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VALUE CONFLICTS IN ENERGY SYSTEMS

Tristan Emile de Wildt

VALUE CONFLICTS IN ENERGY SYSTEMS

Dissertation

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by

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When I started my bachelor at TPM in 2008, I had no other rationale for choosing this study than that it just felt right. It's only after that I realised that what had attracted me the most was the multidisciplinary character of it, and the integration of different worlds. Reflecting on my family history and the life that my parents chose to build in France makes it evident that this aspect has been there all along. This thesis, I believe, is no exception as I have tried to integrate insights from ethics of technology, behavioural science, systems engineering and computational approaches. The notion of values plays a central role in combining these worlds.

This PhD has been quite a journey, both academically and personally. Academically as many divergent scientific notions needed to be integrated under the umbrella of one research project. When I felt lost, I believe that intuition, doing 'what feels right', is what has helped me the most. In some way, the importance of intuition and emotions are possibly still underestimated in the scientific process. Personally because life is anything but a long calm river. I am incredibly thankful to every person who helped me to go through these stages, either by sharing life experiences or simply; by being there for me.

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Tristan de Wildt
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CONTENTS

GLOSSARY

Design	The ensemble of regulatory and technical elements that composes a system.
Energy system	An infrastructure contributing to the energy supply chain.
Moral acceptability	"A reflection on a new technology that takes into account the moral issues that emerge from its introduction" (Taebi, 2016).
Social acceptance	"The fact that a new technology is accepted—or merely tolerated—by a community" (Taebi, 2016).
Tactic	A means to address value conflicts embedded in an energy system design.
Value	“Lasting conviction or matter that people feel should be strived for in general and not just for themselves to be able to lead a good life or realise a good society” (van de Poel and Royakkers, 2011).
Value change	A change in the relative importance of values over time.
Value conflict	A situation where the realisation of one value is at the expense of another value in a design.

List of abbreviations and acronyms

ABM	Agent-based Modelling
AMI	Advanced Metering Infrastructure
ECF	Environmental Conversion Factor
EMA	Exploratory Modelling and Analysis
GHG	Greenhouse Gases Emission
HAN	Home Area Network
IT	Information Technology
LDA	Latent Dirichlet Allocation
ODD+D	Overview, Design Concepts and Details + Decision
PCF	Personal Conversion Factor
PRIM	Patient Rule Induction Method
PV	Photo-Voltaic
R&D	Research and Development
SCF	Social Conversion Factor
WAN	Wide-Area Network

Summary

This thesis introduces an approach to support the long-term social acceptance of energy systems by addressing value conflicts embedded in regulatory and technical designs. When designing energy systems, the realisation of some values can conflict with the realisation of other values. The decision to deploy energy systems therefore inevitably entails a prioritisation of some values over others. Societal groups that do not agree with this prioritisation may decide to oppose or not to support the deployment and use of these systems. Lack of social acceptance may occur during the planning phase, but also at a later point in time as a result of value change. This can be caused by a growing mismatch between values prioritized in energy systems and how societal groups are affected. To support the social acceptance of energy systems, value conflicts embedded in energy systems need to be addressed. Methods to do so were however lacking. This thesis provides a methodological contribution by demonstrating how the literature on data science and the complexity sciences can be used to address value conflicts. This thesis answers the following research question:

- *How can value conflicts embedded in energy systems be addressed in support of social acceptance?*

We summarise how probabilistic topic modelling and agent-based modelling are used to address value conflicts embedded in energy systems and outline our main conclusions and contributions.

An approach to explore multidisciplinary literature addressing values

In chapter 3, we present a method to explore the multidisciplinary literature addressing values. Existing tactics to address values and value conflicts may originate from a wide range of scientific fields. However, the relevant literature cannot be accurately captured using traditional keyword searches. In scientific articles, authors tend to refer to values in a latent manner. Values are often not explicitly named, but a wide range of words indicate that some values are discussed. To find existing tactics to address value conflicts, an approach was required to cope with latent values in the academic literature.

The approach developed to explore the multidisciplinary literature addressing values is based on probabilistic topic modelling and semantic fields. Probabilistic topic modelling is a text mining approach to cluster a large number of texts (e.g. scientific articles) based on the topics that they address (e.g. specific values). This is done by an algorithm in an autonomous manner. Semantic fields are sets of words that refer to a common idea (e.g. a value). In our approach, probabilistic topic models are used to start from a very wide range of scientific articles potentially addressing values and progressively separate the relevant literature from the rest. Semantic fields of values are used in case the resulting set of articles still contains a number of non-relevant articles.

This approach was tested for the value *justice* in the energy literature. It resulted in a more complete overview of justice issues caused by energy systems than one obtained using traditional keyword searches. We found that mainly the literature on the smart electricity grid and electricity markets frequently addresses the value justice without naming this value explicitly.

Exploring the literature addressing value conflicts embedded in energy systems
In chapter 4, we demonstrate the approach developed in chapter 3 by identifying existing tactics to address value conflicts embedded in the smart electricity grid. Value conflicts addressed in the literature have been clustered into six groups:

- Value conflicts between *reliability* and energy *efficiency* on the one hand, and *environmental sustainability* on the other. These conflicts relate to the challenge of coping with intermittent electricity produced by renewables. Tactics include demand response strategies and enhanced smart metering.
- Value conflicts between *privacy* on one hand and *reliability*, *environmental sustainability*, and *efficiency* on the other. These conflicts relate to privacy issues in smart electricity grids. Tactics include intrusion detection systems and encryptions systems.
- Value conflicts between *justice* on the one hand and *reliability*, *competitiveness* and *environmental sustainability* on the other. These conflicts relate to socioeconomic injustices that can result from the smart grid. Tactics include procedures to account for user cultural and economic diversity.
- Value conflicts between *efficiency* and *justice*. These conflicts relate to fairness issues that could occur in household electricity trading. Tactics include improved market and distribution allocation schemes.
- Value conflicts between *justice* on one hand, and *reliability*, *competitiveness* and *environmental sustainability* on the other. These conflicts relate to fairness issues with regard to the spatial distribution of energy systems. Tactics include a better identification of the local impacts of energy systems.
- Value conflicts between *safety & health*, *efficiency*, *competitiveness* and *reliability*. These conflicts relate to product development. Tactics include technology standards to ensure sufficient safety and reliability.

The third group of value conflicts is the most worrying in terms of social acceptance. It may be responsible for causing severe socioeconomic injustices during the deployment of the smart electricity grid. However, the smart electricity grid is also critical for integrating a larger share of intermittent renewable energy sources into electricity grids. Tactics to resolve embedded value conflicts are limited.

An approach to identify value conflicts embedded in energy systems
In chapter 5, we present an approach to identify value conflicts embedded in energy systems. Whether an energy system embeds value conflicts depends on its technical and regulatory characteristics, but also on the social, economic and physical properties

of the geographical locations where it is deployed. The number of intertwined factors influencing whether value conflicts are embedded in energy systems means that they may be difficult to identify using simple human cognition.

Our approach relies on the capability approach, agent-based modelling, and the scenario discovery technique. The capability approach is a moral framework which claims that individual capabilities (i.e. freedoms) to achieve well-being is of fundamental moral importance. Individual capabilities are dependent on people's resources and conversion factors. An agent-based model is a type of simulation model that is well suited to study heterogeneous and dynamic systems. Agents in the model represent households with different resources (e.g. income) and conversion factors (e.g. education and housing). These agents aim to realise their capabilities/values. The realisation of capabilities by agents may go to the expense of the realisation of capabilities by other agents. Hence, the realisation of capabilities may be in conflict. Using the scenario discovery technique, the approach identifies capability conflicts in energy system designs and in the city districts they occur.

This approach is tested by exploring capability conflicts embedded in decentralised energy systems. We identify three types of capability conflicts. First, some capability conflicts may be inherent to technological choices. Switching to decentralised energy systems may give households more *control* over their energy supply, but this might involve more risks in terms of affordability of energy (*emotions*). Second, capability conflicts may occur within one type of population. Switching to decentralised energy systems may allow households to become more *environmentally sustainable*. However, this may lead to inclusiveness issues (*affiliation*) for immediate neighbours who are not able to participate. Third, capability conflicts may occur between different types of populations. Households that switch to decentralised energy systems dissociate themselves from contributing to economies of scale created by the national energy supply. While households with higher incomes gain more *control* over their energy consumption and become more *environmentally sustainable*, energy affordability (*emotions*) decreases for lower income households.

An ex ante assessment of long term social acceptance by addressing value conflicts embedded in energy systems

In chapter 6, we address value conflicts embedded in sustainable heating systems for city districts using a real-world case of a community driven heating initiative in The Hague, the Netherlands. The community energy project considered three types of sustainable heating systems. The first type is a 70°C district heating system. Possible heat sources are waste heat from industry located in the port of Rotterdam or collective thermal heat from a geothermal plant and a collective heat pump. This system would require the installation a new heat network in the district. A heat exchanger would replace gas boilers in households. The second type is a 40°C district heating system supplied by collective geothermal heat and is combined with individual heat pumps or electric boilers. This system would require many adjustments to homes. Individual heat pumps or electric boilers would be needed to top up the heat to 60°C. Standard radiators would have to be replaced by low temperature ones or by floor heating and houses would have to be thermally insulated. Here also, the installation a new heat network is required in the district. The third type is an all-electric heating system, supplied by heat pumps, electric boilers or a combination of them. This system would also require major adjustments to homes, similar to those mentioned above. We identify value conflicts embedded in each heating system. These value conflicts are then evaluated based on their consequences in terms of social acceptance. We suggest design requirements and policy guidelines to cope with embedded value conflicts.

Our results showed that, for the 70°C district heating system, the option with waste heat seems to be the most preferable with regard to embedded value conflicts. Two value conflicts are still embedded in this system. The first is between *environmental sustainability* and *autonomy* on the one hand, and *affordability* on the other. This district heating system may lead to higher heating costs. However, heating affordability may also increase for some households (those with high heat demand). These households tend to be the ones with higher incomes and living in individual houses. Tactics to resolve this conflict include subsidies and other means of financial support. The second value conflict is between *environmental sustainability* and *autonomy* on the one hand, and *inclusiveness* on the other. Households can become more environmentally sustainable and autonomous, but tenants and low-income households may not be able to participate in the initiative. Tactics to resolve this conflict include social inclusion activities.

Our results show that, for the 40°C district heating system, the option with electric boilers is the most preferable with regard to embedded value conflicts. Three value conflicts are still embedded in this system. The first is between *comfort* and *affordability*. This system requires households to purchase a large number of appliances and apply thorough thermal insulation. While it contributes to greater comfort, costs may be high. This conflict mostly concerns higher income households, since this heating system is probably not affordable for others. A possible measure could be to encourage a better consideration of energy labels in the value of houses, for example through tax incentives. The second conflict is between *environmental sustainability* and *autonomy* on the one hand, and *inclusiveness* on the other and is similar to the one in the 70°C district heating system. The third value conflict is between *environmental sustainability* and *autonomy* on the one hand and *affordability* on the other. Households using this system may incur higher heating costs. Heat affordability decreases for all households. Tactics to resolve this conflict include subsidies and information campaigns to help households cope with investment risks.

Our results show that, for the all-electric heating system, the option with electric boilers is the most preferable with regard to embedded value conflicts. Two value conflicts are still embedded in this system. The first is between *environmental sustainability* and *autonomy* on the one hand, and *affordability* on the other. Changes in houses are limited to thermal insulation and the purchase of electric boilers, and only affect high-income households. However, heating costs may increase considerably due to higher electricity consumption. Subsidies can be provided to support the thermal insulation of houses. The second conflict is between *environmental sustainability* and *affordability* on the one hand, and *inclusiveness* on the other. This value conflict mostly affects higher income households. Tactics to resolve this conflict include policy measures to promote the environmental benefits of electric boilers powered by green electricity.

Conclusions and contributions

In this thesis, we answer the following question: How can value conflicts embedded in

energy systems be addressed in support of social acceptance? We use probabilistic topic modelling to explore how the academic literature addresses value conflicts. Identified tactics can be used to specify design requirements and policy guidelines in support of the social acceptance of energy systems. Agent-based modelling is used to identify value conflicts embedded in energy systems that result from the heterogeneous properties of the affected population. Agent-based models provide insights about the type of population affected by value conflicts and hence about the severity of the resulting lack of social acceptance. This thesis contributes to the literature on social acceptance by demonstrating how long-term acceptance can be supported by drawing on insights from ethics of technology. Additionally, we provide a systematic and practical approach to integrate human values in the regulatory and technical design of infrastructures, which is critical for supporting the ongoing energy transition.

Samenvatting

Dit proefschrift introduceert een aanpak om de sociale acceptatie van energiesystemen op lange termijn te bevorderen. Bij het ontwerpen van energiesystemen kan de realisatie van sommige waarden in conflict zijn met de realisatie van andere waarden. De beslissing om een energiesysteem te gebruiken leidt dan onvermijdelijk tot het geven van voorrang aan sommige waarden boven andere. Maatschappelijke groepen die het niet eens zijn met deze keuze kunnen ervoor kiezen om het gebruik van dit energiesysteem tegen te gaan. Een gebrek aan sociale acceptatie kan al tijdens de eerste ontwerpfase ontstaan, maar ook later, wanneer het systeem al in gebruik genomen is. Dit kan veroorzaakt worden door een groeiende discrepantie tussen de geprioriteerde waarden in energiesystemen en hoe maatschappelijke groepen worden beïnvloed. Om de sociale acceptatie van energiesystemen te bevorderen, moeten waardeconflicten tijdens de ontwerpfase aangepakt worden. Tot nu toe was er een gebrek aan methoden om dit mogelijk te maken. Dit proefschrift toont aan hoe literatuur over data- en complexiteitswetenschap hiervoor gebruikt kan worden. Dit proefschrift beantwoordt daarmee de volgende onderzoeksvraag:

- *Hoe kunnen waardenconflicten in energiesystemen geadresseerd worden om hiermee sociale acceptatie te bevorderen?*

Probabilistische onderwerp modellen zijn in dit onderzoek gebruikt om de wetenschappelijke literatuur over waardeconflicten te verkennen. Geïdentificeerde oplossingsrichtingen kunnen gebruikt worden om ontwerpvoorschriften en beleidsrichtlijnen op te stellen ter bevordering van sociale acceptatie onder belanghebbenden. Met behulp van agent-gebaseerde modellen kunnen waardeconflicten in energiesystemen geïdentificeerd worden, waarbij de heterogene karakteristieken van de populatie een rol spelen. De agent-gebaseerde modellen in dit onderzoek geven inzicht in welk type populatie getroffen wordt door waardevoorkeuren en dus hoe zwaar de gevolgen kunnen zijn met betrekking tot sociale acceptatie. Dit proefschrift draagt bij aan de kennis over sociale acceptatie. Het proefschrift laat zien hoe lange termijn acceptatie van energiesystemen bevorderd kan worden door gebruik de maken van inzichten uit de literatuur over ethiek van technologieën. Daarnaast wordt een systematische en pragmatische aanpak gepresenteerd om menselijke waarden in de ontwerpen van infrastructuren te integreren. Dit is van groot belang om de energietransitie te laten slagen.

