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Master Thesis

The role of value change in the emergence of Local Renewable Energy Communities;

An Agent Based Modelling approach to illustrate the decision-making behavior of citizens regarding their electricity supply

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Extended Summary

The accessibility and affordability of small scale renewable energy sources cause a shift towards an decentralized energy system with distributed electricity generation. Together with the increased attention to responsible innovation, the polycentric development of multiple governing authorities gives room for social innovation. This empowers citizens to become prosumers via Local Renewable Energy Communities (LREOs). Despite the trend towards more polycentricity, the mismatch between the existing regulations and rules - with focus on system efficiency, reliability and affordability – and the growing attention to new sustainability related concerns of social equality, environmental well-being and energy autarky is seen as the cause for the emergence of LREOs. This manuscript explores how these new sustainability related concerns, evoked by climate events, influences the value systems of citizens and subsequently lead to the emergence of LREOs. By using agent based modelling approach, this research incorporates multiple scales of analysis, diverse agent configuration and focus on the emergence of structures at the societal level from individual actions.

The constructed agent based model uses an illustrative approach to showcase how the impact of disruptive climate events changes the value systems of citizens. Over the course of the simulation the citizens take part in the three core mechanisms of the model. First citizens slowly become responsible citizen by recognizing the sustainability related concerns evoked due to climatic disrupting events. Second, due to social learning and the recognition of the sustainability related concerns, citizens change their value prioritization. Third, citizens decide, based on their responsibility, value prioritization (motives) and leadership capacities, to adjust their energy provision by choosing between i) Fossil fuel market (market entity that supplies fossil fuel generated electricity), ii) Sustainable market (market entity that supplies sustainable generated electricity), iii) individual pv-owner (citizens buy solar pv panels for individual use), and iv) joining/initiating an LREO. In this thesis I will show that in each of these core mechanisms, values and value change play a dominant role.

The experiments show that during the process of recognizing the sustainability related concerns, citizens from the value orientation *Growth* and *Personal-Focus* mainly struggle to acknowledge their own contribution to the problem of climate change, while citizens from the *Social-Focus* and *Self-Protection-Focus* population scenarios tend to stagnate because of disbelieve in the impact of individual actions. For the second mechanism, change in value prioritization, the analysis have shown that within the *Mixed* population scenario, the social pressure of friends hinder citizens to ascribe more priority to sustainable related values. Interestingly, within populations with a homogeneous value prioritization the combination of social learning and the completion of the responsibility-cycle led to the increased prioritization of the sustainability related values of universalism and benevolence. These so-called divergent patterns of change in value prioritization is more often observed among social networks with citizens who were social competent and receptive to new opinions (*Growth* and *Personal-Focus*value orientations).For the third mechanism, the emergence of LREOs, the experiments demonstrate that only within the population scenarios with the *Growth* and *Mixed* value orientations the emergence of LREOs was visible. This was due to the fact that only within these two scenarios, populations contained a large group of citizens i) who recognized the concerns of sustainability, ii) who were community-oriented, iii) who were willing to act, iv)

whom of which a small group was capable to lead, and v) who jointly agreed on the organisational form and technology in-use. The experiments have shown a big diversity in the agency, goals and preferences between different population-scenarios.

This research made a methodological contribution by introducing the new concept of perception thermometers to study the impact of value-weighted experiences, events and information on the value prioritization system of citizens. Next to the perception thermometers, the scientific contribution of this research study showcases how to integrate new values (e.g. energy justice) within the existing Value Circumplex of Schwartz by considering it as a change in value specification. Moreover, this research used a holistic approach of analysing the emergence of LREOs as it combines external factors (e.g. consistent energy policies) with social factors (e.g. disagreements during board meetings due to the different motives of individuals) and individual characteristics (e.g. responsibility, motives, leadership capacities). Applying this multiple perspective of studying the emergence of LREOs in practise, creates a better understanding why LREOs emerge and how to stimulate/facilitate their founding process. These insights allow a more in-depth understanding of the emergence LREOs and can equip relevant researchers and practitioners with fruitful knowledge.

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Glossary

- Character Traits: Character traits are defined as endogenous basic tendencies that influence patterns of thoughts, feelings, and actions and that can be altered by exogenous interventions, processes, or events that affect their biological bases (McCrae & Costa Jr, 2008). Factor analysis has shown that there are five distinguishable character traits combined in the OCEAN-model: Openness to Experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (McCrae & Costa Jr, 1992; Goldberg, 1993).

- Community energy: Community energy is found in diverse legal, organisation and financial forms, and may involve the participation in project development and/or sharing collective benefits in which people pursue sustainable energy behaviours as a group, together with other community members (Hewitt et al., 2019; Sloot et al., 2018).

- Distributional Justice: Distributional justice recognises both the physically unequal allocation of environmental benefits and ills, and the uneven distribution of their associated responsibilities (Jenkins et al., 2016, p. 176).

- Intergenerational justice: Intergenerational justice is based on the idea of extending the term of equality, which assumes that pains and pleasures of equal intensity are to be given the same value, regardless of the identity of the person to whom they belong, with the temporal component of future generations (Barry, 1997, p.96) .As future generations cannot be held responsible for the physical environment the inherit, and given the deserve equal opportunities as current generations, valuing intergenerational justice means behaving in such a way that ensures the conservation of what matters for future generations (Barry, 1997, p. 106)

- Institutions: Instituions are defined as “codifiable systems of social structures (in particular norms and rules) that lead to an inclination to act in specific ways” (Graebner & Ghorbani, 2019, p. 24)).

- Local Renewable Energy Organisations (LREOs): LREOs are defined as organizations, initiated and managed by actors from civil society, that enable the collective procurement of electricity-generating technologies or actually provide (i.e. generate, treat or distribute), electricity derived from renewable resources for consumption by inhabitants, participants or members (Boon & Dieperink, 2014).

- Procedural Justice: Procedural justice concerns the call for equitable procedures that engage all stakeholders in a non-discriminatory way in the decision-making processes that govern the distributions outlined above (Jenkins et al., 2016, p. 178).

- Recognition Justice: "Recognition justice is more than mere tolerance and states that individuals must be fairly represented, that they must be free from physical threats and that they must be offered complete and equal political rights” (Jenkins et al., 2016, p. 177).

- Responsibility: Living an ecologically sustainable life by ‘taking no more than a fair share’ . Criteria for living responsibly is i) acknowledging the issue (a common-sense mechanism), ii)

willingness to give up standards that cause the unbalance (an unwillingness-denial mechanism), iii) information (lack of knowledge mechanism), iv) believe that individual behavior makes a difference (moral disengagement mechanism) (Robeyns, 2017).

- Schwartz Basic Value Theory (BVT): The socio psychologist Schwartz developed a concept of ten values that describes "trans-situational goals, varying in importance, that serve as the guiding principles in the life of a person or group" (Schwartz, 1994).

- Social Innovation: "Innovation that is social in its means and which contributes to the low carbon energy transition, civic empowerment, and social goals pertaining to the general wellbeing of communities (Hoppe & De Vries, 2019, p. 4).

- Sustainability: Within this thesis, the definition for the term sustainability follows the argument of Barry (1997), who argues that sustainability is closely related to intergenerational justice and defines it as 'the conservation of what matters for future generations' (Barry, 1997, p. 106). Sustainability is a broad concept and can be specified in many different ways and therefore is conceptualized as concept containing altruistic values (procedural justice, distributional justice, and recognition justice), and biospheric values (environmental well-being). (Steg & De Groot, 2012). Within the Schwartz Value Circumplex, sustainability is considered to be a sub-value of both benevolence as universalism (Steg & De Groot, 2012; Dietz et al., 2005).

- Values: values are defined as "desirable, transsituational goals that vary in their importance as guiding principles in people's lives" (Roccas et al., 2002, p. 790).

- Value change: According to van de Poel (2018) change in values can occur due to social developments and by new technologies. Although van de Poel (2018) distinguishes between five different types of value change, within this research only change in value prioritization, change in value specification and change in values that are relevant for design will be used as those are the three most relevant within this topic. Within this project, value change is assumed to be a gradual process in which the cumulative effect of multiple interactions over time will lead to moments of introspection in which an agent reevaluates its prioritization and relevance of its values. Moments of introspection are used to model value change because it is based on the assumption that value change only occurs whenever an agent is exposed to new insights/experiences over a longer time period (months/years).

- Value Sensitive Design (VSD): VSD is defined as "specific strategies and techniques that help researchers and designers to explicitly incorporate the consideration of human values into their work" (Davis & Nathan, 2015).

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Chapter 1

Introduction

1.1 Problem of socio-technical change

The worldwide climate crisis and the increasing inequalities (economical profits and control) led to the rise of values like sustainability (Barry, 1997), energy democracy (Kunze & Becker, 2014) and climate justice (Schlosberg, 2009). The emerging relevance of these values have a significant impact on the energy sector since it is a main contributor to this climate problem with emitting approximately 28% of global Greenhouse Gas (GHG) emissions primarily from burning fossil fuels (Foster & Bedrosyan, 2014). In the Netherlands, the old centralized energy systems that mainly run on fossil fuels result in around 45 billion kg GHG (CO^2-equivalent) entering the atmosphere annually (Statline, 2019). Although the Dutch society is willing to take action in changing energy arrangements (ninety percent of the population finds sustainability important (de Witt & Schmeets, 2018)), the existing centralized energy system experiences path dependencies (i.e. self-reinforcing mechanisms that causes a gradual decrease in available options until only one (often inferior) technology remains (Onufrey & Bergek, 2015)) due to sunk investments and long-term contracts (Lowitzsch et al., 2020; Geels, 2002; Unruh, 2002). This triggers numerous discussions about design and governance of energy systems aligned with relevant values to foster low-carbon energy transition and overcome existing path-dependencies (Correlje & Groenewegen, 2009; Van de Poel, 2013; Hoppe & De Vries, 2019).

In the Dutch policies, energy democratization and decentralization are considered to be a pathway to reach goals set by the Paris Climate Agreement ((Van Vuuren et al., 2017). The innovation in renewable energy technologies allows local communities to address their concerns about climate change by becoming prosumers and organizing themselves within Local Renewable Energy Communities (LREOs). LREOs are organisations, initiated and managed by citizens, which enable the collective procurement of electricity technologies and/or production of electricity derived from renewable resources for consumption by inhabitants, participants or members ((Boon & Dieperink, 2014)). LREOs provide opportunities for a just and sustainable energy generation, distribution and supply as well as inclusive democratic decision making (Brown et al., 2020). Although the LREOs share in the Dutch energy system is increasing (from 50 initiatives in 2010 to 623 initatives with 97,000 members in 2020 (Schwenke, 2021), comprehensive rules and regulations to support LREOs are still in an early stage (Lowitzsch et al., 2020). Despite this trend towards more polycentricity, most existing rules and regulations in which LREOs are operating are still based on obsolete cultural norms, traditions, strategies and values (Unruh, 2002; Heldeweg & Saintier, 2020). So the formal

institutions (rules, regulations) are not in line with the norms and values of the end users of the system (Heldeweg & Saintier, 2020). This lack of alignment hinders the further development of LREOs as issues emerge like whether LREOs may supply non-members of energy or whether 'vertical bundling' (fulfilling simultaneously both the role of distributor and producer) is allowed (Heldeweg & Saintier, 2020). This leads to the challenges of misrecognition and even failure of LREOs (Proka et al., 2018; Warbroek et al., 2019).

This complex challenge of limited institutionalisation of LREOs within the Dutch energy system is a logical consequence of the way the current Dutch energy system has grown over the last few decades. The combination of energy systems being complex configurations of agents, technologies and institutions (Vermaas et al., 2011), and the focus on reliability, affordability and efficiency resulted in a rigid and inflexible system (Scholten & Künneke, 2016). This system is problematic because it assumes that the highest institutional level (cultural norms, values and traditions) is static (Correlje & Groenewegen, 2009). In practice however, cultural norms, values and traditions may change their meaning over time and thus create pressures on the socio-technical system to adapt to a more sustainable environment (Geels, 2002; van de Poel, 2018). In order to improve the design of the socio-technical energy system by making it more robust, adaptable and flexible, it is important not to look just at institutions and technologies but also at citizens who are the driving vehicles in the low carbon energy transition. As citizens are the central agents within the complex socio-technical system who tackle the collective-action problem of climate change by proactively alter the existing energy regime, it is important to understand how the recognition of the sustainability related concerns of energy justice, environmental well-being and energy autarky leads to the emergence of LREOs on a community level.

1.2 Literature review

To understand the background of the emergence of LREOs within the Dutch energy system a comprehensive literature review is conducted to shed a light on 1) energy transitions, 2) the shift from monocentric to polycentric governance, 3) social innovation and LREOs, and lastly, 4) values within LREOs.

1.2.1 Energy Transition and Social Innovation

Within the last 200 years, the world experienced two major energy transitions: from biomass to coal (19th century) and coal to oil/gas (20th century) (Fouquet, 2016). During these transitions, the underlying values (e.g., efficiency, affordability, and acceptability) and governance (monocentric) remained relatively stable, while the major changing component was the shift in energy sources and technologies (Scholten & Künneke, 2016). The significant externality of the fossil-fuel powered Dutch energy system is its contribution to climate change. The realization of this increasing problem resulted in the current transition from big fossil fuel plants to decentralized renewable energy sources.

This transition is fuelled from top-down by the national government (Dutch Climate Agreement) and from bottom-up by grassroots social innovations like LREOs (Schreuer & Weismeier-Sammer, 2010). In particular, the energy generated by local communities facilitates a shift to a more decentralized system in which parts of the network operate autonomously without

the direct supervision of the distribution system operator (Grabowski & Roberts, 1996). The development of a more decentralized system, together with the unreliable energy flow of renewable energy sources, results in increasing pressures upon the existing design of the Dutch energy system (Geels & Schot, 2007). At the same time, due to social innovation, the role of citizens within this socio-technical system is also changing. Besides being customers of energy, citizens also become energy suppliers (prosumers) and start organizing themselves to founding LREOs. This development is visible with the number of LREOs in the Netherlands in 2021, increasing to 623 communities with a total of 85.000 registered members (Schwenke, 2021).

1.2.2 Monocentric to Polycentric systems

According to Ostrom (2010), polycentric systems are more efficient in operating in decentralized systems as the hierarchy between higher-level authorities and lower-level users is absent. Due to the call for more civic empowerment within the energy system and new technologies that enhance the possibility to strive for civic empowerment, the energy system shifts from a monocentric towards a polycentric system. A polycentric system is defined as a system with multiple semi-autonomous authoritative entities on different scales instead of one monocentric unit (Sovacool & Van de Graaf, 2018). An example of the multiple authoritative entities within the current Dutch energy system is the founding of the Regional Energy Strategies, in which citizens, public entities, and private companies work together to formulate a strategy towards more sustainable use of energy regions (Hoppe & Miedema, 2020).

1.2.3 Social innovation and LREOs

One of the driving factors for this shift from government to governance is the movement of social innovation. Hoppe & De Vries (2019) define social innovation as "innovation that is social in its means and which contributes to the low carbon energy transition, civic empowerment, and social goals pertaining to the general well-being of communities (p. 4). One of the examples of social innovation within the energy sector is the introduction of community energy. In the 1990s during the constructing of on shore wind farms citizen participation was often absent which resulted in rejection of projects by local people (Wolsink, 2000). Trials of similar project in which the benefits was shared with the local citizens, lead unsurprisingly to more acceptance; community energy was born (Warren & McFadyen, 2010). Community energy 'is found in diverse legal, organisation and financial forms, and may involve participation in project development and/or sharing collective benefits (Hewitt et al., 2019). Examples of community energy are sustainability movements like transitions town initiatives and ecovillages, but probably the most well-known form of community energy are Local Renewable Energy Organisations (LREOs) (Hewitt et al., 2019). LREOs are described as "organisations, initiated and managed by agents from civil society, that aim to educate or facilitate people on efficient energy use, enable the collective procurement of renewable energy or technologies or actually provide (i.e. generate, treat or distribute), energy derived from renewable resources for consumption by inhabitants, participants or members" (Boon & Dieperink, 2014, p.298). To narrow down the variety of organisations, the definition of Boon and Dieperink is reduced the following description: "LREOs are organisations, initiated and managed by agents

from civil society, which enable the collective procurement of renewable electricity technologies or actually provide (i.e. generate), electricity derived from renewable resources for consumption by inhabitants, participants or members". Within the organisations of LREOs there are two different types of organisations. The first group are only occupied with the collective procurement of energy technologies, which are intended for individual use, while the second group of LREOs focus on the collective realisation of energy projects including the procurement, installation, maintenance of energy technologies. Within this last organisational form, the ownership and revenues of the energy projects are divided among all community members (Koirala et al., 2016). Although a number of LREOs also engage in collective insulation, energy saving and thermal technologies (Koirala et al., 2016), the focus within this research is for practicability reasons on electricity producing technologies. Within the electricity producing technologies there is dichotomy between wind farms and solar pv panels (Koirala et al., 2016). As the organisational that only focuses on the collective procurement of technologies can not be combined with a wind farms, the focus is on solar pv.

1.2.4 Values in LREOs

Within socio-technical systems, like the Dutch energy system, values have a dominant role as they form the foundations of existing institutions, norms, and practices (Williamson, 2000). Where in the previous decades the main focus was to maintain a *reliable* energy system which is *accessible* to both consumers and suppliers and which results in an *affordable* and *efficient* energy system. The rise of responsible innovation, in combination with climate changing events, causes a switch towards sustainability related concerns of energy democracy, environmental well-being and energy autarky (Brown et al., 2020, p.4). Supporters of prosumerism and LREOs argue that these social innovations lead to more just outcomes in the form of distributional equity, inclusiveness and fairness. Furthermore, Brown et al. (2020, p.4) argue that the distributed forms of ownership, financing and revenue sharing may facilitate local value retention, economic development and reduce inequality.

1.3 Knowledge Gap and Research Question

The accessibility and affordability of small scale renewable energy sources cause a shift from centralized energy systems with large scale power plants towards a decentralized energy system with distributed electricity generation. To govern the coexistence of large scale centralized power plants and distributive energy production, the authoritative structure moves from one centralized authority (monocentric) towards a polycentric governance structure with multiple authorities on the different levels in the system (Ostrom, 2010; Sovacool & Van de Graaf, 2018). Together with the increased attention to responsible innovation, this polycentric development gives room for social innovation, which empowers citizens to become prosumers via LREOs (Hoppe & De Vries, 2019; Heldeweg & Saintier, 2020). Despite the trend towards more polycentricity there is a mismatch [1] between the existing regulations and rules - with focus on system efficiency, reliability and affordability

[1] An example of this mismatch is the current regulation on unbundling prohibiting that one single authority is both user and owner of a network. The underlying reason for unbundling should encourage competition on the supply side of the system. In some cases however, this combination of network use and ownership is vital for the existing of LREOs.

– and the growing attention to sustainability related concerns of environmental well-being, social equality and energy autarky, evoked by climate changing events (Brown et al., 2020). These new emerging concerns cause a change in the value systems of individuals (Brown et al., 2020; Correlje & Groenewegen, 2009; van de Poel, 2018). However, the way in which this change in values occurs and how it leads to the emergence of LREOs is still unknown. By combining theories of i) value change (van de Poel, 2018) ii) responsibility (Robeyns, 2017) iii) leadership (Martiskainen, 2017) with iv) the founding process of LREOs (Boon & Dieperink, 2014) this study aims to explore the two following knowledge gaps. First, it explores how climate changing events cause changes in value systems of individuals from heterogeneous populations with different value orientations. Second it explores how this change in value systems results in collective action directed towards the emergence of LREOs.

Translating these two knowledge gaps into tangible research inquiries leading to the following research question:

'In what way does the recognition of the sustainability related concerns of energy justice, environmental well-being and energy autarky, evoked by disruptive climate events, induce change in the value systems of citizens and lead to the emergence of LREOs?'

1.4 Research scope

Within the scope of this research I consider LREOs as emerging socio-technical systems because multiple citizens (agents) decide to collectively start a new organisation (institution) to jointly generate electricity using renewable energy technologies (technology) (Vermaas et al., 2011). Moreover, being a socio-technical system in which technical artifacts (renewable energy technologies) are embedded within a social network (community), LREOs can also be considered as a complex adaptive system (Nikolic & Ghorbani, 2011; Scholten & Künneke, 2016). Within the complex system theory, it is assumed that the system's behavior as a whole could be explained by the decisions made at every moment by every individual within that system (Nikolic & Ghorbani, 2011, p. 44). Therefore, I assume that the occurrence of LREOs is a result from set of collective agreements that emerge from the interactions and decisions made by citizens with heterogeneous cognitive architectures.

1.4.1 Research goal

Answering the main research question will result in a three-folded knowledge deliverable (KD). First, this thesis will distil a new vision into how these new concerns related to sustainability causes a change in value specification of citizens. Second, it investigates how this recognition, in combination with social learning, lead to changes in value prioritization. Third, this thesis illustrates how LREOs emerges in neighbourhoods (KD-3) by combining the recognition of the sustainability related concerns of energy justice, environmental well-being and energy autarky via the responsibility mechanism (KD-1), the change in value prioritizations(KD-2).

1.4.2 Methodology

To accomplish this research goal this thesis uses a computational method. The reason for choosing an computational method is three-folded. First, as the emergence of LREOs is a complex phenomenon, a computational method forces one to be precise and as the computer program needs to be complete and exact in order to let it work (Gilbert, 2008). Second, the computational method helps to create an understanding of functioning of the mechanism of recognition, value change and LREO founding process (Edmonds, 2017). Third, in comparison with emprirical research, computational modelling allows to understand the relations between the integrated components by performing infinite experiments in which each component can be isolated from external factors (Gilbert, 2008). Within empirical research, where everything is connected, this isolation is almost impossible.

Within the computational methods, Agent-based simulation has been chosen as it allows in contrast to other computation methods (e.g. variable-based approaches) the representation of multiple scales of analysis, temporal scale, diverse agent configuration and the emergence of structures at the societal level from individual action (Gilbert, 2008). For this research these are prerequisites as 1) I assume that LREOs is a niche innovation and emerges from interactions on a individual level by heterogeneous agents and 2) it will provide an analytical tool to extract data on the different scales of analysis (both individual level and LREO level).

Within this thesis, the use of Agent-based modelling has an illustrative purpose, because it allows to capture my theoretically informed understanding of the role of values in the emergence of LREOs as it visualizes the complex interactions at work and hence appreciate these complexities better (Edmonds, 2017). Where Edmonds (2017) recommends to use an concrete example, I stick to a more abstract illustration of the emergence of LREOs to avoid case-specific factors that negatively impacts the generalizability.

1.4.3 Sub-Questions

To illustrate this new vision on the emergence of LREOs with a modelling approach, this thesis uses three step process of model conceptualization, model formalisation and model experimentation. The sub-questions listed below serve as a guideline for this three-step process. The first three questions are used to build a theoretical underpinning which will be used as a conceptualization of the model. The last three questions will be used for the experimental setup to illustrate how the the emergence of LREOs is influences by the three mechanisms of i) the recognition of the sustainability related concerns, ii) the change in value prioritization, and iii) the leadership capacities.

1. What are values and value change?
2. What is the role of values in socio-technical systems and institutional change?
3. What is the founding process of LREOS?
4. In what way is sustainability recognized within the value system of Dutch citizens (mechanism 1)?
5. What is the influence of social learning and the recognition of the sustainability related concerns on the value prioritization of Dutch citizens (mechanism 2)?

6. What is the influence of mechanism 1 & 2 on the emergence of LREOs?

1.5 Relevance for Industrial Ecology

Studying the impact of the recognition of new concerns related to the value of sustainability on the emergence of LREOs is relevant for the field of Industrial Ecology in three different ways. At first, the research will take a social-technical perspective as it explores how individuals organize themselves by creating new institutions within a socio-technical system; the Dutch energy system in transition. This understanding will help with designing a more robust, adaptive and flexible Dutch energy system. Second, this study researches how to conceptualize the recognition of the concept 'sustainability' in the value systems of individuals within an agent based model. Third, this research adds to the field of agent-based modelling and social simulation by the introduction of the concept of 'perception thermometers' to model the change in value prioritization of agents over time

1.6 Outline

The outline of this thesis report is visualized in Figure 1.1. The thesis starts with a theoretical underpinning (Chapter 2) which combines the theories of value change(van de Poel, 2018), responsibility (Robeyns, 2017), leadership (Martiskainen, 2017) and the founding process of LREOs (Boon & Dieperink, 2014) to create an better understanding how changes in socio-technical systems occur.

Next, the theoretical framework is converted into an agent based model of the formalisation described within Chapter 3 which follows the ODD protocol of Grimm et al. (2010). Section 4.1 includes the model verification and the global sensitivity analysis that shows importance of each input variable in determining the output variance of the three key performance indicators: the average responsibility level of the population, the average value change of the population and the total number of LREO-supporters. This chapter is followed by Chapter 5 that describes the setup and results that will answer the last three subsections. This report will finish with Chapter 6 which will answer the sub-questions and main research questions, and will discuss the contributions of this work to the research field of LREOs and Agent Based Modelling, the limitations of this thesis and the recommendations for suggestions for future research and recommendations to energy scholars, ABM modelers, and policy makers an interest groups dealing with polycentricity.

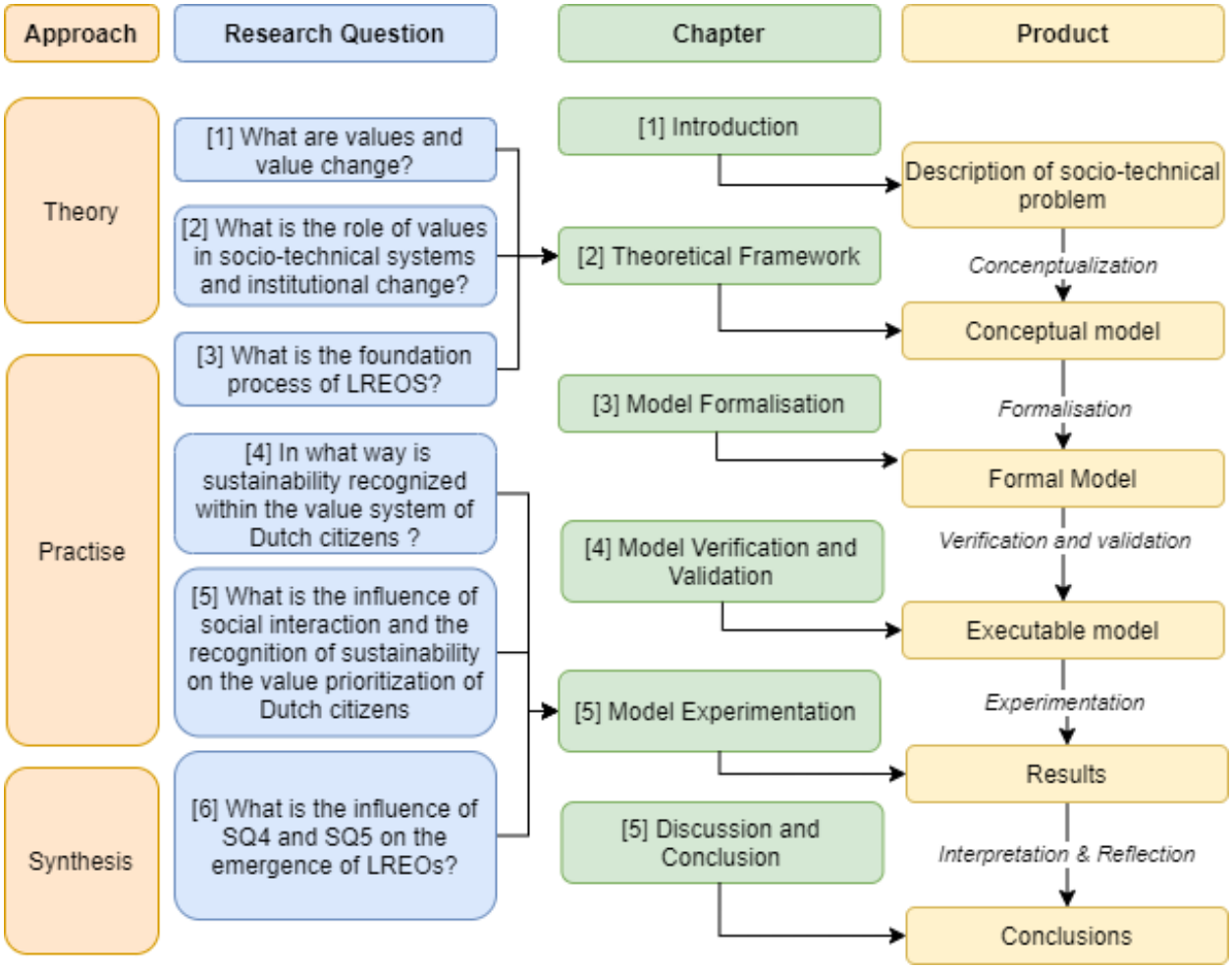


FIGURE 1.1: Outline of this Thesis

Chapter 2

Theoretical Underpinning

This chapter describes the different theories that will be used as a conceptualization for the model formulation in chapter 3. This chapter is divided in to two parts. The first part (section 2.1) describes how agents (citizens), technologies and institutions interact with each other within the socio-technical systems of LREOs. The agent as the main decision making entity plays a central role within this system. Within the model the focus will be on the cognitive architecture of agents, the relation between changing values of agents and technology and the relation between agents and institutions. This first section will answer sub-question 1) on values (Section 2.1.1) and value change (Section 2.1.2); and sub-question 2) on the role of values in the change of energy systems (Section 2.1.3). The second part of this theoretical underpinning (Section 2.2 is centralized on the founding process of LREOs in which the focus is on the conditions on both the individual level (Section 2.2.1 as also the community level (Section 2.2.3.

