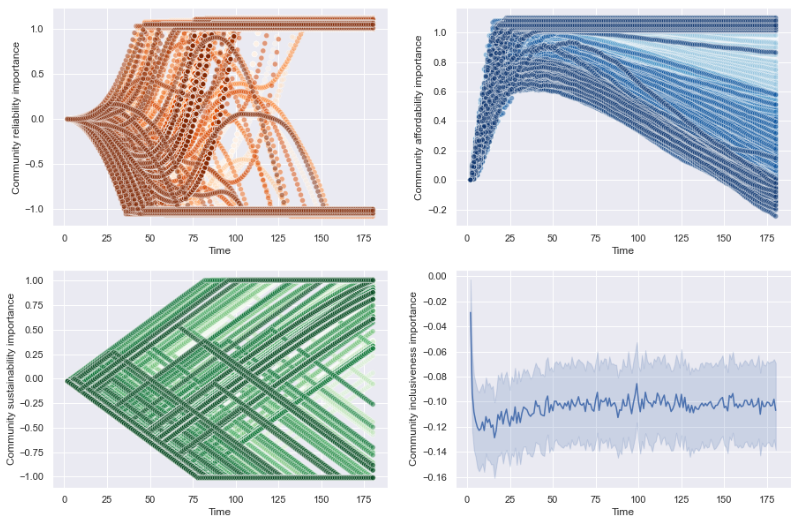

Figure C.11: Impact of combination of dynamic pricing and uncertainty on community value importance indicators

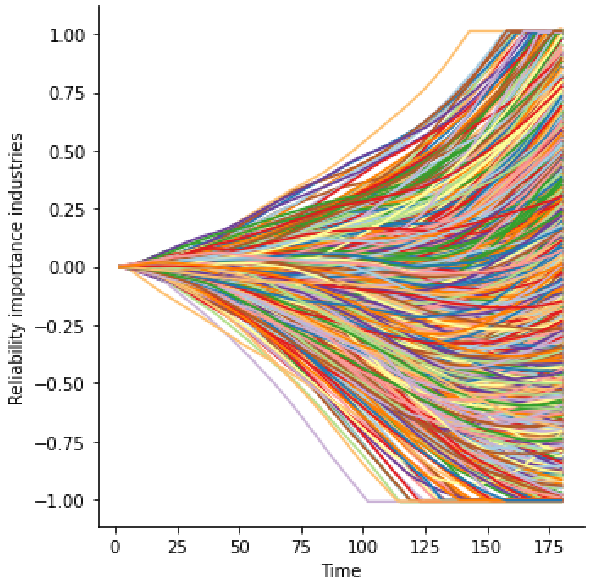

Figure C.12: Impact of combination of policies and community formation on reliability importance industries

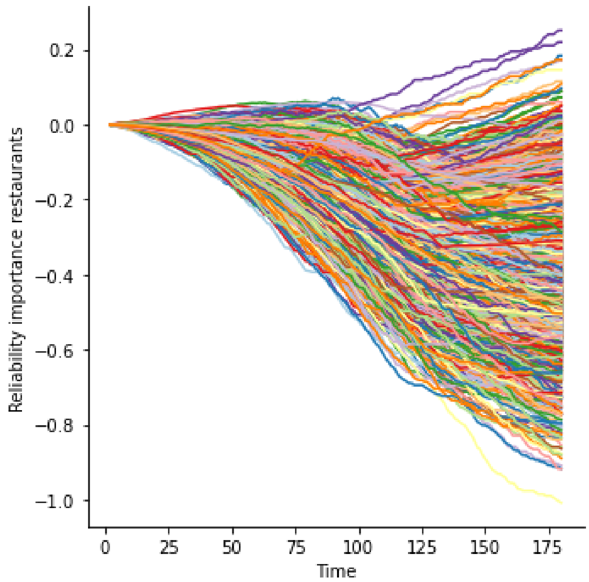

Figure C.13: Impact of combination of policies and community formation on reliability importance restaurants

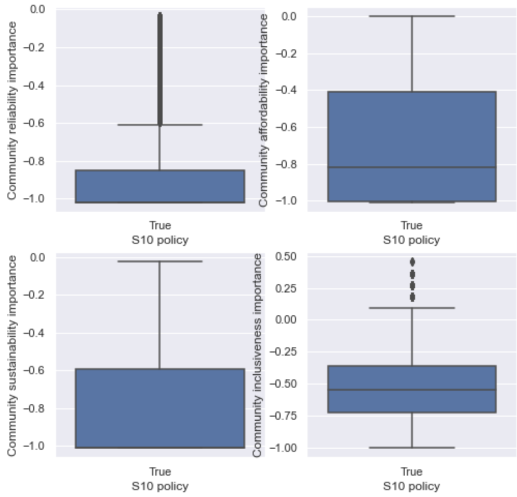

Figure C.14: Impact of combination of policies and community formation on community importance box plot

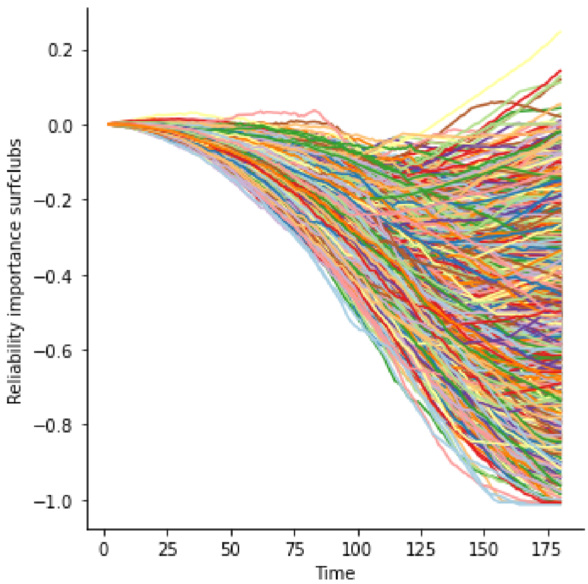

Figure C.15: Impact of combination of policies and community formation on reliability importance surfclubs

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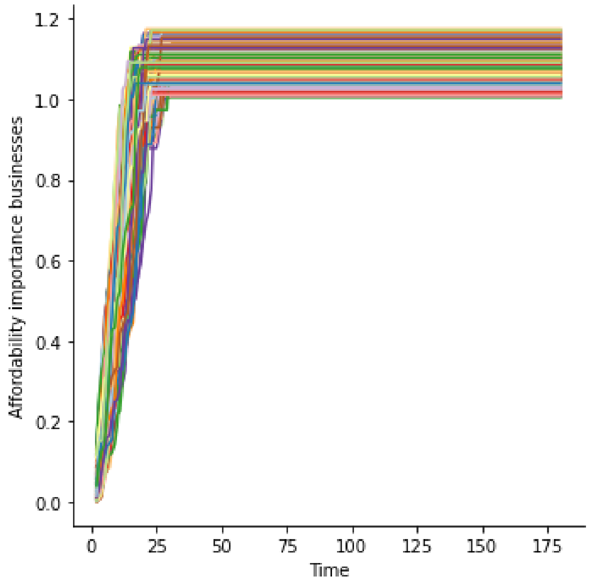

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Figure C.16: Impact of dynamic pricing policy on affordability importance of Business