1

INTRODUCTION

1.1. Motivation

This section introduces the motivation for this thesis. We explain why the social acceptance of energy system is difficult to support. A promising approach is to address the value conflicts that are embedded in energy systems. We identify two main research challenges that need to be addressed using this approach.

1.1.1. Energy systems and contestations

Energy systems are key to human well-being. Energy systems are infrastructures that are used at different levels of this energy supply chain: resource extraction, conversion to power or heat, transportation and end-use conversion (Ajah, 2009). The relationship between stable energy supply and economic growth has been widely acknowledged in the literature (Cleveland et al., 1984, Gagnon, 2008). Low energy efficiency and energy return on investment lead to a loss of welfare, productivity and to economic decline (Cleveland et al., 1984, Ligtvoet et al., 2016). Over time, human well-being in a general sense can be affected: satisfaction of fundamental physical needs and mental and psychological well-being (Lambert et al., 2014). Energy systems can therefore be described as socio-technical systems (Verbong and Geels, 2007). They are shaped as a result of interactions between societal actors, technologies and regulations (Hughes, 1987).

The deployment and operation of energy systems is often contested by societal actors. Opposition often occurs during the planning phase (Wolsink, 2007a). A well-known example is the citizens' protests against the construction of wind farms, due to their visual impacts (Wolsink, 2000). Other examples include protests against carbon capture and storage, shale gas and transmission lines (Brunsting et al., 2011, Cuppen, 2018, Feenstra et al., 2011, Komendantova and Battaglini, 2016). Sometimes, contestation occurs during the operation phase. Protests against natural gas extraction in the province of Groningen only started several decades after deployment, when the frequency of earthquakes increased (Voort and Vanclay, 2015). Energy systems can be contested at different societal levels, for example the parliamentary level in the case of smart meter legislation in the Netherlands (Cuijpers and Koops, 2012).

Although contestations can be seen as a way to flag societal concerns, they can also be deeply problematic. Recurrent protests against wind farms are problematic given the urgency of the energy transition. Significant technological innovations are required to decrease greenhouse gas emissions produced by electricity supply and to anticipate depleting fossil fuel resources (Correljé et al., 2015). Protests against energy transition related projects have been observed for all technological options: "wind energy, biogas installations, transmission lines, carbon capture and storage, shale gas, natural gas, gas storage, solar fields and so on" (Cuppen, 2018). These protests have led to significant delays in deploying technological and regulatory solutions (Devine-Wright, 2005, Masden et al., 2015, Owens, 2004, Shaw, 2011). Finding more effective ways to address contestations against energy systems is therefore urgent.

1.1.2. THE DIFFICULTY OF SUPPORTING THE SOCIAL ACCEPTANCE OF ENERGY SYSTEMS

The occurrence of contestations against the deployment of infrastructures means that there is a lack of social acceptance. Social acceptance refers to the appraisal of a technology's deployment and operation by stakeholders. It conveys both the more passive notion of 'accepting' the technology, i.e. not resisting its deployment, and the more active one in terms of support (Batel et al., 2013). Three dimensions of social acceptance can be identified (Wüstenhagen et al., 2007). Socio-political acceptance refers to the degree of support at the broader level (e.g. regional or national), through law and political debates. Community acceptance relates to support at the local level, by local authorities and residents. Market acceptance refers to technology adoption and companies' willingness to invest. A lack of social acceptance may ultimately lead to delays in system deployment (Owens, 2004), early decommissioning (Voort and Vanclay, 2015) or even project cancellation.

Social acceptance can be supported through the specification of design requirements and policy guidelines during the planning phase. A lack of social acceptance entails that a share of stakeholders has decided to oppose or not to support an infrastructure. Often this occurs because the infrastructure does not align with their interests or values. To support social acceptance, stakeholder concerns about the infrastructure can be identified. This can be done using participatory methods, by involving stakeholders in decision-making processes (Cuppen, 2018, Devine-Wright, 2011, Stirling, 2008). Design requirements and policy guidelines can be specified to accommodate stakeholder interests and values. Correljé and Broekhans (2015) for example discuss how storm surge barriers in the Netherlands were successfully adjusted to limit ecological repercussions. Necessary design requirements and policy guidelines to support social acceptance are preferably identified during the planning phase. Later changes during the deployment or operation phases may be more costly or even infeasible.

Supporting social acceptance is difficult in the case of energy systems for two reasons. First, it is difficult to oversee the negative impact of energy systems which could potentially lead to a lack of social acceptance. Energy systems tend to be large infrastructures that affect a wide range of stakeholders. These includes citizens, local authorities, governments and companies (Chappin, 2011). The wide range of affected stakeholders means that it might be difficult for energy system designers to assess the actual impact of an energy system and hence to take adequate measures to support social acceptance. Additionally, the impact of an energy system on stakeholders might change over time. Protests against gas extraction in the Dutch province of Groningen only started decades later when earthquakes became more frequent (Voort and Vanclay, 2015). To effectively support social acceptance, the changing impact of an energy system on stakeholders needs to be taken into account. Energy systems are however typically deployed for several decades and it is uncertain how they may impact stakeholders in the future.

Second, it is difficult to evaluate which negative impacts of energy systems may ultimately result into a lack of social acceptance and therefore need to be addressed as priority. The implementation of design requirements and policy guidelines typically require additional financial resources. Also, their realisation may be in conflict. For example, it might be impossible to ensure that an energy system guarantees both user privacy and user accountability. Supporting social acceptance thus inevitably requires selecting some design requirements and policy guidelines over others. A typical solution is to base this selection on current stakeholder preferences. The difficulty in the case of energy systems is that there is often a large gap between preferences stated by stakeholders during the planning phase, and their actual acceptance during deployment and operation phases. Stakeholder preferences may for example change over time as they learn from the actual impact of energy systems. As a result, it is difficult to foresee which design requirements and policy guidelines need to be selected to support short and long term social acceptance.

The difficulty of supporting the social acceptance of energy systems raises the question of how this should be interpreted and addressed. Recently, some scholars in the literature have expressed a different view about contestations against energy systems. Rather than trying to avoid them, they can also be seen as some form of social participation (Hajer, 2003). Contestations "challenge existing institutions and create new political spaces" (Cuppen, 2018). They are also useful to guide the decision-making process and to reveal societal and ethical risks (Taebi et al., 2016). While we acknowledge this point, the urgency to install sustainable energy systems and the typically high amount of (public) money involved means that more effective ways to support the social acceptance of energy systems need to be researched.

1.1.3. SUPPORTING SOCIAL ACCEPTANCE BY ADDRESSING EMBEDDED VALUE CONFLICTS

Energy systems typically embed value conflicts. The literature on ethics of technology argues that technologies and regulations are value-laden (Van de Poel, 2009). Values are defined as "lasting convictions or matters that people feel should be strived for in general and not just for themselves to be able to lead a good life or realise a good society" (van de Poel and Royakkers, 2011). Examples of values frequently discussed in relation to energy systems are efficiency, environmental sustainability, justice, privacy and autonomy (Demski et al., 2015, Milchram et al., 2018b). The realisation of technological and regulatory designs of energy systems often requires trade-offs between values (Van de Poel, 2015). Larger wind turbines are more favourable in terms of environmental sustainability, but their deployment can create larger issues of landscape authenticity (Söderholm and Pettersson, 2011). In the smart meter, more frequent transmission of consumption data favours grid reliability, but raises consumer privacy issues (Jackson, 2014). Energy system designs therefore embed value conflicts. Their deployment inevitably entails a decision to prioritise some values over others.

Identifying value conflicts embedded in energy systems is useful to anticipate a lack of social acceptance. Prioritising values may mean favouring some societal groups over others. For example, the deployment of wind turbines favours the general public over local communities living close to wind farms (Wüstenhagen et al., 2007). Disfavoured societal groups may decide to oppose or not to support the deployment of energy systems during the planning phase. A lack of social acceptance may also occur later in the deployment and operation phases, as a result of value change. Value change refers to changing relative importance of values over time (van de Poel, 2018b). Future developments may affect how societal groups are affected in terms of values. For example, smart meters have been tolerated in some regions due to their benefits in terms of environmental sustainability (Hess and Coley, 2014). However, the increasing usage of information technology and changing life patterns could lead to political debates about privacy and to actions from consumer groups. Identifying scenarios that could lead to value change can be used to anticipate a lack of social acceptance. Design requirements and policy guidelines can then be specified in support of social acceptance.

Supporting the social acceptance of energy systems by addressing embedded value conflicts has two advantages. First, specified design requirements and policy guidelines do not rely on the precarious prediction of stakeholder opinions and decision-making. This is critical in the case of energy systems since it is impossible to predict decision-making for multiple decades. Rather, we focus on identifying broad socioeconomic futures (scenarios of value change) that could potentially give reasons to stakeholders not to accept energy systems. This information can be used to specify design requirements and policy guidelines in support of the social acceptance. Second, relying on a normative analysis allows for the consideration of a wider range of stakeholder concerns that may lead to a lack of social acceptance in the deployment and operation phases. This is different from a descriptive analysis, which inherently tends to concentrate on stakeholders concerns that are perceivable during the planning phase. Our choice to support the social acceptance of energy systems by addressing embedded value conflicts is further detailed in chapter 2.

1.1.4. Research challenges

We encounter two main methodological challenges in addressing value conflicts embedded in energy systems in support of their social acceptance: (1) coping with the fact that values are latent concepts and (2) coping with the difficulty of identifying value conflicts embedded in energy system designs.

The first research challenge is to cope with the fact that values are latent concepts because there are often no single word that indicate that a value is addressed in a document. The academic literature proposes a large range of tactics to address and resolve value conflicts. For example, encryption methods can be used to protect consumer privacy in the smart meter (Wang and Lu, 2013). These tactics may originate from a wide range of scientific fields: engineering, social, legal and economics. However, the relevant literature addressing value conflicts cannot be accurately captured using traditional keyword searches. Values are latent concepts (Deerwester et al., 1990). In most cases, scientific articles do not mention the values that they address. Rather, a broad range of interchangeable words indicates that some values are discussed. For example, scientific articles addressing privacy issues may not necessarily use the word 'privacy' but use words such as 'encryption', 'cyber' or 'hacker'. The fact that values are often latent in scientific articles means that a large range of existing tactics may remain hidden in literature searches. An approach is needed to cope with latent values in scientific articles.

The second research challenge is to cope with the difficulty of identifying which value conflicts are embedded in different energy system designs. Whether two values are in conflict depends on the properties of the energy system, but also on characteristics specific to the location where this energy system is deployed. For example, the deployment of electric cars may allow individuals to become more environmentally sustainable. The realisation of environmental sustainability may however conflict with the realisation of fairness specifically in a neighbourhood with disparate income. The more affluent population is able to adopt electric cars while the less affluent population is left behind. Fairness issues could also be explained by physical factors. Some households in the neighbourhood may not have access to parking spaces where private chargers can be installed. Often a combination of intertwined factors explains whether value conflicts are embedded in energy systems and it can then be difficult for the human mind to evaluate whether two values are in conflict in a specific case. Finding empirical proofs of embedded value conflicts is not always possible since a lack of fulfilment of some values does not always translate into immediate (and visible) stakeholder protests against energy systems (i.e. a lack of social acceptance). An approach is therefore needed to identify which value conflicts are embedded in energy systems.

1.2. RESEARCH DESIGN

Addressing value conflicts embedded in energy systems can contribute to support their social acceptance. There is however a substantial methodological gap to conduct such an analysis. Section 1.1.4 identifies two main research challenges that need to be addressed. We present the research design to address these challenges.

1.2.1. RESEARCH OBJECTIVES

Supporting the social acceptance of energy systems is challenging. Reasons include the difficulty to foresee their societal impact on short and long term, and to predict stakeholder opposition or lack of support. The research objective is the following:

- To support the design of socially accepted energy systems.

To fulfil this objective, conceptual and methodological gaps need to be addressed. First, a conceptualisation of the relationship between a lack of consideration of values and social acceptance needs to be proposed. This entails integrating insights from two separate scientific fields: ethics of technologies and the literature on social acceptance. Second, methods and approaches need to be developed to address value conflicts in energy systems. The current literature on ethics of technology is insufficient for this purpose, which means that methods typically used in other fields need to be integrated. To fulfil the research objective, the following sub-objectives need to be met:

- To propose a conceptualisation of the relationship between a lack of consideration of values and social acceptance.
- To develop necessary methods and approaches to address value conflicts in energy systems.
- To apply these methods to support the social acceptance of energy systems.

1.2.2. RESEARCH QUESTIONS

We support the long-term social acceptance of energy systems by addressing value conflicts embedded in technological and regulatory designs. This is done by pragmatically drawing on insights from ethics of technology. Our central research question is:

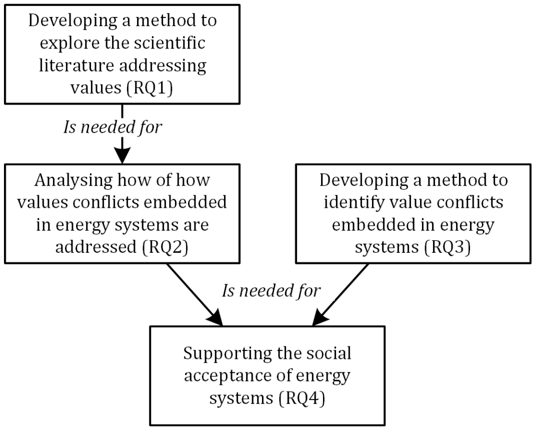

Figure 1.1: Relation between research questions

- **How can value conflicts embedded in energy systems be addressed in support of social acceptance?**

To do so, four questions need to be answered. The relationship between these questions is visualised in Figure 1.1. We introduce the four research questions in this section and explain how they are connected.

First, it is necessary to identify scientific articles providing tactics to address value conflicts and suggesting solutions to resolve them. Scientific articles, however, tend to refer to values in a latent manner. This means that the relevant literature may be difficult to capture using traditional keyword-based searches. A method is required to identify scientific articles based on the values that they address. Our first research question is:

- RQ1: How can multidisciplinary literature addressing values be systematically explored?

Second, using the method developed through RQ1, we can analyse how value conflicts embedded in energy systems are addressed by the academic literature and identify suggested tactics. Our second research question is:

- RQ2: How are value conflicts embedded in energy systems currently addressed?

Third, value conflicts embedded in energy system designs need to be identified. The occurrences of value conflicts are complex as they may result from a wide range of intertwined factors. Simulation models, such as agent-based models, can be used to account for system complexity (see section 2.4.2) and to identify which value conflicts are embedded in various energy systems. Our third research question is:

- RQ3: How can a simulation model be conceptualised and specified to identify value conflicts embedded in energy systems?