2.1 Change in socio-technical systems of LREOs

Socio-technical systems are hybrid systems in which complex technological artefacts (e.g. Dutch energy system) operates in an environment that involves people, institutions and rules (Vermaas et al., 2011, p. 69). Such hybrid systems can be viewed from a technical perspective describing the causal properties and components, but can also be examined as the function it has in a context of human actions (Vermaas et al., 2011, p. 69). Within this research the latter perspective is used with studying how the combination of interaction between agents and the environment (i.e. climate change), and between agents, and technological innovation induces changes in the value system of citizens and lead to changes in the Dutch energy system.

2.1.1 Values of Agents

This section describes how the values are defined (2.1.1.1), how the prioritization of value changes over time, how sustainability relates to the value system of Schwartz and finally the relation between character traits and values.

2.1.1.1 Values in social psychology

In social psychology, values are described as “trans-situational goals, varying in importance, that serve as the guiding principles in the life of a person or group” (Schwartz, 1994, p. 21). Within his Basic Value Theory Schwartz distinguishes, based on 56 different values, between ten different values

which are all present in value systems of every citizen in the world (Schwartz, 2012). These ten values are universalism, benevolence, conformity, tradition, security, power, achievement, hedonism, self-direction & stimulation (Schwartz, 2012). Based on years of research, Schwartz ordered the relationship of these 10 values within a value circumplex (see Figure 2.1) (Schwartz et al., 2012)). Values that are placed on the opposite site of the circle (e.g. universalism & power) are antagonistic with each other (Schwartz et al., 2012). For example, striving for universalistic goals often conflict with power-related goals. This automatically means that rational individuals that give a high prioritization to universalism automatically give a low priority to the value of power. Simultaneously, values that are next to one another in the circle have congruent characteristics. For instance, striving for universalism-related goals often go hand in hand with benevolence-related goals. Therefore, these values are often prioritized equally. Based on the antagonistic and congruent characteristic of value systems, you can distinguish between four groups of value orientations which prioritize one half of the circle over the other (*Social-Focus*, self protection anxiety avoidance, *Personal-Focus* and *Growth anxiety free*.

FIGURE 2.1: Overview of the ordering of the ten universal values within the Schwartz Circumplex (Schwartz et al., 2012)

2.1.1.2 Values and Character traits

Whereas values describe the long-term goals of individuals, character traits describe how people tend to act in different situations. Character traits are defined as "endogenous basic tendencies that influence patterns of thoughts, feelings, and actions and that can be altered by exogenous interventions, processes, or events that affect their biological bases" (McCrae & Costa Jr, 2008, p. 165). Factor analysis has distinguished five unieuqe character traits which are represented in the OCEAN-model: Openness to Experience (facets: fantasy, aesthetics, feeling, action, ideas, values), Conscientiousness (facets: competence, order, dutifulness, achievement striving, self-discipline, deliberation), Extraversion (facets: warmth, gregariousness, assertiveness, activity, excitement seeking and positive emotions), Agreeableness (facets: trust, straightforwardness,

altruism, compliance, modesty, tender mindedness), and Neuroticism (Anxiety, angry hostility, depression, self-consciousness, impulsiveness, vulnerability) (Schmitt et al., 2007, p. 191). Each group of traits are independent from each. This implicates that having affiliation with one group of traits, does not relate to having an affiliation with other groups of traits. Where values are often referred to as goals that indicate "what people consider important", traits describe "what people are like" (Roccas et al., 2002, p. 790). A good example of differences is described by Roccas et al. (2002) who says that the trait 'competence' "refers to the frequency and intensity of competent actions and ideas that an individual exhibits" while the value 'competence' refers "to the value refers to the importance that an individual attributes to demonstrating competence as a guide to action" (p. 790). Although values and traits are two different concepts, the meta-analysis of 60 different studies by (Parks-Leduc et al., 2015) shows that there is a significant correlation between four of the five (all except neuroticism) OCEAN traits (see Figure 2.2). These correlations between values and traits will be used as input for configuring the cognitive architectures of the citizens within the agent based model.

	Openness to Experience	Agreeableness	Extraversion	Conscientiousness	Emotional stability
Power	−.06	**−.42**	**.31**	.05	.03
Achievement	.11	−.24	**.31**	**.17**	−.01
Hedonism	.09	−.11	**.20**	−.19	.01
Stimulation	**.36**	−.05	**.36**	−.16	.02
Self-direction	**.52**	−.07	.17	.01	−.01
Universalism	**.33**	**.39**	−.05	−.02	−.03
Benevolence	.13	**.61**	−.05	.07	−.01
Conformity	**−.27**	**.26**	−.17	**.27**	−.05
Tradition	**−.31**	**.22**	−.25	.10	−.03
Security	**−.24**	.00	−.05	**.37**	−.03

Note. Generalizable results (in bold) refer to results for which the 80% credibility interval does not include 0.

FIGURE 2.2: Correlations between Schwartzs values and OCEAN traits (Parks-Leduc et al., 2015, Table 10)

2.1.1.3 Values and Sustainability

Within the famous Brundtland report of the United Nations sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987, p.41). As future generations can't be held responsible for the physical environment they inherit, and given they deserve equal opportunities as current generations, the definition of sustainability of Brundtland is closely related to inter-generational justice which means "behaving in such a way that ensures the conservation of what matters for future generations (Barry, 1997, p.56). Sustainability is a broad concept and can be specified in many different ways. This thesis follows the argument of Steg & De Groot (2012) who conceptualize it as a new concern that includes biospheric values (i.e. environmental conservation) and altruistic values (procedural justice, distributional justice, and recognition justice). Recognition justice is more than mere tolerance and states that individuals must be fairly represented, that they must be free from physical threats and that they must be offered complete and equal political rights (Jenkins et al., 2016, p. 177). Distributional justice recognises both the physically unequal allocation

of environmental benefits and ills, and the uneven distribution of their associated responsibilities (Jenkins et al., 2016, p. 176). Procedural justice concerns the call for equitable procedures that engage all stakeholders in a non-discriminatory way in the decision-making processes that govern the distributions outlined above (Jenkins et al., 2016, p. 178).

Studies of Dietz et al. (2005) and Steg & De Groot (2012) researched how sustainability relates to the Schwartz's value circumplex. Within their research they showed that there is a strong correlation between giving a high priority to sustainability (biospheric and altruistic values) and the self-transcendence values (universalism and benevolence) (Dietz et al., 2005; Steg & De Groot, 2012). Therefore in thesis I suggest that sustainability is not a new value besides the ten universalic Schwartz's values, but a new way of specifying, conceptualizing and prioritizing the universalism value and the benevolence value.

2.1.1.4 Change of value prioritization

According to Sagiv et al. (2017) the value prioritization of individuals is formed during their childhood. When reaching the age of adolescence, the value prioritization of people stabilizes (even over longer time spans of 8 years) (Sagiv et al., 2017). One of the exceptions in which change in value prioritisation do change, is in the case of major life transitions (e.g. moving to another country) (Sagiv et al., 2017). Where Sagiv et al. (2017) solely focused on emperical research on value prioritization, Usó-Doménech & Nescolarde-Selva (2016) argue that the value prioritization of individuals is dependent on his/her belief system, as belief systems implicitly or explicitly define what is good or valuable. Within this thesis it assumed that the implications of climate changing events can have such a drastic impact that it changes the belief system of individuals, or as Sagiv et al. (2017) would describe it; consider the implications of climate changing events as 'major life transitions'. Subsequently, changes in belief system (i.e. recognizing sustainability) will cause changes in value prioritization. As recognizing sustainability is related to specifying the self-transcendence values differently (see Section 2.1.1.3), it is assumed that people that change their belief system by recognizing sustainability, will also give more priority to the self-transcendence values. As these self-transcendence-values are antagonistic with the self-enhancement values of power and achievement this means that those people will give less priority to power and achievement values. Similar as changes in value prioritization, it is assumed that the adaptations in belief systems (e.g. recognizing sustainability) occurs gradually over time (Usó-Doménech & Nescolarde-Selva, 2016). Moreover it assumed that the magnitude of change is based on the impact of the implications of climate change (i.e. so experiencing more severe information/events leads to higher chance of recognizing sustainability). Lastly, the magnitude of change is agent specific as it is based on the character traits and educational level of the individual (Abdollahi et al., 2017; Wuertz, 2015).

2.1.2 Changing values and innovation

When aiming to improve existing socio-technological systems and deal with externalities effectively, it is essential to note the term responsible innovation. According to Van den Hoven et al. (2013) (2015), responsible innovation can, in the realm of innovation, be referred "to whatever invites,

accommodates, stimulates, enhances, fosters, implies or incentivizes responsible action" (p. 111). In which responsible action is: 1) to obtain all relevant knowledge and consequences of the different options available, 2) evaluate both outcomes and options effectively in terms of moral values, 3) use the considerations of 1 and 2 as requirements for design and development of systems. The goal of responsible innovation is to "expand the set of relevant feasible options regarding solving a set of moral problems" (Van den Hoven et al., 2013, p. 111). Allowing system actors the freedom to apply responsible innovation gives actors the opportunity to adjust the system according to their changing values using approaches like Value Sensitive Design (VSD).

Within the scientific literature, VSD is defined as specific strategies and techniques that help researchers and designers to explicitly incorporate the consideration of human values into their work (Davis & Nathan, 2015; Friedman et al., 2013). VSD theory can be categorized as follows: 1) it provides opportunity of stakeholder engagement in the process of design, 2) its practitioners use tripartite levels of analysis: conceptual (conceptualize values), empirical (collect stakeholders values) and technical (translate values into design properties), 3) and it defines values as what is considered to be good for individual or a group (Friedman et al., 2013). Within VSD theory, it is assumed that designers can distinguish which values are relevant for design before the commissioning of technologies (van de Poel, 2018). Within long-lasting socio-technical systems, like Dutch energy systems, the values relevant for design and value prioritization that determine the technologies and institutions in use are subject to change during the system's use. Acknowledging this value change phenomenon and incorporating it in the design approach helps create adaptable, flexible, and robust socio-technical systems (van de Poel, 2018).

In his critique of VSD, van de Poel (2018) distinguishes between five different value change types by bringing energy systems examples. The first type of value change is the emergence of new values, which were not considered at all during the initial design phase of systems. Van de Poel (2018) refers to a value like sustainability that was not considered as value during the setup of many current energy systems. The second type is a change in values' relevance for design. Values like energy justice were considered as values but were not considered relevant to the system's design. The third type of change is a change in the relative importance of values over time. With regards to the energy system in the first stage, accessibility was valued as more important (expanding the network), while later on, the focus was more on efficiency as the fuel costs rose and the major part of the population at that point connected to the system (decline in the importance of accessibility). The fourth type of value change is changes in the way the meaning of the value is clarified. The last type of value changes are changes in the way values are specified. The fourth type focuses on the conceptualization of values itself; the fifth type focuses more on how values are translated into norms and design requirements.

Applying these insights of value change on the work of Steg & De Groot (2012) on connecting sustainability with Schwartz value circumplex, this thesis focuses on three of the five types of value change: 1) the change in values that are relevant for design through (2) specifying the self-transcendence values (i.e. universalism and benevolence) differently because of the recognition of the sustainability related concerns (see Section 2.1.1.3. The third form is the change of value prioritization due to the recognition of the sustainability related concerns (see Section 2.1.1.4) and due to social learning. These forms of value change are important as the recognition of

the sustainability related concerns (within belief system) and value prioritization (intention) are a prerequisite for starting/joining an LREO initiative.

2.1.3 The role of values in changing energy systems

Within this section I explain why in my view values are a important driver for the emergence of LREOs within the Dutch energy system. I will start with a short description of the institutional framework of Williamson (2000), followed by discussing the mismatch between new values and existing formal rules. The last section use the institutional framework of Ostrom (2010) to discuss how LREOs emerge from this mismatch.

In 2000 Olivier Williamson presented his four levels of institutions with on the top the social embeddedness level, consisting of the informal institutions like traditions and norms (Williamson, 2000). Although Williamson does not explicitly consider values within the highest level, Correljé et al. (2015) argues that "values are reflected in informal institutions as exogeneous variables of importance" (p. 643). They are considered to change slowly and emerge out of millions of interactions between individuals. Below the social embeddedness level, at the institutional environment, the informal institutions are translated into formal rules (constitutions, laws, property rights) which set the rules of the game. At the third level, governance is centralized around how the firms and organisations are governed through formal and informal institutions. The fourth level comprises the day-to-day interactions between different organisations. The four different levels interact with each other as the higher hierarchical levels set the boundaries of how the lower level of institutions should perform, while reversely outcomes on the lower level of institutions push the existing boundaries to urge the higher levels to adapt.

However, economists assume that, during the design of energy markets, the highest institutional level, the informal institutions, are assumed to be static, (the orange arrow in Figure 2.3 is absent in system design) (Correljé et al., 2015). But according to (Heldeweg & Saintier, 2020, p.2) in reality these informal institutions do change and the complex socio-technical systems with long-term investments struggle to maintain alignment with the informal institutions. On the basis of Williamson's theory on four levels of institutions, I presume that there is a lack of normative alignment between the informal institutional level and the formal institutional level because of the new values[1] of sustainability, energy justice and autarky (Brown et al., 2020) that can't be institutionalised by the formal institutions due to path-dependencies of the existing socio-technical regime (pink arrow in Figure 2.3)(Geels, 2002; Scholten & Künneke, 2016). Therefore, together with the innovations of small scale energy technologies, these new values drive citizens to take a proactive role which causes the emergence of LREOs and prosumership on the third institutional level. Heldeweg & Saintier (2020) argue that LREO, next to constitutional orders and competitive markets, is a third institutional environment with its own characteristics. In his view, the institutional environment of LREO is a combination of constitution orders and competitive markets and makes it possible to foster decentralized energy democratization (Heldeweg & Saintier, 2020). So, to foster the development of LREOs it is required that "the normative alignment between

[1]Note that within the institutional framework of Williamson values are the foundation of the informal institutions. This means that they are shared by a large part of the community within the system. The Schwartz values resembles individual goals and by sharing their opinions, individuals can translate their individual Schwartz values into informal institutions.

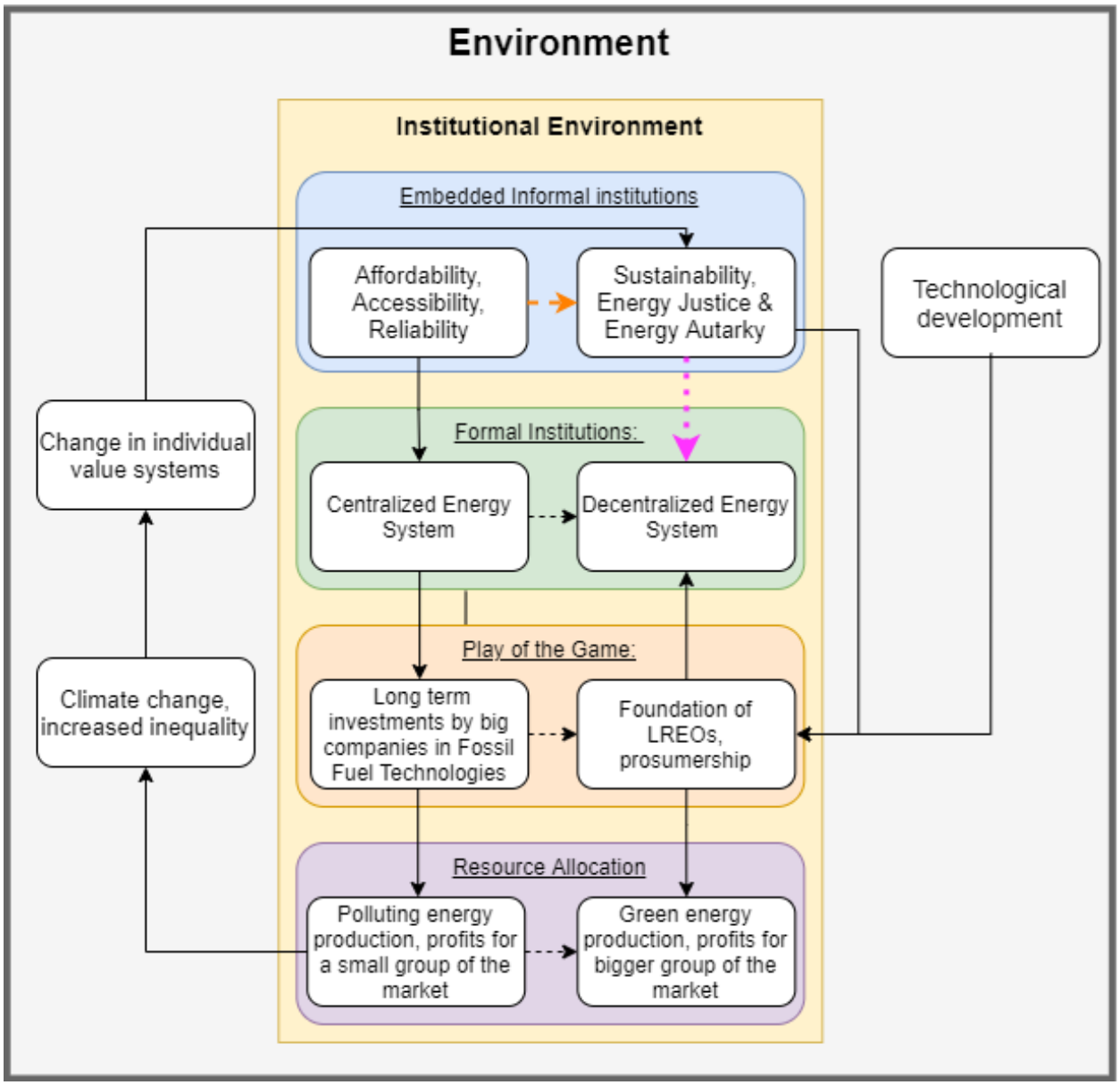


FIGURE 2.3: The mismatch between changing values and existing formal institutions leading to the emergence of LREOs

the institutional environment and community governance structures, relational arrangements risk invalidity, becoming legally void, or (other- wise) being unlawful, to possibly cause liability" (p.8). This institutionalization is important as it helps to resolve issues like whether LREOs may supply non-members of energy or whether 'vertical bundling' (fulfilling simultaneously both the role of distributor and producer) is allowed.

So to understand the emergence of LREOs, it is important to study how informal institutions change over time. To incorporate this temporal component, the institutional framework of Williamson has to be extended with a temporal space. Ostrom accomplished this in 2005 with the Institutional Analysis and Development framework. Within this framework Ostrom introduced the term action situations which she (as cited in Siddiki et al. (2011, p. 7)) defined as "the social space

where participants with diverse preferences interact, exchange goods and services, solve problems, dominate one another, or fight (among the many things that individuals can do in such domains)". The output of these action situations result in prescriptions for repeated interactions which can be considered institutions (Siddiki et al., 2011, p. 7). The action situations occur at different levels which follow the similar hierarchical order as the four levels of institutions of Williamson. Starting from top-down with the meta constitutional level (developing concept of the 'game'), the constitutional level (determining the rules of the 'game', the collective choice (determining the play of the 'game') and at the bottom the operational level (the play of the 'game'). Within this thesis the emergence of LREOs occurs through the collective meet-ups of citizens with diverse preferences, that collectively decide to unite to organize their energy supplier in a different way. So with regards to the theory of Ostrom, the action situations of LREOs influence both the level of collective choice (organizing an LREO) and the operational level (using energy generated by the LREO).

2.2 The process of founding an LREO

Where the previous part of this theoretical underpinning discussed why from a socio-technical perspective LREOs emerge, this last section will explain which motivations drive individuals to start or join LREO initiatives Section 2.2.1, what capacities the leading individuals have (Section 2.2.2) and which steps LREOs walk-through to become a vital organisation (Section 2.2.3.

2.2.1 Motives for involvement

Sloot et al. (2019) researched the importance of financial, environmental and communal motives in the involvement of LREOs. According to their research both communal and environmental motives are positively correlated with the involvement in LREOs. Financial motives however,do not relate to the indicators of involvement, meaning that individuals only having financial motives are not involvement in LREOs. Besides the communal, environmental and financial motives, research of Reijnders et al. (2020) also showed that being in control over the energy supply also is in important motive for being involved in LREOs. Based on the researches of Reijnders et al. (2020) and Sloot et al. (2019) it assumed that environmental awareness [2] and communal motives are shared among all involved members in LREOs. Moreover, having one of more of the motives of i) need for control, ii) environmental well-being and/or iii) financial motives are a second perquisite for involvement.

Environmental awareness is conceptualized by recognizing sustainability within the belief systems of individuals. To recognize sustainability as a concern and to act accordingly, humans have to realise they can take no more than a fair share of resources. However, the claim that we as people take more than their fair share is often denied due to four control mechanisms (Robeyns, 2017). These four control mechanisms are i) not having the information about the inequality and environmental effects (lack of knowledge mechanism), ii) not acknowledging the impact of own standard behavior (a common-sense mechanism), iii) disbelieve that change in individual behavior makes a difference (moral disengagement mechanism, and iv) unwillingness to give up standards that

[2]Environmental awareness differentiates from environmental well-being as environmental awareness is related to the belief system of individuals (being aware of climate change), where environmental well-being is related to the value system (finding it important to maintain environmental well-being)

cause the unbalance (an unwillingness-denial mechanism) (Robeyns, 2017). Within this research, the first three control mechanisms are considered to be changes in the belief system of individuals [3](see Section 3.1), while the fourth mechanism, unwillingness-denial mechanism is related to the value prioritization of individuals.

2.2.2 Leadership

Next to the possession of particular motives and belief systems Martiskainen (2017) showed that leadership capacities also play a big role in the initiation of LREOs. Martiskainen (2017) conducted research on important capacities to start initiatives on an individual level. Within her research,Martiskainen (2017) showed three different capacities that help nursing niche innovations and LREOs in particular. First, the voicing of expectations is important to manage expectations of the participants within the project in order to stimulate community building and trust (Martiskainen, 2017). Second, learning, as it is important to be able to pursue information and communicate that information to others (Martiskainen, 2017). Third, it is important to have networking skills to create a network with both the community and other stakeholders to find necessary financial and institutional support (Martiskainen, 2017; Ghorbani et al., 2020).

2.2.3 Factors on a communal level

Besides the motives and capacities on an individual level, also community factors play a big role in the successful foundation of LREOs. Boon & Dieperink (2014) questioned members of 26 different LREOs in the Netherlands and came up with a framework on the founding process of Dutch LREOs. This framework consists of four steps: i) the occasion to start an LREO initiative, ii) the local perception of an LREO, iii) the local support and acceptance of the LREO, and lastly iv) the assessment of the applied technology of the LREO. For the four steps within this framework Boon & Dieperink (2014) identified, based on 65 interviews, 26 factors that are important in the founding process of those 26 LREOs. These 26 factors are divided into six different groups: i) macro developments (e.g. environmental awareness), ii) technological characteristics (e.g Independency from energy countries and market players, increased reliability), iii) economical characteristics (e.g enhanced social cohesion), iv) governmental interventions (e.g. consistent energy policies and capacity building), v) market and society (e.g. examples of existing LREOs), and lastly vi) organisational characteristics (e.g. shared ownership and benefits).

The presented factors of Boon & Dieperink (2014) are closely related to the values and institutions described in the two previous sections. The values of Schwartz can be linked with the following factors of Boon & Dieperink (2014): i) degree of social cohesion (high priority to benevolence value), ii) division of ownership and benefits (high priority to universalism value (i.e. energy justice)), iii) independency from energy corporations and energy countries (high priority to the autonomy value), iv) sense of pride (high priority to the achievement value) Reijnders et al. (2020); Brown et al. (2020). On the other side the following factors can be ascribed to the different levels of institutions: formal institutions (consistent energy policies, feed back possibilities), play of

[3]These three process are referred to as responsibility-mechanism

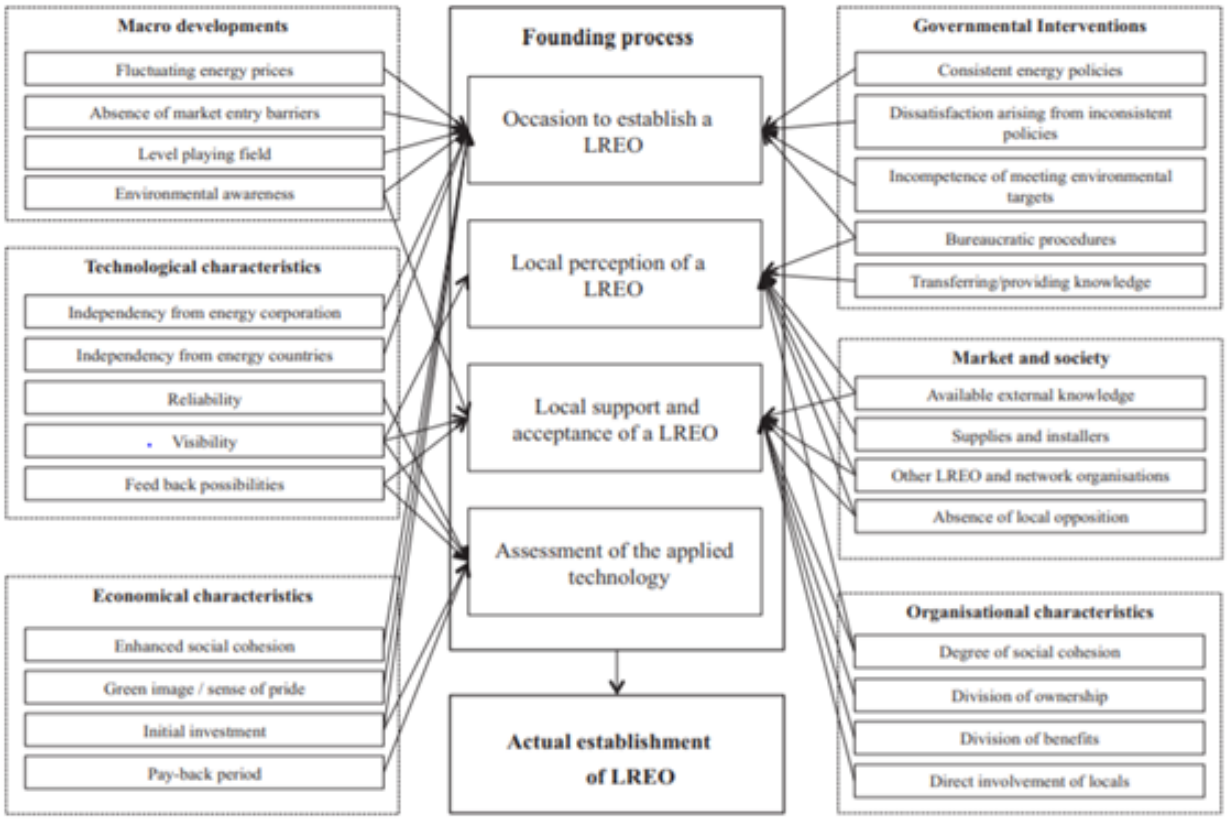


FIGURE 2.4: 26 factors that play a role in the founding process of LREOs from Boon & Dieperink (2014)

the game (absence of market entry barriers, bureaucratic procedures, providing knowledge), resource allocation (division of ownership and benefits, fluctuating energy prices) Künneke (2008).

2.2.4 Modelling the founding of LREOs in ABM

Ghorbani et al. (2020) also studied the emergence of LREOs within an Agent Based Model. Within their model Ghorbani et al. (2020) successfully integrated the theory of Martiskainen (2017) on leadership with the motives of environmental concern, trust, and personal gain to study the behavioural factors that influence the emergence of LREOs. Within their research Ghorbani et al. (2020) showed that a high number of citizens with leadership capacities is conducive for the successful establishment of LREOs. Where the study of Ghorbani et al. (2020) mainly focused on behavioral dynamics within the emergence of LREOs, this study is centralized around the required cognitive components (motives, responsibility and leadership capacities) for the participation in LREOs.

Chapter 3

Model Conceptualisation and Formalization

This chapter describes how the conceptual model is formalized within Netlogo 6.1.2. To structure the description of the agent based model in a concise and neat manner, this section starts with a short description of the conceptual model followed by the model formalization that follows the ODD (Overview, Design concepts, Details) protocol of Grimm et al. (2010). Lastly, a complete overview of all assumptions can be find in Section 7.1.

3.1 Conceptual model

The purpose of this model is to illustrate how the recognition of the sustainability related concerns, evoked by climate events, will affect the value systems of citizens in such a way that it leads to the emergence of LREOs. The model represents a mini world with 4000 citizens which are divided into three equal neighbourhoods based on their income. Each citizen represents a homeowner (adult) who has authority over how to organize their electricity supply. These citizens are equipped with value prioritization systems (Schwartz et al., 2012; Ghorbani et al., 2021), OCEAN-traits (McCrae & Costa Jr, 1992; Goldberg, 1993), income, education level and leadership level that all together influence the decision making behavior. At the start of the simulation, every citizen is unaware of climate change and consume electricity generated by market entities who use fossil fuels. Over the course of the simulation (see Figure 3.1), information about climate events causes citizens to recognize sustainability (belief system), which will - depending on their value prioritization (desire) and leadership-level (capacity) - lead to the new plans to change their energy supply from an energy provider using fossil fuels to sustainable alternatives (intention).