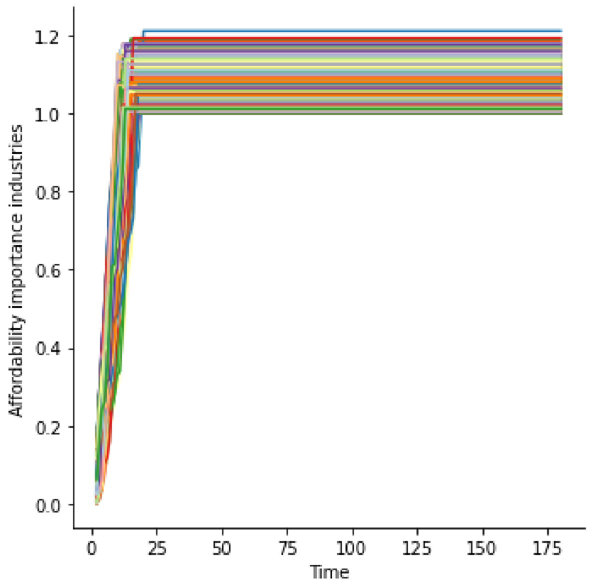

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Figure C.17: Impact of dynamic pricing policy on affordability importance of industries

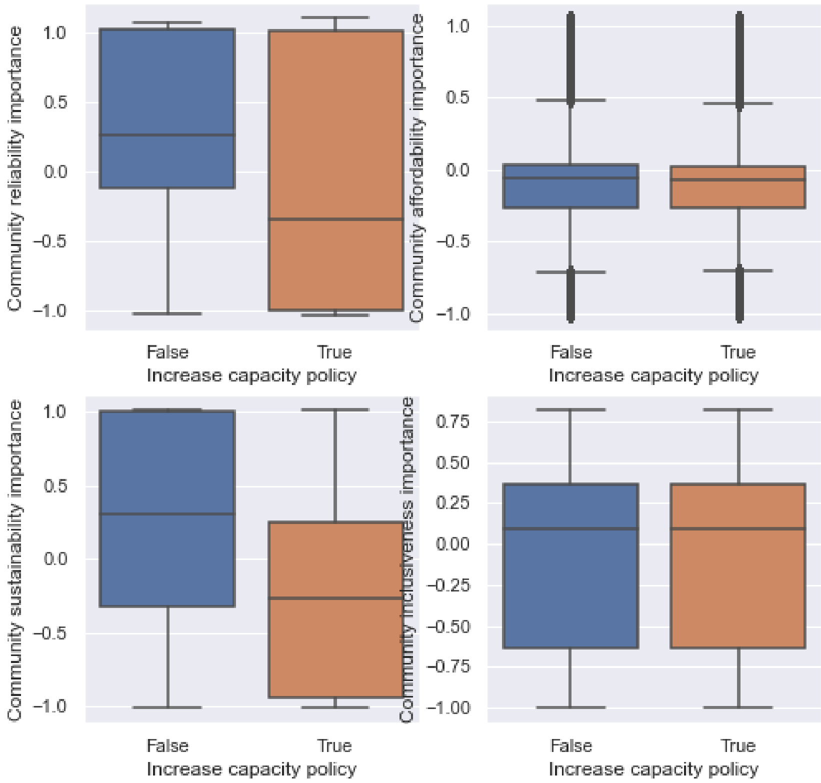

Figure C.18: Box plot of impact of combination of increasing capacity and uncertainty on community value importance indicators

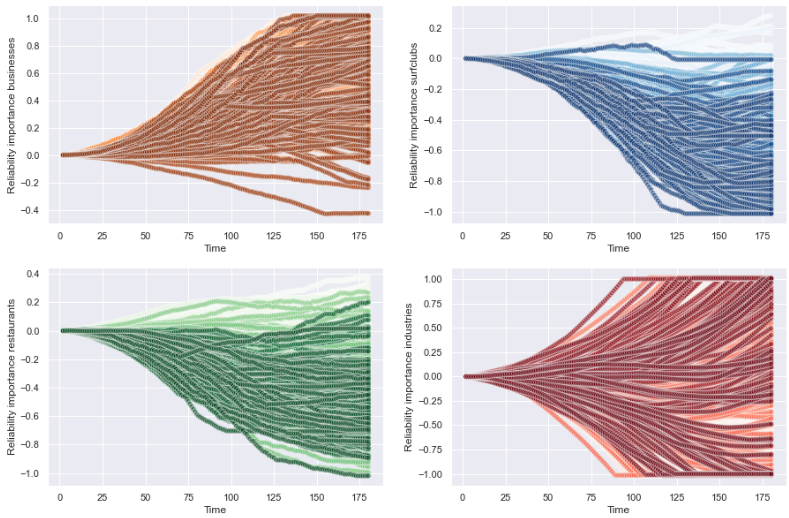

Figure C.19: Impact of combination of policies and combination of uncertainties on consumer reliability importance indicators

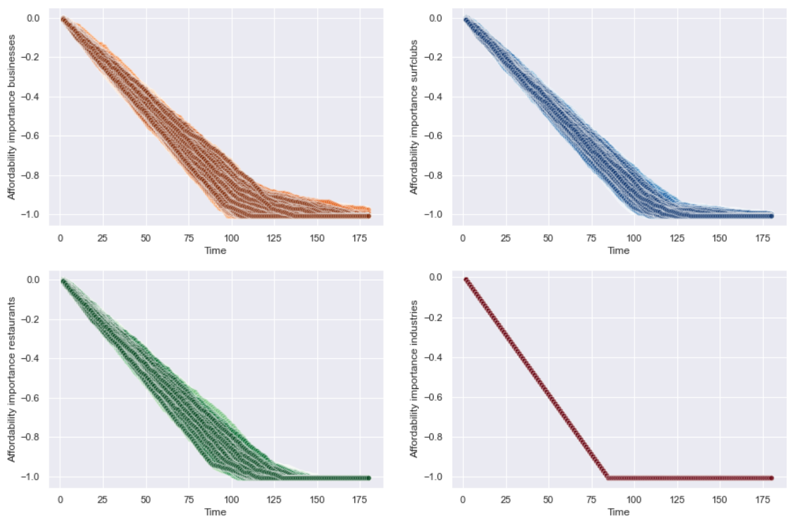

Figure C.20: Impact of combination of policies and combination of uncertainties on consumer affordability importance indicators