Fourth, the social acceptance of energy systems can be supported by addressing embedded value conflicts. This can be done using tactics identified through RQ2 and the simulation model proposed through RQ3. We use a case of community driven heating initiative in the Hague, the Netherlands, to demonstrate this approach. Our fourth research question is :

- RQ4: How can we assess ex ante the social acceptance of household sustainable heating systems at the city district level by addressing value conflicts?

1.2.3. RESEARCH SCOPE

The scope of this research is limited in five main ways: the technological systems addressed (energy systems), the type of factors considered that may lead to a lack of social acceptance (values), the status of values, a conceptualisation of values as singular entities and the type of assessment performed to support the social acceptance of energy systems.

First, our research focuses on energy systems. We choose to view energy systems as a socio-technical system (Hughes, 1987). This is because both the technological properties of these systems as well as the regulations used to govern their deployment and operation may impact the consideration of values and whether value conflicts are embedded in designs. For example, wind farms contribute to environmental sustainability. Regulation that supports ownership at the community level can contribute to distributive justice (Cowell et al., 2011).

Second, we focus on specific factors that may lead to a lack of social acceptance: the consideration of values in technological and regulatory designs. This choice is advantageous as we do not have to rely on the precarious prediction of stakeholder decision-making to support the social acceptance of energy systems. Also, we do not overlook underlying ethical concerns that some stakeholder may not be able to defend. Other types of factors may however also lead to a lack of social acceptance. These include stakeholder norms and interests. As a result, we do not aim to suggest that specified design requirements and policy guidelines in this research will guarantee social acceptance.

Third, we view values as responses to new morally problematic situations but do not study the actual emergence of new values. A debate exists within ethics about that status of values. Values can be seen as free-standing entities or as responses to new morally problematic situations (Boenink and Kudina, 2020). In the case of the former, values exist independently from certain phenomena and can be attached to technologies to evaluate their societal impact. In the case of the latter, values are "evaluative devices" (Boenink and Kudina, 2020) that arise with technological development to understand and evaluate their impact (cf. Dewey (1922)). In this thesis, we select values that have been identified as relevant to energy systems by the academic literature. These values have therefore been considered as necessary responses to problematic situations caused by energy systems. However, the study of processes leading to the emergence of new values is not part of the scope of this thesis as it represents a significant additional research challenge.

Fourth, we choose to conceptualise values as singular entities. For each value, multiple conceptualisations may exist (Taebi et al., 2020). For example, privacy can be understood as bodily or as informational privacy (Koops et al., 2017). Next to conflicts between values, conflicts may also exist between different conceptualisations of values. In this thesis, we choose to conceptualise values as singular entities because we are mostly interested in providing a methodological contribution on how to address value conflicts. The exploration of potential conflicts between both values and conceptualisations of values would be a considerable additional task.

Fifth, we support the social acceptance of energy systems by drawing on insights from ethics of technology. Two types of assessments can be performed to evaluate the societal appraisal of technologies (see section 2.2.1). Social acceptance assessments evaluate or predict whether stakeholders choose to oppose or not to support the deployment of a technology. Such assessments are usually descriptive, addressing "the state of affairs" (van de Poel, 2016). Moral acceptability assessments evaluate whether technologies are 'good' in a moral sense, taking the moral issues that their deployment and operation might create in account (Taebi, 2016). Such assessments are usually normative, using a value theory (Schroeder, 2016). The aim of such assessments is not to predict stakeholder choices, but to evaluate if social justice is preserved. A normative analysis of moral issues provides advantages to anticipate a potential lack of social acceptance in the case of energy systems. These advantages are further explained in chapter 2.

1.2.4. OUTLINE

The structure of this dissertation is explained in this section and follows the structure of research questions presented in section 1.2.2.

Chapter 2, we present the theoretical background. We explain why we choose to support the social acceptance of energy systems by addressing value conflicts embedded in regulatory and technical designs. We then demonstrate the contributions of the fields of complexity sciences and data sciences to address value conflicts.

Chapter 3 answers our first research question. We develop a comprehensive approach to explore the multidisciplinary literature addressing values.

Chapter 4 uses the approach developed in chapter 3 to answer our second research question. We evaluate how value conflicts embedded in energy systems are currently addressed by the academic literature and identify suggested tactics.

Chapter 5 answers our third research question. We develop a simulation model to identify value conflicts embedded in energy systems.

Chapter 6 answers our fourth research question. We use tactics identified in chapter 4 and the simulation model developed in chapter 5 to support the social acceptance of sustainable heating systems for city districts.

Chapter 7 discusses the societal and scientific contributions of this thesis. We suggest a research agenda to further address value conflicts embedded in energy systems in support of their social acceptance.

2

THEORETICAL BACKGROUND

In this chapter, we show how the social acceptance of energy systems can be supported by addressing value conflicts embedded in energy systems. In section 2.1, we first introduce the scientific fields that are relevant to address the social acceptance of energy systems. We explain that while this field of research is growing, it is still difficult to specify effective design requirements and policy guidelines to support the social acceptance of energy systems. To explain why this is the case, we distinguish between assessments of the social acceptance and moral acceptability of technologies in section 2.2. An assessment of social acceptance encompasses a descriptive analysis of whether a technology is accepted by stakeholders. An assessment of moral acceptability entails a normative analysis of moral issues caused by a technology. In section 2.3, we explain how the limitations of a descriptive analysis of social acceptance can be overcome by addressing value conflicts embedded in energy system designs. Methods to address value conflicts are however lacking. In section 2.4, we show how the literature on data science and the complexity sciences can be used to address this research gap. We conclude this chapter by providing an overview of how our research is positioned in the academic literature in section 2.5.

2.1. DIFFICULTY OF SUPPORTING THE SOCIAL ACCEPTANCE OF ENERGY SYSTEMS

Scientific research addressing the lack of social acceptance of energy systems is growing. While the deployment of these systems was originally mainly addressed from a technological and economic perspective, research including social aspects has increased since the 1990s (Batel et al., 2013, Gaede and Rowlands, 2018). We can identify two main scientific fields addressing social acceptance: innovation management, social psychology and behavioural science. In the field of innovation management, a share of the literature focuses on new product development and on product characteristics to support adoption (Carlsson and Stankiewicz, 1991, Geels, 2002, Rogers, 1995). Product characteristics influencing adoption relate to a product's competitive advantage, usability, and compatibility (Gerstlberger et al., 2014, Shum and Watanabe, 2009). Another area of research is a firm's strategic manoeuvring and use (van de Kaa et al., 2011). The literature from social psychology and behavioural science focuses on individual decision-making, influenced by social processes. Stern1999 suggests that values, beliefs, and norms influence individual acceptance through social movement. The Technology Acceptance Model (Davis, 1989) proposes that perceived usefulness and perceived ease of use influences users' acceptance of technologies.

While research on the social acceptance of energy systems is growing, their lack of acceptance is persistent and difficult to address. In particular, an (unexpected) discrepancy often occurs between the perceived social acceptance during the planning phase and the actual social acceptance during the deployment and operation phases of energy systems. Positive attitudes and intentions towards an energy system are often erroneously assumed to automatically lead to product adoption (e.g. Hai et al. (2017)). For example, political discussions about privacy concerns in the deployment of the smart meter came as a surprise and delayed its deployment for many years (Cuijpers and Koops, 2012). Addressing this potential lack of social acceptance also remains challenging. Misinformation is often assumed to be the reason for stakeholder opposition to energy system deployment, but information campaigns often fail to contribute to social acceptance (Taebi, 2016, Wolsink, 2007a). Even if technical and regulatory solutions may sometimes exist, growing mistrust between stakeholders means the effectiveness of these solutions tends to be contested (e.g. Brunsting et al. (2011), Dresner et al. (2006), Shaw et al. (2015)).

The difficulty of supporting the social acceptance of energy systems is largely problematic from a societal perspective. This is often the case for both societal groups in favour and against the deployment of energy systems. Protests against the deployment of renewables are a serious threat to the success of the (urgent) energy transition (Demski et al., 2015). However, privacy issues caused by the deployment of smart meters (Ellabban and Abu-Rub, 2016) and socioeconomic inequalities created by low carbon innovations (Sovacool et al., 2019) seriously affect human well-being.

2.2. SOCIAL ACCEPTANCE AND MORAL ACCEPTABILITY OF ENERGY SYSTEMS

In this section, we distinguish between assessments of the social acceptance and the moral acceptability of technologies. The first assesses whether technologies are accepted by stakeholders. These assessments are usually descriptive. The second identifies moral issues caused by technologies. Such assessments usually entail using a normative approach. The distinction is necessary because the former, which seems to be the straightforward choice to support social acceptance, has structural limitations in the case of energy systems. The aim of the latter is not primarily to support social acceptance. However, such analyses provide insights that can be helpful in the case of energy systems. In this section, we present the advantages and limitations of both types of assessments to specify design requirements and policy guidelines in support of the social acceptance of energy systems. In section 2.2.2, we explain how a normative analysis of moral issues caused by energy systems can be helpful in identifying underlying sources of concerns

Table 2.1: Overview of differences between assessments of the moral acceptability and social acceptance and of technologies

	Assessments of the social acceptance of technologies	**Assessments of the moral acceptability of technologies**
Objective	Anticipate stakeholder opposition or lack of support	Evaluate moral issues created by the deployment and operation of technologies
Type of analysis	Descriptive analysis, based on empirical data	Normative analysis, based on a value theory
Level of analysis	Stakeholders (e.g. citizens, companies)	Society
Typical scientific fields	Innovation management Social psychology Behavioural science	Ethics of technology

that might result in a (future) lack of social acceptance. In section 2.2.3, we explain how a descriptive analysis of the social acceptance of an energy system can be more effective in finding a range of design requirements and policy guidelines in support of social acceptance. Section 2.2.4 summarises the advantages and limitations of both approaches.

2.2.1. ASSESSMENTS OF SOCIAL ACCEPTANCE AND MORAL ACCEPTABILITY

In this section, we examine the distinction between social acceptance and moral acceptability assessments for technologies. These two types of assessments differ in terms of their objectives of analysis and in terms of how they are carried out. These differences are summarised in Table 2.1.

Research assessing the *social acceptance* of technologies aims to evaluate if they will be accepted by stakeholders. Social acceptance can take multiple forms depending on the type of technology and the stakeholder subject to acceptance: adoption of innovations, creation of favourable policies, and absence of citizen protests (see Wüstenhagen et al. (2007)). Studies assessing the social acceptance of technologies tend to place stakeholders (e.g. citizens or companies) at the centre of analysis (Roeser and Steinert, 2019). Typical analyses aim at understanding and anticipating the choices of these actors leading to the (non-) acceptance of a technology. An example is the Technology Acceptance Model (Davis, 1989) which aims to understand how perceived usefulness and perceived ease-of-use affect system use. These analyses are descriptive, addressing "the state of affairs" (van de Poel, 2016). Factors influencing the acceptance of technologies are typically identified empirically, by means of interviews, surveys, or by observation of stakeholder behaviours. Research assessing the social acceptance of technologies typically originates from the fields of innovation management, social psychology, and behavioural science.

Research assessing the *moral acceptability* of technologies aims to make technologies better from a moral perspective. Assessments are typically carried out in terms of values. A technology is considered to be better if it sufficiently considers a range of moral values, such as privacy, autonomy, and trust (Friedman et al., 2006). Relevant values are typically established normatively, for example through the use of a value theory (Schroeder, 2016). Examples of value theories are utilitarianism, resourcism, and the capability approach (Wells, 2019). In contrast to research assessing the social acceptance of technologies, the aim is not to predict the decisions and actions of particular stakeholders, but to evaluate if social justice is preserved for societal groups affected by the technology (Gauttier, 2019). Research assessing the moral acceptability of technologies typically originates from ethics of technology and philosophy. A central approach is Value Sensitive Design (Friedman et al., 2006), which aims to proactively embed values into technical designs (Manders-Huits, 2011). Moral acceptability assessments of energy systems are rarer in the academic literature compared to social acceptance assessments.

Although *moral acceptability* assessments principally aim to evaluate the morality of technologies, an analysis of the moral issues caused by a technology can be useful to anticipate a future lack of social acceptance. One justification provided by ethicists of technology to address moral issues caused by technologies is that it could reduce stakeholder opposition or lack of support (Gauttier, 2019, Oosterlaken, 2014). The difficulty is that the relationship between underlying moral issues and social acceptance is often ambiguous. For example, smartphones tend to embed privacy issues (Roux and Falgoust, 2013) but are still widely used due to network effects. A technology may not be morally acceptable but may still be accepted by users (Roeser and Steinert, 2019).

In section 2.2.2 and 2.2.3, we discuss how both types of assessments can help to support the social acceptance of energy systems. In section 2.2.2, we explain that an assessment of social acceptance may not identify all underlying sources of concerns that could eventually result in stakeholder opposition or lack of support during the long-term planning horizon of energy systems. A normative analysis of moral issues caused by energy systems can bring to light a wider range of concerns. In section 2.2.3, we explain that while exposing a wide range of concerns, a normative analysis of moral issues does not help to select the most effective design requirements and policy guidelines. Specifying and implementing additional design requirements and policy guidelines can be costly. However, as the relationship between underlying moral issues and social acceptance is often ambiguous, it is unclear which design requirements and policy guidelines should be prioritised.

2.2.2. IDENTIFYING SOURCES OF CONCERNS

In this section, we explain why a normative analysis of moral issues caused by energy systems is more useful to identify underlying sources of concerns that could lead to a lack of social acceptance during their life-cycle. To do so, we first need to explain how a lack of stakeholder opposition or lack of support might emerge from underlying sources of concerns.

Whether stakeholders decide to oppose or not to support an energy system is influenced by at least four main factors (see Figure 2.1). First, the energy system must have a negative impact, which may relate to individual interests (e.g. decrease of housing value, loss of market share) or to broader societal considerations (e.g. socio-demographic injustices, climate change). Second, stakeholders must be able to perceive these negative impacts. For example, the smart meter might negatively affect households in terms of privacy, but consumers might only perceive privacy issues if data breaches occur. Third, stakeholders must have the opportunity to oppose or not to support an energy system, for example through political representatives or consumer organisations. Some societal

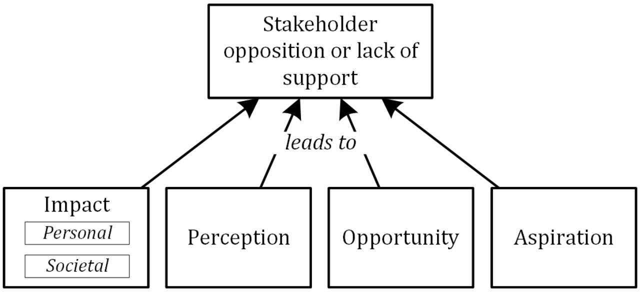

Figure 2.1: Factors leading to stakeholder opposition or lack of support

groups may be misrepresented and may not have the opportunity to act. Fourth, stakeholders must also have the desire to oppose or not to support an energy system. Even if an energy system has some negative impacts, stakeholders might only react if they see sufficient benefits in doing so.