Sustainability is recognized by completing a three-step process (responsibility mechanism) of gathering information, acknowledgement of one's own contribution, and believe in individual impact (Robeyns, 2017)[1]. The chances to successfully complete this three-step responsibility process is increased for those with a high educational background (based on a combination of traits and access to education (income)) and high scores for the conscientiousness, openness to experience, agreeableness and extraversion traits. Completing the responsibility mechanism for the first results in a change in belief system of citizens that allows them to choose alternative energy suppliers.

[1]The fourth control mechanism, the willingness to change current standards is not included in the responsibility cycle but is related to the value prioritization (willingness) of individuals

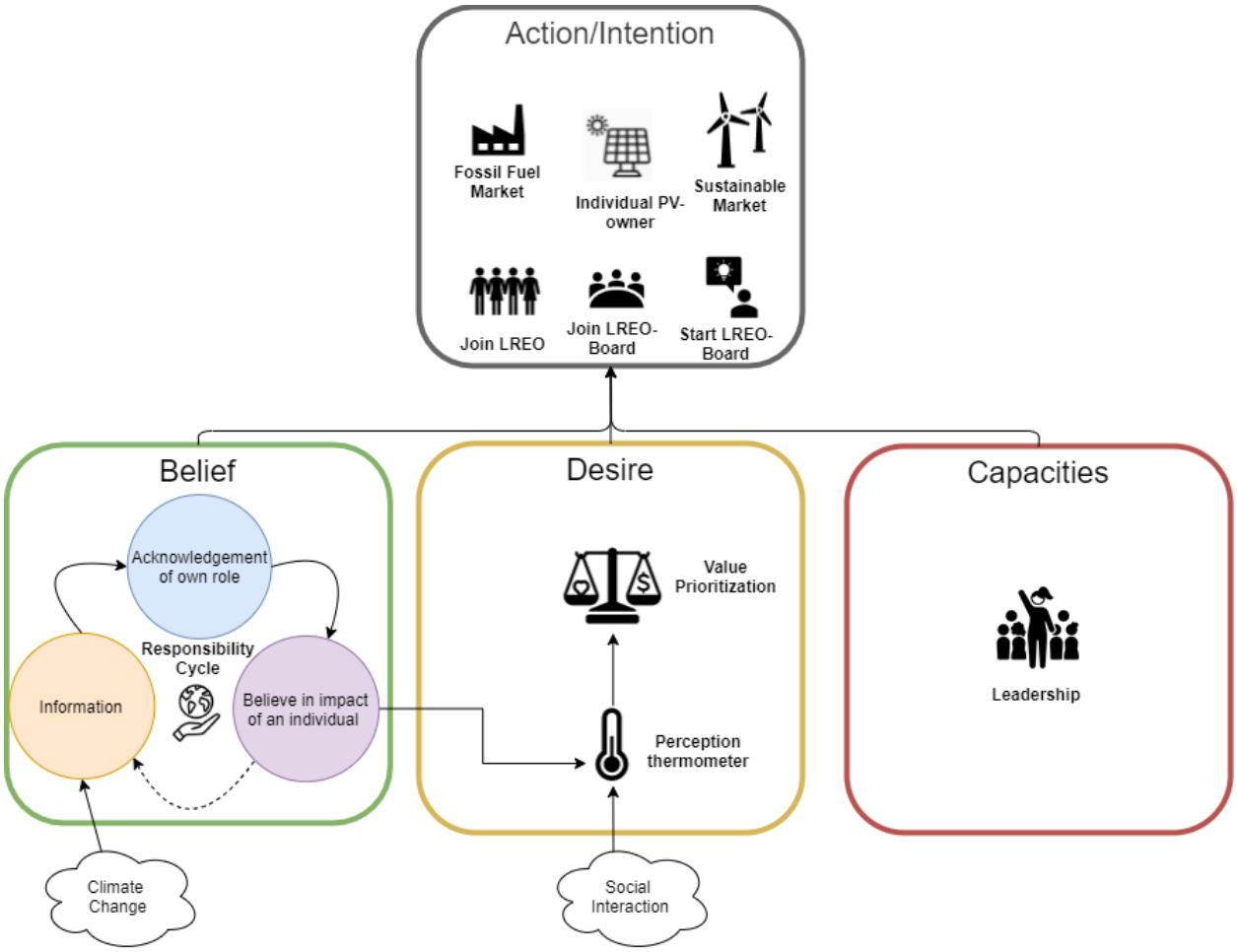


FIGURE 3.1: The cognitive architecture of agents expressed in the belief, desire & intention model of Georgeff et al. (1998)

Completing the responsibility mechanism for the second time or more, will indirectly result in an increase prioritization in self-transcendence values and a decrease in self-enhancement values.

The desire of citizens to change supplier is conceptualized by using value prioritization as motives for different actions. The motives to change energy supplier can be for sustainability reasons (both climate change and energy justice by prioritizing universalism and benevolence), energy autarky (by prioritizing self-direction) and financial profit (by prioritizing power). The prioritization of values are influenced by interactions between citizens and their environment. Instead of directly influencing the prioritization of value systems, completing the responsibility mechanism and interactions between citizens will change perception thermometers of values that act as an buffer between the experiences (e.g. change in belief systems) and value prioritizations. So only when citizens are subject to constant pressures of uniform directed experiences, the perception thermometers will start to boil/freeze and the prioritization will the related value will increase/decrease.

The third component that influence the available energy supplying alternatives is the capacity to lead. Having the leadership capacities depends partly on the openness and conscientiousness traits and on the other hand on the external factors like education level, capacity

training and consistent energy policy by the government and existing examples of LREOs (see Section 3.3.7). Citizens who are capable to lead can start start or join the board of an LREO, while others with lower leadership capacities can only support LREO initiatives.

Citizens who recognize sustainability (belief system), have the right value prioritization (desire), are community oriented (prioritize benevolence) and have leadership capacities, decide to start an LREO initiative. LREO initiatives have to go through a four-step process (board formation, agree on organisational form, agree on technologies and finding supporters) before the LREO can be considered 'founded' (see Figure 3.2). Whenever the formation process fails at one of the steps (e.g. due to disagreements or not having enough members), the LREO will be dissolved. In the case of the absence of LREOs within their neighborhood, citizens who have the belief and desire to change energy supplier, will choose to switch to a commercial sustainable energy supplier. Alternatively citizens who recognize sustainability (belief system), and have sufficient income, but are not community oriented, will decide to purchase solar pv-panels on an individual basis.

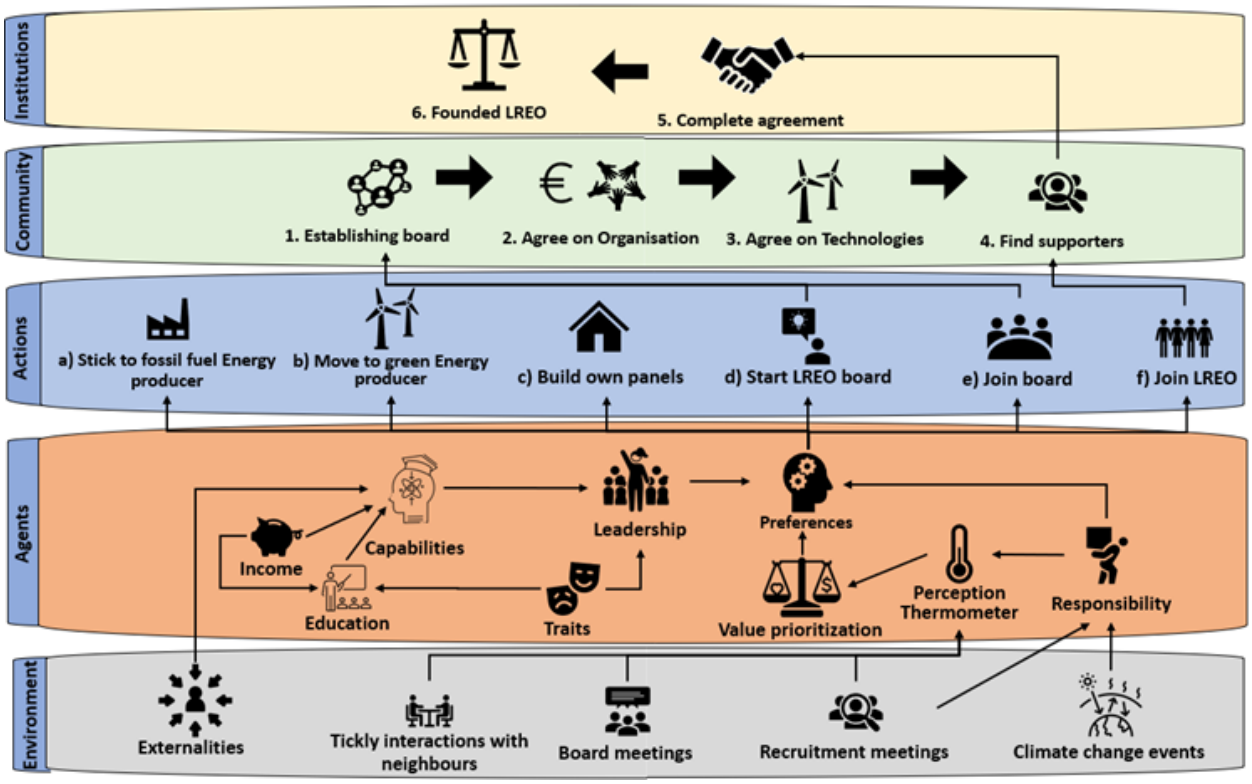


FIGURE 3.2: Conceptual model which shows the five different levels within the model: environment, agent, actions , community and institutions.

3.2 Modelling Purpose

The purpose of this agent based model is to illustrate the role of value change on the emergence of LREOs within the Dutch Energy system. During this simulation, citizens, with predefined attributes (e.g. values, traits, education and income), walk through a three-step process of integrating sustainability within their personal value system, which will ultimately influence their decision

making for selecting their preferred energy resource. The central goal of the model is to see how the adoption of sustainability induces a change in prioritization and specification of values and how these changes will eventually lead to the emergence of LREOs.

3.3 Entities, state variables and scales

This model contains two different entities: citizens and LREOs. The central entity (citizens) within the model are 4000 adults which represent the head of households that have authority over the way they organize their energy provision within their household (e.g. homeowners, tenants with authority over their energy contracts). The citizens within the model have seven different attributes: values, character traits, responsibility-level, education, income, leadership, energy-supplier.

3.3.1 Citizens: Values

First of all, citizens are equipped with the ten personal values from the Schwartz value circumplex (see Section 2.1.1). Personal values determine the preferences of individuals during the decision-making process of organizing their energy provision. Based on the value orientation to which the citizens belong, each personal value is given a number between 0 (low prioritization) and 100 (high prioritization). To generate the value systems of individuals I selected four different value orientations: *Growth*, *Personal-Focus*, *Self-Protection*, and *Social-Focus*. Within each value orientation, each of the affiliated personal values has a high prioritization, while conflicting personal values have a low prioritization (see Table 3.1). To generate unique value systems, the personal values are determined using a normal distribution in which the mean is high (**value-facet-mean** [2]= 75) and low (100 - **value-facet-mean** = 25) for respectively affiliated and conflicting values. The standard deviation for the normal distribution can be adjusted with the **value-std-dev** parameter (default = 15).

In order to create coherent value systems, the value systems of individuals are adjusted in such a way that personal values that are closer to one another within the Schwartz Value Circumplex (e.g. benevolence & universalism) should have similar importance levels, while values that are on the opposite side of the circle should have dissimilar importance levels (see Figure 3.3). The configuration described above is based on the value configuration used in Ghorbani et al. (2021).

3.3.2 Citizens: Character traits

Citizens are equipped with five different traits based on the OCEAN model of McCrae & Costa Jr (2008): Openness to experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (see Section 2.1.1.2). Similar as for the personal values, the traits have a value between 1 and 100 in which a score of 1 means a low affiliation with the given trait while a score of 100 means a high affiliation with the given trait. According to McCrae & Costa Jr (2008) "the development of personality traits occurs through intrinsic maturation, mostly in the first third of life but continuing across the lifespan; and through other biological processes that alter the basis of traits" (McCrae & Costa Jr, 2008, p. 165). Within the model the character traits are assumed to be static as 1)

[2]Within this chapter, descriptions in **'bold'** show the adjustable input parameters of the model

TABLE 3.1: Value score for the different groups of value orientations (Schwartz et al., 2012)

	Growth	***Personal-Focus***	***Self-Protection***	***Social-Focus***
Self-Direction	High	High	Low	Low
Stimulation	High	High	Low	Low
Hedonism	High	High	Low	Low
Achievement	Low	High	High	Low
Power	Low	High	High	Low
Security	Low	Low	High	High
Tradition	Low	Low	High	High
Conformity	Low	Low	High	High
Benevolence	High	Low	Low	High
Universalism	High	Low	Low	High

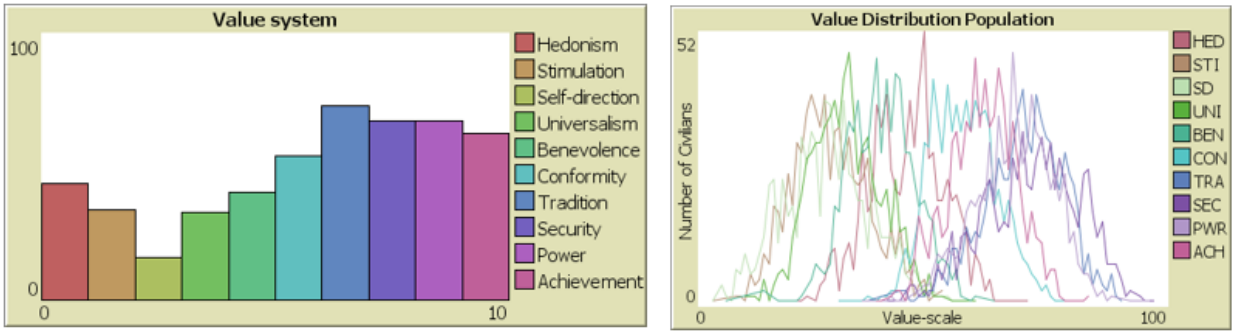


FIGURE 3.3: Value system of citizens with a *Self-Protection* value orientation with on the left side a visualization of the value prioritization of one individual and on the right side the distribution of value prioritization of the whole population.

the citizens impersonate adults after the first third of their lives and 2) the external events and interactions that occur during the simulation do not affect the biological processes that alter the basis of traits. Traits play a role in determining i) the leadership skills of an individual, ii) on the impact of information, iii) the education level, iv) the adoption of new values, v) the impact of interactions on their value system and vi) social learning.

The configuration of traits is based on the meta-analysis of Parks-Leduc et al. (2015) on the correlation between Schwartz's values and OCEAN traits. Their meta-analysis has shown a consistent correlation between OCEAN traits (all except neuroticism) and Schwartz's values (see Figure 2.2 and Table 3.2). As traits only partly correlate with values, it is assumed that to compute the trait system of an individual the OCEAN traits are drawn from a random normal distribution with a weighted mean based on the individual' value system and an adjustable standard deviation parameter called **trait-std-dev** (default = 10). As the neuroticism trait does not have any significant correlation with any of the Schwartz' values, the neuroticism trait is computed based

on a random normal distribution with a mean equal to the **neuroticism-trait-population** (default = 50) and a standard deviation equal **trait-std-dev** + **neuroticism-extra-std-dev** (default = 8) to compensate for the lack of variety.

TABLE 3.2: Correlations between OCEAN-traits and Schwartz values based on Figure 2.2 in Parks-Leduc et al. (2015)

OCEAN-traits	**Related Values (relationship)**
Openness	Stimulation (*Pos*), Achievement (*Pos*), Universalism (*Pos*), Conformity (*Neg*), Tradition (*Neg*), Security (*Neg*)
Conscientiousness	Achievement (*Pos*), Conformity (*Pos*), Security (*Pos*)
Extraversion	Power (*Pos*), Achievement (*Pos*), Hedonism (*Pos*), Stimulation (*Pos*)
Agreeableness	Power (*Neg*), Universalism ((*Pos*), Benevolence, (*Pos*), Conformity (*Pos*), Tradition (*Pos*)
Neuroticism	-

3.3.3 Citizens: Responsibility-level

The **responsibility-level** attribute indicates the degree to which citizens have adopted sustainability within their personal value system. At the start of the simulation, the **responsibility-level** of every citizen equals the state of ignorance (step 0). Over time the **responsibility-level** will change due to the responsibility-mechanism from the state of ignorance towards the state of being informed (step 1), the state of acknowledgement (step 2), up to the state of believing in the impact of individual change (step 3) (see Figure 3.10 and Table 5.1). For a full description of the responsibility mechanism see Section 3.6.2.

3.3.4 Citizens: Income

The income level determines in which neighbourhood citizens live and their capacities to take a leadership role in acting on a community level. To generate a validated income distribution within the simulated population, the income distribution of the Netherlands in 2019 (Statline, 2021) is regenerated (see Figure 3.4) using a gamma distribution determined by the α equals capital-alpha (default = 6), and λ equals capital-lambda (default = 0.014) times the **income-modifier** (default = 80) with a minimum level of 4000.

3.3.5 Citizens: Neighbourhood & friendly neighbours

The simulated population is divided into three separate neighbourhoods with an equal number of citizens. The top $\frac{1}{3}$ of the population with the highest income level live in the neighbourhood "high-income", the second $\frac{1}{3}$ of the population lives in the "medium-income" neighbourhood and the $\frac{1}{3}$ with the lowest income levels live in the "low-income" neighbourhood. Each citizen has a friendly relationship with an adjustable number #**neighbour-friends** (default = 7) of other citizens from

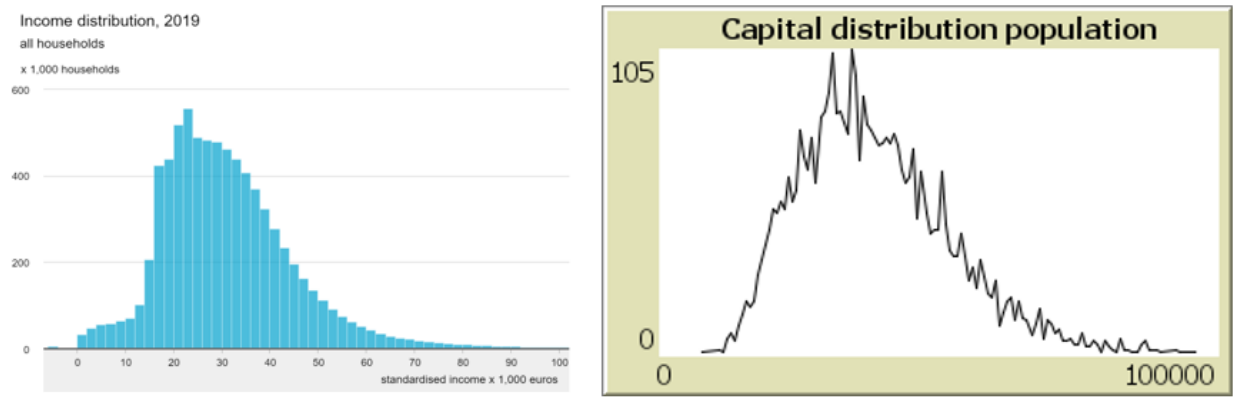


FIGURE 3.4: Comparison of the income distribution within the model (the right picture) and the actual income distribution of the Dutch society in 2019 according to Statline (2021)

the same neighbourhood. These friendly neighbours are important within the change in value prioritization procedure (see Section 3.6.6).

3.3.6 Citizens: Education level

The education level of citizens can vary between three levels: high, medium, and low. Research by Hazrati-Viari et al. (2012) has shown that there is a positive correlation between the level of education and the conscientiousness and the openness to experience traits. So scoring high (trait $>$ **high-educ-trait-level** (default = 42)) or medium (trait $<$ **medium-educ-trait-level** (default 25)) on both traits results in respectively high or medium education level. Data comparing education and income however show that on average citizens with a higher education level earn more money than citizens with a lower educational background) (OECD, 2020). Moreover, research has shown that growing up in a high-income family rather than a low income family will give children three times the chance of achieving an college qualification and five times the chance earning a university degree (Rotterdam, 2020). As educational performances are related to the traits of citizens (which are independent of income), it is assumed that lower-income neighbourhoods have limited access to education **access-to-education-high-income** (default = 100%), **access-to-education-medium-income** (default = 80%), and **access-to-education-low-income** (default = 60%). Within the model the educational level determines the capacity to process information and to take a leadership role. For the processing of information every citizen has an information modifier which reduces the impact of the information during the responsibility mechanism. The information-modifier is the product of agreeableness-trait, openness-trait and the **high-/medium/low-education-information-modifier** (see Figure 3.10 in Section 3.6.2). It is assumed to be more open and the more agreeable an individual is to new information on a particular topic, the bigger the impact the information has on the belief system of an individual.

3.3.7 Leadership level

The leadership level of citizens indicates whether citizens are capable of starting LREOs. The leadership level of citizens is determined by the combination of leadership skills and the capacity reduction parameter. Leadership skills is a combination of three core processes: learning (pursuing information and communicate that information to others), coupling of expectations (formulate and manage expectations about the project, and network formation (create a network with both the community and other stakeholders) (Martiskainen, 2017; Ghorbani et al., 2020)). Within this model, the learning process is linked to the openness trait (Facet O5: Ideas) (Schmitt et al., 2007, Table 3), and the coupling of expectations and network formation is linked to the extraversion trait (respectively Facet E3: Assertiveness and Facet E1: Warmth) (Schmitt et al., 2007, Table 3). The other determinant of the leadership levels is the capacity-reduction parameter. The capacity-reduction parameter is a combination of citizen-dependent and external factors that influence the ease/difficulty to start an LREO (see Figure 3.5). For each of the factors; 1) having a low education level, 2) a low-income level, 3) the absence of **capacity-training**, 4) the absence of **consistent energy policy**, and 5) the absence of an existing LREOs, the capacity-reduction parameter will be increased equal to the **leadership-reduction-due-circumstances** (default = 3) parameter. So the final leadership level of citizens is high for citizens of which the leadership skills minus the capacity-reduction score is higher than the **high-leadership-threshold** (default = 70) and 'medium' for citizens of which the leadership skills minus the capacity-reduction score is higher than the **medium-leadership-threshold** (default = 65). All other citizens have low leadership skills.

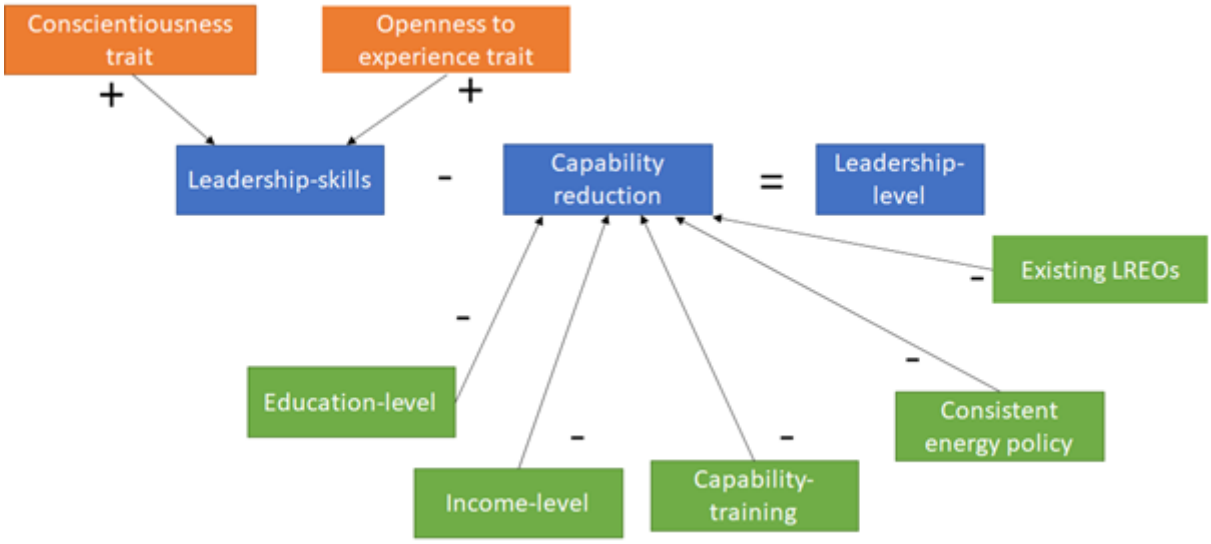


FIGURE 3.5: Factors influencing the leadership level of citizens

3.3.8 Citizens: Energy Supplier

Citizens can select between 4 different energy suppliers: 1) Fossil fuel market (market entity that supplies fossil fuel generated electricity), 2) Sustainable market (market entity that supplies

sustainable generated electricity), 3) individual pv-owner (citizens buy solar pv panels for individual use), and 4) LREO (citizens organize themselves in a Local Renewable Energy Organisation (LREO) to start energy projects on a community level or to jointly purchase energy technologies. Within the organization of an LREO citizens can have an active role (board membership) or a passive role (supporter).

3.3.9 LREOs

The other entity within the model are LREOs. LREOs are hatched by citizens and have to go through a founding process to exist until the end of the simulation (max 10 years). If the founding process fails, the LREO dissolves (dies). During the founding process LREOs go through the following sequence of states: 1) start of the board, 2) looking for board members, 3) agree on organizational form, 4) agree on technology, 5) looking for supporters, 6) founded. LREOs are located in one specific neighbourhood and only those citizens that are living in the same neighbourhood as where the LREO is located can become members or supporters. LREOs differ from another on organisational form (collective purchasing vs energy project), technology (sustainable sourced vs cheap sourced), location (neighbourhood) and the number of supporters.

3.3.10 Temporal and spatial scale

One time step in the model is equal to one week in reality and the simulations are run for ten years years (520 ticks). The time period of 10 years is chosen because the focus of this model is on the emergence of LREOs caused by individual value change and not on the dynamics that occur within LREOs after the foundation. Tests have shown that simulating the model for ten years provides enough simulation time for the recognition of the sustainability related concerns and the emergence of LREOs (see Section 4.1). The model does not have a spatial scale.

3.4 Process overview and Scheduling

The order in which the procedures are scheduled within the model is visualized in Figure 3.6 (white boxes are executed by the observer, red boxes are performed by citizens and green boxes are performed by LREOs). Procedures executed by citizens and LREOs are executed in a random order and state values calculated by a process are updated immediately (asynchronous updating). Last, time moves forward in discrete steps.

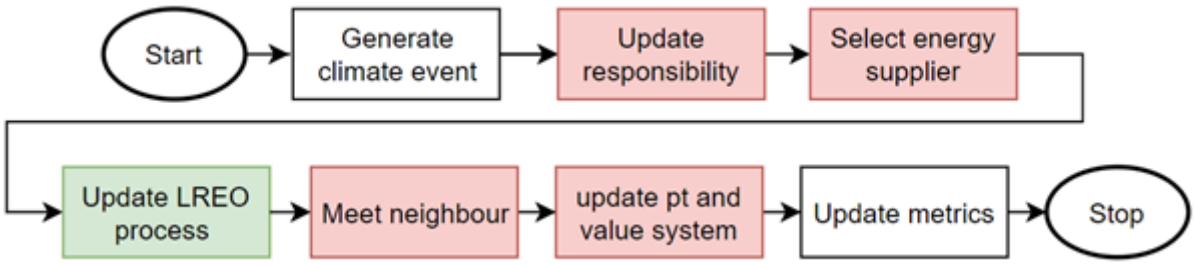


FIGURE 3.6: Overview of the sequences of the different procedures within the model

3.5 Design Concepts

3.5.1 Basic Principles

The underlying hypothesis of this model is to illustrate how the recognition of the sustainability related concerns, caused by climate events, will affect the value systems of citizens in such a way that it leads to the emergence of LREOs. To add the dynamic component to cognitive architectures of citizens the existing theories (see Figure 3.7) on value prioritization (Schwartz et al., 2012), traits (McCrae & Costa Jr, 2008) and leadership (Martiskainen, 2017) are combined with the theory on responsibility (Robeyns, 2017) and usage of the new concept of perception thermometers to model change in value prioritization (For full explanation of each theory see Chapter 2). Next, based on the theory of value sensitive design (Van de Poel, 2013), the dynamic cognitive architecture is linked with capacities to let citizens select a preferred option out of a limited set of options on how to organize their energy supply. These decisions could ultimately result in the emergence of LREOs, which follows a founding process based on the research of Boon & Dieperink (2014). The model will provide insights on how different types of theories can be combined into a workable cognitive architecture and also showcases how this cognitive architecture can be used in a real-world scenario of selecting energy-provision.