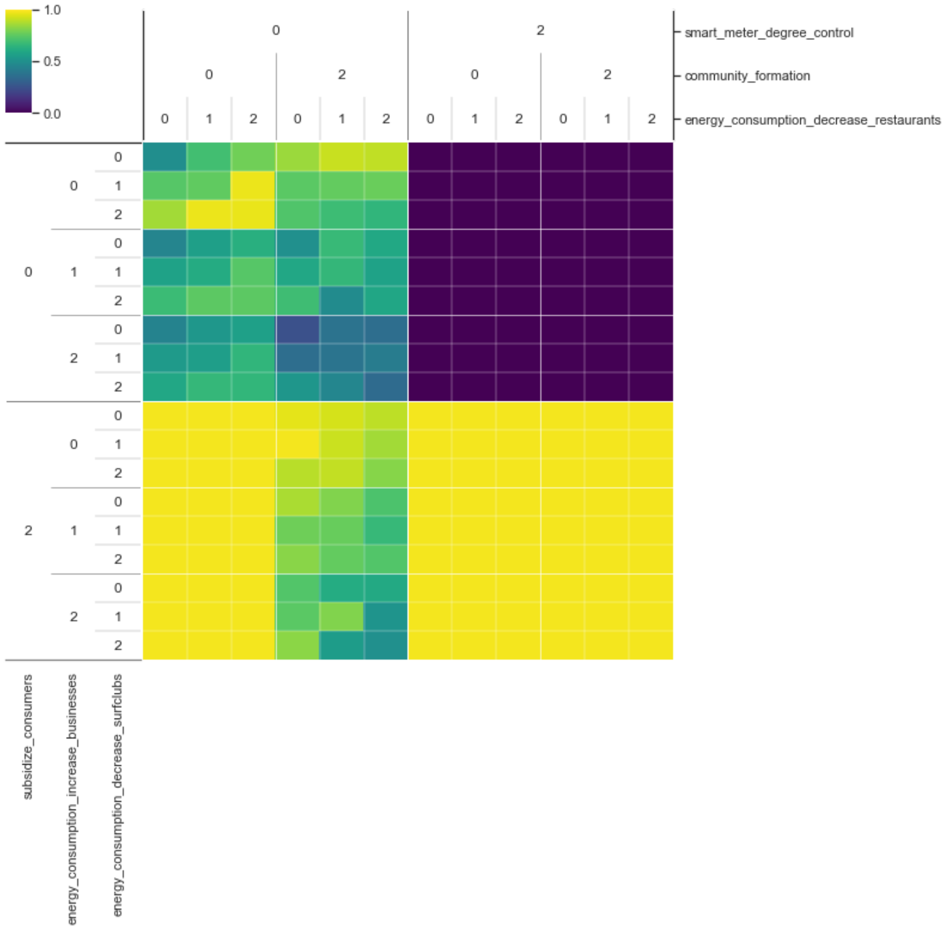

Figure C.21: Scenario discovery of combination of policies and uncertainties on affordability importance less than 0

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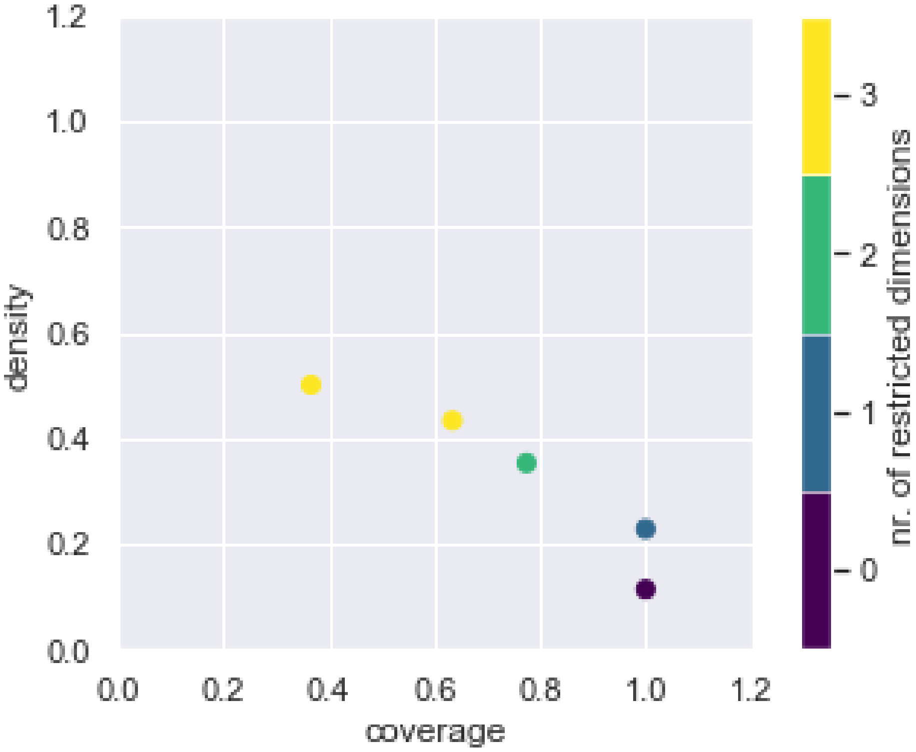

Figure C.22: Scenario discovery of combination of policies and uncertainties on affordability importance more than 0

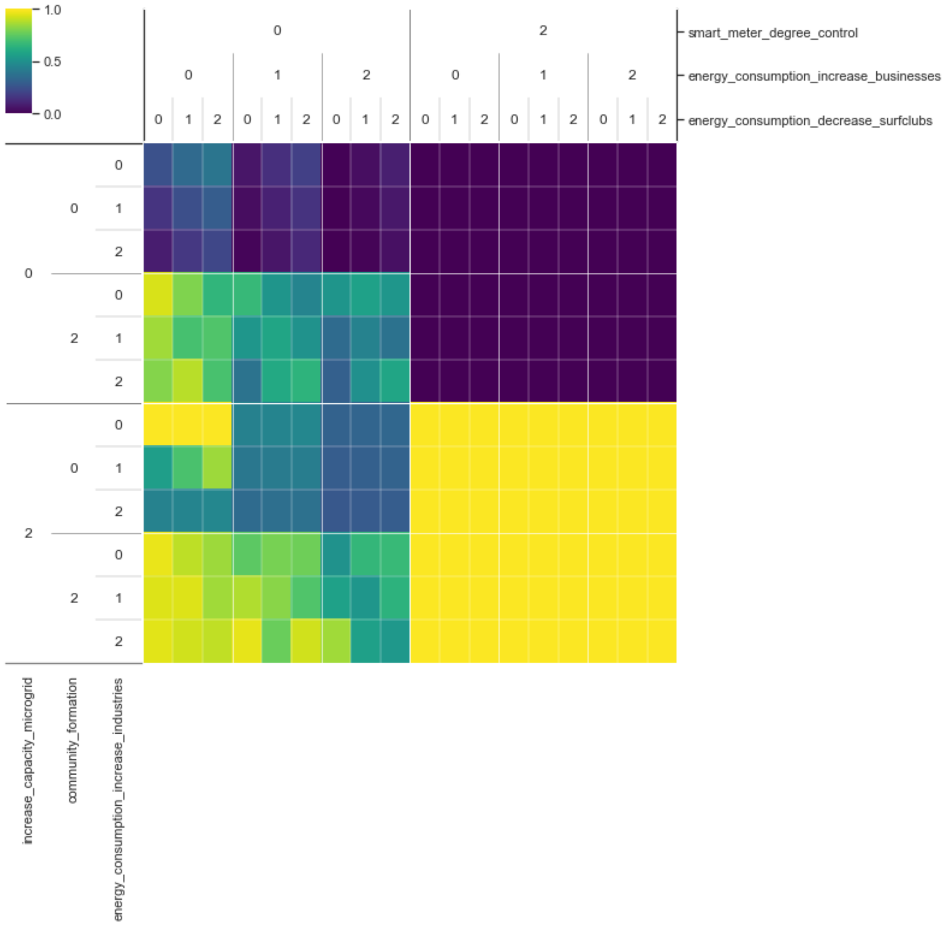

Figure C.23: Scenario discovery of combination of policies and uncertainties on reliability importance less than 0