LIMITATION OF A DESCRIPTIVE ANALYSIS OF SOCIAL ACCEPTANCE TO IDENTIFY SOURCES OF CONCERNS

Carrying out a descriptive analysis entails assessing the state of affairs, to what actually occurs and is perceived by humans (van de Poel, 2016). This means evaluating or predicting whether the deployment or use of an energy system may actually lead to stakeholder opposition or lack of support. Such an analysis can be carried out through consumer surveys or by examining the interactions between project owners and affected stakeholders (Cuppen et al., 2015).

The limitation of descriptive analyses is that they can only approximate the current and future negative impact of technologies, and hence merely estimate the range of stakeholder oppositions or lack of support that might occur during the entire life-cycle of a technology. This approximation is even more problematic when the life-cycle of technologies is long because it becomes more and more uncertain whether the 'snapshot' of social acceptance made before a system's deployment matches the range of stakeholder oppositions or lack of support that might occur during the life-cycle of these technologies. In the rest of this section, we explain how impact, perception, opportunity, and aspiration might change over time in the context of energy systems, and why descriptive analyses performed during the planning phase might fail to capture future stakeholder opposition or lack of support.

Impact. The impact of energy systems may change over time. Large social, economic, and technological changes might occur during the life-cycle of infrastructures. This might affect the way energy systems are used and their societal consequences. For example, socioeconomic inequalities might increase in case of an economic depression, which may affect a certain share of the population because they cannot afford energy services. Hence, while stakeholders might have no reason to oppose a technology during the planning phase, this might change in the future.

Perception. The perception of the negative impact of energy systems may change during their life-cycle for both project planners and affected stakeholders. First, it might be difficult for project planners to perceive who is affected by a technology before its deployment because its impact is not visible yet. Often stakeholder groups only emerge "in reaction to the outcomes of ongoing decision-making processes" (Pesch et al., 2017). Therefore, it is not always clear who to include in the decision-making process. Second, stakeholders themselves might not be able to adequately understand how they are affected by an infrastructure until they are actually confronted with its consequences (Pesch et al., 2017). For example, they might not be aware of the consequences of personal data breaches until such breaches occur. Hence, while consumer surveys might initially indicate technology acceptance, this might change over time.

Opportunities. The opportunity to oppose or not to support energy systems may change over time. Stakeholders might initially accept a technology only because there is no other alternative (van de Poel, 2016). They might also not oppose the deployment of infrastructures because they lack organisational structures that can defend their interests. However, these stakeholders could use future opportunities to oppose or not to support the energy system.

Aspiration. The aspiration to oppose or not to support energy systems may change in at least two ways. First, stakeholders might choose to prioritise conflicting concerns and interests differently over time. It is often assumed that stakeholders represent a clear and coherent set of societal values (Pesch et al., 2017). As a result, these stakeholders are expected to accept infrastructures when these set of values are fulfilled. Stakeholders, however, face internal conflicts of their own. For example, Mouter et al. (2018) provide an example of the consumer-citizen duality, or conflict, in each individual for transportation: the 'driver' prefers speed while the 'citizen' favours safety. Over time, stakeholders might make different choices with regard to these internal conflicts. Hence, while no social opposition or lack of support is perceived initially, this might still emerge in the future. Second, decision-making processes with multiple stakeholders tend to be prone to strategic behaviours and to the consequences of past relationships or projects among stakeholders (de Bruijn and Ten Heuvelhof, 2008). A stakeholder might choose not to act because this might affect other decisions in which the same stakeholders are involved. This might change in the future.

The fact that descriptive analyses can only approximate the range of underlying stakeholder concerns means that it can only approximate the range of stakeholder oppositions or lack of support that might occur during the life-cycle of energy systems. The imprecise appraisal of the negative impacts of energy systems means that inadequate or insufficient design requirements and policy guidelines might be implemented to support their social acceptance during deployment and operation phases. Later design and policy adjustments during the deployment or operation phase may be more costly or even infeasible.

ADVANTAGE OF A NORMATIVE ANALYSIS OF MORAL ISSUES TO IDENTIFY SOURCES OF CONCERNS

The advantage of a normative analysis of moral issues is that they can point to sources of concerns that may not appear to affect social acceptance initially but could do so in the future. By analysing how societal groups are affected in terms of moral issues, we do not limit the analysis to factors that have an immediate and straightforward impact on social acceptance. For example, Nussbaum (2011) suggests ten central capabilities which can be used as guidelines to design technologies and policies that preserve human freedoms. Capabilities include *Emotions*, i.e. the ability to relate to other individuals and objects, and *Play*, i.e. the ability to take pleasure in recreational activities. A lack of consideration of these concerns in energy system designs may not immediately lead to a lack of social acceptance during system deployment. This is because stakeholder groups may not be able to perceive these underlying concerns or have the opportunity or aspiration to act (see Figure 2.1). A lack of consideration of the capability Emotions (e.g. how a technology affects social inclusion) may be difficult to apprehend and express by individuals. It might also be difficult to capture by means of surveys because such a concern is not tangible. However, ultimately, these underlying concerns may progressively contribute to some form of lack of social acceptance (e.g. societal unrest). The 'yellow jackets' movement in France, resulting from the increasing socioeconomic inequalities caused by sustainability policy, is such an example (Mehling, 2018).

2.2.3. SELECTING DESIGN REQUIREMENTS AND POLICY GUIDELINES IN SUPPORT OF SOCIAL ACCEPTANCE

Once sources of concerns are identified, design requirements and policy guidelines can be specified to support social acceptance. In this section, we first explain the limitations of a normative analysis of moral issues caused by energy systems to select design requirements and policy guidelines in support of social acceptance, and then identify the advantages of descriptive analyses.

LIMITATION OF A NORMATIVE ANALYSIS OF MORAL ISSUES TO SELECT DESIGN REQUIREMENTS AND POLICY GUIDELINES IN SUPPORT OF SOCIAL ACCEPTANCE

The limitation of a normative analysis of moral issues is that it tends to result in a large number of specified design requirements and policy guidelines. This is especially the case for energy systems, since they can affect a large number of societal groups (Chappin, 2011). However, selected design requirements and policy guidelines is inevitable since their implementation may require resources and some could even be conflicting. For example, it might not be possible to ensure both user *privacy* and *accountability* in information systems. A solution could be to evaluate design requirements and policy guidelines based on their impact on social acceptance. Such an evaluation could help to select most important measures in support of social acceptance. The literature on ethics of technology is however rather unclear about how different design options might affect social acceptance (Oosterlaken, 2014). A reason might be that ranking options based on their effect on social acceptance is not the focus of moral acceptability assessments. Societal groups that do not have the means to voice or defend their concerns could become the victims of such ranking.

Table 2.2: Advantages and limitations of descriptive analyses of social acceptance and normative analyses of moral issues to support the social acceptance of energy systems

	Advantages	Limitations
Descriptive analysis of the social acceptance of energy systems	• Shows which concerns stakeholders consider to be important during the planning phase and are claimed to potentially lead to a lack of social acceptance.	• Might ignore underlying concerns that are not visible or revealed during the planning phase but may affect social acceptance during the deployment or operation phase.
Normative analysis of moral issues caused by energy systems	• Points to a wide range of concerns that might lead to a lack of social acceptance during the (long) life-cycle of energy systems.	• The range of underlying concerns identified might be large. The question is which should be addressed in priority to support social acceptance.

ADVANTAGE OF A DESCRIPTIVE ANALYSIS OF SOCIAL ACCEPTANCE TO SELECT DESIGN REQUIREMENTS AND POLICY GUIDELINES IN SUPPORT OF SOCIAL ACCEPTANCE

The advantage of descriptive analyses is that they inherently target a range of concerns that have a strong effect of social acceptance. Descriptive analyses aim to assess the state of affairs and describe what actually occurs and is perceived by humans: stakeholder oppositions, lack of support, or stated intentions to oppose. Logically, concerns that are at the source of such behaviours and intentions may be important considerations to be addressed in support of social acceptance. A descriptive analysis is thus useful to directly target a range of important concerns and hence to identify a range of effective design requirements and policy guidelines in support of social acceptance. The limitation is however that, due to the long long-term planning horizon for energy systems, such analysis may not be able to capture all concerns that may eventually lead to a lack of social acceptance (see section 2.2.2).

2.2.4. SUMMARY OF ADVANTAGES AND INCONVENIENCES

In section 2.2.2 and 2.2.3, we discussed the advantages and limitations of normative analyses of moral issues and descriptive analyses of the social acceptance of energy systems (see table 2.2). Neither of the two analyses seem to be completely adequate to support the social acceptance of energy systems. Normative analyses of moral issues caused by energy systems help to identify a wider range of underlying concerns that could lead to stakeholder opposition or lack of support during the life-cycle of energy systems. However, they introduce a wide range of additional design considerations, and it is unclear how they contribute to social acceptance. Descriptive analyses of the social acceptance of energy systems may help to directly target a range of important design requirements and policy guidelines that can prevent stakeholder opposition or lack of support. However, such assessments may not reveal a number of important sources of concerns that are likely to lead to a lack of social acceptance during the long-term planning horizon of energy systems.

2.3. Normative analysis of moral issues to support social acceptance

In this thesis, we choose to perform a normative analysis of moral issues to support the social acceptance of energy systems for two reasons. First, these analyses are rarer in the academic literature. Hence, we can provide a different perspective to support their social acceptance compared to the rest of the literature. Second, the impact of moral issues in terms of social acceptance can be derived from value conflicts that energy systems embed. Insights about resulting problems of social acceptance can be used to select more effective design requirements and policy guidelines. In section 2.3.1, we explain how value conflicts can ultimately result in a lack of social acceptance. In section 2.3.2, we demonstrate how to identify conditions that could lead to value conflicts resulting in a lack of social acceptance. In section 2.3.3, we show how to support the social acceptance of energy systems by addressing embedded value conflicts.

2.3.1. From underlying moral issues to social acceptance

Designing energy systems almost always entails making trade-offs between values. The literature on ethics of technology argues that technologies are value-laden (Winner, 1980). Designing and improving technologies often corresponds to better realising some values, for example *efficiency*, *safety*, or *affordability*. Moral issues exist when values are not sufficiently realised in technological and regulatory designs. The realisation of multiple values may however be in conflict. Due to technological and regulatory limitations, it is often impossible to realise multiple values at the same time. For example, making a technology safer often involves additional costs thereby decreasing its *affordability*. As a result, a trade-off between the two values needs to be made. Value conflicts are almost inherent to energy systems. This is explained by the large number of societal groups that are typically affected by their deployment and operation, and hence the high number of values involved. Examples of well-knowns value conflicts occurring in energy systems are *environmental sustainability* versus *landscape authenticity* in wind farm deployment (Söderholm and Pettersson, 2011), and *privacy* versus *grid reliability* in the case of the smart meter (Jackson, 2014).

The fact that energy systems embed value conflicts means that they are prone to a lack of social acceptance. Deploying energy systems that embed value conflicts inevitably means prioritising some values over others. For example, the deployment of the smart meter entails prioritising *grid reliability* over *privacy*. In some cases, prioritising values may result in favouring some societal groups over others. In the case of wind energy, local residents are disfavoured in terms of *landscape authenticity*. Electricity consumers are affected by potential *privacy* issues caused by the smart meter. The fact that some societal groups are disfavoured means that they might decide to oppose or not to support the energy system. Residents living close to wind turbines may decide to oppose the building permit process. Electricity consumers may decide not to adopt smart meters or refuse their installation by the grid operator in their homes. Mechanisms leading to a lack of social acceptance are described by the technology acceptance model (Davis, 1989), the literature on diffusion of innovations (cf. Rogers (1962)) and on opinion dynamics (cf. Friedkin and Johnsen (1999)).

2.3.2. IDENTIFYING CONDITIONS FOR A LACK OF SOCIAL ACCEPTANCE

Whether value conflicts lead to a lack of social acceptance depends on whether societal groups exist that are disfavoured by the prioritisation made between conflicting values. Value conflicts may not be inherently problematic. As discussed in section 2.3.1, the impact of an energy system may not be the same for all societal groups. In some cases, the prioritisation made between values may not reflect how some societal groups are affected. For example, some households may be more affected by privacy issues in the smart meter than others. Reasons could be that their smart meter is connected to numerous other appliances or because they frequently go on holiday and leave their houses empty. In case such societal groups exist, conditions exist for a lack of social acceptance to occur.

We use the expression 'conditions for a lack of social acceptance' since the lack of fulfilment of some values may not always or immediately lead to a lack of social acceptance. This is because other factors also influence stakeholder decision-making to oppose or not to support energy systems (see Figure 2.1). However, there is a mismatch between how values are prioritised in an energy system and how some societal groups are affected by it. In this case, conditions exist that give (moral) reasons to societal groups to oppose or not to support energy systems.

Conditions for a lack of social acceptance to occur may also appear over time because the way energy systems affect societal groups may change. Privacy in the smart meter may not necessarily be an important value for some consumers initially as they are not strongly affected. However, multiple economic, social, and technological developments may occur that change the relative importance of values (see section 2.2.2). This is referred to in the literature as value change (van de Poel, 2018b). For example, the increasing usage of connected appliances in homes may mean that more data may become available for unintended users. Progressive advances in hacking techniques may mean that current privacy norms are no longer valid. The importance of privacy for some societal groups could therefore increase over time and may become more important than the value with which it is in conflict (see Figure 2.2).

2.3.3. ADDRESSING VALUE CONFLICTS IN SUPPORT OF SOCIAL ACCEPTANCE

The social acceptance of energy systems can be supported based on normative analyses of moral issues in the following way. First, we need to identify value conflicts embedded in energy systems so that we can anticipate potential problems of social acceptance. Second, we need to explore the consequences of embedded value conflicts on social acceptance. This can be done by identifying societal groups who are disfavoured by the prioritisation among values and can be used to evaluate the severity of social acceptance issues. For example, under-prioritized values in energy systems might relate to vulnerable societal groups. We also need to assess whether conditions for a lack of social acceptance exist or could occur in the future (see section 2.3.2). Third, the information gathered in the previous steps can be used to address value conflicts embedded in energy systems. Some innovations might exist that can help to resolve some of these conflicts (Van de Poel, 2015). Design recommendations and policy guidelines can be used to provide a more adequate balance between conflicting values. Other measures could be implemented ex ante in anticipation of future value change.