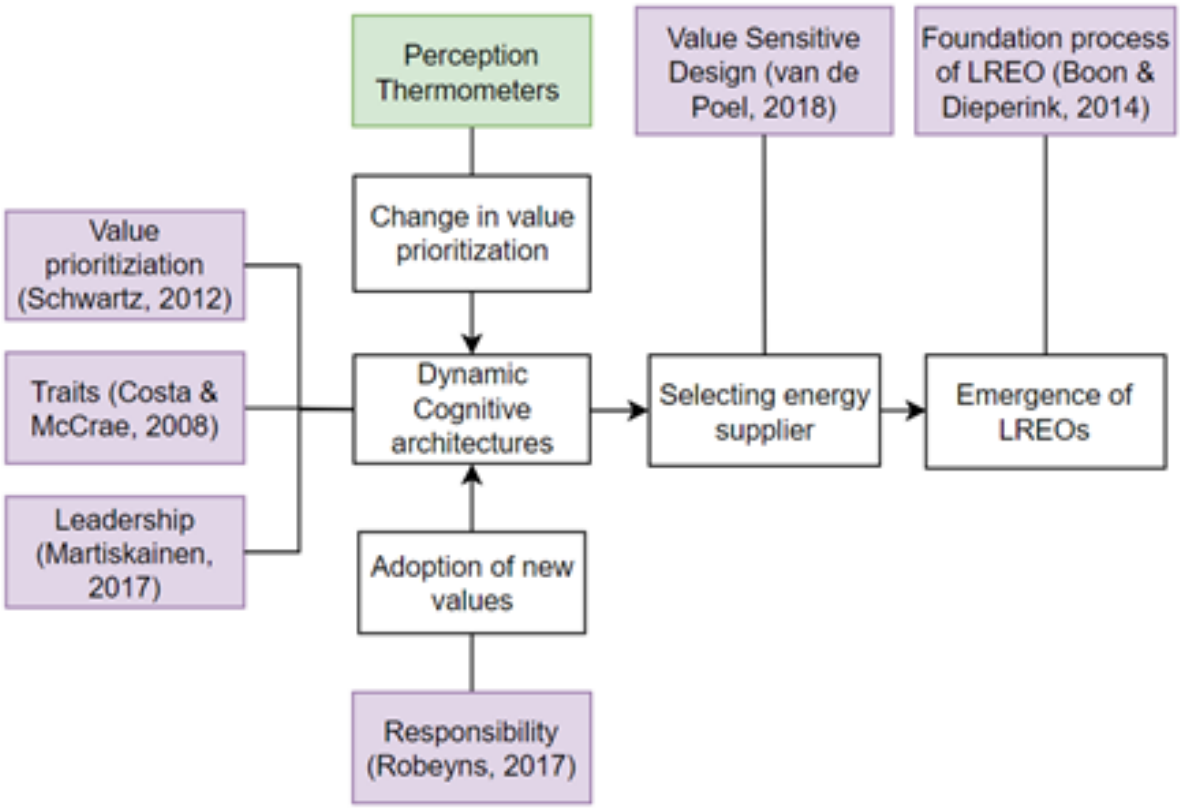


FIGURE 3.7: Overview of the different theories used within the model

3.5.2 Emergence

The emergent output of the model are the establishment of LREOs, which vary in the number of board members, disagreements during foundation, and supporters and which have differences in organisational form and in material sources (Boon & Dieperink, 2014). The model outcome is a combination of the strength and stochasticity of climate changing events, the value orientation(s) within the population, the externalities influencing the leadership capacities and stochasticity during value adoption.

A second form of emergence is visible in the change of value prioritization. Due to completion of the responsibility in combination with social learning by social competent and receptive individuals of homogeneous populations (populations with similar value orientations) the ascribed importance to sustainability related values increases. This trend is however not visible in the heterogeneous populations (see Section 5.2.2.1 and Section 5.2.2.2 for more information).

3.5.3 Adaptation, objectives, learning, prediction and sensing

The adaptive attributes that citizens have are having different preferences for organizing their energy supply due to changes in their responsibility level and value prioritization. Citizens are assumed to be completely rational and to know which options will satisfy which values in which magnitude. Preferring option A over option B does not imply being more successful than someone valuing option B over A. So, the only objective that drives people to make alternative decisions on their energy supply is to check whether their current preferences are satisfied by current decisions made. The learning aspect of this model is quite limited. The only existing feedback loop is integrated in the board formation of LREOs. Whenever a board member decides to leave a board, due to a disagreement on organization form or technology, he/she will not join the same board when it's looking for new board members. Lastly, the model does not contain any form of comparing predictive consequences with realised consequences that results in the adaptation of behavior, nor does citizens use any form of sensing within the model. New information on climate change is assumed to be immediately known to every citizen within the model.

3.5.4 Interaction and stochasticity and Collectives

Interaction between citizens occurs during three different occasions; tickly neighbouring-friends meetings, board meetings, recruitment meetings. These are direct interactions as citizens with convincing characteristics (high score on extraversion trait) directly adjust the perception thermometers of citizens which are more accommodating (high score on agreeableness trait).

Stochasticity is used in the responsibility mechanism as the climate change events are generated by an exponential distribution. Moreover, continuing to the next step of responsibility is also party random. Where for the impact of climate changing events stochasticity is used to create behavior with a specified frequency, for continuing to the next step of responsibility however stochasticity is used as simplification for the process why people grow to the next step or not. Next, for simplicity reasons, the social networks (neighbouring-friends) within neighbourhoods are also generated randomly (see Figure 3.8). Within the model LREOs are the only collective entity. LREOs emerge as organisations when individual citizens are able to establish a board, come to

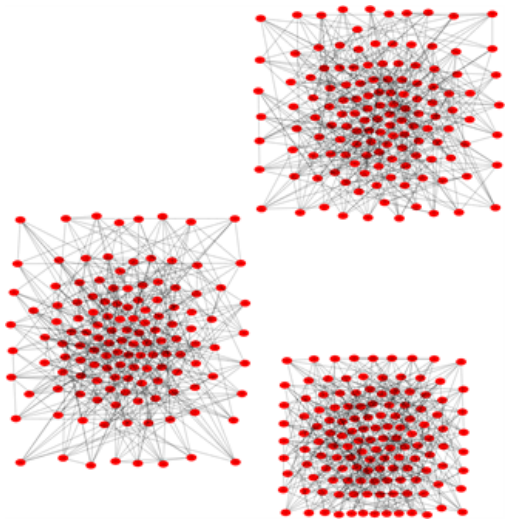


FIGURE 3.8: Overview of the connection between friendly-neighborhood relationships within the model

agreement on the organisational form and material sources, and find enough supporters within the neighbourhood within a limited amount of time.

3.5.5 Observations

The model output generated the following key performance indicators:

1. Number of citizens per responsibility level (0 = unaware. 1 = informed, 2 = acknowledging, 3 = believing, 4 = willing, 5 = capable),
2. Average responsibility-level of the entire simulated population,
3. Average percentage of value change for each value of the entire simulated population,
4. Number of LREO-supporters.

Each of the indicators are collected every tick to see how the different indicators differ under different circumstances over the course of the simulation

3.5.6 Initialization

At the start of the simulation there the simulated environment consists of 4000 citizens equally distributed among the three neighbourhoods based on their income-level. Each citizen has seven random friends from their own neighbourhood which they tickly meet. At the initial state every citizen is unaware of the climate problem meaning that their responsibility level is at step 0 (unaware) and the information tank is empty. In Table 3.3 for every topic the input-parameters are listed with the default setting. Default settings without a reference are assumptions. The model does not use external input data to represent time-varying processes."

TABLE 3.3: Overview default settings input-parameters

Topic	**Input-Parameter**	**Default setting**
General	Static-Seed?	False
	# Neighbour-friends	7
	Population	4000
Values	Population-scenario	*Mixed*, *Growth*, *Personal-Focus*, *Self-Protection*, *Social-Focus*
	Value-facets-mean	75
	Value-std-dev	15
	Value-system-calibration-factor	20 (Heidari et al., 2020)
	Value-change-para	5
Traits	Trait-std-dev	15
	Emotionality-trait-population	50
	Emotionality-extra-std-dev	8
Income	Capital-alpha	6 (Statline, 2021)
	Capital-Lambda	0.014 (Statline, 2021)
Education	Access-to-education-high-income	100
	Access-to-education-medium-income	80
	Access-to-education-low-income	60
	Medium-educ-trait-level	25
	High-educ-trait-level	42
	High-education-information-modifier	1
	Medium-education-information-modifier	0.75
	Low-education-information-modifier	0.5
Leadership	High-leadership-threshold	65
	Medium-leadership-threshold	60
	Capacity-training?	True
	Consistent-energy-policy?	True
	Leadership-reduction-due-circumstances	3
Impact information	CC-event-mean-exponential-distribution	3
	Percentage-reading-news	100

	Raw-recruiting-information-impact	30
Perception Thermometers	Pt-rsq-modifier	0.08
	Ptc-neighbour-meeting	8
	Ptc-board-meeting	8
	Ptc-climate-awareness	40
	Ptc-recruiting-event	17
Selecting energy supplier	Willingness-to-switch-threshold	65
	Community-threshold	50
Responsibility mechanism	Responsibility-threshold	5
	First-order-awareness-threshold	75
	Second-order-awareness-threshold	20
Individual PV owners	Initial-price-pv-panels	38000
	Floor-price-pv-panels	12000
	Price-decay-pv-panels	0.0008
Individual PV owners	Min-board-members	5
	Max-board-members	8
	Min-supporters	30 (Schwenke, 2021)
	Max-ticks-to-find-supporters	10
	Max-ticks-establish-board	10
	Project-vs-purchase-preference	65

3.6 Submodels

3.6.1 Process: Generate-climate-event

A simulation round starts with the generation of the impact of the climate-changing event, which will be used as input of the responsible mechanism. The impact is stochastically determined by an exponential distribution of which the mean is determined by **CC-event-mean-exponential-distribution** (default = 3). In Figure 3.9 an example is given of how the impact evolves over a period of two years (104 ticks).

3.6.2 Process: Update-Responsibility

The submodel update-responsibility resembles the process within the minds of citizens to recognize sustainability concerns about the environment caused by climate changing events. During this process, citizens recognize sustainability by placing sustainability within the transcendence value orientation of the Schwartz' value complex. Sustainability is not seen as a separate new value but

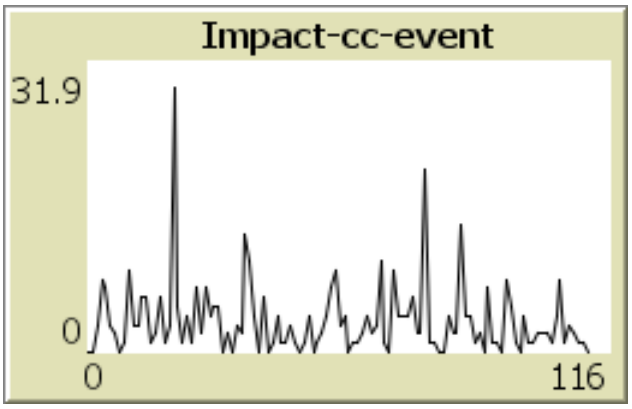


FIGURE 3.9: Example of the magnitude of the impact of the climate events within the model

as a new way of specifying the Universalism and Benevolence values (Dietz et al., 2005; Steg & De Groot, 2012). Next to the recognition of the sustainability related concerns, the responsibility mechanism also works as a driver for giving more importance (prioritization) to the sustainability-related values of benevolence and universalism. The responsibility mechanism is based on the work of (Robeyns, 2017) that describes four control mechanisms that humans use to not act in a responsible way. These four control mechanisms are 1) the knowledge mechanism in which people don't have the sufficient amount of knowledge about the problem (climate change), 2) the in acknowledgment mechanism in which humans don't acknowledge their own contribution to the problem, 3) believe mechanism in which humans don't believe that changing behavior on an individual level will result in solving the problem and 4) the willingness mechanism in which humans are (not) willing to give up comfort and old habits. Within this model the first three control mechanisms make up the responsibility mechanism, the fourth mechanism, the willingness, is conceptualized by preferring sustainable over other alternatives by prioritizing the sustainable related values over other values.

The submodel 'update-responsibility' can be called on two occasions:1) every tick after the generate-climate-event and 2) during a recruiting-event of an LREO looking for supporting members. Within this submodel (see Figure 3.10) agents walk through the responsibility mechanism that will eventually lead to the recognition of the sustainability related concerns within the personal values (first cycle) and change in value prioritization (other cycles). During the first step of the mechanism, citizens accumulate awareness about climate-changing events in an information tank. As the actual awareness of climate change varies for individuals, the increase of the information tank is determined by the product of the impact of the event (e.g. recruiting-event/climate event) and the information modifier. The information-modifier is an individual attribute that is the product of the educational level (high-/medium-/low-education-information-modifier), the agreeableness-trait, and the openness-trait. Whenever the information tank is filled up to the **-order-awareness-threshold** (default = 75), the responsibility level increases to step 1 (being informed). The second and third step of the responsibility mechanism is to reach the stage of acknowledgment of one's own role and the belief in individual change through two different steps. At first, it is assumed that to reach these stages the individual awareness increase should be higher than a given threshold. This threshold resembles the moment of reflection in which people reflect on their

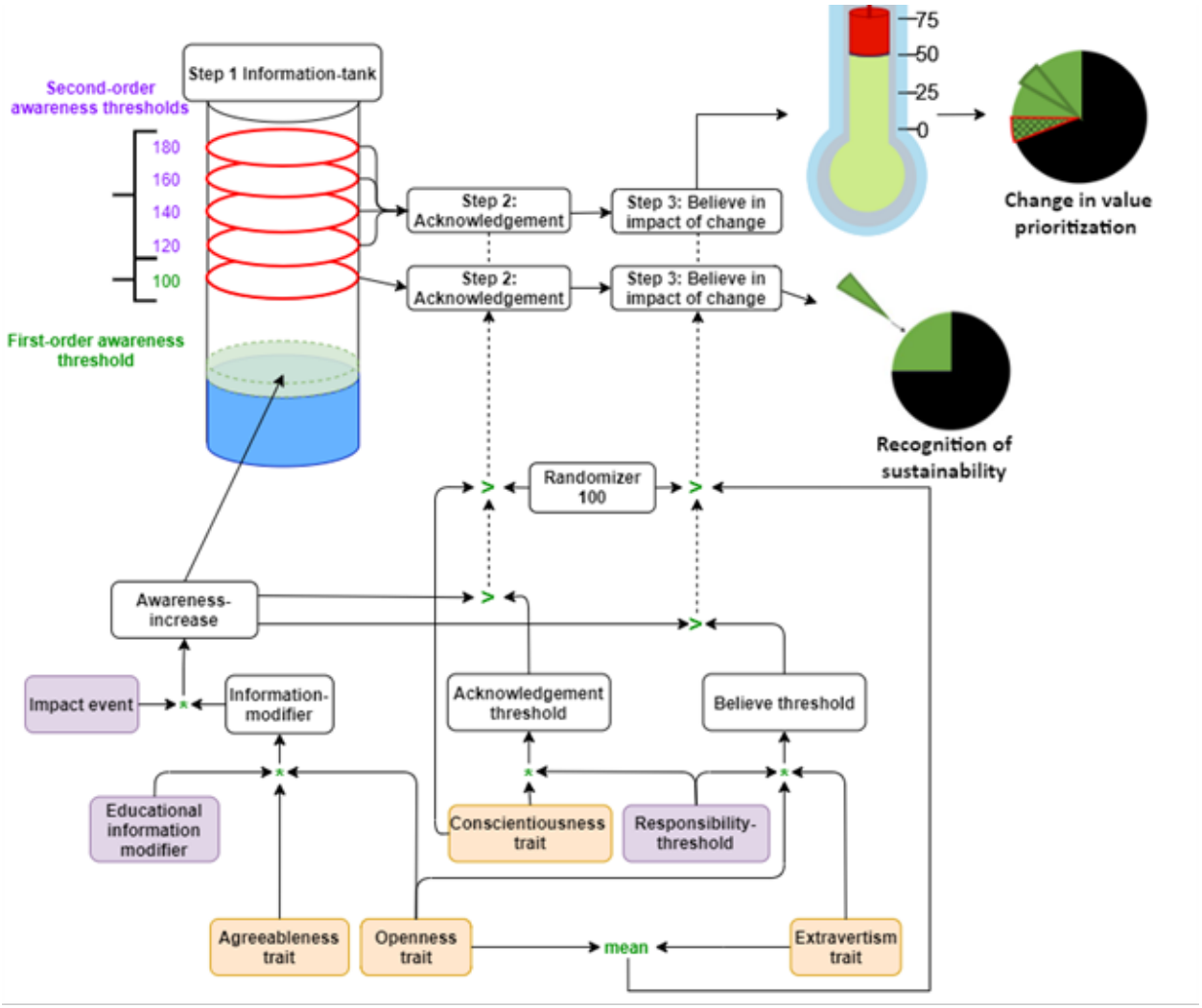


FIGURE 3.10: Flow diagram of the responsibility mechanism

actions and adapt according to their new beliefs. As some individuals are more conscious in their actions than others these thresholds are character-based. The acknowledgment threshold is the product of the conscientiousness trait and the global variable **responsibility-threshold**, and the belief threshold is the product of the mean of the openness trait and extraversion trait with the **responsibility-threshold**. Second, to add some randomness to this process and create emergent behavior, the related trait(s) should be higher than a randomizer (0-100). In this way, individuals that score higher on respectively conscientiousness and/or extraversion and openness are more likely to reach the acknowledgment and belief stage. Whenever individuals reach the stage of belief they have completed the responsibility mechanism and successfully recognized sustainability within the Schwartz value circumplex. Recognition of a concept however does not mean you give priority to the concept, so individuals continue with a new responsibility mechanism by filling the information tank up the second threshold (defined by the **second-order-awareness-threshold**). Completing the responsibility mechanism for the second time (or more) will indirectly change the prioritization of values by increasing the perception thermometers of the sustainability-related values (universalism

and benevolence) with the **ptc-climate-awareness** parameter.

3.6.3 Process: Selecting energy producer

This submodel determines how citizens select their energy supplier. Citizens can select between four different types of energy supply. At the start of the simulation, every citizen has an energy contract with a market party who uses fossil fuel sourced energy. Based on their attributes, which develop overtime during the simulation, citizens can change their energy supplier to 1) a market party using sustainable technology to generate electricity (SM), 2) buy PV panels for individual use (pv-panels), or 3) start/join a local renewable energy community (LREO). Within this submodel, citizens walk through two selection procedures. During the first procedure (Figure 3.11), citizens with FFM as an electricity supplier have to decide whether they want to switch to a sustainable market (SM) supplier. Citizens who have successfully recognized sustainability (completing the responsibility cycle) and who give a high priority to sustainability-related values (μ (benevolence, universalism) > **willingness-to-switch-threshold** (default = 65)).

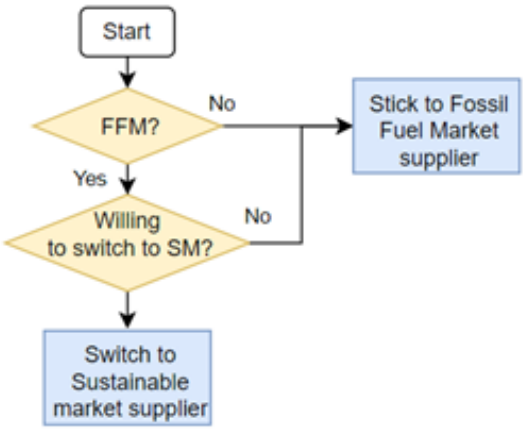


FIGURE 3.11: Flow diagram of selecting sustainable market supplier.

During the second procedure, every citizen with FFM or SM as electricity supplier (so also citizens that switched supplier during the first procedure), will go through this procedure to see whether they are willing and capable to change their energy supplier to pv-panels or to an LREO (see Figure 3.12). Citizens who already own pv-panels or who are a member of a founded LREO are assumed to stick to their chosen energy supplier due to sunk investments. For citizens to change they first have to be willing to do so. Citizens are considered to be willing to change their supplier, whenever they successfully recognize sustainability (completing the responsibility cycle at least ones). Moreover, citizens also are required to give a high priority (> **willingness-to-switch-threshold**) to one of the following values: 1) power, self-direction or μ (benevolence, universalism). These values are essential as it is assumed that citizens can have three different motives (profit (power), autonomy (self-direction), and/or sustainability (μ (benevolence, universalism)) to change their energy supplier (Brown et al., 2020). When citizens are prepared to change their supplier they have to choose whether they want to start/join an initiative on a community level (LREO) or

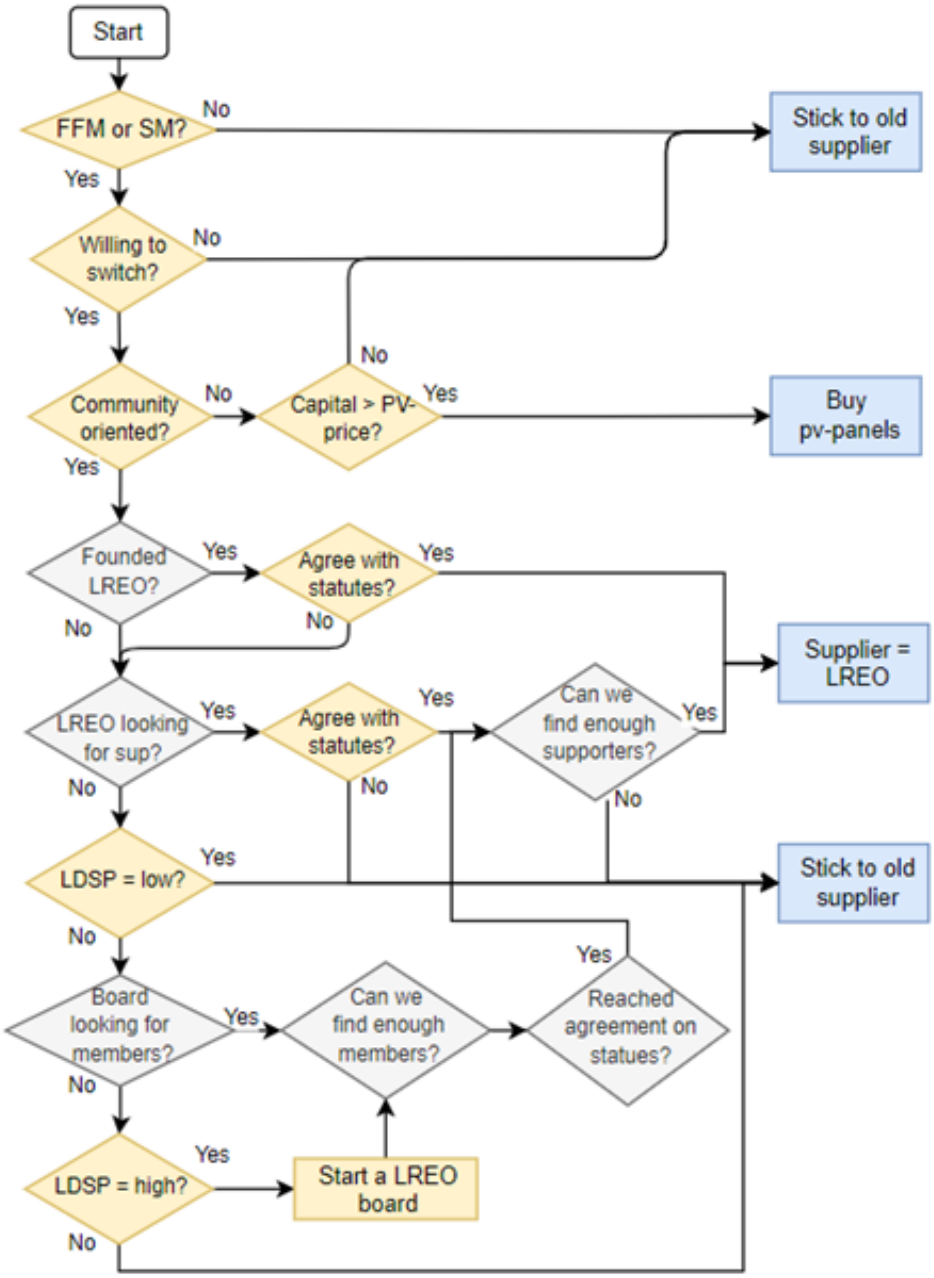


FIGURE 3.12: Flow diagram of selecting LREO or solar pv-panels on individual basis.

whether they want to remain on the individual level (pv-panels). The leading factor to decide to act on a community-level is based on how much priority is given to the benevolence value which can be related to the importance given to the well-being of others within your direct environment (Schwartz et al., 2012). Citizens who are not community-oriented decide to buy pv-panels for individual use whenever they can afford it. It is assumed that the price of pv-panels decreases whenever more citizens buy them. So the initial price is set to 52.000 which means that 16 percent of the citizens who have a yearly income that is equal to or higher than 52.000, can afford it. Every time someone

buys pv-panels the price decreases (**price-decay-pv-panels** (default = 0.0008) down to the **floor-price-pv-panels** (default = 12.000). Citizens that do not have the required amount of income will stick to their old energy supplier (FFM or SM).

Whenever a citizen is willing to switch and is community-oriented it first checks whether there already is a founded LREO within their neighbourhood. If the citizen agrees with the statutes of the LREO (organisational form and the source of technology) he/she will become a supporting member and change their energy supplier to LREO. If there is no existing LREO within the neighbourhood or the citizen does nott agree with the statutes of the existing LREO, he/she will start looking for an LREO which is looking for supporting members. Whenever the citizen agrees with the statues of the LREO and the LREO can find enough other interested citizens within the given time-period, the LREO will be established and the citizen will become a supporting member and change their energy supplier to LREO. If there is no LREO which is looking for supporters within their neighbourhood, the citizen, if it's leadership level is medium or high, will look for an LREO which is looking for board members. If there is no LREO looking for board members the citizen can, if having a high leadership level, start an LREO board. Whenever the LREO can find enough board members in the given time-period, agree on organisational form and source of technology and find enough supporters, the LREO will be established and the supporting citizens will change their energy supplier towards LREO. If the process fails at any given time point, or citizens don't have the required leadership capacities, they will remain at their current energy supplier. They can however still try again during the next time-step.

3.6.4 Process: Update-LREO-process

As described in Section 2.2 Boon & Dieperink (2014) describe 26 factors that contributed to the successful establishment of 22 LREOs in the Netherlands. Based on the expertise of my supervisor Dr. Thomas Hoppe, an expert in the field of LREOs, I selected 9 out of these 26 factors to be implemented within the model. Table 3.4 shows for each of these factors how they are implemented within the model.

3.6.4.1 Establishing a board

The LREO establishing process contains 5 different steps (see Figure 3.13). First, a citizen has to initiate an LREO by starting a board. Second, the initiator has to find enough other citizens who are willing to become a board member of the LREO within the given time-frame (**max-ticks-to-establish-board** (default = 10). The LREO moves the following step whenever board consists of the maximum number of board members (**max-board-members** (default = 8)) or the number of board members is higher than the minimum required number (**min-board-members** (default = 5) after the **max-ticks-to-establish-board**. If the LREO fails to accomplish this requirement the LREO will be dissolved.