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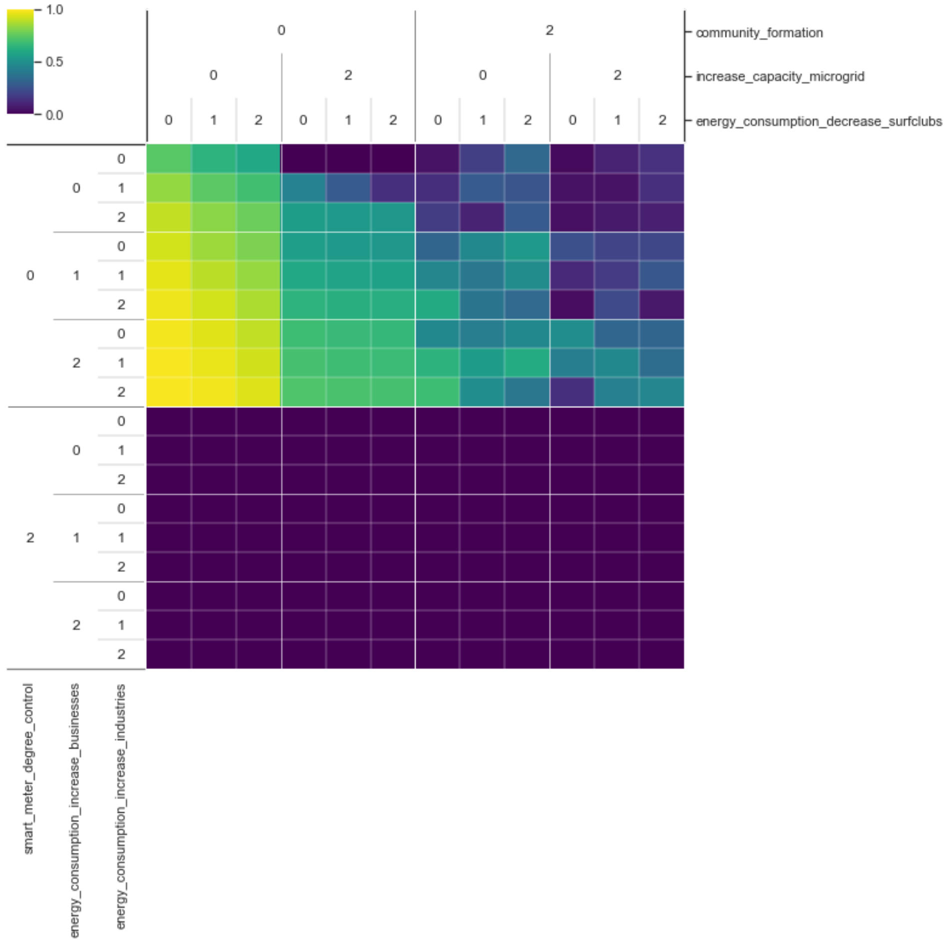

Figure C.24: Scenario discovery of combination of policies and uncertainties on reliability importance more than 0

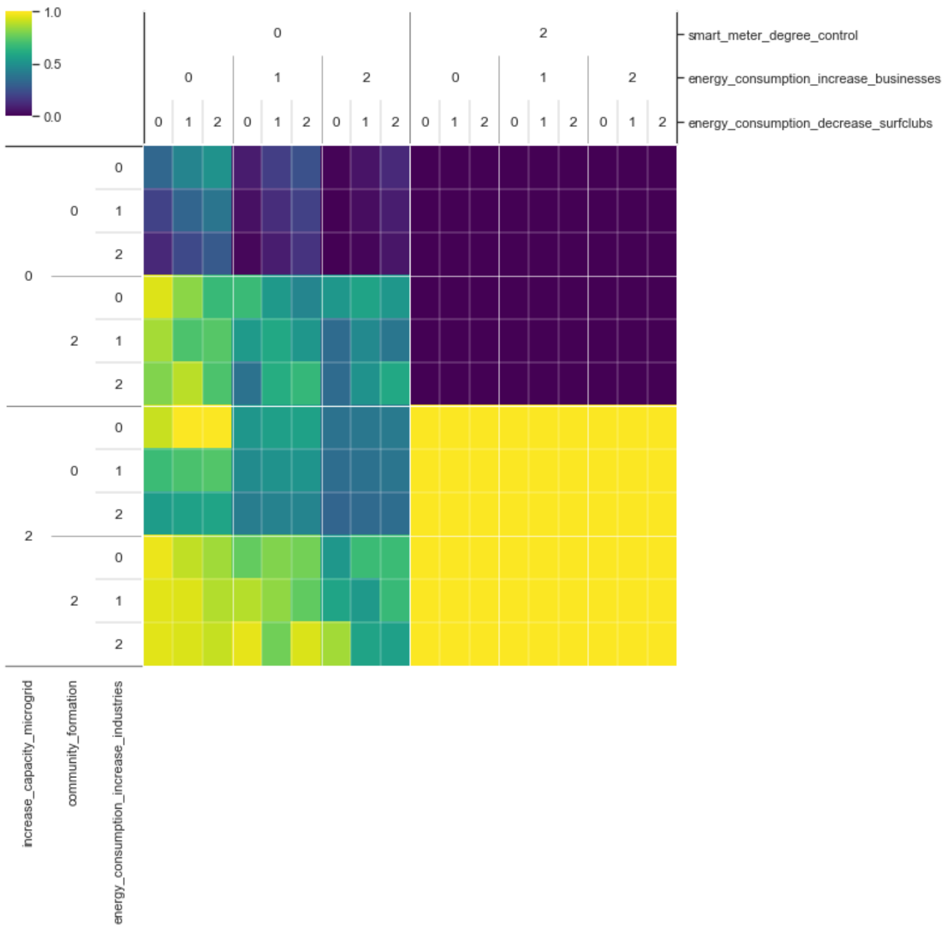

Figure C.25: Scenario discovery of combination of policies and uncertainties on sustainability importance less than 0

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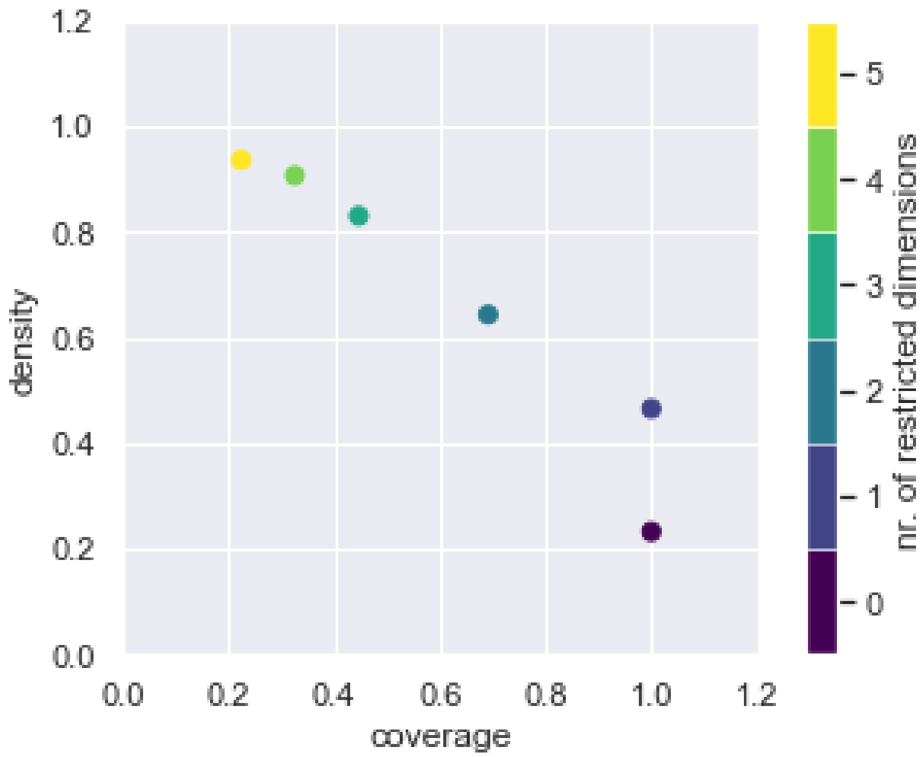