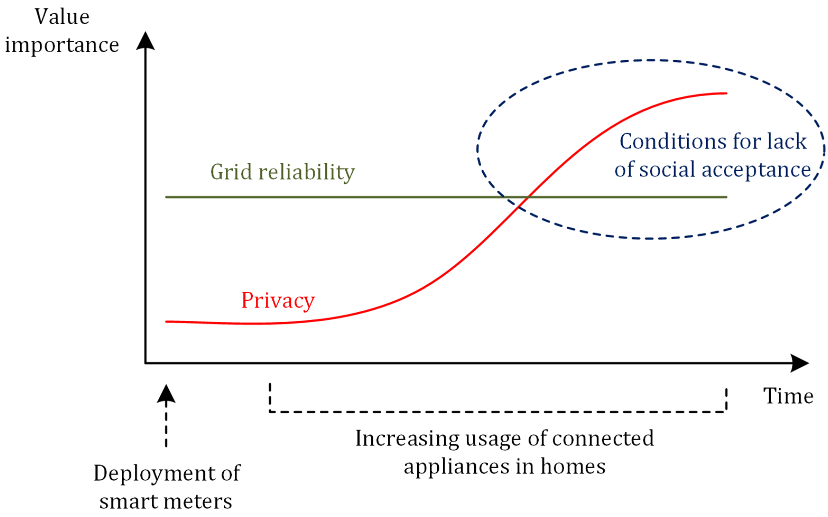

Figure 2.2: Example of possible value change leading to a lack of social acceptance of the smart meter

2.4. CONTRIBUTION OF THE DATA SCIENCE LITERATURE AND COMPLEXITY SCIENCES

Addressing value conflicts embedded in energy systems comes with new research challenges (see section 1.1.4). The first challenge (coping with latent values) can be addressed using the data science literature. This literature is helpful to identify academic literature addressing latent topics. This is further explained in section 2.4.1. The second challenge (identifying value conflicts) can be addressed using the literature on complexity sciences. Simulation models can be used to explore the occurrence of value conflicts in specific cases and to identify the affected population. This is further explained in section 2.4.2.

2.4.1. CONTRIBUTION OF THE DATA SCIENCE LITERATURE

Data science is the discipline of gaining insights and knowledge from data (Dhar, 2013). One approach in data science is text mining. Text mining entails the computer assisted discovery of information from written resources (Hearst, 1999). It seeks to "identify words or phrases that could explain possible underlying content and structures (relationships) in the data" (Yau et al., 2014). By analysing the frequency and simultaneously occurring words in written documents, text mining tools can provide an understanding of the content of these documents. An example is probabilistic topic modelling (Blei et al., 2003), which allows texts to be classified by topics that they address. Probabilistic topic models have proved to be promising to analyse the content of scientific articles, for example to map different fields of science (Glenisson et al., 2005, Yau et al., 2014).

Text mining is useful to cope with the fact that most scientific articles address value conflicts in a latent manner and with the large diversity of scientific fields from which these articles originate. Scientific articles may provide tactics to cope with value conflicts. However, these tactics may originate from a wide range of scientific fields. Due to the large number of articles that address value conflicts, computer assisted methods are required. The problem is that values are often discussed in a latent manner in scientific articles. This means that there is not always a clear word that designates that an article addresses a value, for example *privacy*. Rather a range of words is used to refer to the notion of privacy. Often, the human mind is able to understand such nuances, but not computers. Probabilistic topic modelling (Blei et al., 2003) was developed to cope with this issue.

In chapter 3 we develop a method to identify scientific articles based on the values that they address. In chapter 4, we apply this method to analyse how value conflicts embedded in energy systems are addressed in the academic literature and we identify tactics to deal with these conflicts.

2.4.2. CONTRIBUTION OF COMPLEXITY SCIENCES

Complexity science is the study of complex systems. It consists of a range of theories and tools originating from different disciplines (e.g. mathematics and ecology) to study non-linear systems (Benham-Hutchins and Clancy, 2010). A system is complex when its elements are diverse and can influence each other in multiple ways (Miller and Page, 2007). Socio-technical systems (Hughes, 1987) are examples of complex systems; a network of stakeholders acts and reacts to each other and to a technical system or artefact (Dijkema et al., 2013). Complex systems are often difficult to understand by using human cognition. This is because the chain of reactions between system elements reacting to each other is complex. Therefore, complexity sciences often rely on the use of simulation models. A simulation method widely used in complexity science is agent-based modelling (Epstein and Axtell, 1996).

The occurrence of value conflicts in designs is complex. Value conflicts occur when the realisation of one value goes at the expense of the realisation of another value. For example, one household chooses to realise its value *environmental sustainability* by purchasing solar panels. This may influence the social *inclusiveness* of another household that is not able to purchase such solar panels. This other household might choose to take action to improve *inclusiveness*, for example by forming or joining other citizen groups. This chain of reactions is complex due to the number of households that can be involved (e.g. in a city district) but also because the reaction might depend on the characteristics of the households themselves (e.g. their income level). Complexity science is also useful to understand the impact of embedded value conflicts in terms of social acceptance. Simulation models can help to identify affected stakeholders and thus help to evaluate the severity of underlying concerns. For example, inclusiveness issues caused by the lack of accessibility of solar panels can be considered to be more severe if they affect secluded societal groups.

We develop an agent-based model to identify value conflicts embedded in energy systems in chapter 5. In chapter 6, we apply this model to a case of a community driven heating initiative in the Hague, the Netherlands. We show how the simulation model can help to identify value conflicts embedded in sustainable heating systems and to select preferable systems in support of social acceptance.

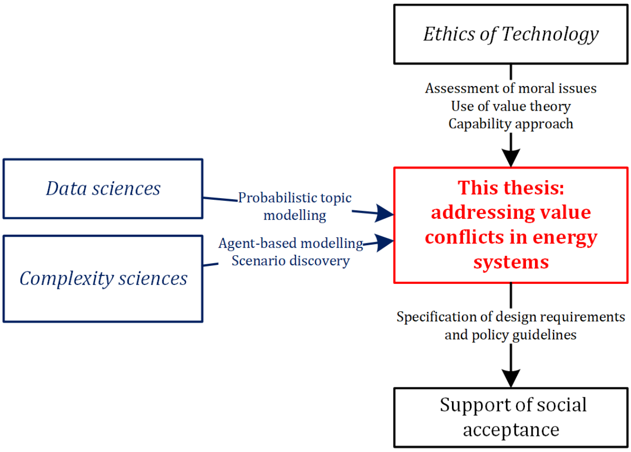

Figure 2.3: Research positioning

Throughout chapters 5 and 6, we conceptualise values as capabilities (Nussbaum, 2011, Sen, 1992). We do this for pragmatic reasons as there is, to our knowledge, no other literature available on how to conceptualise values in such a way that the occurrence of value conflicts in socio-technical systems can be tested. Through the distinction between resources and conversion factors (the means-ends distinction), and the distinction between functionings and capabilities, the capability approach provides a dynamic framework that can be used to identify the occurrence of capability conflicts. We discuss this choice in section 7.1.2.

2.5. RESEARCH POSITIONING

This section provides an overview of the positioning of this thesis in the academic literature (see Figure 2.3). With this work, we aim to support the social acceptance of energy systems through the specification of design requirements and policy guidelines. This is done by addressing value conflicts embedded in energy systems. We draw on insights from ethics of technology. Specifically we assess moral issues caused by energy systems. Relevant values are identified based on a value theory. Remaining challenges however exist in doing so. Methods from data sciences and complexity sciences can be used to address these challenges. The capability approach of Sen (1992) and Nussbaum (2011) is used to conceptualise values and identify embedded value conflicts by means of simulation models.

3

A comprehensive approach to reviewing latent topics addressed by literature across multiple disciplines

This chapter proposes an approach to capturing and reviewing academic literature addressing latent topics across multiple scientific fields. A topic is latent when it is often addressed using a broad range of words instead of a single one. Examples of latent topics are moral values. When topics are latent, a traditional keyword-based approach is often ineffective and therefore inappropriate. As a result, academic literature addressing latent topics tends to be fragmented thereby constraining efforts to address similar and complementary research challenges. A novel approach to reviewing the literature by utilising both semantic fields and probabilistic topic models has therefore been developed. We illustrate this approach by reviewing the literature addressing the value 'justice' in the energy sector and compare this with a regular keyword-based approach. The new approach results in a more complete overview of the relevance of energy justice as compared to the traditional keyword-based approach. This novel approach can be applied to other latent topics including other values or phenomena such as societal resistance to technologies, thereby leading to an increased understanding of existing relevant literature and the identification of new areas of research.

This chapter is based on the work published in the peer-reviewed international journal Applied Energy (de Wildt et al., 2018). The first author has conceptualised and performed the research. The other authors have performed an advisory role.

3.1. INTRODUCTION

The academic literature addressing the consideration of moral values in the deployment of technologies is growing. Friedman (Friedman, 1996) defines moral values as "what a person or group of people consider important in life". Examples are privacy, safety, trust and justice. Key scientific fields, including ethics of technology, institutional design, sociology and social psychology address moral values explicitly. In ethics of technology, scholars aim at pro-actively embedding the moral values of stakeholders into the design of technologies (Manders-Huits, 2011). By doing so, their ethical acceptability can be increased, eventually decreasing the risk of future societal opposition (van den Hoven et al., 2015). The field of institutional design researches and proposes governmental interventions in the form of institutional arrangements (Correljé et al., 2015). In sociology and social psychology, moral values, beliefs and norms are considered to influence how individuals perceive and hence respond to the deployment and operation of technologies (Dietz et al., 2005, Huijts et al., 2012, Stern, 2000). By addressing moral values, they aim to evaluate and improve the societal contribution of technologies and regulations for the wide range of stakeholders they affect.

However, literature addressing moral values is largely fragmented. Moral values are discussed in a wide range of scientific fields as well, including very technical ones. For example, privacy issues and potential solutions are often addressed in the fields of electrical and computer engineering (Fan et al., 2011, Mohsenian-Rad et al., 2010). Safety is largely considered within the field of material sciences (Cabana et al., 2010, Kamaya et al., 2011). While the identification of potential sources of concern tends to be performed by social scientists, technical fields may provide very pragmatic and detailed solutions to the lack of value fulfilment. Hence, the fragmentation of the literature constrains the design of technologies that better fulfill moral values. Without adequate technical solutions, identified ethical concerns may remain unsolved. And without an understanding of the potential societal concerns of technologies, proposed technologies may be rejected by the public, whereas they may have other strong societal benefits as well.

One important reason for the fragmentation of this literature is that it is difficult to capture scientific articles addressing similar moral values by means of traditional literatures searches. Researchers using forward and backward citation analyses rely dangerously on past scientific work already bridging scientific fields of interest (Wang and Blei, 2011). By using keyword searches in indexed databases they may force a focus on highly cited articles, thereby omitting potentially relevant contributions of smaller fields. This is particularly problematic given the current exponential growth of scientific publications. Moral values are often addressed in a latent manner within scientific articles and their denomination is domain specific, thereby making them more difficult to capture using a limited number of search terms.

The challenge addressed in this chapter is how to review literature that 1) bridges scientific fields, and 2), where the reviewed topic is latent. In accordance with the field of text-mining, latent topics are described as polysemous and synonymous (Deerwester et al., 1990). In these cases, no single word is unanimously used for a topic. Contrary to this, a wide range of words may be used to refer to elements of it. These same words may also refer to notions other than the topic of interest. For example, authors may use the word 'just' to refer to the idea of justice, although it may also be used to refer to the notion of simplicity. In literature reviews, latent topics often relate to complex concepts like societal phenomena (such as societal resistances), specific societal expectation of technologies (such as moral values) or technological concepts (such as the smart electricity grid). In cases like these, literature searches that rely less on the enumeration of a set of specific words are required.

This chapter proposes an approach to address this challenge by answering the research question: *How can multidisciplinary literature addressing similar latent topics be captured?* The proposed approach starts with a traditional keyword search and adds two distinct methods. Using probabilities topic models, we are able to identify topics addressed by a large set of potentially relevant articles less dependent on their scientific fields or very specific word use. As topics related to social phenomena or societal expectations of technologies tend to be smaller topics in the literature, probabilities topic models are less helpful. In these cases, articles addressing these smaller topics are captured using semantic fields created in multidisciplinary teams. The proposed approach leads to a greater visualisation and understanding of how similar (latent) topics are addressed across multiple scientific fields, thereby leading to the identification of new areas of research.

This chapter is structured as follows. First, the limitations of traditional literature searches in capturing the literature addressing latent topics across different fields are introduced in section 3.2. This section also provides an introduction to probabilistic topic models and their limits in identifying latent scientific topics. Second, an approach to capture latent topics addressed by multiple scientific domains is proposed in section 3.3. Third, an illustration of this approach is presented in section 3.4. This illustration shows new types of research and design insights that can be gained by capturing the range of literature addressing the value justice in the energy sector. Finally, section 3.5 discusses research results and gives some practical implications for multidisciplinary research and future research steps.

3.2. THEORY

3.2.1. TRADITIONAL LITERATURE SEARCHES AND LIMITATIONS

Two main types of systematic literature searches are usually used to perform a review of the literature, viz. keyword searches, and forward / backward citation searches (Adams et al., 2007). Both types of searches have limitations when reviewing latent topics addressed by multiple scientific fields. These limitations are explained below.

KEYWORD SEARCHES

A keyword search starts with the identification of a list of search terms which is believed to adequately represent words that authors may use to address a topic of interest. A query is then used in an indexed database such as Web of Science or Scopus to retrieve the set of articles of interest for further analysis. The success of a keyword search is measured by the extent to which search results match the set of articles of interest (see figure 4.1). Typically, a keyword search is performed iteratively, as a learning process is required to ensure a better match.

An adequate match between search results and the set of articles of interest becomes more difficult if the topic researched is more latent. In these cases, search results tend

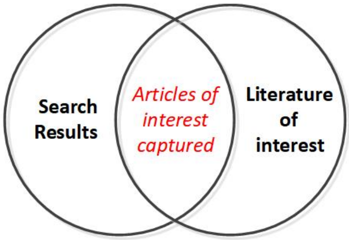

Figure 3.1: Targeted literature in a keyword search

to include many irrelevant articles, and an important number of potentially relevant articles may not be captured either. To cope with this, one strategy could be to use search terms that refer to a wider notion of the topic of interest. For example, the search term ‘energy’ could be used to capture a wider range of articles addressing electric batteries. This however could lead to capturing a larger range of irrelevant articles and thereby making the isolation of relevant articles within the set of articles retrieved more difficult. Inversely, the use of more narrow words could exclude a large set of articles of interest. To illustrate this, we take the example of three topics with a high degree of latency. The first refers to a technological concept (the smart electricity grid), the second to a social phenomenon (societal resistance to infrastructures) and the third to a design consideration for technologies (privacy).

The smart electricity grid embraces a wide range of technologies designed to control imbalances between electricity supply and demand, as well as to support the integration of consumers as active participants in the electricity supply chain (Clastres, 2011). The latency associated with the concept of the smart grids is explained by the fact that it relies on a wide range of diverse technologies: smart meters, batteries, solar panels, etc. The search term ‘smart grid’ when used in an indexed database could result in the exclusion of a large number of articles addressing technologies of use, or potential use, in the smart grid. An alternative would be to specifically mention the names of all technologies, but this would require knowledge of all relevant terms in advances. Also, these same technologies may be used in other technological contexts. Although not relevant for the review, these articles will be included in the search results.