3.6.4.2 Agree on statutes

During the second and the third step the board members come together and set up the statutes of the LREO. During the second step they decide on the organisational form, while during the

TABLE 3.4: Overview of the factors of Boon & Dieperink (2014) implemented within this model

Selected factors from Boon & Dieperink (2014)	**Description of Implementation**
Environmental awareness	The environmental awareness (i.e. responsibility) is a requirement for citizens to participate within an LREO.
Independency from market corporations	One of the decisive parameters that make citizens willing to participate in an LREO is because they give a high priority to the self-direction value. This assumptions is related to the willingness to be self-reliant and to be independent from market corporations and energy countries.
Independency from energy countries	
Consistent energy policies	The consistent energy policies, providing knowledge influence and network organisations the leadership-level of citizens with a binary parameter (on or off). Whenever there are no consistent energy policies or no provision of knowledge, citizens need to score higher on leadership-traits to be able to start an LREO initiative.
Transferring/providing knowledge	
Other LREOs and network organisations	
Degree of social cohesion	Social cohesion (i.e. community-orientation) is the determinant factor whether people who are willing towards a more sustainable energy supply choose organizing an LREO over pv-panels for individual use.
Division of ownership	The equal division of ownership and benefits is not explicitly implemented but are assumed to be one of the underlying principles of the LREOs.
Division of benefits	
Direct involvement of locals	The direct involvement of locals is ensured as it is a requirement to live in the same neighbourhood as the LREO to join it.

third step they decide on the type of material source of the used technology. For the organisational form citizens can choose between a collective purchasing LREO and an energy-project LREO. A collective purchasing LREO is an LREO in which the purchase of energy technology (pv-panels) is done collectively which reduces the cost significantly. The purchased technology however will be installed on the houses of citizens themselves and the technology is owned by the individual members themselves. The other organisational form, energy-project LREO, goes a step further as they start a collective project in which the LREO itself exploits a technology of which the members will earn the benefits (energy/profit). For the statute on technology, citizens can choose between more expensive but sustainable sourced materials and a cheaper less sustainable sourced option. The preference for each of the statutes are value based which means that each of the options is linked to a value. Prioritizing one value more than the other determines the preference of the citizen. A preference can be critical or non-critical. A critical preference resembles whether an element of the LREO is essential for the citizen to participate in the project. It assumed that a preference is critical for a citizen whenever the prioritization of the preference-related value is higher than the stubbornness (100 - agreeableness-trait) of the citizen. The statute-meetings can have three

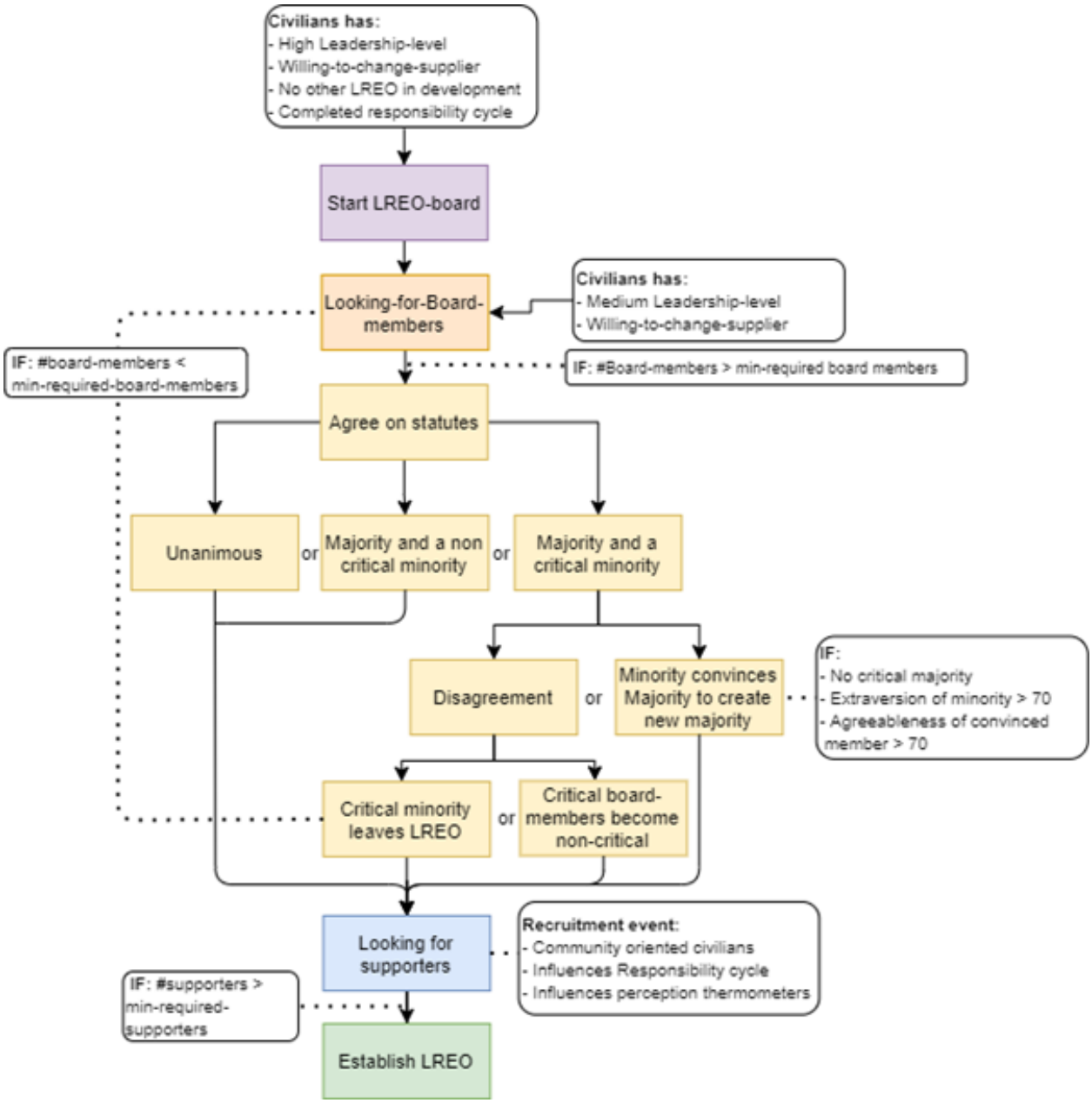


FIGURE 3.13: Flow diagram of the founding process of an LREO.

different types of end result. Result one, all citizens have the same preference and the LREO moves to the next step of the establishing process. Result two, the majority prefers option A over B while the minority prefers option B over A, but the option B is for everyone within the minority not critical. Result three, almost the same accounts as for result two but in this case option B is for one or more board members within the minority critical. The situation in the case of result three can have two different consequences. First of all, the minority can, under certain conditions, convince other board members of the majority to change their preference to the preference of the minority to create a different majority. These conditions are however that 1) no one of the majority should have a critical preference, 2) the highest convincing-power of the board members within the minority is higher than the convincing-threshold (default = 70) and 3) that only those board members with a

high agreeableness trait (convincing-threshold) will change their preference. If the critical minority is not able to convince enough board-members to create a new majority, the board-members are in disagreement. The disagreement can be resolved in two different ways: 1) board members of the critical minority can leave the board and LREO or 2) due to change in value prioritization the critical preference becomes a non-critical preference. The moment when board members will leave the board depends on their perseverance and can differ between 1 tick (emotionality-trait = 100) and 15 ticks (emotionality-trait = 0). If the number of board-members drops below the **min-board-members** threshold, the LREO goes back to the looking-for-board-members stage. Board members that have left the LREO will be added to the leaving-list and cannot join the LREO as board-member again.

3.6.4.3 Finding supporters

After agreeing on the organisational form and on technological sourcing the LREO needs to find enough supporters that support the statutes of the LREO. The max number of supporters is set to thirty (min-supporters) based on the average number of supporters of LREOs in the Netherlands (Schwenke, 2021). During the first tick of step 4, the LREO organizes an recruitment meeting in which the board-member with the highest score on the extraversion trait (most convincing) will try to convince other citizens in their neighbourhood to join the LREO. All the citizens that are community-oriented will join the recruitment meeting. During the recruitment meeting the leading board-member will impact the responsibility cycle of the present citizens by (raw-recruiting-information-impact). In this way, the board-members make their neighbourhood more aware of the acting responsible in the light of climate change, but also advertise to let citizens join their community. Every citizen within the neighbourhood that completed the responsibility cycle at least once and for which the statutes of the LREO do not conflict with their critical preferences (if they have them) will join the community as a supporter. If the LREO can find enough supporters within the set time-limit (max-time-to-find-supporters) the LREO will be established. After the establishment citizens can still join the LREO. Leaving the LREO after establishing the LREO is however assumed to be impossible. LREOs can only move one step forward each tick and the duration can vary between 13 up to 50 weeks (based on how long it takes to find enough board members, come to an agreement and to find supporters). Within a neighbourhood multiple LREOs can exist next to each other (with different statutes) but only one LREO at the time can be in development phase (step 1 to 4).

3.6.5 Process: Meet-neighbour

After the update-LREO-process each citizen meets one of their friendly-neighbours within the submodel meet-neighbour. Meeting with a friendly-neighbour will affect the perception thermometers. This effect will described in the next section (see Section 3.6.6).

3.6.6 Process: Update-perception-tanks-and-value-system

During every occasion that citizens meet other citizens (neighbour-meetings, board-meetings, recruitment-meeting) they exchange insights on how they perceive the world. These meetings will

influence the value system of individuals via the perception-thermometers. Within the model, value change is assumed to be a gradual process in which the cumulative effect of multiple interactions over time will lead to moments of introspection in which an agent reevaluates the prioritization and relevance of its values. The reason why moments of introspection are used to model value change is based on the assumption that value change only occurs whenever an agent is exposed to new insights/experiences over a longer time period (months/years) (Sagiv et al., 2017; Usó-Doménech & Nescolarde-Selva, 2016). Within this model, moments of introspection lead to a revaluation of an agent's value prioritization. The moments of introspection are modeled by introducing the new concept of perception thermometers. Each personal value is equipped with a perception thermometer and the experienced outcome of (inter)actions will result in a change in temperature of the perception thermometer of that particular value. This mechanism works as follows, during the interactions between two citizens, both individuals take once the role of influencer and once the role of follower. If the convincing power (extraversion trait) of the influencer is higher than the agreeableness of the follower, the perception thermometers will adapt it's temperature according to how the values prioritization between the influencer and follower differs. For example, if the influencer prioritizes the achievement value with a 85, and the follower prioritizes the same value with a 40, the temperature of the perception thermometer of the follower will increase with an event-based parameter (**ptc-neighbour-meeting** (default = 8), **ptc-recruitment-event** (default = 17), **ptc-board-meeting** (default = 8)). Next to interaction with citizens, also completing the responsibility cycle after the first time will result in a change in the perception thermometers. As sustainability is related to the values of benevolence and universalism, the perception thermometers of benevolence and universalism will increase with the **ptc-climate-awareness** (default = 42) parameter, while the perception thermometers of their antagonistic values, achievement and power, will decrease with the same amount. Applying this mechanism, results in significant value change

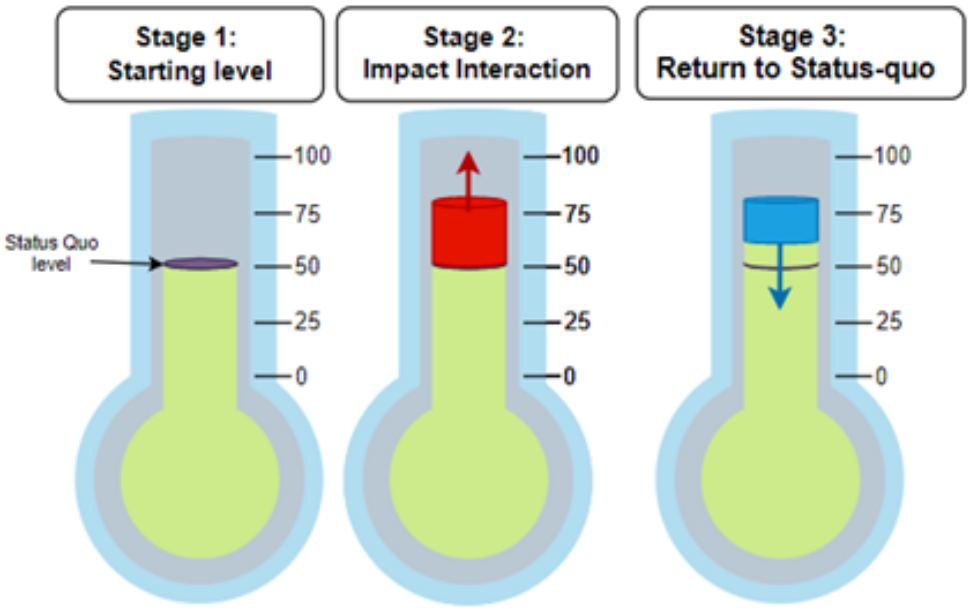


FIGURE 3.14: Visualisation of the change in perception thermometers during a tick.

in a relatively short time period. So to remain in line with the Schwartz Theory on values, I suggest that the impact that interactions have on individuals diminishes as time passes by. Therefore, during each tick, the perception thermometer will return a small amount towards the level of status-quo (see stage 3 in Section 3.6.6). The magnitude of this return to the status quo is equal to the mean of the negative of the agreeableness trait and the negative of the openness-trait times the **pt-rsq-modifier** (default = 0.08). It is assumed that citizens who are not open to new insights and experiences and who have a stubborn attitude (negative agreeableness) are less likely to change their value prioritization.

Whenever a perception thermometer of a value falls below 0 °C or rises above 100 °C, it causes a moment of introspection in which the agent reprioritizes the value of the related perception thermometer. A freezing thermometer will lead to a decrease in the importance of the related value, while a boiling perception thermometer will result in an increase in the importance of the related value). After the reprioritization the perception thermometer will be back to the status quo level of 50 degrees.

Chapter 4

Verification, Validation and Sensitivity Analysis

This chapter discusses the model verification (Section 4.1) and model validation (Section 4.2). Where model verification is used to ensure that the model is build right without any modelling artefacts, model validation is to make sure that the right model is configured for the overall modelling purpose: illustrate how LREOs emerge in the Netherlands (Calder et al., 2018). Lastly, with the sensitivity analysis Section 4.3 the robustness of the model output is tested by varying the input parameters using a Global Senstivity Analysis (GSA).

4.1 Model verification

The verification of this model consist of the three phases depicted by Nikolic & Ghorbani (2011): i) single-agent testing, ii) interaction testing, iii) multi-agent testing.

Single-agent testing is used to verify whether a single agent behaves expected under a variety of circumstances by performing sanity checks to examine single agents outputs to normal operating inputs, extreme value tests and dynamic signal testing (Nikolic & Ghorbani, 2011).

Interaction testing indicates whether interactions of agents within the minimal model setting (for this model it is set to 21 agents) occur correctly (Nikolic & Ghorbani, 2011). These single-agent and interactions tests were repeatedly performed after implementation of each sub-model to ensure verification and to avoid modelling artefacts.

In the third phase of verification, called multi-agent testing, the model variability is tested by performing many repetitions (100-1000) of the model and examining the statistics of the outcomes, across a number of output variables (Nikolic & Ghorbani, 2011). With the number of repetitions set to $N = 150$ the skewness and kurtosis of the output variables (#Responsible Citizens (A), LREO-consumers (B) and Average-Responsibility (C)) at $t = 520$ for the *Mixed* population scenario are close to the desired levels of respectively 0 and 3 (see Figure 4.1). Based on this test, the number of repetitions in the final experiments is set at $N = 150$. With performing these three test, the model is considered to be verified.

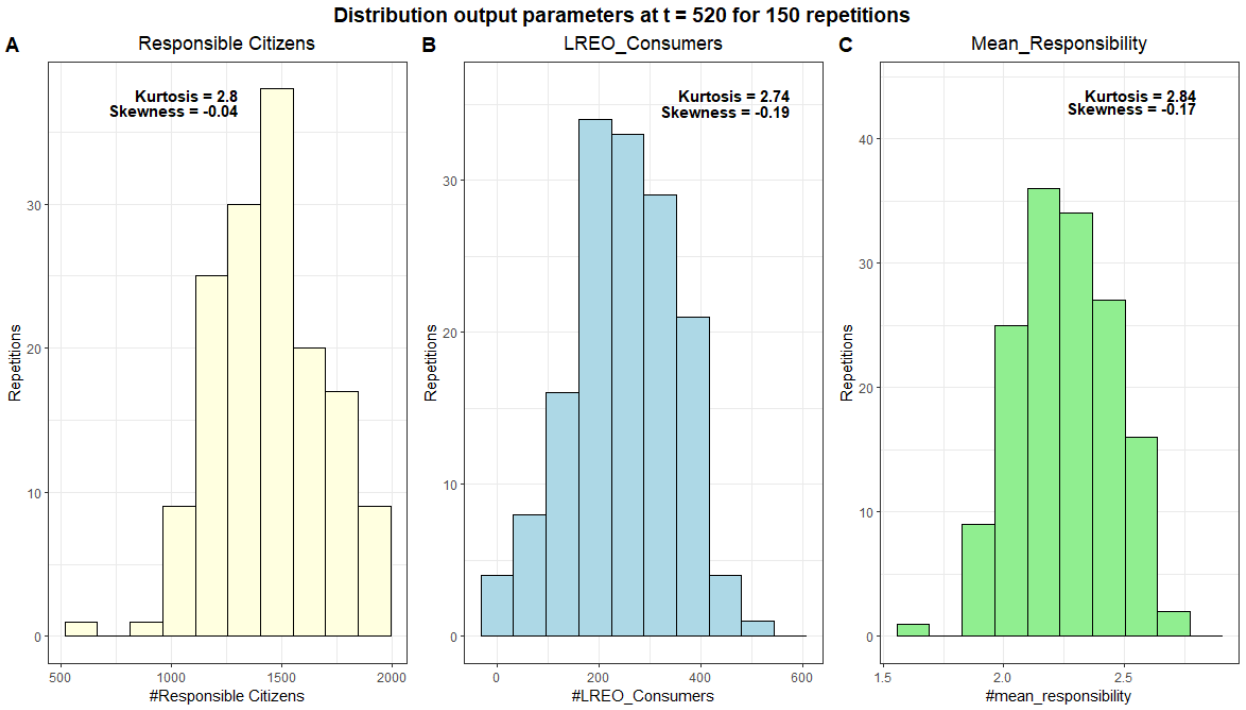


FIGURE 4.1: The overview of the variability for the three output-parameters: #Responsible Citizens (A), LREO-consumers (B) and Average-Responsibility (C).

4.2 Model validation

The validation of the model concerns checking whether the outcomes of the model correspond with observed reality (Nikolic & Ghorbani, 2011). As this research has an illustrative modelling purpose with describing how in general LREOs emerge within the Netherlands over the course of ten years, it would be a complex case to compare the modelling results with real life data. The complexity of this comparison would require to follow multiple Dutch neighborhoods over a long time period of 10 years. Moreover, the assumptions of the model that citizens do not have interaction with the world outside of the neighborhood, have over the course of ten years the same friends who all come from the same neighbourhood, and that no citizen moves in or out of the neighbourhood, would in reality impossible to duplicate.

So to make sure that this agent-based model is able to illustrate how LREOs emerge in the Netherlands, the model used various existing theories to strengthen the conceptualization and assumptions. The theories used are from Schwartz et al. (2012) on personal values, (Steg & De Groot (2012) on linking sustainability with Schwartz values, Usó-Doménech & Nescolarde-Selva (2016) on the impact of changing belief systems (recognition of the sustainability related concerns) on value prioritization, McCrae & Costa Jr (2008) on character traits, Martiskainen (2017) on leadership in LREO, Robeyns (2017) on responsibility and Boon & Dieperink (2014) on the founding process of LREOs. Moreover, the LREO founding process has been validated by using the expertise of Dr. Thomas Hoppe who is an expert in this research field. Lastly, data from Statline (2021) and Rotterdam (2020) has been used for the configuration of the educational level and income of agents.

4.3 Sensitivity analysis

This section is will discuss the performed sensitivity analysis that examines the robustness of the emergent properties of the model. Section Section 4.3.1 discusses the settings of the sensitivity analysis, while Section 4.3.2 visualizes the results.

4.3.1 Setup GSA

Sensitivity analysis is used to i) gain insights in how emergent behavior is generated in the model, ii) examine the robustness of the emergent properties of the model, iii) the variability of the model output when differing the input parameters (ten Broeke et al., 2016). To reach this objective, a Global Sensitivity Analysis (GSA) is executed that indicates the contribution of the variation of each input parameter to the total variance of the output parameters (Ligmann-Zielinska & Sun, 2010). The advantage of performing a GSA over the more common one factor at a time (OFAT) method, is that a GSA is able to cover a much wider range of the parameter space and takes into account the complex interactions between factors in determining emergent properties. Within the GSA the first order Sobol indices (Si) indicate for each input parameter the fractional contribution to the variance of the output parameter, independently from the other input-parameters. Next, the total-effect Sobol indices (STi) combines the fractional contribution (i.e. Si) with the interaction of the given input parameter with the other parameters. The higher the Si or STi of a input parameter relative to others, the more influential it is in determining a model's behaviour.

As agent based models are dynamic and include a time component, I used the Time-Depended Variance Decomposition approach in which for each selected input-parameter the Si and STi is computed for each given time-step which results in a $t - SI$ and $t - STi$. By applying this method a better understanding is gained of how the sensitivity of the model to the input-parameter variability evolves over the course of a simulation. The sample settings for of the input parameters to configure the Si and STi are generated by using latin hypercube sampling (LHS). LHS guarantees a uniform sampling of parameter settings given the sampling range constrained to a limit of X samples (in this case 200) (Van Dam et al., 2012).

A GSA is conducted for each of the three core mechanism within the model: i) the recognition of the sustainability related concerns, ii) the change in value prioritization and iii) the emergence of LREOs. The minimum and maximum values of the sampling range of each of the input parameter for each output parameter is shown in Table 4.1. The parameters settings derived from the LHS has been used to run the simulations. To reduce the number of runs, the static-seed has been activated. Afterwards, the $t - SI$ and $t - STi$ has been generated in RStudio using the sobol2007 function from the sensitivity package (Pujol et al., 2015).

Table 4.1: Settings of the input parameters for the GSA of responsibility-level, total prioritization change and number of LREO-consumers.

General settings	
Input-Parameters	**Value**

Static-seed?	True
Population-setting	*Mixed*

Responsibility-level of total population

Input-Parameters	**Minimum Value**	**Maximum Value**
Value-std-dev	3	20
Trait-std-dev	3	20
Responsibility-threshold	1	9
CC-event-mean-exponential-distribution	2	8
Raw-recruiting-information-impact	10	50

Total absolute change in value prioritization

Input-Parameters	**Minimum Value**	**Maximum Value**
Pt-rsq-modifier	0.04	0.12
Ptc-neighbour-meeting	4	12
Ptc-board-meeting	5	15
Ptc-recruiting-event	12	24
Ptc-climate-awareness	34	50
Value-change-para	2.5	7.5

#LREO-consumers

Input-Parameters	**Minimum Value**	**Maximum Value**
High-leadership-threshold	65	75
Medium-leadership-threshold	55	65
Leadership-reduction-due-circumstances	1	5
Min-supporters	15	50
Min-board-members	3	6
Max-board-members	6	10
Community-threshold	40	60
Willingness-to-switch-threshold	55	75

4.3.2 GSA results

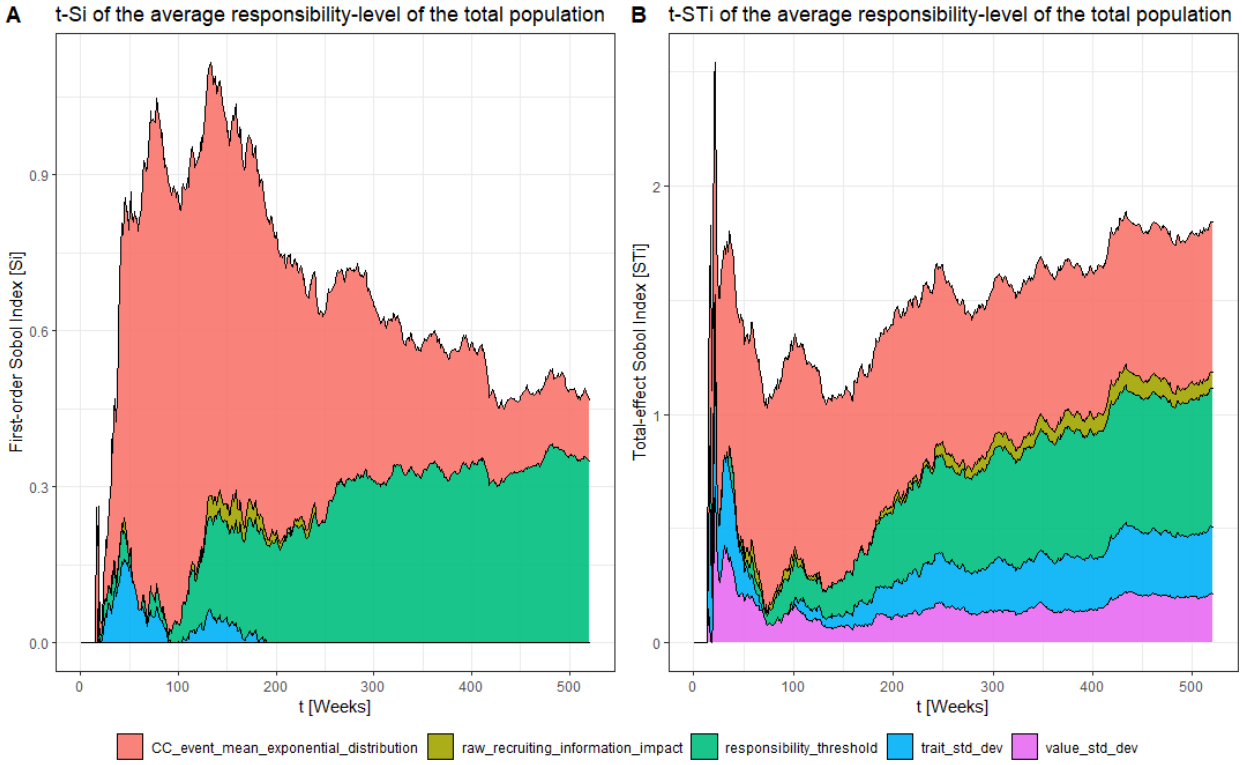


FIGURE 4.2: The contribution of each input parameter to the variance of the output variable: responsibility-level.

This section discusses the results of the three GSA performed within this research. The first GSA is about the recognition of the sustainability related concerns which is expressed by the average responsibility-level of the total population parameter. Exhibit A & B in Figure 4.2 show the Si and STi for the five input parameters. This figure show that the cc-event-mean-exponential-distribution and responsibility-threshold parameters have the biggest contribution to the variance of the average responsibility-level of the total population. Another interesting highlight of this GSA is the value-std-dev parameter only influences the average responsibility-level through the interaction with other parameters. This can be explained by the fact that for the responsibility-mechanism traits play a direct role but values not (see Section 3.6.2). But as the values determine the trait distribution of the population, the value-std-dev parameter is only visible in the total-effect graph ($t - STi$ and not on the first order graph ($t - Si$).

Another highlight to point out is that the contribution of the raw-recruiting-information-impact parameter, which is increases of awareness of potential LREO-supporters during the supporter recruiting-meetings of a developing LREO, is also rather low. A logical consequence as these meetings only occur ones or twice during the simulation.

The second GSA, visualized in Figure 4.3, shows the Si (Exhibit A) and STi (Exhibit B) for the six input parameters used within the sensitivity analysis of the average sum of the

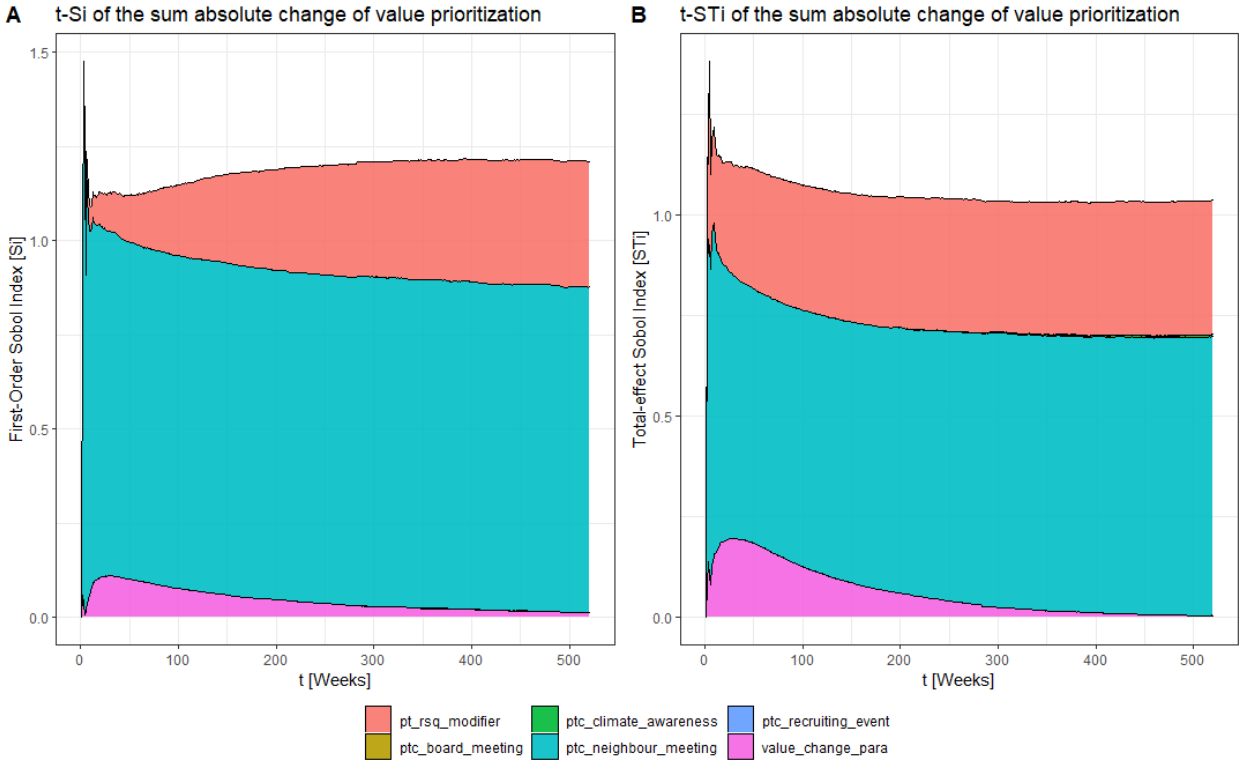


FIGURE 4.3: The contribution of each input parameter to the variance of the output variable: the total absolute change of value prioritization.

absolute change in prioritization of the ten personal values for the total population[1]. Although six different input-parameters has been used within this analysis, only three of them (pt-rsq-modifier, ptc-neighbour-meeting and value-change-para) show a significant contribution to the variance in the prioritization. This can be explained because of the combination of two origins. First the fact that these parameters do not directly cause a change in value prioritization, but that these influence the perception thermometers, that operate as buffers (see Section 3.6.6. Second, the ptc-board-meeting, ptc-climate-awareness, and ptc-recruiting-event parameters are only used in specific occasions (i.e. board meetings) which apply only for a limited number of citizens at a limited number of time steps. The combination of the limited use of these parameters with the existence of perception-thermometers, cause that the ptc-board-meeting, ptc-climate-awareness, and ptc-recruiting-event parameters do not contribute to the variance of the average sum of the absolute change in prioritization of the ten personal values for the total population.

The last GSA shows the sensitivity of the number of LREO-consumers to eight different input-parameters (see Figure 4.4. The number of LREO-consumers is a better indicator than the number of LREOs to show the emergence of LREOs as just counting the founded LREOs does not give any insights in the support of the movement. The Si (Exhibit A) and STi (Exhibit B) in Figure 4.4 depict that the emergence of LREOs starts to the earliest after 120 weeks. Moreover it shows that the leadership-reduction-due-circumstances and the community-threshold

[1]e.g. the parameter indicates on average how much the value prioritization of a citizen has changed over the course of the simulation, compared to the start of the simulation.