Figure C.26: Scenario discovery of combination of policies and uncertainties on sustainability importance more than 0

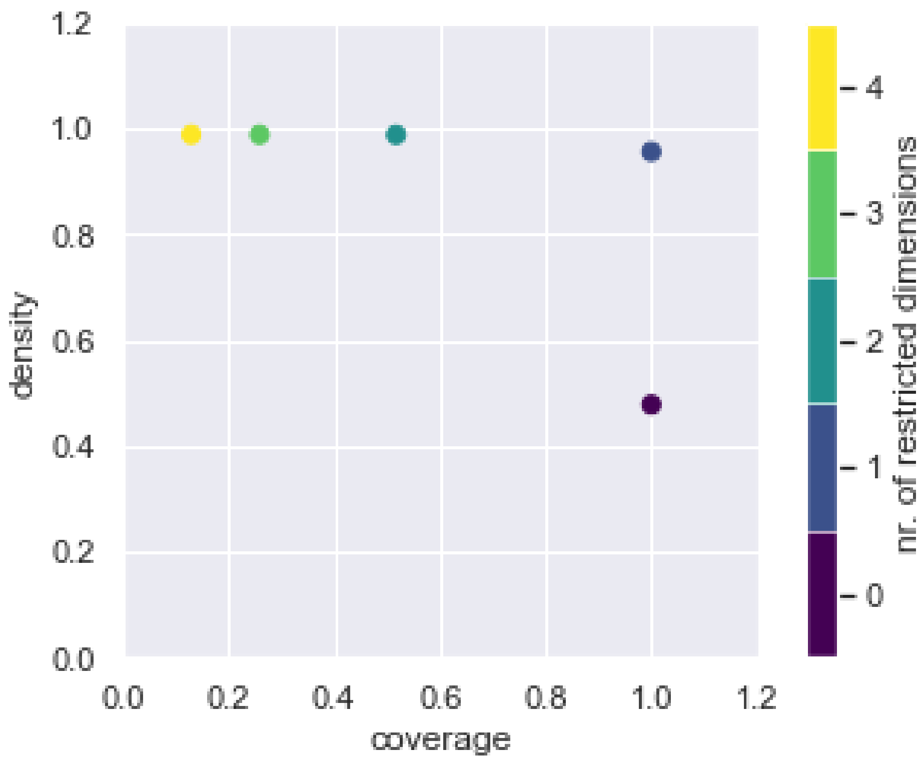

Figure C.27: Scenario discovery of combination of policies and uncertainties on inclusiveness importance less than 0

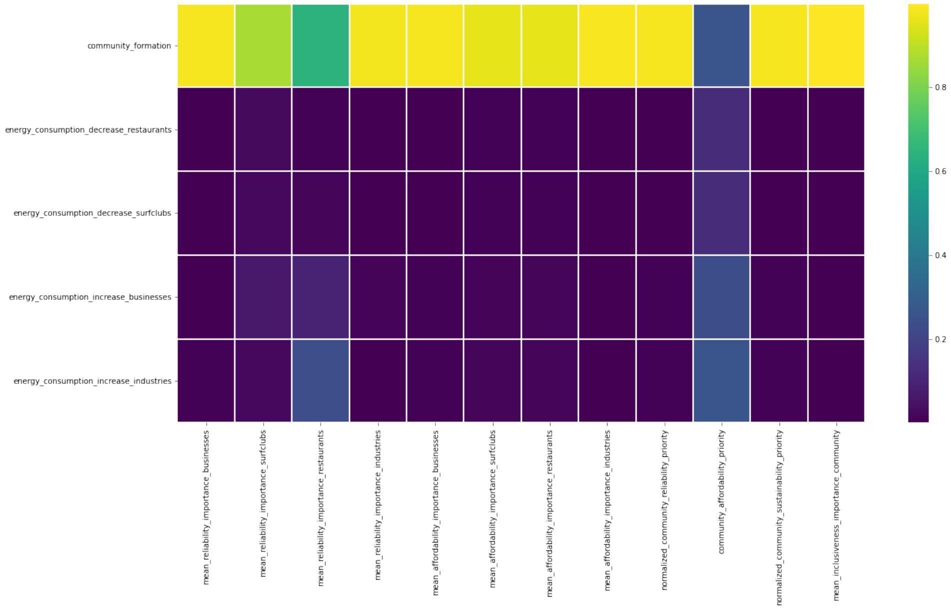

Figure C.28: Feature scoring energy consumption rate of consumers and community formation scenario

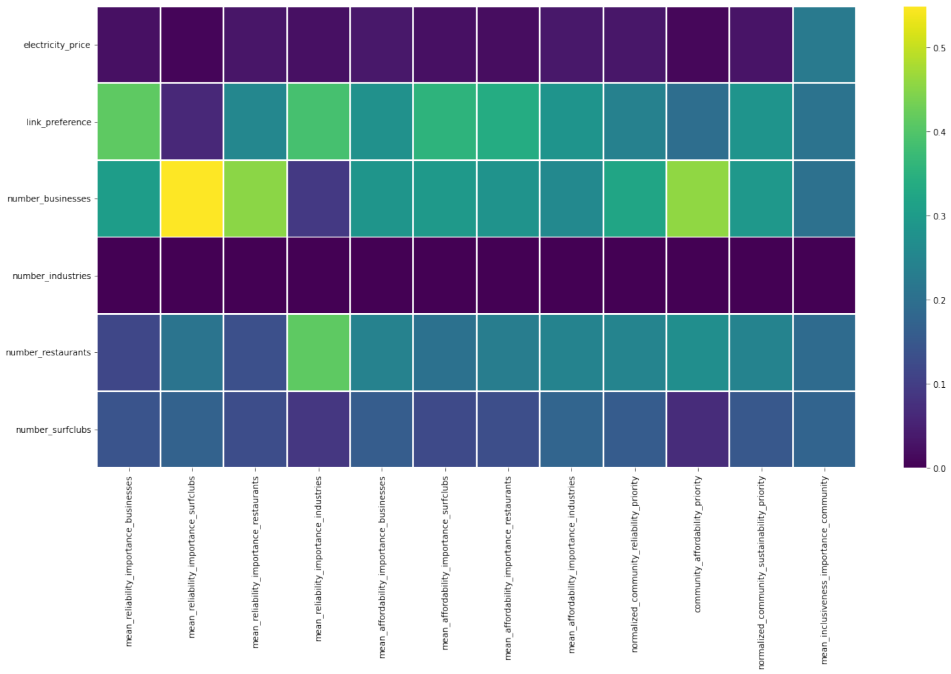

Figure C.29: Feature scoring by varying number of stakeholder, electricity price and link preference