The introduction of large scale infrastructure projects is often met by societal resistance and opposition (Bidwell, 2013, Brunsting et al., 2011, Hall et al., 2013, Israel et al., 2015). The latency of societal resistance as a topic is illustrated by the wide range of terms authors use when referring to it. Examples include social protests, societal protests, public resistance, public protests, public mobilisation, technology acceptance, technology acceptability. This long list suggests that there may be a wider range of words authors can choose from when addressing societal resistance. Some authors directly address specific sources of societal concern like a lack of privacy, safety or fairness of technologies, without mentioning the notion of societal resistance as such. In cases like this, searching for articles discussing societal resistance to large scale infrastructures by using a traditional keyword-based approach would run the risk of omitting a large number of articles that may be of relevance but which might be published in other scientific fields.

The notion of privacy is becoming increasingly important in the energy sector due to the progressive introduction of information technologies to improve grid management. The latency of the word privacy comes from the fact that it is addressed differently in multiple scientific fields. Social sciences tend to address the issue of privacy from a human perspective, describing ethical and societal issues at stake for individuals (Balta-Ozkan et al., 2013, Cuijpers and Koops, 2012). The fields of computer science and electrical engineering tend to tackle the issue of privacy from a technical perspective and frequently use terms such as 'cyber-attack', 'hacking' and 'data leak' without necessarily mentioning the word 'privacy' (Lin et al., 2012, Yan et al., 2013). It would be difficult to capture literature of interest here without knowing this set of words in advance. They would all need to be included in the search query before the technical literature addressing potential privacy problems could be included in the set of articles finally retrieved. This would, however, inevitably lead to capturing irrelevant literature on cybersecurity issues that may not pose a privacy problem but would be pertinent to protect electricity grid equipment.

FORWARD AND BACKWARD CITATION SEARCHES

In a citation search, a limited number of articles that are considered to be central to the literature of interest are initially selected. Forward and backward searches are then performed, by examining scientific articles citing and cited by articles of the initial reference set. Additional iterations can be performed depending on the research scope, and to review second and third generation articles (i.e. articles cited by the references of the initial articles).

The use of forward and backward citation searches is advantageous when reviewing latent topics as it does not rely on specific keywords that might be used differently across multiple scientific fields. However, forward and backward citation searches rely on previous work that has already bridged multiple disciplines (Wang and Blei, 2011). This carries the risk that potentially relevant citation networks that are less connected to other fields are excluded from search results. One way to address this limitation would be to use a larger set of articles as a starting point. This however implies knowing the set of potentially relevant fields in advance.

3.2.2. THE PROMISES OF PROBABILISTIC TOPIC MODELS

There are several ways to capture a wider set of scientific articles across multiple scientific fields. One is proposed by Chappin and Ligtvoet (2014) in the form of a more systematic forward and backward citation analysis. The starting point of the analysis involves collecting articles from an indexed database using key terms and linking them by author and reference similarity. This allows the creation of co-author networks (i.e. showing which authors have worked together on specific articles (Stokes and Hartley, 1989)) and citation networks (i.e. which articles cite each other (Garfield, 1972)). As the starting point of the analysis is a large set of articles captured using keywords, the analysis is less dependent on a limited number of articles as a starting point. Neither is it dependent on articles having previously bridged multiple scientific fields of interest. However, it remains dependent on the specific keywords used to capture the initial set of articles. Additionally, this approach aims primarily at understanding the citation structure of the literature and provides little information about its content. This is a strong limitation when attempting to understand how a topic is addressed in different scientific fields. A more promising approach to reviewing latent topics across multiple scientific fields would be to use probabilistic topic models.

A probabilistic topic model is a text-mining tool originating from the field of scientometrics (Blei, 2012, Griffiths and Steyvers, 2004). Computational tools are used to enable topic models to identify topics addressed by a large set of documents by means of an algorithm. For example, if a large set of documents addressing wind and solar energy is provided to a model as an input, it would be able to retrieve these topics by identifying which words are frequently used within a single article while passing through the text of the articles.

Latent Dirichlet Allocation (LDA) is the most commonly used type of probabilistic topic model (Blei and Lafferty, 2009) and is an unsupervised method. This means that except for the digital copies of the set of articles of interest and a few model parameters (such as the number of topics to be found by the model), no other information such as topic titles or words relating to topics needs to be provided as an input for the identification of topics. Hence topics are identified by the model in an autonomous way. A topic model may discover multiple topics addressed within one single article. For example, if an article addresses both wind and solar energy, one possible outcome of the model would be that the article discusses the topic of wind energy for 70% and solar energy for 30%.

An interesting property of a topic model is that it is less dependent on the use of very specific words to identify topics. Instead, the model relies on a larger set of words that authors use to address a specific topic. For example, articles addressing the topic of batteries may use the word ‘battery’ but also ‘lithium-ion’, ‘discharge’ and ‘capacity’. As a topic model identifies topics not based on individual words but on a range of words that are used within articles to address this topic, the model may find that two articles both address the topic of batteries, even if one article does not mention the term ‘battery’. This property is highly relevant for capturing latent topics addressed by a wide range of scientific communities. If two scientific communities frequently address privacy issues, one using the word ‘privacy’ and the other ‘cyber-attacks’, but both using terms like ‘information’, ‘consumption data’ and ‘sensitive’, the model would be able to conclude that the same topic was addressed.

A second interesting property is that the accuracy of topic identification increases with the number of documents provided as an input to the model. The higher the number of documents, the better the autonomous ‘training’ of the model. As a result of this, the large number of potentially relevant scientific articles addressing a latent topic of interest is no longer a challenge but has become an advantage.

3.2.3. Related work

Topic models, and in particular LDA models, have been applied to various types of documents including emails, scientific articles and newspaper archives (Blei and Lafferty, 2009) or to classify images (Blei, 2012). In Griffiths and Steyvers (2004), the authors demonstrate the use of topic models for reviews of the literature. A set of abstracts of papers published in the Proceedings of the National Academy of Sciences is used to explore the topics addressed by these articles. By doing so, they demonstrate the consistency between topics extracted by the model and the topics that were initially selected by the authors of the papers.

Although a large number of scientific articles from the field of computer sciences address probabilistic topic models as a methodology, actual applications to literature reviews are limited. From these we were able to identify two reasons for authors to use topics model. The first is an exploration of the relative size of topics within a broader field of research. By applying topic models to perennial crop literature, Kane (Kane et al., 2016) discovered the dominance of rice and wheat publications over articles addressing soil biology and carbon dynamics, thereby suggesting a bias in the literature. In the hydropower development literature, Jiang (Jiang et al., 2016) found that most articles discuss post construction issues rather than construction technology. The second reason is the identification of emerging topics addressed by a scientific community. Wei (Wei et al., 2017) used a topic model to identify emerging subjects of patents in the area of shale gas technology. Grubert (Grubert, 2017) used a topic model to show that life cycle assessment literature tends to concentrate increasingly on climate change issues rather than on health and pollution problems.

3.2.4. INTERMEDIARY CONCLUSIONS

While several articles have already attempted to demonstrate the relevance of probabilistic topic models to support more systematic and comprehensive literature reviews, in particular when multidisciplinary research is of interest (see (Grubert and Siders, 2016) and (Nunez-Mir et al., 2016) for a discussion), its application is still relatively low. We attribute this lack of application to the minimum level of programming skills required to apply topics models, but also to their limited ability to isolate a very specific topic of interest. As most types of topic models are unsupervised, topics generally found are merely the large ones. Hence, insights provided by the use of topics models are limited to overall observations about the composition of the literature and its trends. This is sufficient to get a general understanding of the literature, but not to target a specific (latent) topic of interest. For these cases, an adjusted approach is necessary.

3.3. PROPOSED APPROACH

This section presents an approach to identify and review articles addressing latent topics. Examples of latent topics are privacy matters, societal resistance or the smart electricity grid. Often, we are interested in the consideration of latent topics within a larger context, for example, within the energy sector. This larger context may be latent as well. The proposed approach relies on the use of probabilistic topic models and semantic fields. The probabilistic topic models were introduced in section 3.2.2, and the semantic fields will be discussed in section 3.3.1. The approach is presented in section 3.3.2.

3.3.1. SEMANTIC FIELDS

A semantic field is composed of a set of words referring to a common idea (Murphy, 2003). For example, words such as fairness, neutrality and legitimacy all refer to the idea of justice and are therefore part of its semantic field. Hence, if these words are observed in a scientific article, we can deduce with a reasonable amount of certainty that the article addresses the value justice, whether the article actually mentions the word ‘justice’ or not. To create the semantic field of a word, the following sources of information can be used: speakers’ judgments, corpus-based studies, thesauruses and dictionaries, computational models of lexical knowledge, psycholinguistic experimentation, naturally occurring and experimental data and discourse analysis (Murphy, 2003).

The use of semantic fields presents two challenges. First, there are no strict rules to define the semantic relationship between words in a semantic field. According to Murphy (Murphy, 2003), most authors agree that "antonymy, synonymy, hyponymy and the like" are valid relationships. Second, some words are synonymous. Hence, a certain word might only point to the topic of interest if it is used in a specific context. An example of this would be the word ‘private’. It could refer to privacy but could also indicates something entirely unrelated like a non-publicly owned company. When faced with these two challenges, semantic fields should be created with care and should preferably involve sector experts.

3.3.2. APPROACH

This section presents an approach for identifying and reviewing the literature addressing latent topics. A flowchart of the proposed approach is presented in Figure 3.2. In step 1, a large set of articles is extracted from an online database using a broad keyword to ensure the inclusion of a maximum number of potentially relevant articles. In step 2, probabilistic topic models are used iteratively to progressively reduce the dataset towards the desired set of articles addressing the latent topic of interest. If the latent topic is small, the topic model will, in most cases, not reduce the dataset to exclusively relevant articles. A semantic field of the latent topic is therefore created within a multidisciplinary team in step 3. This semantic field is used to capture articles addressing the latent topic within the dataset that was previously reduced using the topic model in step 4. This dataset refers to the context of consideration of the latent topic of interest, for example the energy sector. Finally, the literature is analysed in step 5. The description of the proposed approach is followed by an illustration in section 3.4 in which articles addressing the latent topic ‘justice’ in the energy sector are captured and reviewed.

STEP 1: DATA EXTRACTION IN AN ONLINE DATABASE

First, a database containing an initial set of articles needs to be created. To do this, articles are downloaded from an online database using a search term that is broad enough to ensure that the maximum number of potentially relevant articles is included. For example, if a latent topic within the energy sector is of interest, then an adequate search term would be ‘energy’. The trade-off here is between the inclusion of a maximum number of potentially relevant articles and the time required to download this large set of articles from indexed databases. Most databases have download limits to the number of articles that can be downloaded simultaneously, thereby requiring articles to be downloaded in successive batches.

STEP 2: ITERATIVE CREATION OF A TOPIC MODEL

After data has been extracted, topic models are created iteratively, excluding a set of irrelevant articles at each iteration. The Gensim package (Rehurek and Sojka, 2010) is used

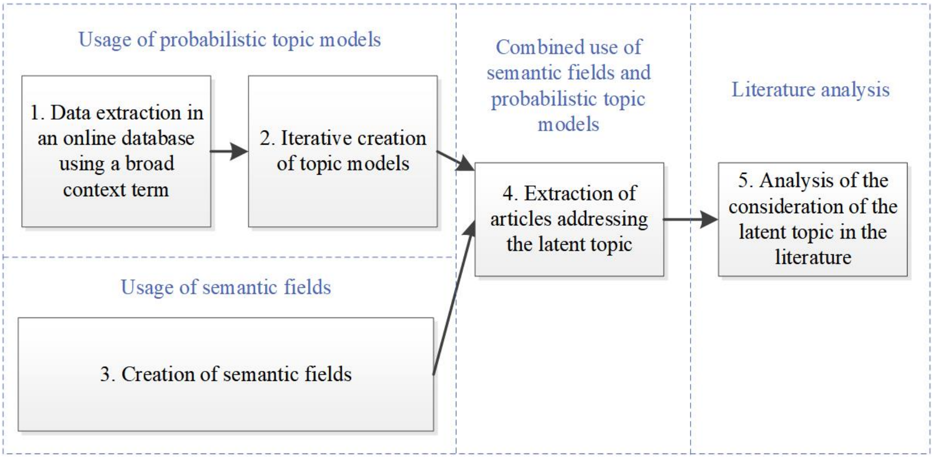

Figure 3.2: Flowchart of the proposed approach

for this. 'Jupyter' and 'Ipython' are used for data analysis and 'pyLDAvis' for visualisations of the topic model created (Mabey, 2015). Creating a topic model requires providing an initial number of topics to be found by the algorithm. This is an important step as the initial number of topics set by the modeler greatly influences the outcome. Measures of model quality can be used to guide this decision; these include the perplexity measure (Waal and Barnard, 2008) or topic coherence (Mimno et al., 2011). Measures are only indicators of model quality and human judgment of the topics generated by the model is mandatory.

Articles can be excluded at each iteration by using thresholds. As a topic model indicates how much of each of the topics it addresses in each article (for example 30% for topic 1, 40% for topic 2, etc.), articles in which the topic of interest is not sufficiently addressed can be removed from the dataset. A new topic model is than created based on the reduced dataset. The iterative creation of topic models ends when the latent topic of interest is found in one or more of the topics identified by the model. If this topic cannot be found, the topic model that relates to the wider context of interest is used (for example the energy sector). A semantic field of this topic is created to identify articles addressing the latent topic in step 3.

STEP 3: CREATION OF SEMANTIC FIELDS

If the latent topic of interest is small (represents a limited number of articles within a broad context), the topic model will, in most cases, be unable to find this topic autonomously. A semantic field of words that relate to this latent topic then needs to be created.

As different scientific communities may address this topic using different words, this diversity should be reflected in the semantic fields created. This can be done by means of a workshop, grouping experts from the different scientific communities that might address this topic. These experts should have a background in the larger context of consideration of the latent topic as well.

These semantic fields can be created by the following process. First, an initial list of words referring to the topic can be drawn up using online thesauruses. Examples of suitable thesauruses are the English Oxford Living Dictionaries (Oxford University Press, 2017), the Roget's International Thesaurus (Dictionary.com, 2016), the Merriam-Wester Dictionary of Synonyms and Antonyms (Merriam-Webster, 2017), and the Collins Online Thesaurus (Collins, 2017). The antonyms, synonyms and 'related words' suggested by online thesauruses are extracted from them. Next, workshop participants are asked to remove words from this initial list that do not match the following two conditions: (1) it is highly probable that a scientific author would use this specific word to refer to this topic and (2) when seen in scientific articles, it is highly probable that this word refers to only this topic. Participants are also asked to add words they feel are missing. A voting system can be used to guide decision-making on word additional and removal.

STEP 4: EXTRACTION OF ARTICLES ADDRESSING THE LATENT TOPIC

Following step 3, articles in the reduced dataset that mention at least one of the words of the semantic field are isolated. It is possible to gain insight into the contexts in which this latent topic is frequently discussed (for example in relation to certain technologies) by looking at the topics to which they were assigned by the topic model.