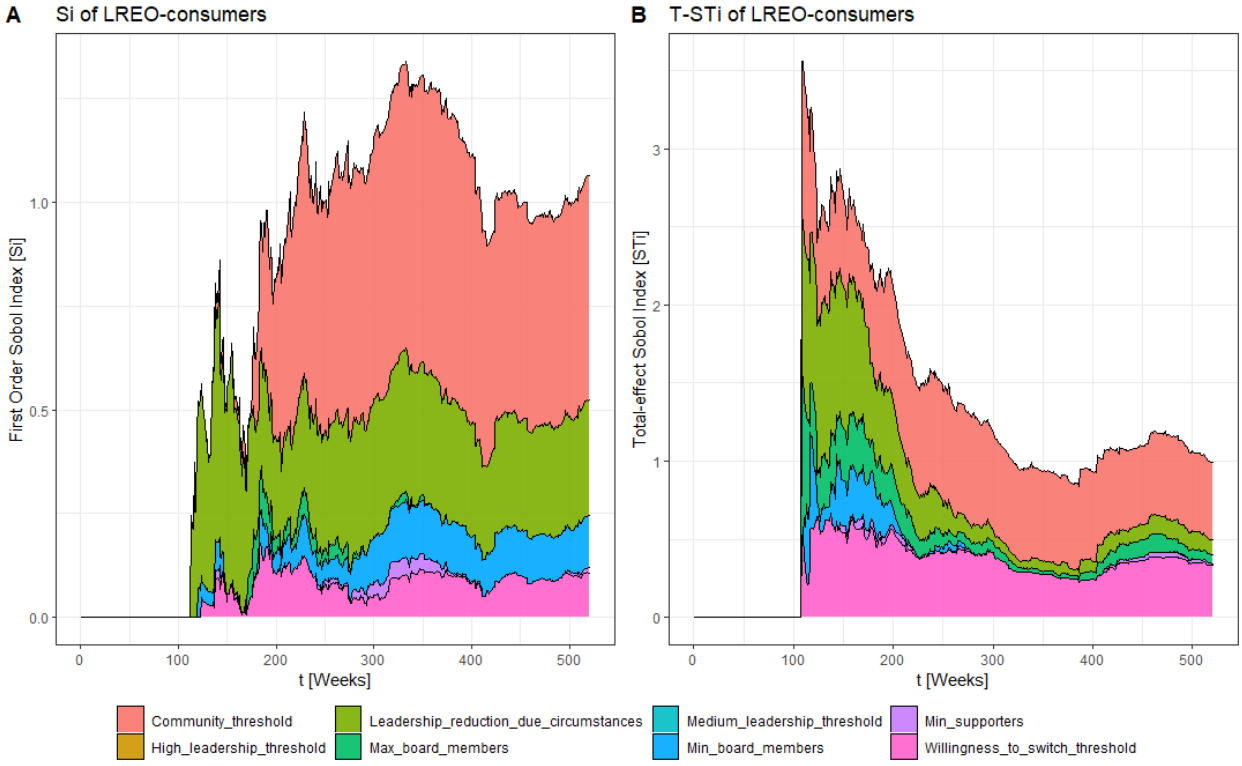


FIGURE 4.4: The contribution of each input parameter to the variance of the output variable: #LREO-consumers.

parameters have the highest contribution to the variance of the number of LREO-consumers. The medium-leadership-threshold parameter lacks any contribution to the variance of the number LREO-consumers. This is due to the fact that the medium-leadership-threshold has a particular small sampling-range as it is restricted by the high-leadership-threshold parameter (see Section 3.3.7).

Chapter 5

Experiments and Results

This chapter describes the setup (Section 5.1) and the results (Section 5.2) from the experimentation phase. This chapter will answer the following three sub-questions of which the first two sub-questions will be used as input for the last sub-question:

1. In what way is sustainability recognized within the value system of Dutch citizens (mechanism 1)?
2. What is the influence of social learning and the recognition of the sustainability related concerns on the value prioritization of Dutch citizens (mechanism 2)?
3. What is the influence of mechanism 1 & 2 on the emergence of LREOs?

FIGURE 2.1: Overview of the 4 different values orientations from the Schwartz Circumplex (repeated from page 10)

5.1 Experimental setup

The goal of the experimentation phase is to illustrate one interpretation how the change in value specification and change in value prioritization, caused by climate events, lead to the emergence

of LREOs. As described within the conceptual model (Section 3.1), the model consists of three core mechanisms: i) the recognition of the sustainability related concerns evoked by climatic disrupting events, ii) the change in value prioritization due to social learning and the recognition of the sustainability related concernsand iii) the emergence of LREOs due to collective actions from responsible citizens. Within each of these core mechanism, values and value change play a dominant role. To showcase the impact of values on each of the three mechanisms I will experiment with five different scenarios. In each of this scenarios the population is equipped with a different value orientation: i) *Growth*, ii) *Personal-Focus*, iii) *Self-Protection*, iv) *Social-Focus* and v) *Mixed* (equal combination of the first four groups) (see Figure 2.1). The settings of the input parameters of these experiments are similar to the settings visualised in Table 3.3 in Section 3.5.6. To ensure the validity of the results, the number of repetitions for each scenario has been set to 150.

5.2 Experimental results

The main argument of this thesis is that the requirements for the existence of LREOs within populations are: a significant group of citizens (thirty or more) who i) responsible (recognizing sustainability related values like environmental well-being and energy justice evoked due to climate events), ii) posses the willingness (both being community-oriented and have sustainable, financial or autonomy motives), and iii) of which a small part (four or more) possess the leadership capacity to start an initiative. Figure 5.1 shows that of the five population-scenarios, only in the populations

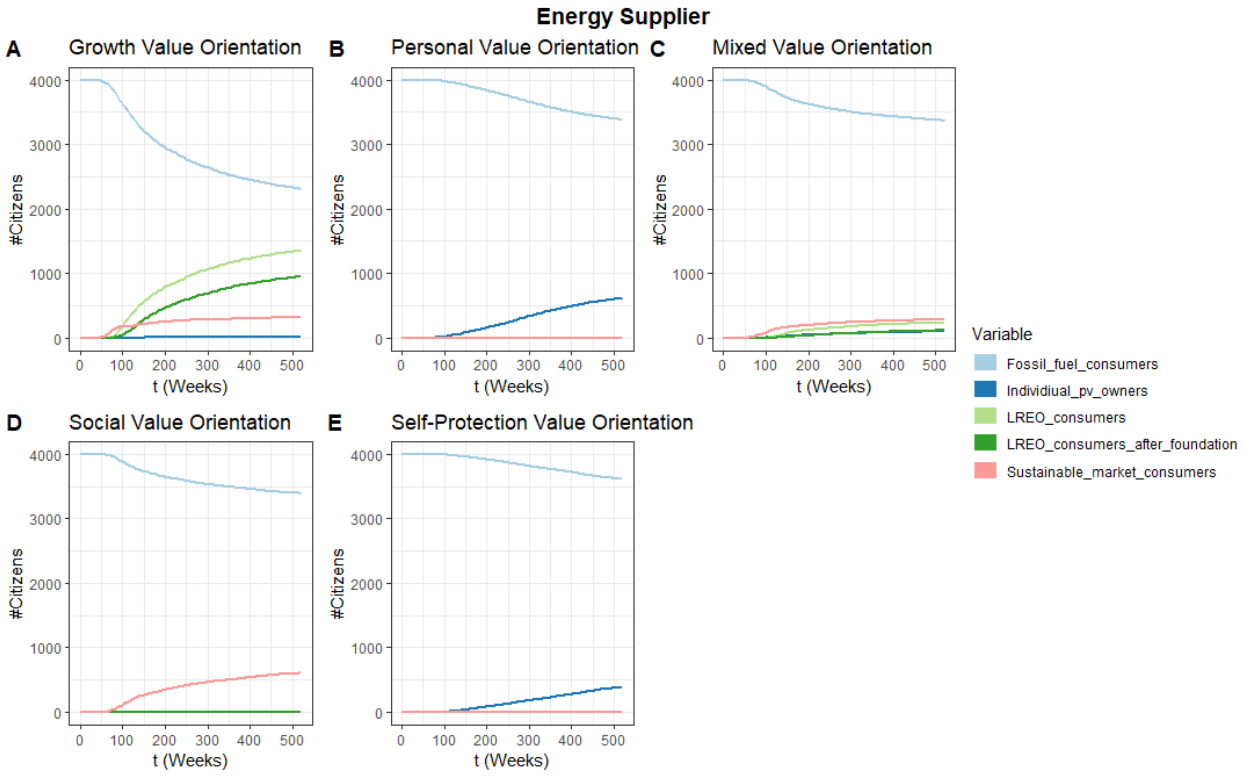


FIGURE 5.1: The number of consumers per energy supplier over time while *allowing* change in value prioritization for the five different population-scenarios.

with a *Growth* (Exhibit A) and a *Mixed* (Exhibit C) value orientation is the emergence of LREOs visible. In the next three paragraphs I will, using the three requirements of Responsibility, Willingness, and Capacity (RWC), explain why LREOs only in some communities emerge.

5.2.1 Responsible citizens

Becoming a responsible citizen is next to willingness and leadership capacity, one of the three requirements for citizens to become involved within LREOs. Citizens become responsible whenever they recognize and acknowledge the problem of climate related concerns of energy justice (altruistic component) and environmental well-being (biospheric component), caused by climate changing events. During this responsibility process, citizens redefine how they specify their transcendence values (Universalism & Benevolence) by adding these concerns of energy justice and environmental well-being (see Section 2.1.1.3 for more information). The responsibility process involves the completion of the so-called responsibility cycle, which consists of i) the accumulation of information on climate change, ii) the acknowledgement of ones role in the climate problem and iii) the believe that individual change makes a difference in tackling the climate problem (see Section 3.6.2 for more information). The position of citizens within their responsibility process varies from Step 0 (Unaware) to Step 3 (Responsible) and is visualised in Table 5.1. The responsibility-level is a cumulative process meaning that acquiring Step 2 requires the fulfillment of Step 1. To understand this rather abstract process I will give an example. Imagine a citizen who always uses his car when going out for buying groceries. Over time, the citizen accumulates information about the impact of fossil-fueled vehicles on the climate making him aware of the problem (Step 1). Next, after a big item on the news about fossil-fuel pollution of fossil-fueled cars, he realizes that his own role (step 2) within this problem as he uses his car even for small distances (e.g. shopping groceries). Then, at a neighbourhood meeting, he notices that all his neighbours use their bike to shop groceries and he starts to believe (step 3) that if we all make a small adjustment to our lives, we can collectively tackle the collective problem of climate change. The citizen successfully completed the responsibility cycle and is now labeled as an responsible individual.

Completing the responsibility cycle for the first time transforms citizens from being irresponsible to responsible [1]. Completing the responsibility-cycle for the second time or more will impact the value prioritization of citizens (see Section 5.2.2). An attempt to complete the responsibility-cycle for the second time could for example be related to a different topic (i.e. electricity use) or a more extreme change (i.e. also stop using car for larger distances).

Figure 5.2 shows how the distribution of the responsibility-level of the population evolves over time for each of the five population scenarios. Populations with the value orientation of *Growth* (Exhibit A) and *Personal-Focus* (Exhibit B) have a much higher recognition of the sustainability related concerns(responsibility-level of 3 or higher) compared to the other populations. To showcase why these differences occur for citizens with different value orientations I displayed in Figure 5.3 how

[1] A responsible citizen does not always behave responsible as responsible behavior is also related to a person's willingness and capacity to act

TABLE 5.1: Overview of the responsibility-levels.

Responsibility-level	**Description**
Step 0	Unaware
Step 1	Informed
Step 2	Acknowledging
Step 3	Responsible

the climate events affect the responsibility of citizens[2] from the four different value orientations[3] for one year for one single simulation. Each individual transforms the global variable impact of climate events (green line in Figure 5.3) into the so-called awareness increase (red line in Figure 5.3) based on their traits and education level (see Section 3.6.2). The higher the awareness-increase the faster a citizen accumulates information and reaches Step 1 (Informed) of the responsibility cycle. Whenever the awareness increase (red line) surpasses the acknowledgement threshold (to reach Step 2) or believe threshold (to reach Step 3) a citizen takes one step further towards becoming a

[2]The three citizen specific variables (Awareness Increase, Acknowledgement Threshold & Believe Threshold) are population averages meaning that the individual scores for these parameters are higher or lower than the visualised lines.

[3]The population scenario with the *Mixed* value orientation is not included within this figure as the population of the *Mixed* value orientation is a combination of the other four population-scenarios

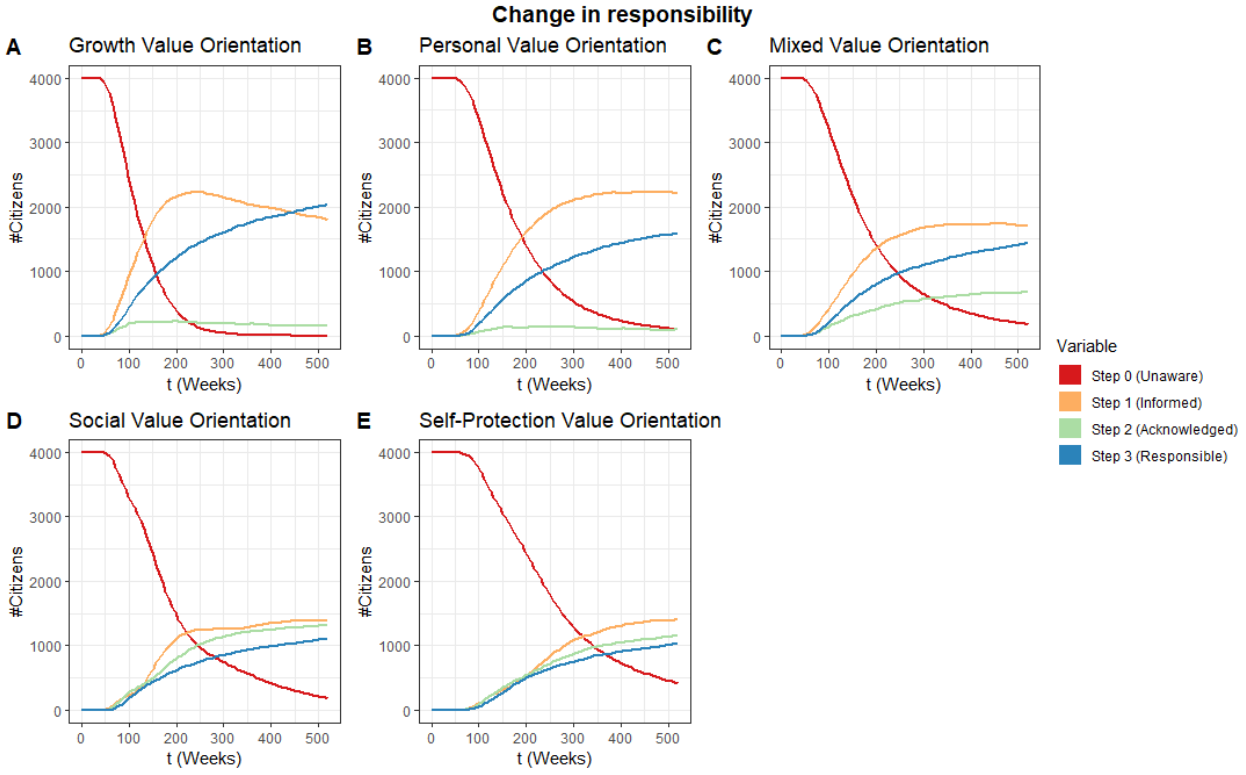


FIGURE 5.2: Overview of the number of citizens per responsibility-level over the course of the simulation for the 5 different population scenarios.

responsible citizen. Figure 5.3 shows three important insights.

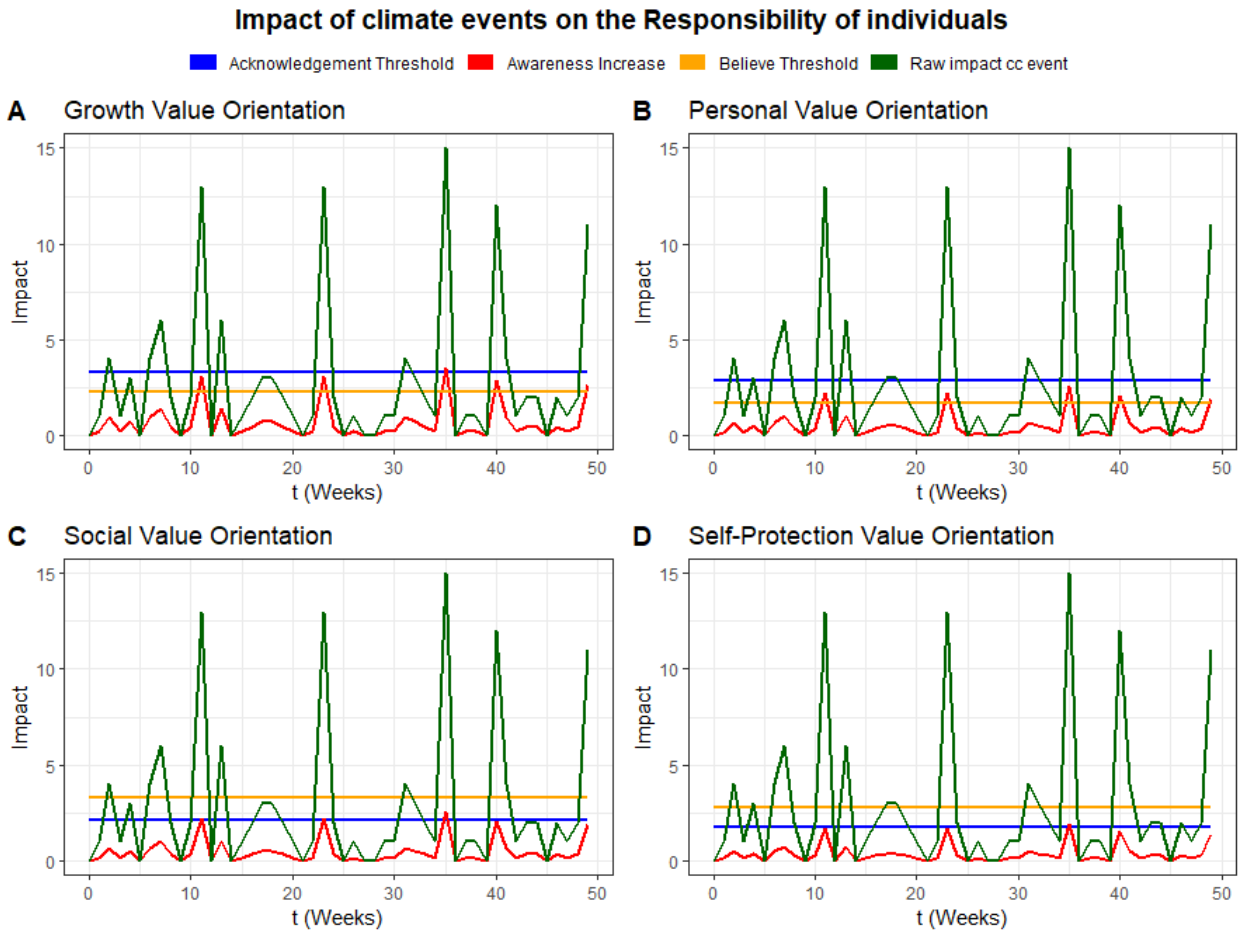


FIGURE 5.3: Overview of the change in value prioritization for each of the five population scenarios.

First it depicts that on average the citizens from the *Growth* Value Orientation are the first to reach Step 1 (informed) as the awareness-increase of those citizen (red line) is the highest, followed by the citizens from the *Personal-Focus* value orientation, *Social-Focus* value orientation and lastly *Self-Protection* orientation. Second it is visible that on average the acknowledgement threshold is higher for the *Growth* and *Personal-Focus* value oriented populations, while the believe threshold is higher for the *Social-Focus* and *Self-Protection* value oriented populations. This difference does explain why there is a relatively large group of citizens with a responsibility level at Step 1 (Informed) in the *Growth* and *Personal-Focus* value oriented populations and not the other two. Third Figure 5.3 shows that, although the type of thresholds differ, the level of these thresholds is quite similar across the different population groups. So the question remains: why are there more responsible (step 3) citizens in the *Growth* and *Personal-Focus* value orientations than in the two population groups? The answer to this question lies in the difference in awareness-increase between the population groups. For the former two populations group the awareness-increase is on average much higher which indicates a higher chance to surpass the thresholds towards becoming a responsible citizens.

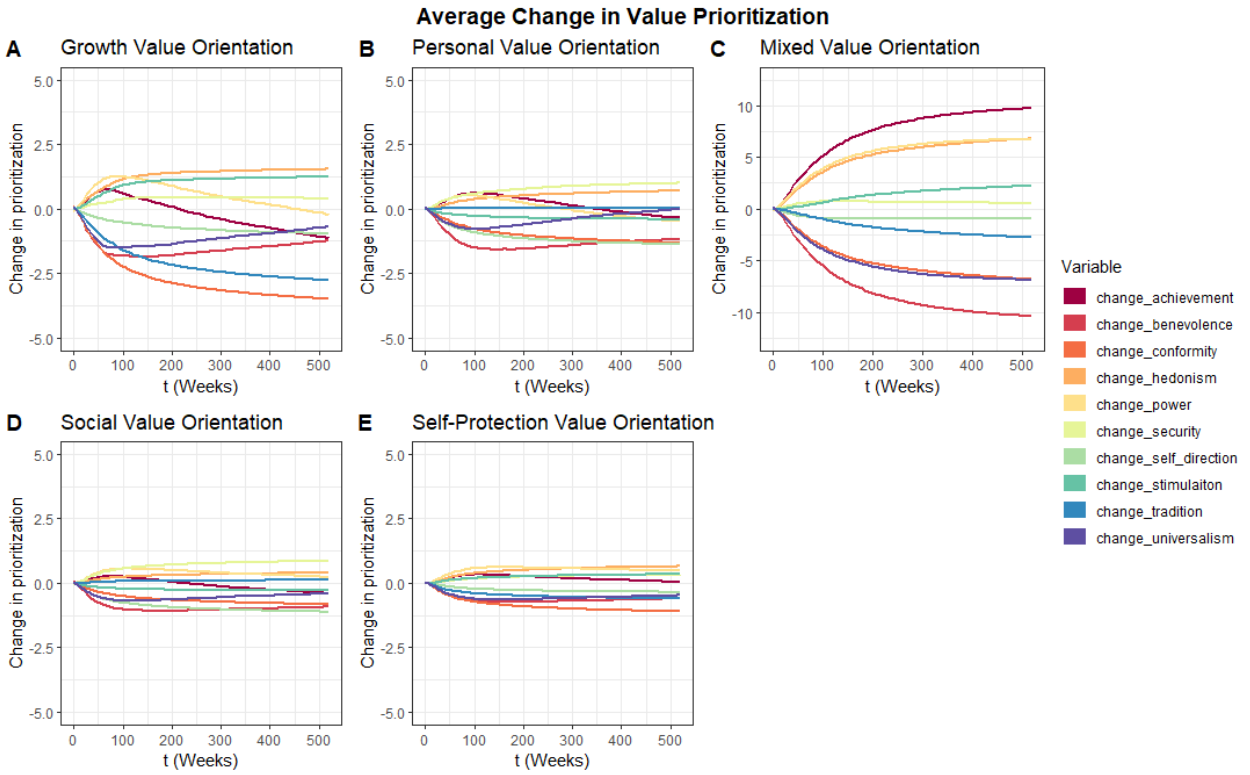
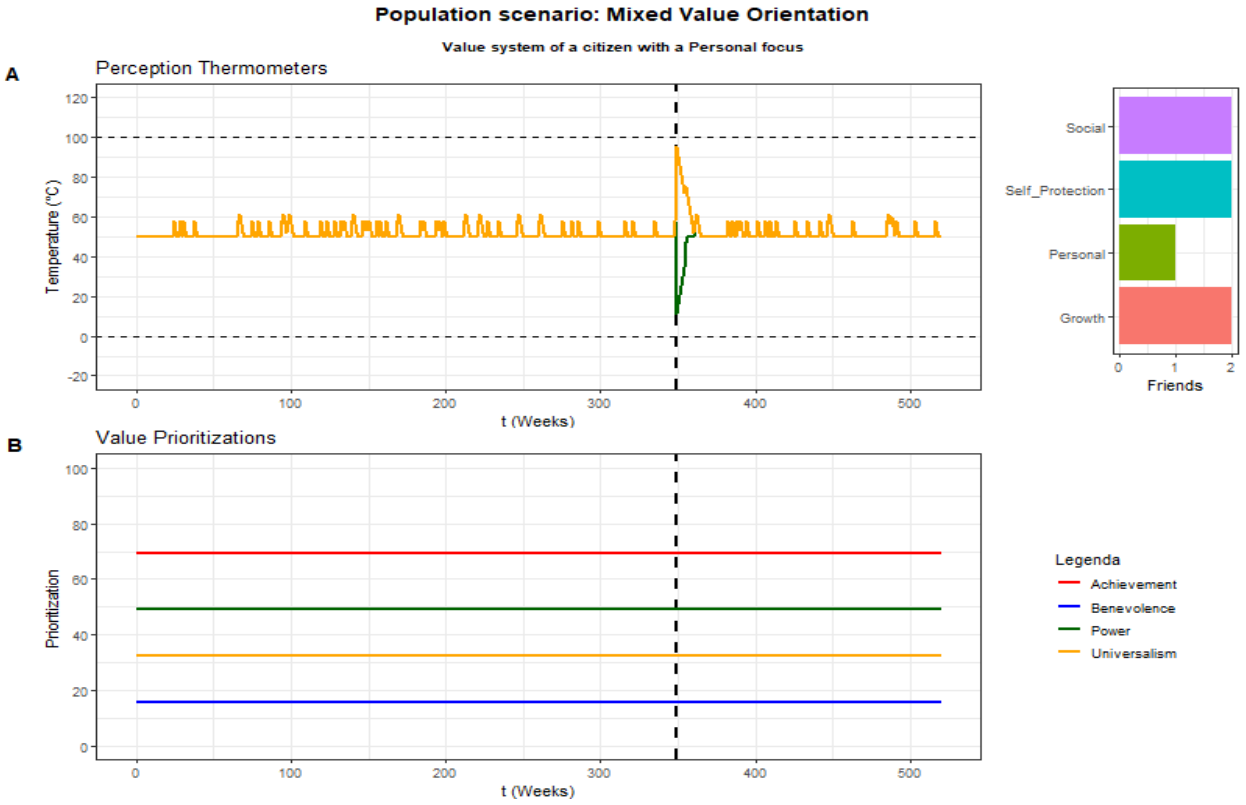


FIGURE 5.4: Overview of the change in value prioritization for each of the five population scenarios.

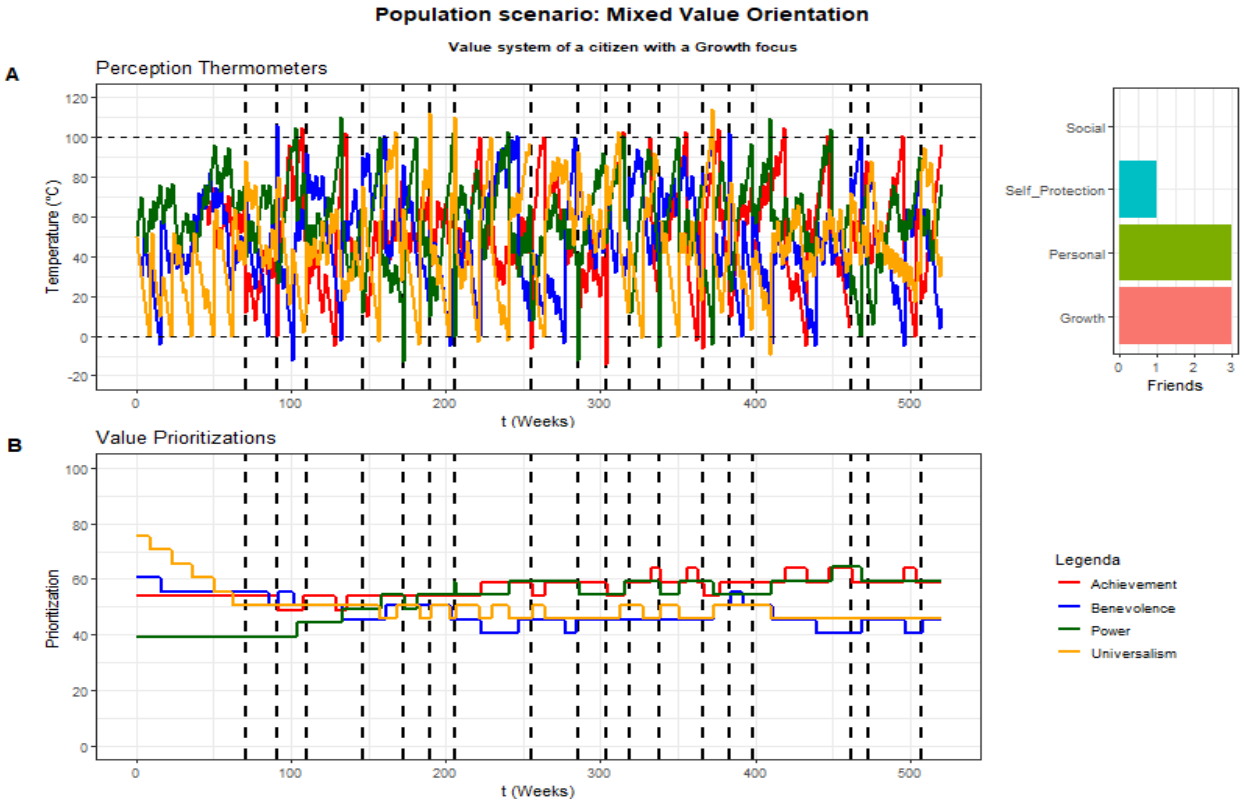
5.2.2 The change in value prioritization

The value prioritization of citizens determines their willingness to participate in LREOs. The willingness of citizens to participate is a combination of prioritizing the benevolence value (community-oriented) with the benevolence and universalism values (sustainability motive), power value (financial motive) and/or self-direction value (autonomy motive) (see Section 2.2.1). The change in value prioritization, is visualized in Figure 5.4, which shows for each personal value the magnitude and direction of change compared to the starting points.