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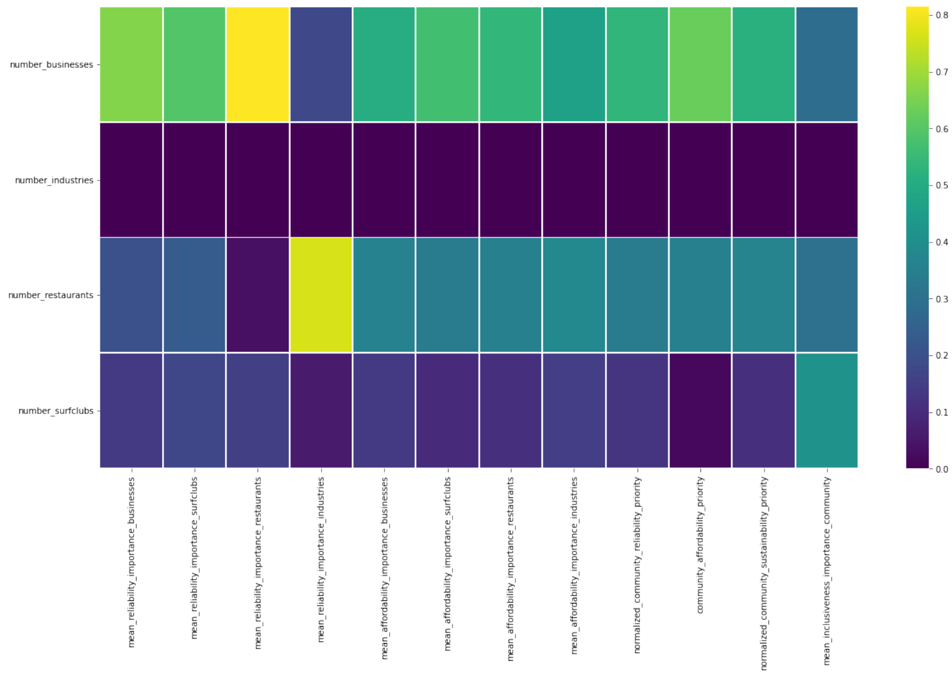

Figure C.30: Feature scoring by varying only number of stakeholder

D

MODEL SPECIFICATION

Table D.1: Overview of model specifications

Level	Variable	Value/range	Source
Community	Number of businesses	[1, 3] Default: 3	Microgrid case study (Noordelijk Havenhoofd, Scheveningen)
	Number of surfclubs	[1, 4] Default: 4	Microgrid case study (Noordelijk Havenhoofd, Scheveningen)
	Number of restaurants	[1, 3] Default: 3	Microgrid case study (Noordelijk Havenhoofd, Scheveningen)
	Number of industries	1	Microgrid case study (Noordelijk Havenhoofd, Scheveningen)
	Total annual energy consumption	102600 (kWh /year)	The data is assumed
	Total annual energy supply	Fuel mix capacity (Solar 1.875 kW + Wind 5 kW + Diesel 5 kW) = 102600 (kWh /year)	The data is a result of formulation calculated by the total fuel mix capacity of a typical community micro-grid adapted from (Adefarati and Bansal, 2019; Pl
	Electricity price	0.5 (€/kWh)	The data is assumed
	Emissions per kWh grey electricity	0.63	Adapted from Groot (2004)
	Annual Co2 emissions	Diesel capacity * emissions per kWh grey electricity	The data is assumed

	Co2 emission threshold	Annual Co2 emissions * 0.8	The data is assumed
	Community value importance indicators (all four)	1: Very High 0.5: High 0: Indifferent -0.5: Low -1: Very Low Default: 0	Adapted from Kreulen (2019)
	Energy consumption increase businesses	[0.5 1 3.5] (Default 2.5)	The data is assumed
	Energy consumption decrease surfclubs	[0.5 1 3.5] (Default 2.5)	The data is assumed
	Energy consumption decrease restaurants	[0.5 1 3.5] (Default 2.5)	The data is assumed
	Energy consumption increase industries	[0.5 1 3.5] (Default 2.5)	The data is assumed
	Link preferences	[0,1] Businesses ->Surfclubs Surfcliubs ->Restaurants Restaurants ->Industries Industries ->Businesses	The data is assumed
Consumer	Annual income	Businesses: 20000 Surfclubs:10000 Restaurants:13000 Industries: 18000	The data is assumed
	Annual allocated energy supply	Businesses: 900 * 12 Surfclubs: 700 * 12 Restaurants: 700 * 12 Industries: 950 * 12	The data is assumed (The montly consumption is converted to annual consumption)
	Willingness to invest (threshold)	Businesses: Annual income * 0.27 Surfclubs: Annual income * 0.42 Restaurants: 4200 Industries: 5700	The data is assumed. The proportion of income is calibrated to give each agent a specific value rather than a decimal.
	Consumer value importance level	1: Very High 0.5: High 0: Indifferent -0.5: Low -1: Very Low Default: 0	
Policies	Increase in microgrid capacity	[0, 1] Increase supply: 50,000 kW	The data is assumed
	Subsidize consumers	[0,1] Increase investment willingness of consumers : 3000 Euros	The data is assumed
	Dynamic pricing	[0,1] Vary electricity price : random 3 + 0.5 Increase supply: 2500 kW	The data is assumed

	Smart meter control	0: None 1: Partial 2:Full	The data is assumed

D.0.1. Number of consumers

The number of consumers of each type are assumed as per the case study of micro-grid energy system in Noordelijk Havenhoodf, Scheveningen. The numbers are based on the real life spatial location. However, there is a lot of uncertainty in the future regarding the number of consumers in the area. This uncertainty is a structural uncertainty, and as consumers are influenced by their peers regarding consumption behaviour, this places a deep uncertainty in how changes in importance of values can occur in the future with changes in numbers of consumption. This is one of limitations of this model and to keep it simple, a fixed number of consumers were assumed in the base model, however, these were varied in sensitivity analysis to find their impact (see section 6.6). Future research could look into how changes in number of consumers in micro-grid energy system can lead to change in importance of reliability among community for example.

D.0.2. Energy consumption and supply data

For the case of energy consumption and supply data, various micro-grid data used in supporting this was assumed from (Adefarati and Bansal, 2019; Platt et al., 2012) who evaluate ideal cases of micro-grid on the basis of annual energy consumption, capacity of micro-grid and many other indicators. Initially, it is assumed that, the annual energy consumption is equal to annual energy supply. The reason is that it is crucial to understand how slight changes or mismatch between supply and demand can lead to changes in importance of values. Furthermore, this assumption hopes to mimic the operation of utility, who are constantly making both supply and demand meet. However, there is lot of scepticism in formulation of threshold regarding the supply and demand that could lead to high or low reliability importance. Following this, the limitations and assumptions of threshold data are discussed in the next section.

D.0.3. Thresholds

Various thresholds such as annual energy supply, co2 emission threshold, willingness to invest, play a crucial role in deciding the change in importance levels of reliability, sustainability and affordability respectively. However, literature provides no example of the threshold data that specifically fits in measuring these value importance indicators. For instance, among different indicators of sustainability used by Jha et al. (2020) GHG emissions are a crucial indicator for sustainability, however, Jha et al. (2020) fails to base the indicators on real world consumption data but rather only bases it with qualitative data. This is similar for the cases of other value importance indicators. This difficulty in matching the technical data with qualitative value importance indices is one of the limitations of this research. Further, the uncertainty in the annual energy supply, willingness to invest, co2 emissions translate an uncertainty in changes in importance of values in future.