STEP 5: ANALYSIS OF THE CONSIDERATION OF THE LATENT TOPIC IN THE LITERATURE

The analysis of the latent topic in the literature is performed in step 5. This analysis can be performed manually or by using other computation tools, such as the co-citation analyses as proposed by Chappin (Chappin and Ligtvoet, 2014).

The application of the approach introduced in this section is demonstrated by an illustration of the way in which the latent topic 'justice' is addressed in the energy sector in section 3.4.

3.4. ILLUSTRATION: JUSTICE IN THE ENERGY LITERATURE

This section provides an illustration of the proposed approach presented in section 3.3. It illustrates an analysis of the consideration of the value 'justice' by academic literature in the energy sector. It identifies which justice issues are addressed within the energy sector, by which community and by which means. The illustration demonstrates the additional insights found using the proposed approach and the relevance of outcomes in performing reviews of the literature. This example from the energy sector covers all activities related to energy extraction, production, transport and consumption, and related policies.

An overview of the experimental configurations is provided in section 3.4.1. After this, the topic models and semantic fields are presented in section 3.4.2. The issue of justice in the energy sector is analysed in section 3.4.3, showing how research outcomes are instrumental for multiple scientific fields. Finally, search results are compared with outcomes of traditional keyword searches in section 3.4.4. An overview of the application of the proposed approach to the value 'justice' in the energy sector is provided in Figure 3.3.

3.4.1. EXPERIMENTAL SETUP

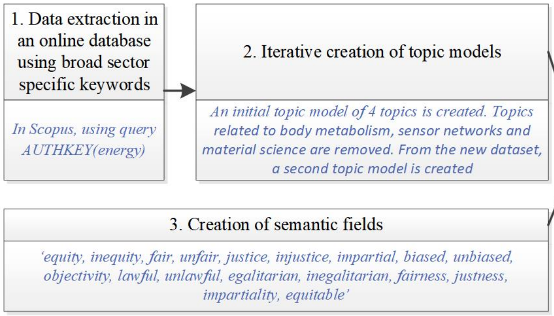

Figure 3.3: Flowchart of the proposed approach applied to the latent topic 'justice'

DATA EXTRACTION

An initial set of articles was downloaded from Scopus, using the query AUTHKEY(energy). The search, performed in March 2018, led to the retrieval of 380,760 articles. Articles were extracted by exporting titles, abstracts and keywords of each article into a CSV file and grouped into a single string using Python. This resulting set of words (the string) was then considered as the text corresponding to an article, which was later used to build the topic model. Text-mining packages such as 'stop-word' and 'nltk' were then used to further process the data (i.e. removing words that did not add any meaning and conversion of strings into substrings).

ITERATIVE CREATION OF TOPIC MODELS

To create topic models, the number of passes (i.e. the number of times the algorithm passes through the set of documents provided as an input) was set to 5, as topics did not appear to change later on. Coherence analyses and manual investigations were performed to evaluate the number of topics found in the model. Topics that were considered relevant to the consideration of the value 'justice' in the energy sector were isolated and articles that were assigned to these topics by the topic model by at least 33% were extracted and placed into a new dataset. In each case, samples were performed to verify the proper extraction of articles. The new dataset was then used to create the next topic model.

CREATION OF SEMANTIC FIELDS

A semantic field of the value 'justice' was created based on online thesauruses. The list of words was then reviewed with researchers representing a variety of backgrounds: (institutional) economics, system engineering, standardisation and ethics. All researchers had a solid background in the energy sector and were well acquainted with the concept of values. The definition of justice provided to researchers was the following "The system is just, impartial, or fair". The final semantic field created can be found in Figure 3.3.

3.4.2. RESULTS

Topic 1	Topic 2	Topic 3	Topic 4
system	protein	network	properties
power	metabolism	wireless	high
renewable	body	proposed	surface
storage	activity	sensor	temperature
efficiency	intake	networks	materials
systems	study	algorithm	density
wind	expenditure	based	transfer
solar	treatment	harvesting	electron
consumption	increased	data	results
building	metabolic	efficient	structure

Figure 3.4: Topics identified in the first topic model

TOPIC MODELS

The outcomes of the first topic model are presented in Figure 3.4. The ten words most frequently used by authors to address each topic are given. The figure shows that only the first topic relates to the energy sector, while the others refer to body metabolism, sensor networks and material science. The presence of the later three topics is not totally surprising as the use of the word 'energy' is obviously not exclusive to the energy sector. As we are only interested the consideration of justice in the energy sector, articles that were sufficiently assigned to topic 1 were extracted to a new dataset.

The second topic model contains 100 topics. The overview of topics can be found in Appendix A.4. As a topic model is only able to present words most frequently used by authors to address a topic, we have provided our own titles to topics. An interactive visualisation of the 100 topics identified by the model can be found online as well as in *((see footnote; link is hidden during the review process, temporarily the visualisation is provided as an enclosed file)*. It shows the thirty most frequently used words for each of the 100 topics. The python code used to perform the analyses can be found using the same link. An overview of the relative size of each topic (the marginal distribution of topics) can be found in Appendix A.5.

The topics found by the topic model can be put in five categories. The first, a large set of topics, relates to specific technologies or infrastructures like smart energy management systems, inverters and wind turbines. The second category refers to energy sources and (undesired) products like carbon emissions, biomass and hydrogen production and fossil fuels. The third includes references to energy governance like energy policy and economic development. The fourth set of topics relates to geographical areas such as cities and communities. The final category comprises topics that refer to specific methods like scheduling algorithms and spatial optimisation.

We found that the articles in the category containing the technological topics generally tended to propose technological innovations and describe control and management methods like new scheduling algorithms. The category containing the energy sources, products, governance and geographical topics mostly included articles containing evaluations related, for example, to the environmental impact of effectiveness of policies. Most of the articles in the final category, proposed simulation models, algorithms and optimisation methods, for example, for the integration and scheduling of different energy system components.

As no topic related to justice issues was found in the new topic model while the new dataset still related to the broader context of interest (i.e. the energy sector), we used a semantic field to capture articles of interest.

SEMANTIC FIELD CREATED

A semantic field of justice was created containing 18 words that can be found in Figure 3.3.

TOPICS FREQUENTLY ADDRESSING JUSTICE

We found 1297 articles containing a word of the semantic field of justice from the dataset adjusted after the first topic model (hence only creating articles addressing the energy sector). In this illustration, we focus our analysis on the ten topics that most frequently addressed the topics of justice (see Table 3.1). Topic numbers and titles are provided in the first two columns. The third column shows the number of articles addressing the value 'justice' found per topic. The fourth column gives the five highest cited articles addressing the value 'justice' per topic. When creating this table, we assumed that an article belonged to a topic if at least 15% of the words in the article were assigned to this topic by the topic model.
Table 3.1 shows that the value 'justice' is frequently associated with all five types of topics identified in section 3.4.1. Justice is addressed together with energy production inputs and outputs ('carbon emissions' and 'fossil fuels'), energy governance ('energy policies', 'energy poverty' and 'energy and economic development'), geographical areas ('communities'), technologies ('smart energy management systems', 'micro-grids', 'nuclear energy') and methods ('load management').

3.4.3. ANALYSIS

The analysis shows how the new approach adds additional insight into the consideration of justice in the energy sector, in the form of ranges of potential injustices covered by the literature and the approaches used to address them. We also show that some ranges of injustice are insufficiently covered in different scientific domains leading to the identification of new opportunities for (multidisciplinary) research.

JUSTICE ISSUES ADDRESSED AND APPROACHES

Appendix A.4 provides an overview of justice issues addressed within the articles mentioned in Table 3.1. Information on the stakeholders affected by these issues and the different approaches used to address them are also provided.

A first type of injustice addressed is the disparity between the CO2 emissions of different countries which can influence their contribution to climate change. While developed countries have historically largely contributed to CO2 emissions, populations of developing countries are the ones that appear to suffer most (Toklu et al., 2010). Several environmental policies to limit CO2 emissions have been introduced. These include carbon taxes but they may hinder economic development in poorer countries. It is unfair to expect developing countries to bear the brunt of these measures as their economic

Table 3.1: Ten topics most frequently associated to the value justice

Topic	Topic titles	Counts	Five highest cited articles
17	Load management	44	Bai et al. (2015), Negash et al. (2015), Zhao et al. (2013) Huang et al. (2016a), Tian et al. (2016)
6	Energy policies	36	Pandey (2002), Sawangphol and Pharino (2011) Cherni and Hill (2009), Lauber and Jacobsson (2016) Balta-Ozkan et al. (2015)
1	Carbon emissions	35	Davis and Caldeira (2010), Raupach et al. (2007) Capros et al. (2011), Chapman et al. (2016), Hyder (2008)
24	Communities	29	Aitken (2010), Cowell et al. (2011), Miller et al. (2013) Bilgili et al. (2016), Sovacool and Scarpaci (2016)
15	Fossil fuels	27	Beretta et al. (2012), Sagar and Kartha (2007), Speck (1999) Beretta et al. (2014), Souza et al. (2017)
2	Smart energy management systems	23	Wang and Huang (2016), Zhang et al. (2015) Mhanna et al. (2014), Paul and Aisu (2012) Aswantara et al. (2013)
42	Nuclear energy	12	Löfquist (2015), Steinbach and Brückmann (2015) Kilb (2015), Kim (2012)
10	Energy and economic development	9	Huijts et al. (2012), Sovacool (2011), Wang et al. (2013) Jenkins et al. (2016), Toklu et al. (2010)
69	Energy poverty	9	Heffron and McCauley (2014), Zhang (2010) Stretesky and Lynch (2011), Walker et al. (2014) Reames (2016a)
8	Micro-grids	6	Hong et al. (2015), Nordman and Christensen (2013) Parisio et al. (2017), Xin et al. (2013) Lamberti et al. (2017)

growth has now become more limited by environmental measures than developed countries were in the past (Hyder, 2008, Raupach et al., 2007, Zhang, 2010).

A second type of injustice addressed is the inequality in access to newer, cleaner energy technology and sources, mostly due to their higher costs. As a result of this, poorer countries, regions and citizens are sometimes deprived of access to newer, cleaner energy and suffer more frequently from ill health and the safety risks related to unsustainable energy production and consumption (Bilgili et al., 2016, Sagar and Kartha, 2007, Souza et al., 2017, Wang et al., 2013). A third and related type of injustice entails inequalities in faculties to support the costs of environmental measures. Energy efficiency measures may, for example, increase the living costs of households and it may be difficult for underprivileged sections of the population to bear these additional costs (Balta-Ozkan et al., 2015).

A fourth type of injustice arises from the health and safety risks of energy production. While the availability of energy can provide benefits to an entire economic area, smaller, local communities are often adversely impacted by pollution and safety incidents (Löfquist, 2015). A fifth type of injustice is related to the deployment of (cleaner) energy infrastructure due to cultural and aesthetic considerations. This is similar to the fourth type of injustice. Although an entire country can benefit from cleaner energy production, communities located close to the production plants are often adversely impacted by their presence.

We noted some injustices that are direction-related to the smart electricity grid. An increasing number of appliances owned by individuals are often connected to a single grid, creating unjust distribution issues. The sixth type of injustice originates from inequalities in conditions of access to the grid. The number of vehicles powered by electricity is increasing and as many of them are connected to the same system of charging stations, the distribution of electricity needs to be fair for all users, especially in locations where there are energy shortages (Aswantara et al., 2013, Paul and Aisu, 2012). A seventh type of injustice arises when multiple users make energy harvesting devices available to the electricity grid. Here, injustices may arise from inequalities in the usage of devices and revenues attributed to users (Hong et al., 2015, Nordman and Christensen, 2013, Parisio et al., 2017, Xin et al., 2013). An eighth type of injustice can be seen in the establishment of local energy communities. Individuals of these communities may, for example, invest different amounts in the local energy network and thereby create unjust issues of distribution of revenues (Wang and Huang, 2016). Finally, a ninth type of injustice is related to fair competition between market participants (Bai et al., 2015, Negash et al., 2015).

Appendix A.4 also shows ways to remediate injustices by both revealing and reducing them. Authors rely on data analysis to reveal injustices, for example, to identify historical disparities in CO_2 emissions (Raupach et al., 2007). Others simply review the academic literature (Chapman et al., 2016, Zhang et al., 2015) or perform case studies, for example through surveys (Aitken, 2010).

We noted other ways to reduce injustices. These include contractual arrangements like the design of improved market rules (Bai et al., 2015). We also noted a frequent discussion on redesigning algorithms to lead to a fairer distribution of energy and revenues (Paul and Aisu, 2012). Finally, some authors simply advocate sustainable development as this is considered to inherently reduce injustices (Toklu et al., 2010), while others aim to both reveal and reduce injustices, such as energy injustice (Heffron and McCauley, 2017, Jenkins et al., 2016).

Relevance of results for scientific fields addressing justice issues

These results first point to new areas of research. The illustration shows that a wide range of injustices are addressed in the literature. However, several injustices have not yet been addressed, leaving potential for more research. For example, the literature explicitly addressing justice in the energy sector tends to be embedded in justice frameworks such as energy justice and environmental justice. We, however, find that this merely concentrates on a limited set of injustices, while these frameworks do not explicitly claim to limit themselves in that. We also found that articles addressing energy justice tend to concentrate on the protection of the underprivileged, whether citizens, regions or countries and are mostly related to climate change, environmental policies and the deployment of renewables. However, Jenkins et al. (2016) explain that energy justice seeks to "apply justice principles to energy policy, energy production and systems, energy consumption, energy activism, energy security and climate change". Hence, injustices that emerge from the deployment of the smart grid are within the scope of energy justice and therefore also need to be addressed. This is especially important when considering the fast roll-out of smart grid technologies, their importance for achieving sustainability goals and societal concerns related to their deployment (Balta-Ozkan et al., 2015, Carbajo and Cabeza, 2018, Cuijpers and Koops, 2012, Sovacool and Dworkin, 2015).

A second finding relates to the potential concerns certain sectors of the population might have about specific technologies. This is particularly relevant for engineers since these concerns could hinder the successful deployment of new technologies. Engineers may be forced to adjust technological designs to prevent deployment issues. We found that the issue of the location of traditional power plants is important as it affects sectors of the population differently. This, however, does not apply to renewable energy sources, as can be seen by the large number of wind energy projects (Wolsink, 2006). When looking at smart grid developments, it is clear that community characteristics also appear to play an important role in the success of technological deployment. Algorithms that distribute electricity and revenues between participants may (unintentionally) prioritise some households over others. This could lead to issues of fairness and trust resulting in the progressive rejection of the technologies proposed.