A positive change of two prioritization points means that on the population level, the average prioritization of the particular value increased with 2 compared to the situation at $t = 0$. Important to note when observing these figures that the scale of the Y-axis differs for each exhibit. The population scenarios which contain only one type of value orientation (Exhibits A, B, D & E) show two trends. The first trend, during the first 50 to 200 weeks, due to social learning, the value prioritization of power, achievement, hedonism and self-direction increases, while the values of universalism, benevolence, tradition and conformity decreases. This is due to the fact that citizens who prioritizes achievement, power and hedonism tend to be more dominant during neighbour-meetings (scoring high on the extraversion trait and low for the agreeableness trait), while citizens who prioritizing universalism, power and conformity tend to be more willing to give up their prioritizations (scoring lower on the extraversion trait and high for the agreeableness trait). This result is in line with the research of Anderson & Kilduff (2009) who showed that within face-to-face groups people with a high social competence (high score on extraversion) attain more influence than



X) Citizen with a *Personal-Focus* value orientation.



Y) Citizen with a *Growth* value orientation.

FIGURE 5.5: Individual value system of two citizens from a *Mixed* population scenario with on the top a citizen with *Personal-Focus* value orientation and on the bottom a citizen with *Growth* value orientation.

others.

The second trend is that due to the repeated completion of the responsibility cycle (i.e. repeated recognition of the sustainability related concerns due to climate events), the prioritization of benevolence, universalism increases while the prioritization of achievement, power decreases (e.g. see exhibit B). What Figure 5.4 reveals is that the populations with the *Growth* and *Personal-Focus* value orientations are much more open to change in value prioritization then populations with the *Social-Focus* and *Self-Protection* value orientations. Moreover, the impact of the recognition of the sustainability related concerns on the value prioritization is much bigger in the case of the former two population-scenarios than in the latter two.

5.2.2.1 The power of social pressure

The interesting part of Figure 5.4 is that the *Mixed* population scenario (Exhibit C) does contain the impact of social learning (trend one), but not the impact of the increased intention to the sustainability related values due to climate events (trend two). To explain this remarkable difference between exhibit C and the other exhibits, I visualised in Figure 5.5 the value systems (both perception thermometers and value prioritizations) of two citizens from the *Mixed* population scenario of which one has *Personal-Focus* (figure X in Figure 5.5) while the other citizen is *Growth* oriented (figure Y Figure 5.5). Change in value prioritization (Exhibit B) occurs when the temperature of the perception thermometers (Exhibit A) of the related value reaches 0 °C or 100 C°C. The temperature of the perception thermometers changes due to social learning and after completion of the responsibility cycle (vertical dashed lines).

Figure 5.5 shows two interesting phenomena. First, the top graph (Figure X), which includes a citizen with a *Personal-Focus*, shows that with the current configuration the completion of the responsibility cycle on itself is not capable to change value prioritization. This means that, over time, value prioritizations of the skeptical citizens[4], irrespective of repeated completion of the responsibility cycle, will remain constant. The second phenomena (Figure Y in Figure 5.5) shows on the other hand that the more flexible citizens, will converge to the value system of the most convincing individual[5] within their social network. This lack of divergence in value systems within the *Mixed* population scenario is best visualized in Figure Y of Figure 5.5 as despite the repeated completion of the responsibility cycle by the citizen, its social network forces a social pressure that urges the individual to maintain the ruling value prioritization of the dominant citizens in its social network (which is in this case a high prioritization of power and achievement and low prioritization to universalism and benevolence). This impact of social pressure on the willingness to act can be linked with the work of Abrahamse & Steg (2013) on the importance of social influence on environmental behavior. Within their research Abrahamse & Steg (2013) show that, based on a meta-analysis of 29 studies, citizens tend to be more willing to change their behavior when supported by their social network.

[4]Skeptical citizens are citizens who are skeptical to the opinion of others and who thus will not adjust their perception thermometers towards the value systems of others

[5]Convincing individuals are individuals who are good in expressing their opinion which causes others to converge their perception thermometers towards the value system of the convincing individual.

5.2.2.2 Divergent patterns of agent behavior

The other homogeneous population scenarios however, and especially within the populations centered around *Growth* and *Personal-Focus*, do possess divergent patterns of changing value prioritizations (Figure 5.4. Divergent patterns of changing value prioritizations are defined as the process during which the value prioritization of one or more citizen(s) moves away from the population average (become more extreme). To understand how this divergent pattern emerges, I will give a short example which is visualised in Figure 5.6. Imagine the situation in which convincing citizen A is befriend with another convincing citizen B (both score high on the extraversion trait). Citizen A prioritizes universalism with 50, while citizen B prioritizes universalism with 52.5. As

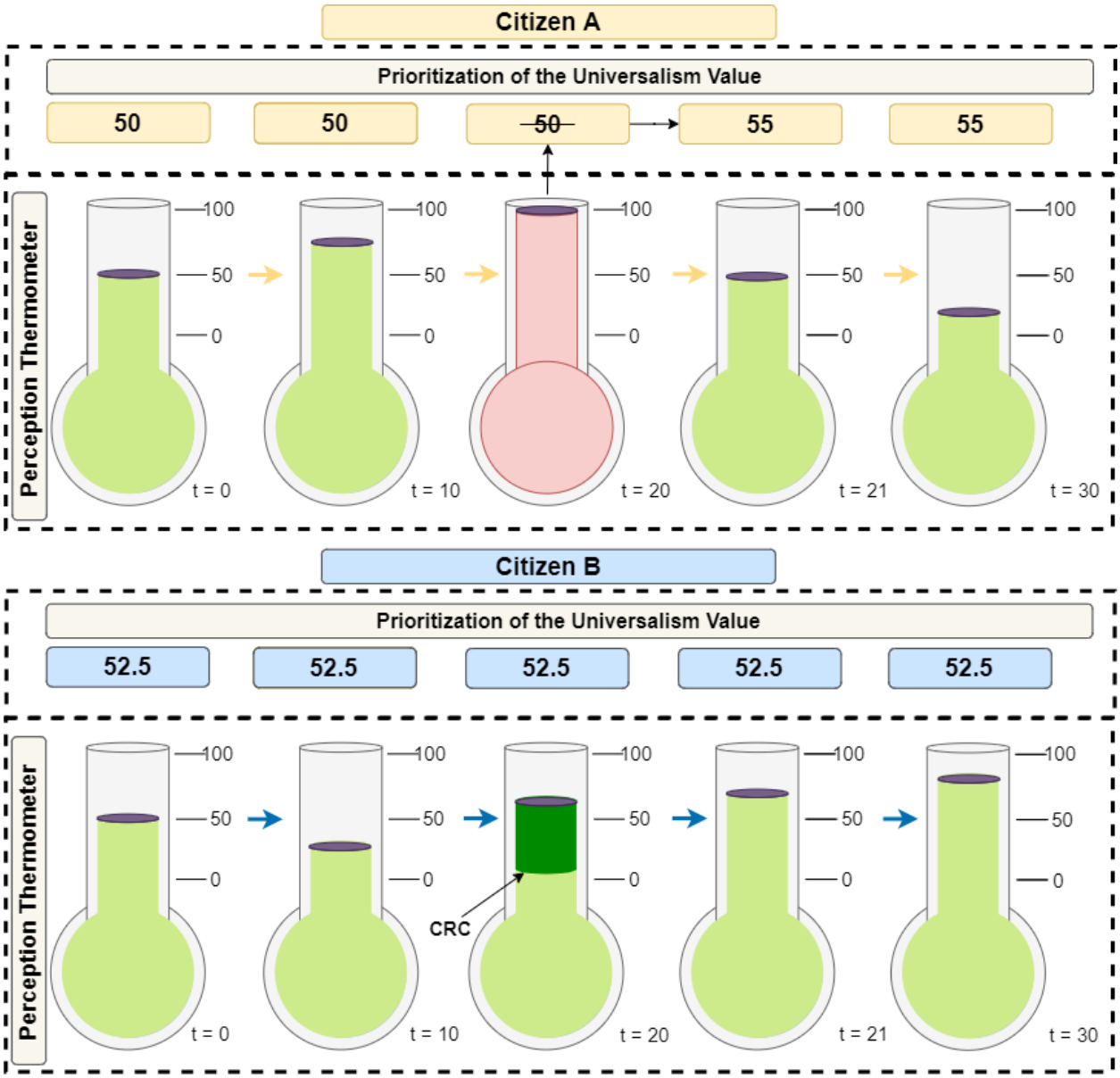


FIGURE 5.6: Divergent patterns of change in value prioritization due to repeated meetings between Citizen A and Citizen B.

both citizens are convincing but are also open to each others viewpoint (both score also high on

the agreeableness trait) the temperature of the universalism perception thermometer of citizen A rises in the direction of citizen B ($52.5 > 50$), while the temperature of the universalism perception thermometer of citizen B slowly decreases towards the level of citizen A ($50 < 52.5$) (see difference between $t = 0$ and $t = 10$ in Figure 5.6). Eventually, after a period of time ($t = 20$ in Figure 5.6), the perception thermometer of Citizen A rises above 100 causing the prioritization of the universalism to increases, citizen B on the other hand, completes within the same time period his responsibility cycle (the dark green boost called Completion Responsibility Cycle (CRC)) in the perception thermometer at $t = 20$ of Citizen B in , which saves his universalism perception thermometer from falling below 0 °C. With Citizen B remaining with the value prioritization of 52.5, citizen A increases its value prioritization from 50 towards 55 (value-change-parameter = 5, see Section 3.6.6). Repeating this process over and over again results in the emergent behavior of divergent patterns of change in value prioritizations.

Based on Figure 5.4 and Figure 5.6 I conclude that this emergent behavior of divergent patterns of change in value prioritization only occurs in homogeneous networks (networks in which citizens have the same prioritizations of values) in which citizens are both socially competent and receptive towards new insights. An important note to this result is that due to the limited scale of this research, the social networks remains the same over the complete time-period and that there is no interaction between citizens and the external world outside of the neighbourhood they live in.

5.2.3 The emergence of LREOs

Figure 5.1 in Section 5.2 showed that LREOs emerge only in two out of the five of the population scenarios. To visualize why this difference exist between these different population scenarios, I visualized the three different requirements for involvement in LREOs. To display the evolution of the Responsibility, Willingness and leadership Capacity (RWC) of the population, I listed the different RWC-levels in Table 5.2). Note that a RWC-level of 4 is required to join an LREO as a supporter, RWC-level of 5 to join the board of an LREO, and RWC-level of 6 to start an LREO initiative. For a successful deployment of an LREO there should be one citizen with RWC-level of 6 (board-initiator), minimal three citizens with RWC-level of 5 or higher (board-members), and thirty citizens with RWC-level of 4 or higher (community-oriented and willing). Lastly, the board members should come to an agreement on the statutes and should find enough other citizens that support these statues and thus are willing to become LREO-supporters.

Based on Figure 5.1 and Figure 5.7 I will explain the lack of LREOs for the *Personal-Focus*, *Social-Focus* and *Self-Protection* population scenarios. The absence of LREOs in the population-scenario with the *Personal-Focus* value orientation is due to a low community-orientation, as there are almost no citizens with an RWC-level of 4 or higher. Citizens within this population-scenario are more individualistic (prioritization of benevolence is lower than 50) which results in a large number of individual-pv-owners (1 out of 4). The population scenario with the *Social-Focus* value orientation is mainly community oriented (no individual-pv-owners) and has the willingness to change (700 sustainable market consumers at $t = 520$), but the population lacks the leadership capacities needed for the initiation of LREOs (see Figure 5.7). The absence of emerging LREOs in the population with the *Self-Protection* value orientation has two causes. First, the majority of the population is not community oriented (around 500 individual-pv-owners at $t = 520$). Second,

TABLE 5.2: Overview of the different states of Responsibility, Willingness and Capacity (RWC).

RWC-level	**Description**
Level 1	Irresponsible
Level 2	Responsible
Level 3	Willing
Level 4	Community-Oriented
Level 5	Capacity to join LREO board
Level 6	Capacity to start LREO

the population, similar as the population of *Social-Focus* value orientation, lacks the leadership capacities to initiate an LREO. The results have shown that the absence of LREOs in populations can be rooted in the irresponsibility of citizens, but can also be related to a lack of willingness, community-orientation and/or leadership capacities of the citizens.

Another interesting trend to number of irresponsible citizens (RCW-level of 1) remains relatively high in every scenario, meaning that the majority of the populations struggle to really understand/acknowledge/believe the problem of climate change.

The last question that remains when studying the emergence of LREOs with this model,

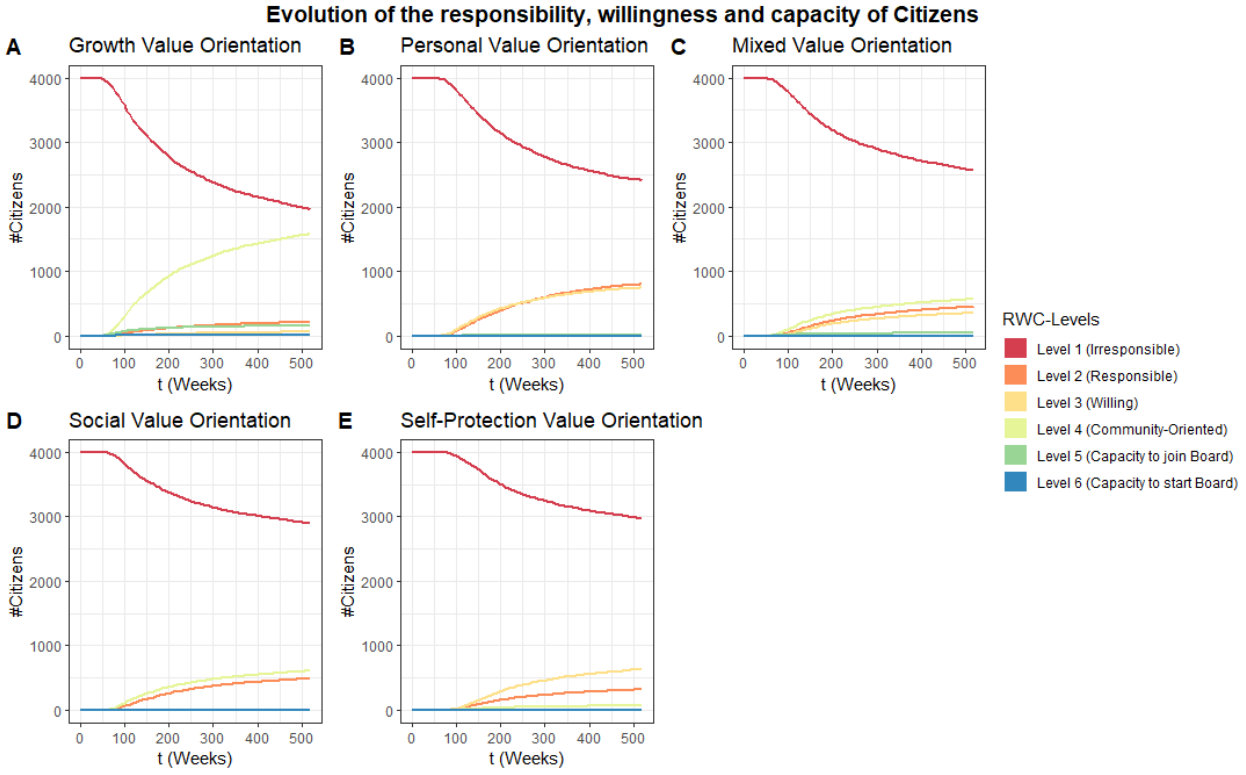


FIGURE 5.7: The number of consumers per energy supplier over time with *allowing* change in value prioritization for the five different population-scenarios.

is whether the change in value prioritization (Figure 5.4, influences the number of LREO-consumers. When comparing Figure 5.1 in which change in value prioritization was enabled, with the scenario in which the change of value prioritization is switched off (see Figure 7.1 in Section 7.2, no significant difference is demonstrated. This means that within this experiment the changes in value prioritization does not have any significant influence on the distribution of the selection of electricity supplier.

5.2.4 Recap of the results

This chapter revealed how the concerns of energy justice and environmental well-being, evoked by climate changing events, caused a change in value specification, value prioritization and the emergence of LREOs. The key takeaways of this result chapter are:

- In the process of becoming responsible citizens, individuals from the *Growth* and *Personal-Focus* value-orientations mainly struggle to acknowledge their own contribution to the problem of climate change.
- Contrarily, citizens from the *Social-Focus* and *Self-Protection* population scenarios tend to stagnate in the process of becoming responsible citizens because of disbelieve in the impact of individual actions.
- The experiments demonstrate that the setup of value prioritizations(i.e. population scenarios) is extremely important for the willingness to change suppliers, as the impact of the change in value-prioritization is only limited on a time-scale of 10 year
- Within populations with heterogeneous value prioritizations, the social pressure of their friends hinders citizens to ascribe more priority to sustainable related values, as the dominant citizens urges individuals to maintain the ruling value prioritizations of (power, achievement and hedonism).
- Within populations with an homogeneous value prioritizations the combination of social learning and the completion of the responsibility-cycle leads to the increased prioritization of the sustainability related values of universalism and benevolence. These divergent patterns of change in value prioritization is more often observed among social networks with citizens who are social competent and receptive to new opinions (*Growth* and *Personal-Focus* value orientations).
- The emergence of LREOs demonstrated that only within the population scenarios with the *Growth* and *Mixed* value orientations the emergence of LREOs was visible. The absence of LREOs in the other populations was rooted in the irresponsibility of citizens (*Self-Protection* and *Social-Focus* population scenarios), but can also be related to a lack of willingness (*Self-Protection* population scenarios), community-orientation (*Personal-Focus* population scenario) and/or leadership capacities of the citizens (*Self-Protection* and *Social-Focus* population scenarios).
- The change in value prioritization does not have a significant impact on the number of LREO-supporters within each of the population scenarios.

Chapter 6

Discussion and Conclusion

This research examined the role of the change in value specification and prioritization on the emergence of LREOs. During this research I had formulated and explored several sub-questions as recapped in Section 6.1. This chapter continues with Section 6.2 that presents a new methodological contribution to agent based modelling. Next, in the (section 6.3), I will discuss the new methodological contribution of perception thermometers. Reflecting on the main findings, I will also discuss the scientific contributions of this research, followed by outlining the limitations (section 6.4) and directions for future research (section 6.5). Finally, I will conclude with a set of recommendations for social scientists, agent based modelers and practitioners engaged with questions concerning the transition to community energy and polycentric governance of social innovations (Section 6.6).

6.1 Main conclusions

This thesis described the cognitive and collective processes of how LREOs emerge by answering the following research question: *'In what way does the recognition of the sustainability related concerns, brought by disruptive climate events, induce change in the value systems of citizens and lead to the emergence of LREOs?'*. In these upcoming paragraphs I elaborate on the conducted research by answering each of the 6 sub-questions, and conclude with the answer to the main research question.

This research started with defining the cognitive processes that play a role in the emergence of LREOs by answering the first sub-question: *'what are values and value change?'*. Supported by the extensive empirical studies (Schwartz, 1994), values are conceptualized as "trans-situational goals, varying in importance, serving as guiding principles in the life of a person or group" [p. 21]. During the selection of electricity providers, the importance ascribed to personal values determines whether citizens choose one form of electricity provision over the other. In social psychology value prioritizations are considered to remain relatively stable, and only changes under a constant pressure of new experiences (Roccas et al., 2002). Within this thesis the experience of sustainability related concerns of energy justice and environmental well-being, evoked by climate changing events, were considered to be such form of constant pressure of new experiences. Value change within this research occurred in three different forms: i) the change in values that are relevant for design; ii) specifying the self-transcendence values (i.e. universalism and benevolence) differently because of the recognition of the sustainability related concerns (see Section 2.1.1.3) and iii) the change of value prioritization due to social learning and the increased recognition of the importance

of sustainability in light of disruption caused by climate change (see Section 2.1.1.4). These forms of value change are important as this research considers the recognition of the sustainability related concerns and value prioritization to be prerequisite for starting and/or joining an LREO initiative.

Next, while continuing with the theoretical exploration, the second question addressed the importance to study the relationship between values and the change of socio-technical systems by answering *'What is the role of values in socio-technical systems and institutional change?'*. Based on the interpretation of the four-levels of institutions of Williamson (2000) by Correlje & Groenewegen (2009), this research ascribed values to the highest institutional level and thus considered values as the the core of socio-technical systems. This research sided with the argument of Brown et al. (2020) that the emergence of the sustainability related concerns of energy autarky and energy justice are evoked by the outcome of the current energy system and climate changing events. Despite the increased attention to polycentric governance, the existing lack of alignment between these new emerging values and the existing formal regime, is considered as the cause for the emergence LREOs as a new form of social innovation to satisfy these new values. Based on this analysis I suggested that LREOs emerge through the collective actions of citizens that have adopted these new values through the recognition of the sustainability related concerns.

As the second question focused more on the rationale why LREOs emerge, the third question, *'What is the founding process of LREOS?'*, addressed the theoretical underpinning of the foundantion process and the prerequisites (motives and capacities) for the initiation of LREOs. The first step of founding process of LREOs is the initiation phase. The prequisities for initiation is a combination of possessing motives and capacities. The shared motives (values) for involvement in community energy are community engagement and sustainable awareness. Besides these shared motives, giving importance to sustainability (including both biospheral and altruistic motives), independency or/and financial gain is set as a requirement for involvement in LREOs. Next to motives, this thesis demonstrated that leadership capacities also play a dominant role in the successful development of LREOs (Martiskainen, 2017). After the initiation, the other founding processes are board formation, agreement on organisation form and technology and lastly recruitment of local support.

By conceptualizing the answers of the first three questions I constructed an agent based model that is used to answer the fourth, fifth and sixth sub-question. This constructed model illustrated in what degree populations with a *Growth*, *Personal-Focus*, *Self-Protection* or *Social-Focus* value orientations recognised sustainability within their value systems and how this recognition led to changes in value prioritizations and emergence of LREOs. With answering the fourth sub-question: *'In what way is sustainability recognized within the value system of Dutch citizens (mechanism 1)?* the model introduced a gradual process in which citizens changed the specification of the transcendence values including the notions of energy just, environmental well-being and energy autarky via the responsibility cycle. This process, based on the control mechanisms of responsibility (Robeyns, 2017), consist of four different stages: Unaware (Step 0), Informed (Step 1), Acknowledging (Step 2), Responsible (Step 3). The experiments demonstrated that the citizens of citizens who recognize sustainability were much bigger in *Growth* and *Personal-Focus* value orientated populations than the *Self-Protection* and *Social-Focus* value orientations. In more detail, a big proportion of the *Self-Protection* and *Social-Focus* value orientated population remained at step

2 of the responsibility process. This implicates that a large part of the population did not recognize sustainability as they are convinced that change on the individual level is not sufficient to solve the climate problem. The irresponsible citizens in the *Growth* and *Personal-Focus*, largely remain at step 1, implicating that these people having trouble with acknowledging their own contribution to the problem of climate change.

The fifth research question, *'What is the influence of social learning and the recognition of the sustainability related concerns on the value prioritization of Dutch citizens (mechanism 2)?'*, showed how the value prioritization of citizens changed over time. Within the model, changes in value prioritizations were caused by social learning (convincing citizens imposing their value prioritization on receptive friends) and the repeated completion of the responsibility cycle. Based on the experiments results, citizens that highly prioritized achievement, power and hedonism tended to be more dominant during neighbour-meetings, while citizens who prioritizing universalism, power and conformity tended to be more receptive. Moreover, populations scenario with *Growth* and *Personal-Focus* value orientations were more receptive to change value prioritization then the populations scenarios with the *Social-Focus* and *Self-Protection* value orientations. Within populations with heterogeneous value prioritizations (*Mixed* population scenario), the social pressure of friends hindered citizens to ascribe more priority to sustainable related values, as during social learning the dominant citizens urged friends to maintain the ruling value prioritizations of power, achievement and hedonism. Controversially, populations with an homogeneous value prioritization had an increased prioritiation of the sustainability related values of universalism and benevolence due to the combination of social learning and the completion of the responsibility-cycle. These so-called divergent patterns of change in value prioritization were more often observed among social networks with social competent citizens who were social competent and receptive to new opinions (*Growth* and *Personal-Focus* value orientations).

By combining the insights of the experiments about the recognition of the sustainability related concerns and the change in value prioritization, the last sub-question, *What is the influence of mechanism 1 & 2 on the emergence of LREOs?*, examined whether LREOs emerged in each of the five population scenarios. The experiments demonstrated that the change in value prioritization has no significant influence on the emergence of LREOs. Of the five population-scenarios, only in the populations with a *Growth* and *Mixed* value orientation was the emergence of LREOs visible. The absence of LREOs in the population-scenario with the *Personal-Focus* value orientation was due to a lack of community-orientation. Citizens within this population-scenario were highly individualistic and therefore preferred individual solutions over collective initiatives. In contrast, the population scenario with *Social-Focus* value orientation was mainly community oriented, but the population lacked the leadership capacities needed for the initiation of LREOs. The absence of emerging LREOs in the population with the *Self-Protection* value orientation had two causes. First, the majority of the population was not community oriented. Second, the population, similar as the population of *Social-Focus* value orientation, lacked the leadership capacities to initiate an LREO.

To conclude, the theoretical utilization was combined with an agent based model to answer the main research question: *'In what way does the recognition of the sustainability related concerns, brought by disruptive climate events, induce change in the value systems of citizens and lead to the emergence of LREOs?'*. The impact of the recognition of the sustainability related concerns on the

value systems of citizens was two-folded. First, the recognition of the sustainability related concerns altered the value system of individuals by placing sustainability within the transcendence value orientation of the Schwartz' value complex. Sustainability was not seen as a separate new value but as new way of specifying the Universalism and Benevolence values. Second, the recognition of the sustainability related concerns, also worked as a driver for generating more importance (prioritization) to the sustainability-related values of benevolence and universalism as changes in belief-systems work as a driver for the reconsideration of value prioritization. This driving force was however only visible in populations with homogeneous value orientations in which the majority of the population was receptive to new ideas and socially competent to create this collective movement. In heterogeneous populations, the social pressure of dominant citizens who prioritized the hedonism, power and achievement values, hindered the increased importance for sustainable related transcendence values. The recognition of the sustainability related concerns of energy justice, environmental well-being and energy autarky, evoked by climate events, is considered as origin for the emergence of LREOs significantly. The experiments demonstrated that only within the population-scenarios with a *Mixed* and *Growth* value orientations the emergence of LREOs was visible. Only these population contained a large group of citizens who i) recognized the concerns of sustainability, ii) who were community-oriented, iii) who were willing to act, iv) of which a small group had the capacity to lead, and v) who together agreed on the organisational form and technology in-use. The surprising absence of emerging LREOs in the *Social-Focus* population scenario is due to lack of leadership capacities.

6.2 Methodological contribution: Perception Thermometers

Although Heidari et al. (2020) and Dignum (2021) are one of the first to study the emergent behavior of people by introducing value prioritization in an agent based model, this research offers the first successful step to model dynamic value prioritization within the cognitive architectures of agents. Where these two studies used a static value prioritization, this research goes a step further allowing the impact of decisions and experiences to influence the value prioritization of individuals. To accomplish this dynamic interaction between values and experiences these research introduces the concept of perception thermometers. The concept of perception thermometers opens up a whole new field of research, as it allows a new way to study the impact of value-weighted experiences (e.g. new knowledge or social learning) on the value prioritizations of individuals. The necessity for introducing this new concept of perception thermometers originates from the ruling consensus within social psychology arguing that the prioritization of values remain relatively stable long time periods (Roccas et al., 2002; Jin & Rounds, 2012; Vecchione et al., 2016). So to simulate impact of value-weighted experiences on changes in value prioritization and to prevent eruptive and invalidated behaviour, it is necessary to create this buffer between the environment and value systems.

Perception thermometers function as these buffers as they absorb the impact of value-weighted experiences by increasing (positive weighted experiences) or decreasing (negatively weighted experiences) its temperature. Combining this mechanism with the assumption that the impact of value-weighted experiences diminishes over time, the temperature of the perception thermometers always tend to return to the level of status quo (see Section 3.6.6 & Figure 5.5).

So only after continuous and one-sided impacts of value-weighted experiences, change in value prioritizations will occur (see Section 3.6.6 for more information on the functioning of perception thermometers within this research).

This methodological contribution to agent based modelling practices also expands the opportunity to study emergent behaviors of social dynamics. Within this research the use of perception thermometers, showed the role of social pressure on the value prioritization of heterogeneous groups (see Section 5.2.2.1), while showing patterns of radicalisation in homogeneous groups (see Section 5.2.2.2).

6.3 Scientific contribution

Next to the methodological contribution of introducing the new concept of perception thermometers, this research also has a three-folded contribution to the scientific community. At first, it builds upon existing research of Ghorbani et al. (2020) on the formation process of LREOs using agent based modelling. Where the study of Ghorbani et al. (2020) assumes that all citizens within the model are 'responsible' and willing to cooperate within initiatives, this research takes a step back with first studying how the process of the recognition of sustainability related concerns occurs before focusing on the formation process of LREOs. This approach allows to generate insights in why citizens with certain value systems are more willing to cooperate in these initiatives then others.