D.0.4. VALUE IMPORTANCE INDICATORS

Kreulen (2019) assumes in his research regarding changes in belief and value system, that importance of values can be distinguished at different levels. Although, the author distinguishes these importance levels on a subjective level, this study takes an inspiration from the importance levels and applies it for the case of normative values. However, one limitation here is that practical examples of such importance levels are rare and are merely conceptual. This limitation is related to incommensurability of values, where values measured in different units cannot be compared or scaled (Martinez-Alier et al., 1998; Munda, 2004; van de Poel, 2015). In practical sense however, there is basic notion of differentiation of changes in values or situation compared to the status quo. This study places emphasis on this differentiation rather than abstract levels of value importance.

D.0.5. LINK PREFERENCES

Maintaining relations and network is normal to see in real world cases. Consequently, they prefer to get connected or interact with people of their interests. The formulation of this uncertainty variable was inspired from Siebert et al. (2017), who assumes that specific interaction between consumers lead to changes in consumption behavior of others. These interaction can be based on resource dependency or purely local rationality. Here the link preferences are either random or structured as shown in the table D.1.

E

Model Verification

This section follows the various steps of verification as per van Dam et al. (2013).

E.1. Tracking agent behaviour

In this section, the method of recording and tracking of agent behaviour is carried out to test whether agents behave as per the conceptual agent behaviour. There is a variety of ways this can be done as per van Dam et al. (2013). Here, we choose to record inputs, states and output of agents.

E.1.1. Tracking base case behaviours

Recording the inputs at setup
Whether each of the agent is initialized with right values as specified. There were three errors noticed here: First, it is seen that all initial values are setup as specified except initial value of reliability priority for surfclubs wasn't 0. This is because a duplicate variable with value 0.5 is entered after it was initialized with zero. This is corrected. Second, reliability and affordability priority for industry and restaurants weren't specified, which gave out unstable increase/decrease in their reliability and affordability priority. Lastly, due to no initialization of allocated energy supply for industry, it projected low reliability priority even though it decreased its annual consumption, this was rectified and observed to give stable result.
Corrected and confirmed

Increase annual energy consumption at specified time scale
Whether each agent's increase in annual energy consumption at base case, is as per their heterogeneous times scales at which they increase with their respective rate of increase. It is seen that all agents start to increase their consumption at their specified time scale. **Confirmed**

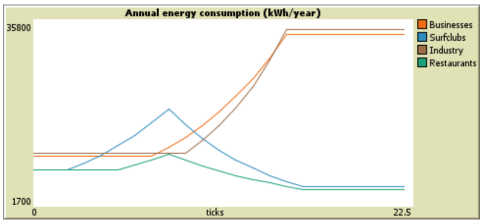

Figure E.1: Evolution of annual energy consumption of consumers over specified heterogeneous time scales

Increase annual energy consumption at respective rate of increase
Whether each agent's increase in annual energy consumption at base case, is as per their respective rate of increase. It is seen that all agents start to increase their consumption at their specified increase rate. **Confirmed**

E

Increase in annual consumption and its affect on reliability priority of consumers and community
Increase beyond allocated supply which increases annual consumption of consumer should have an distinguishing effect on reliability priority. In general, the assumption that increase in annual consumption lowers reliability priority should be true. Further, due to increase in individual consumption level, the assumption that reliability priority at community level should increase should be true. Both these dynamics and behaviours are observed. **Confirmed**.

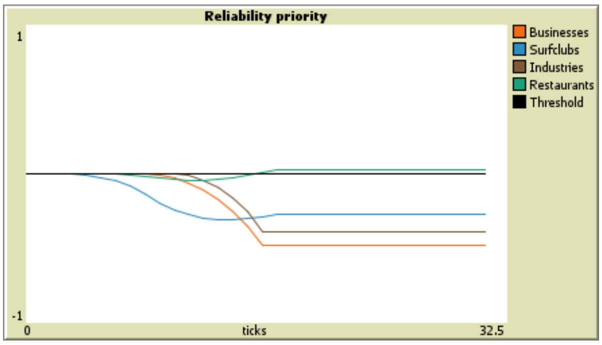

Figure E.2: Evolution of consumer reliability priority

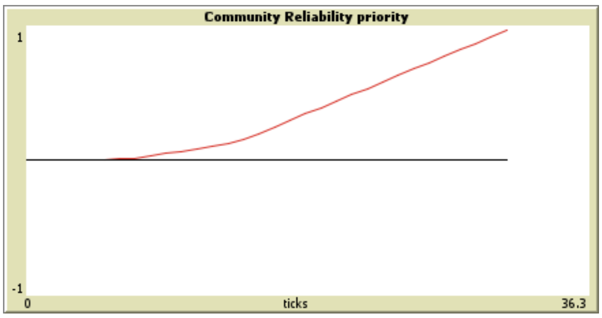

Figure E.3: Evolution of community reliability priority

Increase in annual consumption and its affect on affordability priority of consumers and community

Whether increase in annual consumption of consumer beyond their allocated supply leads to increase in consumption cost and as a result increase their affordability priority. Futher, as community affordability priority is mean of affordability priority of consumer, it should also increase with increase in consumption of consumers. **Confirmed**

Whether an increase in individual consumption causes a deficit in the supply capacity of community. Initially, the supply deficit was projected as supply surplus. This was corrected by checking the formulation of total annual energy supply. **Corrected and confirmed**

E.1.2. TRACKING DECISION-MAKING BEHAVIOUR

Social conformity behaviour

Whether all consumers respond to social conformity as specified in their procedures respectively. It should be seen that all consumers conform to each other's consumption decisions at different time intervals.

Although, businesses and surfclubs responded correctly to social conformity by conforming to each others consumption behaviour, it was observed that, due to no specification of initial reliability and affordability priority for restaurant and industries, they did not consider social conformity, as a result there was unreasonable increase/decrease in their consumption. This was easily observed when checking the behaviour of businesses and surfclubs who would match their consumption with their peers in the case of social conformity, conform to unreasonable increasing/decreasing consumption behaviour of industry and restaurants. **Corrected and confirmed**

After the previous behaviour was rectified, it was noticed that all consumers conformed to each other except industries which projected lower reliability priority when all others gave high priority during an instance. This was because industries were not initialized with allocated energy supply. This was rectified and observed to give stable result. **Corrected and confirmed**
Whether the social conformity has a lesser impact on community and consumer reliability priority compared to the base case. It was observed that social conformity not only has a lesser impact on community and consumer reliability priority but also decreases the priority over time. **Confirmed**

Individual satisfaction behaviour

Individual satisfaction is the local rationality that agents have when making decisions of consumption. This will have an impact not only on the consumer increasing the consumption but alson on other consumers consumption level. Because different consumers are sensitive to other consumers differently, different hypothesis are tested to see if the dynamics of decision making follow the conceptual idea of individual satisfaction.

Whether the affects of increase in consumption by businesses influences surfclubs consumption increase to achieve low reliability priority. It is observed that the consequence of consumption increase by businesses indeed influences or causes delay in surfclubs drive to achieve low reliability priority.**Confirmed**

Whether restaurants are twice as sensitive as surfclubs due to changes in consumption by businesses. This was indeed observed that although, restaurants prefer to lower their affordability priority there is an addition in their increase in reliability priority. In other words, the consumption increase by businesses causes faster achievement of lower affordability priority or higher reliability priority for restaurants. This dynamic is observed. **Confirmed**

Whether industries are indifferent to changes in consumption by other consumers. This dynamic was indeed observed. **Confirmed**

Utility intervention and utility control behaviour

Utility intervention and utility control are mimicking the behaviour of real life utility who manage supply and consumption to keep the community reliability power stable.

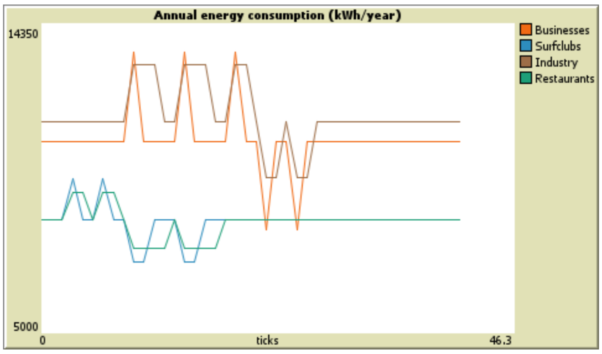

Figure E.4: Evolution of energy consumption during full utility control

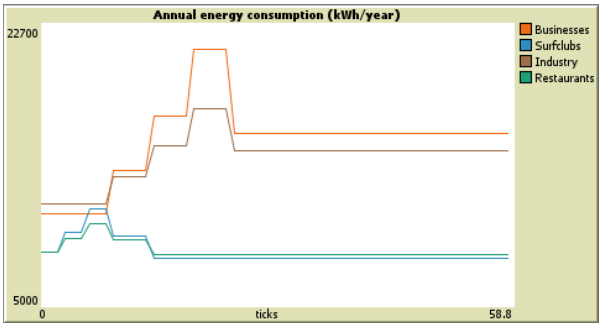

Figure E.5: Evolution of energy consumption during partial utility control

In order to test consumer's actions towards those increasing/decreasing their consumption, the consumers needs to be specified with increase or decrease in energy consumption, otherwise if there is no decision by consumer to increase or decrease, the model should run with a stability in all the indicators of consumption and value priority and not showing any changes in consumption by any consumer.**Confirmed**.

Whether the due to utility intervention and full utility control, the consumption level and reliability priority, affordability priority remains stable for all consumers. This dynamic was observed, it showed that even though consumers increase or decrease their consumption, their consumption is returned back to their allocated energy supply/ initial consumption. **Confirmed**

Whether due to partial utility control, the consumption level and other consumer priorities have slight deviation from initial allocated supply or initial consumption, instead of going through stringent full utility control. It was observed that when utility control is partial, there is slight deviation which slight influences the reliability priority of consumers. **Confirmed**.

E.2. SINGLE-AGENT TESTING

In this section, single-agent testing is performed to check the behaviour of agent is as it was intended in conceptual model.

THEORETICAL PREDICTIONS AND SANITY CHECKS

Updating of annual energy consumption Hypothesis: consumer updates their consumption after it has increased or decreased due to various external influence.
This was tested an observed for a single agent: surfclubs. For instance, surfclubs are pre-defined with annual energy consumption value as 8400 kWh/year, after a single tick in individual satisfaction mode, an input for increase in consumption of about 2.6% is given to the consumer. This results in value 8618.4 kWh/year, which means the agent updates and calculates the consumption correctly as per the formulation of increase in consumption over time. **Confirmed**

Hypothesis: Whether the increase in one agent's consumption causes decrease in consumption in other agent's consumption. This hypothesis is again limited to the individual satisfaction mode. Here, the input given to surfclubs remain similar as mentioned earlier. It happens that during individual satisfaction mode, different consumers are simultaneously increasing or decreasing their consumption level, as a result, it is expected that their consumption output is increased by their own increase rate but also decreased due to decision of businesses.
This hypothesis was tested and observed. It is seen that after the increase of initial energy consumption of surfclubs to 8618.4 kWh/year, the next tick accompanies with a reduction of 237.6 kWh/year which was proportionate increase in consumption by businesses. This lead to a value 8308.8 kWh/year. This means the energy consumption increase causing a decrease in other energy consumption is true **Confirmed**

Hypothesis: In the case of individual satisfaction, the consumers usually are specified with increasing to a certain level of reliability priority for all consumers except restaurants who prefer to increase their reliability priority at the expense of reducing their affordability priority due to their preference for affordability priority. In order to see the output successful, each consumer except restaurants should increase their consumption until it reaches reliability priority level -1 or low priority and whereas restaurants should decrease their consumption such that it reaches reliability priority level 1. This dynamic was correctly observed for each single agent and noted. **Confirmed**

Hypothesis: Whether due to utility intervention, the annual energy consumption remains stable as per the utility intervention procedure. Further, the result should give out stable reliability, affordability consumer priority and stable reliability, affordability, sustainability priority at community level.
To confirm this, one of the agent's time scale based decision was selected, while others decisions were switched off. It was observed that the utility intervention successfully controls to keep the reliability priority and other value priorities stable for consumers and community by decreasing/increasing the consumption level of consumer who increased/decreased their consumption respectively. **Confirmed**

Link preferences at setup
Hypothesis: Whether the consumer will form link with there non preferred peers when their preferred peers are not input into the model.
It was observed that, consumers did not form link with the non preferred peers when their preferred peers weren't present in the environment. This gave an error during the setup, so a condition and a switch was input: If their preferred consumer peers are present in the model only then form link otherwise form link with any other consumer in the environment. **Corrected and confirmed**

E.3. MINIMAL MODEL INTERACTION TESTING

The goal of minimal model interaction testing, is to check whether expected interactions take place even with minimum number of agents in the model.

Hypothesis: In the case of social conformity, the consumers should conform to other consumer behaviour based on their linkage with them.
To observe this and make it simpler and easier to replicate, random seed 49 was chosen with link preference deactivated, which gave single link between businesses and restaurants and a single link between restaurants and industries. It is observed that over time, each of these consumers conform to each others consumption behaviour as shown in the figure below.

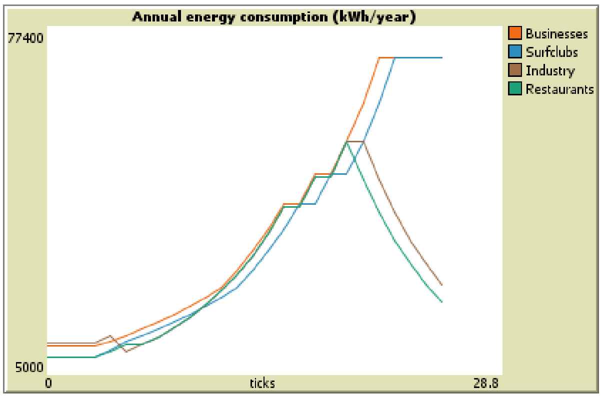

Figure E.6: Social conformity among consumers at random seed 49

Hypothesis: Whether value priorities become stable when the energy consumption becomes stable. It was observed that even after the consumption had become stable, the value priorities went on increasing, this was corrected by limiting the value priorities to increasing or decreasing only when there is a change in energy consumption. **Corrected and confirmed**

Hypthesis: Whether the value priorities limit between -1 to 1 is properly executed.
The previous condition of change in energy consumption was combined with condition of limit between the scale of -1 to 1. This led to results showing stability after energy consumption was stable as well as the priorities remained in the limit of -1 and 1 **Corrected and confirmed**.