Second, by using the theory of value specification by van de Poel (2018), this research substantiate the linkage between sustainability within the Schwartz Value Circumplex. Based on the model conceptualization, I suggest that citizens, after dealing with the three control mechanisms of responsibility (Robeyns, 2017), start to recognize sustainability by integrating the sustainability related concerns within the transcendence value orientation of the Schwartz' value complex. Sustainability is not seen as a separate new value apart from the ten universal values, but as a new way of specifying the Universalism and Benevolence values (Dietz et al., 2005; Steg & De Groot, 2012). Next to the change in value specification, the recognition of the sustainability concerns caused by climate change also works as a driver for a change in value prioritization by giving more importance (prioritization) to the sustainability-related values of benevolence and universalism. The argument for this last statement is based on the assumption that the recognition of the sustainability related concerns is such distracting change leading to the reconsideration of their value prioritizations. In this way this research showcases how to integrate new values[1], within the existing Value Circumplex of Schwartz by the use of change in specification.

Third, this research also builds upon the conceptual framework of Boon & Dieperink (2014) on the founding steps of LREOs. Where Boon & Dieperink (2014) mainly focuses on the external and communal factors that influences the founding process of LREOs, this research expands on this framework by taking into account the responsibility, motives and capacities of individuals and by given the attention to decision making processes within the initiative. This results in a more holistic approach of analysing the emergence of LREOs as it combines external factors (e.g. consistent energy policies) with social factors (e.g. disagreements during board meetings due to the different motives of individuals).

[1] in this case the sustainability related concerns of energy justice, environmental well-being and energy autarky

6.4 Limitations

Despite the scientific and methodological contribution, this research contains several limitations. At first, it is important to keep in mind that the four cognitive attributes (values, traits, educational level, and leadership level), are highly interconnected in the current conceptualization. Within the model, formalisation leadership is based on education (Martiskainen, 2017), while education is based on traits (Abdollahi et al., 2017), and traits are based on value orientation (McCrae & Costa Jr, 2008). By using this approach, it is impossible to examine the first order impact of values [dit loopt niet lekker"the first order impact of values, tenzij het jargon is:)] on the decision making process as it is impossible to control for other cognitive attributes. So changing the settings of the value orientation within the setup will have a significant impact on the final outcome of the model. An example is the lack of emerging LREOs in the *Social-Focus* population scenario due to a lack of leadership capacities. As the leadership capacities are assumed to be dependent on the character traits of individuals, and the character traits distribution is dependent on the value prioritization of individuals, the value system is the deciding determinant for the eventual decision making behavior of the population. In reality however, it not just the value system but the complete cognitive architecture of traits, values, income and education that determines the decision making behavior of citizens.

Within the model, the impact of climate change is simplified by using an exponential probability distribution, and every citizen is assumed to immediately receive the information that is spread. In reality however, the impact of climate change events on the awareness levels of individuals is much more complex as also contradictory information about the concept plays a role. Moreover, external factors like contacts with other people outside the system, technological developments and governmental interventions are not included for simplicity reasons.

Another limitation of this research is that within the founding process of LREOs, the role of supporting-members is limited. Where in practise, supporting-members have a lot of authority on the selection of the goals and resources to achieve those goals, the role of supporting-members in this model is only limited to decide whether the proposed goals and resource deployment is in line with their own motives. In practise the supporting-members have the power the adjust or reject the plans of the board, while within the model this power is only reserved for the board-members. Replacing the simplistic approach with the approach used in practise might have resulted in a small difference in the number of LREO-supporters, but would not influence the big trends of thi

6.5 Future research

For future research I would recommend to validate the different assumptions used within the three mechanisms of the model with empirical data. The first mechanism, the recognition of the sustainability related concerns, is based on linking the control mechanisms defined by Robeyns (2017) with traits and educational level of citizens. It would be interesting in what degree these assumptions are in line with how these processes work in reality. Within the second mechanism, the change in value prioritization, it is assumed that changes in belief system results in change in perception thermometers which eventually can lead to changes in value prioritization. Although

there has been quite some longitudinal research on change in value prioritization (Roccas et al., 2002), it would be interesting to see how the change in value prioritization relates to changes in belief systems.

For the formation of LREOs, I assumed connections between value prioritization and preferences (e.g. linking the value of benevolence with being community-oriented). For future research it would be interesting whether this assumptions can be confirmed or rejected by conducting empirical research on Dutch LREOs.

Where this research mainly focused on the individual characteristics of citizens leading to the emergence of LREOs, the presented model could be further developed to study the social dynamics within the emerging LREOs. Possible research questions could be: i) How do board-members influence the value prioritizations of the other board-members?, ii) How often and on which topic do conflicts occur during the founding process of LREOs?, and iii) What is the influence of the governmental support (e.g. financial, expertise or socially) on the establishment of LREOs in neighborhoods with different characteristics (e.g. income, education, value prioritization)?.

The last recommendation for future research is to apply the model components of dynamic value prioritizations and perception thermometers on the new scientific field of social disruptive technologies. This new field of research focuses on the impact of disruptive technologies on society as a whole. By making the expected consequences of these disruptive technologies value-weighted, the dynamic cognitive architecture as presented in this study could help to understand what the impact of these disruptive technologies is on people's persception of the world around them and how that effects/influences/impacts their decision-making behavior.

6.6 Recommendations to policy makers, interest groups, modellers and scholars

Based on the conducted research I would like to make the following recommendations to policy makers, modellers and scholars working on values and polycentricity.

6.6.1 Policy makers and interest groups:

- This study shows that i) - in every population-scenario - the majority of the population struggle with recognizing the sustainability related concerns of energy justice, energy autarky and environmental well-being; and ii) of those people that recognizes the sustainability related concerns, only a small part showed willingness to change current practises of electricity consumption.

- These two highlights show that to accomplish a major change in the carbon output of the energy system, policy makers can not solely rely on the initiatives of citizens, but should take an hands-on approach with multiple regulations and rules to guide the existing energy system to a more sustainable future.

- Narrowing it down to the support of LREOs in general, I would recommend policy makers and interest groups (e.g. HierOpgewekt, EnergieSamen, Rescoop.eu) to make use of case-specific

approach when supporting LREO-initiatives. This recommendation is based on the fact that the experiments show a big diversity in the agency, goals and motives between different population-scenarios. Where one neighbourhood lacks to expertise and leadership capacities, other neighbourhoods lack capital or do not note the urgency for starting new initiatives. With combining patchwork policies with a more holistic approach that considers the values, beliefs, traits, social tensions, resources (e.g. time and capital), policy makers and interest groups would improve their capability to support LREOs in a variety of neighbourhood.

6.6.2 Agent Based Modellers:

- This research showed a successful attempt to create an agent based model that constructed an theoretically consistent configuration of dynamic cognitive architectures that consists of static character traits and dynamic value prioritization.
- Moreover, creating such a complex architecture on an individual level resulted in the emergence of interesting social behavior like the divergent patterns of value prioritization in populations with a homogeneous value prioritizations.
- These theoretically consistent complex cognitive architecture of agents clearly shows interesting insights and therefore I dare agent based modellers to continue exploring this undiscovered field of research.

6.6.3 Scholars researching the energy transition and polycentric governance:

- For energy scholars within the energy sector I would recommend to stop considering the emergence of LREOs as minor niche innovations, but to see it as the embodiment of a bigger socio-technical problem of the misalignment between the new concerns of sustainability, energy justice and energy autarky and the existing path dependencies formal institutions of the Dutch energy sector.
- With taking this new view, the focus should be centralized around detecting the emergence of new concerns like energy justice. Consequently, the adequately detected concerns should be integrated into the existing socio-technical systems like the energy system.
- Accomplishing these goals of detection and integration, calls for more insights in developing and maintaining socio-technical systems that are adaptive, flexible and resilient to these new concerns.

Chapter 7

Appendix

7.1 Appendix A: Assumptions

As the described model is complex and consists of multiple assumptions, an assumption table is added to the ODD to provide additional clarity Table 7.1.

Table 7.1: Overview of the assumptions within this model

Topic	**Description of the assumption**
Value prioritization	Every citizen has 10 personal values that differ in prioritization based on their value orientation (*Growth*, *Personal-Focus*, self-protection or *Social-Focus*). The prioritization of each value is initially based on a normal distribution with mean 75 or 25 (affiliated/non-affiliated values) and an adjustable standard deviation, and tweaked afterwards using the calibration procedure of (Heidari et al., 2020) to create coherent value prioritization systems.
Character traits	Character traits for individuals are determined by using a normal distribution in which every citizen has a unique weighted-mean. To compute this weighted-mean the correlation table of (Parks-Leduc et al., 2015) is used in which the correlation coefficient are the weights and the individual prioritizations of the correlating values (in bold) function as data points. The standard deviation of the normal distribution is also adjustable.
Responsibility	The responsibility of citizens is based on the four control mechanisms of Robeyns (2017). The first three control mechanism, knowledge, acknowledgement and believe are integrated in the responsibility cycle. Completing this cycle marks people as responsible. The fourth control mechanism, willingness to give up current standards, is assumed to be related to the values of individuals and are therefore considered as a separate component.

Income	The income level determines in which neighbourhood citizens live and their capacities to take a leadership role in acting on a community level. To generate a validated income distribution within the simulated population, the income distribution of the simulated population is visually copied based on the empirical data of the income distribution Netherlands in 2019 (Statline, 2021)
Neighbourhoods, education and friends	Citizens are equally divided into three neighbourhoods, based on their income. Based on the income they live in citizens changes of following an higher education are reduced (Rotterdam, 2020). The education-level of citizens are based on their scores for conscientiousness and extraversion and income (Hazrati-Viari et al., 2012). The lower their education level, the lower the impact of climate changing events. Citizens have 7 random friends, all from their own neighbourhood, that they weekly meet.
Leadership	The leadership level of citizens is assumed to depend on a combination of the scores for the extraversion and conscientiousness traits and external and internal influences. Influences that negative impact the capcity to lead (low education, low income, no capacity-building, inconsistent governmental policies) are compensated with high scores for the extraversion and conscientiousness traits.
Energy-supplier	Every citizen starts with an Fossil Fuel Market entity as energy supplier. It is assumed that every week citizens reconsider whether they want to stick to their current supplier (based on their responsibility, willingness and leadership capacity). Only switching from a market entity (FFM or Sustainable market) to an Individual solar panels or an LREO is possible, not the other way around. This is due to sunk investments due to the high up-front costs.
LREOs	LREOs are located in one specific neighbourhood and only citizens living in that specific neighbourhood can join. LREOs are initiated by a responsible citizen that has the willingness and leadership capacity to do so. LREOs consists of 4 to 8 board members and has a minimal of 30 (including board-members) supporters. LREOs consist of an specific organisational form; collective purchase or energy project and of cheap or sustainable sourced technologies.
Climate changing events	Climate changing events are both the actual experience of extreme weather as also the announcement of climate change as a problem (e.g. presentation of the IPCC climate report, or news on climate events). The impact of the event varies every tick and is transformed to an individual impact based on a person's traits (openness & agreeableness score) and educational level.

Social Learning	Social Learning occurs whenever two citizens meet. Both citizens are ones the influencer and once the follower. Whenever the extraversion score of the influencer is higher than the (100 - Agreeableness score) of follower the value prioritizations of follower will move towards the value prioritizations of the influencer.
Responsibility-cycle	All citizens start with an responsibility-level of 0. Over time the impact of climate change raises their awareness levels until reaching step 1. Next, if the awareness level is higher than the acknowledgement threshold (combination of openness and conscientiousness score) and the believe threshold (combination of openness and extraversion score) people complete the responsibility cycle. The first completion implicates the recognition of sustainability related concerns of energy justice, environmental well-being and energy autarky. Repeating the cycles results in the increase of the perception thermometers of the universalism and benevolence value, and the decrease of the perception thermometers of the power and achievement values.
Perception Thermometers	Perception thermometers are increased/decreased based on the result of social learning (see above) and the completion of the responsibility cycle. If the temperature is below 0 or above 100, the related value decreases/increases in prioritization and the perception thermometer returns to the level of status quo (50). It is assumed that impact that changes the perception thermometer have a diminishing effect which implicates that the temperature of the perception always tends to return to the level of status quo.

7.2 Appendix B: Emergence of LREOs without change in value prioritization

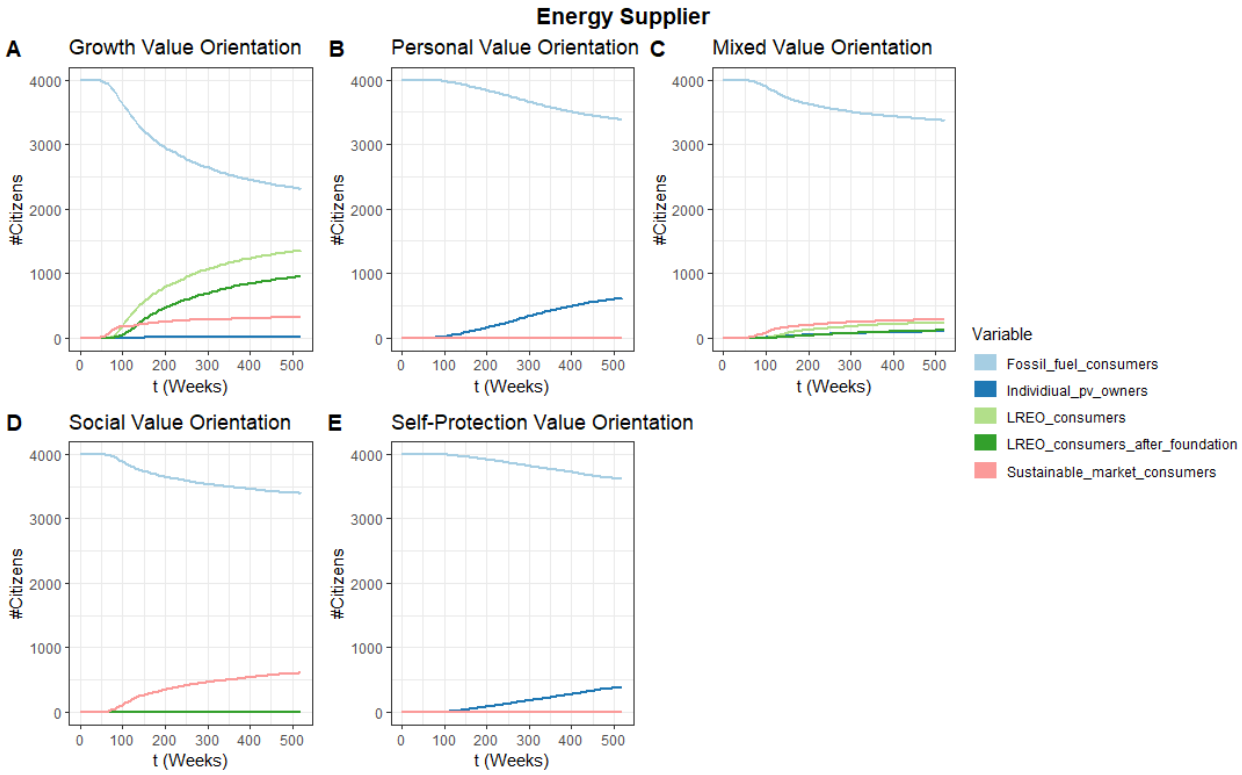


FIGURE 7.1: The number of consumers per energy supplier over time with *NOT allowing* change in value prioritization for the five different population-scenarios.

Bibliography

Abdollahi, A., Hosseinian, S., Karbalaei, S., Beh-Pajooh, A., Keshavarz, Y. & Najafi, M. (2017). The big five personality traits and environmental concern: the moderating roles of individualism/collectivism and gender. *Romanian Journal of Psychology*, *19*(1)

Abrahamse, W. & Steg, L. (2013). Social influence approaches to encourage resource conservation: A meta-analysis. *Global environmental change*, *23*(6), 1773–1785

Anderson, C. & Kilduff, G. J. (2009). Why do dominant personalities attain influence in face-to-face groups? the competence-signaling effects of trait dominance. *Journal of personality and social psychology*, *96*(2), 491

Barry, B. (1997). Sustainability and intergenerational justice. *Theoria*, *44*(89), 43–64. doi:10.3167/004058197783593443
URL http://dx.doi.org/10.3167/004058197783593443

Boon, F. P. & Dieperink, C. (2014). Local civil society based renewable energy organisations in the netherlands: Exploring the factors that stimulate their emergence and development. *Energy Policy*, *69*, 297–307

Brown, D., Hall, S. & Davis, M. E. (2020). What is prosumerism for? exploring the normative dimensions of decentralised energy transitions. *Energy Research & Social Science*, *66*, 101475

Brundtland, G. H., Khalid, M., Agnelli, S., Al-Athel, S. & Chidzero, B. (1987). Our common future. *New York*, *8*

Calder, M., Craig, C., Culley, D., de Cani, R., Donnelly, C. A., Douglas, R., Edmonds, B., Gascoigne, J., Gilbert, N., Hargrove, C. et al. (2018). Computational modelling for decision-making: where, why, what, who and how. *Royal Society open science*, *5*(6), 172096

Correljé, A., Groenewegen, J., Künneke, R. & Scholten, D. (2015). *Design for Values in Economics*, (pp. 1–23). Dordrecht: Springer Netherlands. doi:10.1007/978-94-007-6994-6_24-1
URL http://dx.doi.org/10.1007/978-94-007-6994-6_24-1

Correlje, A. F. & Groenewegen, J. P. (2009). Public values in the energy sector: economic perspectives. *International Journal of Public Policy*, *4*(5), 395–413

Davis, J. & Nathan, L. P. (2015). Value sensitive design: Applications, adaptations, and critiques. *Handbook of ethics, values, and technological design: Sources, theory, values and application domains*, (pp. 11–40)

de Witt, S. & Schmeets, H. (2018). Milieu en duurzame energie: opvattingen en gedrag. *Statistische Trends*

Dietz, T., Fitzgerald, A. & Shwom, R. (2005). Environmental values. *Annu. Rev. Environ. Resour.*, *30*, 335–372

Dignum, F. (2021). Foundations of social simulations for crisis situations. In *Social Simulation for a Crisis*, (pp. 15–37). Springer

Edmonds, B. (2017). Different modelling purposes. In *Simulating social complexity*, (pp. 39–58). Springer

Foster, V. & Bedrosyan, D. (2014). Understanding co2 emissions from the global energy sector

Fouquet, R. (2016). Historical energy transitions: Speed, prices and system transformation. *Energy Research & Social Science*, *22*, 7–12

Friedman, B., Kahn, P. H., Borning, A. & Huldtgren, A. (2013). Value sensitive design and information systems. In *Early engagement and new technologies: Opening up the laboratory*, (pp. 55–95). Springer

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy*, *31*(8-9), 1257–1274

Geels, F. W. & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research policy*, *36*(3), 399–417

Georgeff, M., Pell, B., Pollack, M., Tambe, M. & Wooldridge, M. (1998). The belief-desire-intention model of agency. In *International workshop on agent theories, architectures, and languages*, (pp. 1–10). Springer

Ghorbani, A., de Bruin, B. & Kreulen, K. (2021). Studying the influence of culture on the effective management of the covid-19 crisis. In *Social Simulation for a Crisis*, (pp. 189–230). Springer

Ghorbani, A., Nascimento, L. & Filatova, T. (2020). Growing community energy initiatives from the bottom up: Simulating the role of behavioural attitudes and leadership in the netherlands. *Energy Research & Social Science*, *70*, 101782

Gilbert, G. N. (2008). *Agent-based models*. Quantitative applications in the social sciences. Los Angeles, CA: Sage

Goldberg, L. R. (1993). The structure of phenotypic personality traits. *American psychologist*, *48*(1), 26

Grabowski, M. & Roberts, K. H. (1996). Human and organizational error in large scale systems. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, *26*(1), 2–16

Graebner, C. & Ghorbani, A. (2019). Defining institutions-a review and a synthesis

Grimm, V., Berger, U., DeAngelis, D. L., Polhill, J. G., Giske, J. & Railsback, S. F. (2010). The odd protocol: a review and first update. *Ecological modelling*, *221*(23), 2760–2768

Hazrati-Viari, A., Rad, A. T. & Torabi, S. S. (2012). The effect of personality traits on academic performance: The mediating role of academic motivation. *Procedia-Social and Behavioral Sciences*, *32*, 367–371

Heidari, S., Jensen, M. & Dignum, F. (2020). Simulations with values. In *Advances in Social Simulation*, (pp. 201–215). Springer

Heldeweg, M. A. & Saintier, S. (2020). Renewable energy communities as 'socio-legal institutions': A normative frame for energy decentralization? *Renewable and Sustainable Energy Reviews*, *119*, 109518

Hewitt, R. J., Bradley, N., Baggio Compagnucci, A., Barlagne, C., Ceglarz, A., Cremades, R., McKeen, M., Otto, I. M. & Slee, B. (2019). Social innovation in community energy in europe: A review of the evidence. *Frontiers in Energy Research*, *7*, 31

Hoppe, T. & De Vries, G. (2019). Social innovation and the energy transition

Hoppe, T. & Miedema, M. (2020). A governance approach to regional energy transition: Meaning, conceptualization and practice. *Sustainability*, *12*(3), 915

Jenkins, K., McCauley, D., Heffron, R., Stephan, H. & Rehner, R. (2016). Energy justice: a conceptual review. *Energy Research & Social Science*, *11*, 174–182

Jin, J. & Rounds, J. (2012). Stability and change in work values: A meta-analysis of longitudinal studies. *Journal of Vocational Behavior*, *80*(2), 326–339

Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A. & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. *Renewable and Sustainable Energy Reviews*, *56*, 722–744

Künneke, R. W. (2008). Institutional reform and technological practice: the case of electricity. *Industrial and corporate change*, *17*(2), 233–265

Kunze, C. & Becker, S. (2014). *Energy Democracy in Europe: A Survey and Outlook*

Ligmann-Zielinska, A. & Sun, L. (2010). Applying time-dependent variance-based global sensitivity analysis to represent the dynamics of an agent-based model of land use change. *International Journal of Geographical Information Science*, *24*(12), 1829–1850

Lowitzsch, J., Hoicka, C. & Van Tulder, F. (2020). Renewable energy communities under the 2019 european clean energy package–governance model for the energy clusters of the future? *Renewable and Sustainable Energy Reviews*, *122*, 109489

Martiskainen, M. (2017). The role of community leadership in the development of grassroots innovations. *Environmental Innovation and Societal Transitions*, *22*, 78–89

McCrae, R. R. & Costa Jr, P. T. (1992). Discriminant validity of neo-pir facet scales. *Educational and Psychological Measurement*, *52*(1), 229–237

McCrae, R. R. & Costa Jr, P. T. (2008). The five-factor theory of personality.

Nikolic, I. & Ghorbani, A. (2011). A method for developing agent-based models of socio-technical systems. In *2011 International Conference on Networking, Sensing and Control*, (pp. 44–49). IEEE

OECD (2020). *Education at a Glance 2020*. doi:https://doi.org/https://doi.org/10.1787/69096873-en
URL http://dx.doi.org/https://doi.org/https://doi.org/10.1787/69096873-en

Onufrey, K. & Bergek, A. (2015). Self-reinforcing mechanisms in a multi-technology industry: Understanding sustained technological variety in a context of path dependency. *Industry and Innovation*, *22*(6), 523–551. doi:10.1080/13662716.2015.1100532
URL http://dx.doi.org/10.1080/13662716.2015.1100532

Ostrom, E. (2010). Beyond markets and states: polycentric governance of complex economic systems. *American economic review*, *100*(3), 641–72

Parks-Leduc, L., Feldman, G. & Bardi, A. (2015). Personality traits and personal values: A meta-analysis. *Personality and Social Psychology Review*, *19*(1), 3–29

Proka, A., Hisschemöller, M. & Loorbach, D. (2018). Transition without conflict? renewable energy initiatives in the dutch energy transition. *Sustainability*, *10*(6), 1721

Pujol, G., Iooss, B., Iooss, M. B. & DiceDesign, S. (2015). Package 'sensitivity'

Reijnders, V. M., van der Laan, M. D. & Dijkstra, R. (2020). Energy communities: a dutch case study. In *Behind and Beyond the Meter*, (pp. 137–155). Elsevier

Robeyns, I. (2017). Freedom and responsibility-sustainable prosperity through a capabilities lens. *CUSP Essay Series on the Morality of Sustainable Prosperity*, (4)

Roccas, S., Sagiv, L., Schwartz, S. H. & Knafo, A. (2002). The big five personality factors and personal values. *Personality and social psychology bulletin*, *28*(6), 789–801

Rotterdam, E. U. (2020)
URL https://www.eur.nl/en/news/new-interactive-map-highlights-unequal-distribution-opportu

Sagiv, L., Roccas, S., Cieciuch, J. & Schwartz, S. H. (2017). Personal values in human life. *Nature Human Behaviour*, *1*(9), 630–639

Schlosberg, D. (2009). *Defining environmental justice: Theories, movements, and nature*. Oxford University Press

Schmitt, D. P., Allik, J., McCrae, R. R. & Benet-Martínez, V. (2007). The geographic distribution of big five personality traits: Patterns and profiles of human self-description across 56 nations. *Journal of cross-cultural psychology*, *38*(2), 173–212

Scholten, D. & Künneke, R. (2016). Towards the comprehensive design of energy infrastructures. *Sustainability*, *8*(12), 1291

Schreuer, A. & Weismeier-Sammer, D. (2010). Energy cooperatives and local ownership in the field of renewable energy technologies: A literature review

Schwartz, S. H. (1994). Are there universal aspects in the structure and contents of human values? *Journal of social issues*, *50*(4), 19–45

Schwartz, S. H. (2012). An overview of the schwartz theory of basic values. *Online readings in Psychology and Culture*, *2*(1), 2307–0919

Schwartz, S. H., Cieciuch, J., Vecchione, M., Davidov, E., Fischer, R., Beierlein, C., Ramos, A., Verkasalo, M., Lönnqvist, J.-E., Demirutku, K. et al. (2012). Refining the theory of basic individual values. *Journal of personality and social psychology*, *103*(4), 663

Schwenke, A. (2021). Lokale energie monitor 2020
URL https://www.hieropgewekt.nl/uploads/inline/LokaleEnergieMonitor2020_DEF_lr_16-02_1.pdf

Siddiki, S., Weible, C. M., Basurto, X. & Calanni, J. (2011). Dissecting policy designs: An application of the institutional grammar tool. *Policy Studies Journal*, *39*(1), 79–103

Sloot, D., Jans, L. & Steg, L. (2018). Can community energy initiatives motivate sustainable energy behaviours? the role of initiative involvement and personal pro-environmental motivation. *Journal of Environmental Psychology*, *57*, 99–106

Sloot, D., Jans, L. & Steg, L. (2019). In it for the money, the environment, or the community? motives for being involved in community energy initiatives. *Global Environmental Change*, *57*, 101936

Sovacool, B. K. & Van de Graaf, T. (2018). Building or stumbling blocks? assessing the performance of polycentric energy and climate governance networks. *Energy Policy*, *118*, 317–324

Statline, C. (2019). Slight drop in greenhouse gas emissions
URL https://www.cbs.nl/en-gb/news/2019/19/slight-drop-in-greenhouse-gas-emissions

Statline, C. (2021). Income distribution (standardized income)
URL https://www.cbs.nl/en-gb/visualisations/income-distribution

Steg, L. & De Groot, J. I. (2012). Environmental values. In *The Oxford handbook of environmental and conservation psychology*

ten Broeke, G., van Voorn, G. & Ligtenberg, A. (2016). Which sensitivity analysis method should i use for my agent-based model? *Journal of Artificial Societies and Social Simulation*, *19*(1), 5. doi:10.18564/jasss.2857
URL http://dx.doi.org/10.18564/jasss.2857

Unruh, G. C. (2002). Escaping carbon lock-in. *Energy policy*, *30*(4), 317–325

Usó-Doménech, J. L. & Nescolarde-Selva, J. (2016). What are belief systems? *Foundations of Science*, *21*(1), 147–152

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

Van de Poel, I. (2013). Translating values into design requirements. In *Philosophy and engineering: Reflections on practice, principles and process*, (pp. 253–266). Springer

van de Poel, I. (2018). Design for value change. *Ethics and Information Technology*, (pp. 1–5)

Van den Hoven, J. et al. (2013). Value sensitive design and responsible innovation. *Responsible innovation*, (pp. 75–84)

Van Vuuren, D. P., Boot, P. A., Ros, J., Hof, A. F. & den Elzen, M. G. (2017). *The implications of the Paris climate agreement for the Dutch climate policy objectives*. PBL Netherlands Environmental Assessment Agency

Vecchione, M., Schwartz, S., Alessandri, G., Döring, A. K., Castellani, V. & Caprara, M. G. (2016). Stability and change of basic personal values in early adulthood: An 8-year longitudinal study. *Journal of Research in Personality*, *63*, 111–122

Vermaas, P., Kroes, P., van de Poel, I., Franssen, M. & Houkes, W. (2011). A philosophy of technology: from technical artefacts to sociotechnical systems. *Synthesis Lectures on Engineers, Technology, and Society*, *6*(1), 1–134

Warbroek, B., Hoppe, T., Bressers, H. & Coenen, F. (2019). Testing the social, organizational, and governance factors for success in local low carbon energy initiatives. *Energy Research & Social Science*, *58*, 101269

Warren, C. R. & McFadyen, M. (2010). Does community ownership affect public attitudes to wind energy? a case study from south-west scotland. *Land use policy*, *27*(2), 204–213

Williamson, O. E. (2000). The new institutional economics: taking stock, looking ahead. *Journal of economic literature*, *38*(3), 595–613

Wolsink, M. (2000). Wind power and the nimby-myth: institutional capacity and the limited significance of public support. *Renewable energy*, *21*(1), 49–64

Wuertz, T. R. (2015). Personality traits associated with environmental concern