A third finding relates to the types of approaches used to address justice issues. It appeared that it would be easier to introduce new technologies if local characteristics were considered more carefully. The use of the Community Knowledge Networks proposed by Catney et al. (2013) could, for example, provide a better understanding of community knowledge and practices in relation to consumption. This could be useful when proposing technological solutions in terms of complexity and priorities that individuals in the community have. An improved overview of existing types of approaches may show that a range of potentially relevant technical solutions to address justice issues already exist for social science related fields. This is crucial to ensure that discourse on justice is not limited to the mere identification of issues but is followed by actual adjustments of technological and regulatory designs.

Table 3.2: Comparison between sources of injustices found

Sources of injustices	Proposed approach	Keyword search: ‘justice’	Keyword search: semantic field of justice
1. Historical disparities between countries in carbon emissions and impacts of climate change	5	9	8
2. Inequality of access to newer and cleaner energy technology and sources	11	12	15
3. Inequalities in faculties to support the costs of environmental measures	8	6	13
4. Disparities between benefits and burdens of energy production in terms of health and safety risks	5	7	4
5. Disparities between benefits and burdens of energy production in terms of cultural and aesthetic impacts	4	16	5
6. Inequalities between users in conditions of access to the grid	3	0	1
7. Inequalities in usage of devices and revenues attributed to smart grid users	10	0	4
8. Inequalities between investments by community members and resulting benefits of local energy infrastructures (e.g. micro-grids)	1	0	0
9. Lack of fairness between competitors in electricity markets	2	0	0

3

3.4.4. COMPARISON WITH TRADITIONAL KEYWORD SEARCHES

We compared the results of our proposed approach with the ones of a traditional keyword search by performing two searches without the use of a topic model. In the first case, we only retrieved articles from the initial set of articles that mention the search term ‘justice’. This is equivalent to using the query AUTHKEY(energy) AND TITLE-ABS-KEY(justice) in the Scopus database at the time of the search. As it is doubtful that a researcher would only use the word ‘justice’ when trying to find articles addressing justice, we performed another search using all the words in the semantic field of justice created in section 3.4.1. We analysed the 50 highest cited articles in both searches and identified the different types of injustices, the affected stakeholders and the proposed approach to remediation. Articles that did not address justice as defined in this research were passed over, even though some of them contained a word in the semantic field of justice. Extended outcomes can be found in Appendix A.5 and in Appendix A.6. We compare the results based on the number of articles addressing one type of injustice in Table 3.2. The differences between types of stakeholders affected and approaches for remediation are discussed in the text.

We made four observations from the comparison presented in Table 3.2. First, the proposed approach enabled us to find a wider set of injustices related to the energy sector. When we compared this to the literature found using keyword searches without a topic model, we noted that the latter concentrated primarily on types of injustice related to the environment (injustices 1 to 5). Injustices related to the smart grid and energy markets (6 to 9) were not addressed when the keyword 'justice' was used and were negligible when the semantic field of justice was used. We also noted that no additional types of injustice were found when using the simple keyword searches. Hence, the proposed approach enabled us to find more types of injustice in the energy sector without omitting other types that would have been found using a simple keyword search.

Second, as we found more types of injustice, we also found a wider range of affected stakeholders. While the simple keyword search mainly addressed local communities, poorer populations and future generations, the proposed approach revealed injustices to citizens as consumers, economic actors and economic regions.

Third, the proposed approach enabled us to find more processes for remediation. As the literature addressing injustices related to the smart grid and the design of the market tends to be more technical, we were able to find a wider range of processes aimed at reducing injustices, for example through the redesign of algorithms and market rules.

Fourth, Table 3.2 shows that the types of words used to refer to the value 'justice' vary strongly depending on the scientific field addressing this value. The word 'justice' tends to be used in articles that rely on well-defined justice frameworks, such as energy justice (see Sovacool & Dworkin (Sovacool and Dworkin, 2015)). Other articles do not appear to be embedded in justice frameworks. The words 'equity' and 'inequity' are frequently used in the context of energy policy to describe inequalities between countries or citizens. The words 'fair' and 'fairness' are frequently used to assess injustices in the context of the smart grid and inequality of access to markets or market revenues.

3.5. DISCUSSIONS AND CONCLUSION

This chapter proposes an approach to reviewing latent topics addressed by multiple scientific communities. Starting from a (very) large set of potentially relevant articles, we use probabilistic topic models iteratively to progressively reduce the dataset to one containing articles addressing the latent topic of interest. As topic models are limited in finding smaller latent topics, semantic fields are used to identify relevant articles. This approach enables us to visualise and compare how a specific latent topic, for example justice, is considered in multiple scientific fields and the types of technologies it is frequently associated with.

The approach presented in this chapter provides a more valuable use of probabilistic topic models. While the potential contribution of topic models to review latent topics in the literature is clear, a limited number of applications have been found. We argue that this is explained by the fact that the simple application of topic models only provides high levels insights about a set of articles, such as topic trends or the relative importance of different topics, with limited possibilities to guide the search to a more precise dataset of interest. The proposed approach aims to fill this gap, thereby increasing the value of probabilistic topic models to reviews of the academic literature.

Our work offers three main contributions. First, the proposed approach makes it easier to cope with the exponential growth of scientific articles and publications. As the amount of literature is growing, it is becoming increasingly difficult for researchers to keep track of recent scientific developments that may be of interest for their own research. The use of topic models allows for the execution of more comprehensive and complete reviews thereby supporting quality research. Second, the proposed approach supports research that bridges multiple scientific fields. Certain scientific communities may, for example, have answers to problems that others lack. Also, research from multiple fields may have strong potential for complementarity. For example, Manders-Huits (2011) and Correljé et al. (2015) explain that value sensitive design lacks clear methodologies to systematically include values in designs and cope with value trade-offs. The literature on value sensitive design could benefit from the socio-technical systems literature, as it is more equipped to engage stakeholders and make value trade-offs visible (Taebi et al., 2014). Certain scientific research may raise concerns that require the design or adjustment of technical solutions. As the illustration demonstrates, a large range of sources of injustice can be identified in the energy supply chain, but technical and regulatory solutions are not always clear. Ultimately, a better visualisation of affiliations and an understanding of complementary or conflicting findings by multiple scientific fields addressing similar moral values may point to new research opportunities. Third, we support computer science research by showing the added-value but also the shortcomings that probabilistic topic models have when used to review academic literature. The difficulty to identify small latent topics within a larger set of scientific articles is a strong limitation here, which in our approach, requires the creation of semantic fields.

Our work is particularly relevant for research addressing the design and deployment of technologies. Essentially, all topics are latent, but some more than others. This is particularly true for topics that do not relate to very specific technologies but to vaguer societal phenomena or societal expectations of technologies. As these concepts are more complex and therefore more difficult to grasp, understand and explain, society employs a wide range of terms when referring to them. Different societal groups may use different words to refer to similar ideas, but also understand similar words differently. Technologies are often deployed within a large societal context and different societal groups can be positively or negatively affected by them and may react accordingly, for example, by opposing the installation of new infrastructure. In order to support the deployment of technologies and propose adequate solutions, it is necessary to gain a better understanding of these latent topics. It would be advantageous to consider these latent topics across a range of scientific domains as this would both increase awareness of potential societal concerns (typically identified by fields of social sciences) and would be instrumental in proposing adequate technological and regulatory solutions (typically proposed engineering and policy related fields).

The range of potential applications of the proposed approach is large. We take the value 'justice' as an example in the illustration and show how our approach leads to a better overview and an improved understanding of potential sources of injustice, the different scientific fields that do (or do not) address certain types of justice issues and the existing approaches that may be used to address these issues. The proposed approach can be applied to other values like privacy, safety and security of supply and within narrower contexts, such as the smart electricity grid or nuclear energy, or different economic domains, like transport and ICT. It may be appropriate to apply the Q-methodology if key relevant values at stake are not known in advance (Cuppen et al., 2010, Stephenson, 1953). Extending to the use of expert interviews and discourse analysis methods, the Q-methodology enables improved visualisation of the variety of perspectives that a range of stakeholders have on a particular issue. Other potential applications of our approach include specific societal phenomena, such as public protests against infrastructures, other design considerations for technologies, such as the identification of multiple approaches to address energy efficiency (for example Geng et al. (2017) and Cui et al. (2017)) or technological concepts encompassing a wide range of technologies (for example Li and Zheng (2016)).

A number of limitations should be taken into account when using the approach proposed in this article. First, this approach makes it possible to identify a wide range of articles addressing latent topics but is not equipped to find all leading articles in each of the fields addressing the topic in question nor the most recent. Even if the approach starts with a very large set of scientific articles, it is still a subset of all potentially relevant articles. Second, creating semantic fields is an effective way to cope with the difficulty topic models have in finding smaller topics, but is still limited in coping with the challenges of word polysemy and synonymy as, although created more robustly, we still rely on an enumeration of specific search terms to identify relevant articles. Third, there are methodological limitations to the use of topic models. Using topic models requires setting input parameters such as the number of topics to be identified by the algorithm and the number of times the algorithms pass through the input text. Although we have verified the impact of experimental settings, these choices are always debatable. Finally, the proposed approach makes it possible to identify relevant articles addressing latent topics in a more automated way but does not replace expert judgement. A thorough inspection of results throughout the stages of the search process is recommended.

A key area for future research relates to the use of semi-supervised topic models for literature reviews. Contrary to unsupervised models, semi-supervised topic models allow the user to participate and guide the model learning procedure (Wang et al., 2012). This is particularly relevant for smaller topics that are hard to identify by unsupervised models, for example those related to specific phenomena or to societal expectations of technologies. Usable software implementations are currently, however, still lacking.

4

Conflicting values in the smart electricity grid; a comprehensive overview

This chapter aims to anticipate social acceptance issues related to the deployment of the smart electricity grid by identifying underlying value conflicts. The smart electricity grid is a key enabler of the energy transition. Its successful deployment is however jeopardised by social acceptance issues, such as concerns related to privacy and fairness. Social acceptance issues may be explained by value conflicts, i.e. the impossibility for a technological or regulatory design to simultaneously satisfy multiple societal expectations. Due to unsatisfied expectations concerning values, social discontent may arise. This chapter identifies five groups of value conflicts in the smart electricity grid: consumer values versus competitiveness, IT enabled systems versus data protection, fair spatial distributions of energy systems versus system performance, market performance versus local trading, and individual access versus economies of scale. This is important for policymakers and industry to increase the chances that the technology gains acceptance. As resolving value conflicts requires resources, this chapter suggests three factors to prioritise their resolution: severity of resulting acceptance issues, resolvability of conflicts, and the level of resources required. The analysis shows that particularly the socioeconomic disparities caused by the deployment of the smart electricity grid are alarming. Affordable policies are currently limited, but the impact in terms of social acceptance may be large.

This chapter is based on the work published in the peer-reviewed international journal Renewable & Sustainable Energy Reviews (de Wildt et al., 2019). The first author conceptualised and performed the research. The other authors have performed an advisory role.

4.1. INTRODUCTION

The introduction of the smart electricity grid raises concerns in terms of social acceptance, which might hamper the energy transition. The smart electricity grid is defined as "electricity networks that can 'intelligently' integrate the behavior and actions of all users connected to it (...) in order to efficiently deliver sustainable, economic and secure electricity supplies" (Smart Grids European Technology Platform, 2013). To do so, it incorporates a range of technologies including smart meters, communication technologies, smart home appliances, and distributed energy systems (Jackson, 2014). By efficiently integrating the behavior of all actors, appliances, and facilities at the supply and demand side of the electricity grid, the smart electricity grid supports the deployment of intermittent power sources such as wind and solar power (Clastres, 2011). The social acceptance (Wüstenhagen et al., 2007) of the smart electricity grid is however uncertain, despite favorable policies (Tuballa and Abundo, 2016) and numerous R&D and demonstration projects (Gangale et al., 2017). Issues of socio-political acceptance with regard to privacy have arisen during the deployment of smart meters in the Netherlands (Cuijpers and Koops, 2012). The installation of distributed energy systems affects communities in terms of space and fairness (Devine-Wright, 2008). Market acceptance of smart electricity grid technologies is also uncertain (Broman Toft et al., 2014). Issues of social acceptance are challenging for policymakers and the industry as they hamper the deployment of technologies that may have large societal benefits.

This chapter studies the occurrence of social acceptance issues using a value perspective. A value is defined as "what a person or group of people consider important in life" (Friedman, 1996). Values relate to societal expectations of technologies, both in terms of design objectives and compliance requirements (Tuana, 2015). Examples of values are sustainability, privacy, efficiency, and security of supply. These values can be social, economic, or technical (see section 4.2.1). Unsatisfied expectations concerning values may eventually result in social acceptance issues (Grunwald, 2015), although the underlying causality is often complex. From a value perspective, the difficulty to resolve acceptance issues can be explained by the fact that values are in conflict (Van de Poel, 2009). In that case, a value can only be practically realised in a specific context at the expense of another value. For example, in the smart electricity grid, consumption data can be used to increase security of supply, but can also reveal the load consumption pattern of consumers, thereby raising privacy concerns. Hence, inevitably, the deployment and use of a technology favors some values over others. Value conflicts embedded in technologies are therefore potential sources of social acceptance issues that might emerge during the deployment and operation phases.

The goal of this chapter is to anticipate social acceptance issues that might occur during the deployment and operation phase of the smart electricity grid by identifying underlying value conflicts. For policymakers and the industry, an overview of underlying value conflicts is important to identify potential technological or regulatory adjustments required to increase the chances that the technology gains acceptance. Systematic overviews of conflicting values for a technology are rare in the academic literature, and none could be found about the smart electricity grid. Particularly the diversity of the (type of) sources of information required to build such a list, and the fact that values are often discussed in a latent manner (i.e. not named explicitly in texts or discussions but implied) are problematic. To address these challenges, this chapter uses the approach proposed by de Wildt et al. (2018). This computer-aided approach can extract value conflicts addressed by the literature by passing through a very large set of scientific articles originating from multiple scientific communities. This is done using probabilistic topic models (a suite of algorithms used to systematically discover themes addressed within a range of documents) and semantic fields (sets of words referring to a common idea). As scientific articles may propose solutions to value conflicts, the approach captures both value conflicts addressed by a body of literature as well as solutions for their resolution.

This chapter is structured as follows. Section 4.2 discusses the literature on values and social acceptance and on value conflicts. Section 4.3 describes the method and approach used for this research. Section 4.4 presents the identified value conflicts and innovations proposed by the academic literature for their resolution. Finally, Section 4.5 discusses the prioritisation of conflicts and offers a critical perspective on how they are currently addressed.

4.2. THEORY

4.2.1. VALUES AND SOCIAL ACCEPTANCE

The concept of values is frequently used in the context of social protests emerging from the deployment of technologies. Here, values are frequently discussed in terms of ‘human’, ‘personal’, ‘moral’ or ‘social’ values. Examples of values include *power*, *hedonism* and *tradition* (Schwartz, 2012), or *privacy* and *trust* (Friedman et al., 2006). In this context, values are frequently named to understand the nature of citizens or technology users’ behavior and are assumed to drive social response to the introduction of technologies (Stern and Dietz, 1994). By more carefully considering these values during the design of technologies, the social acceptance of technologies can be increased and potential social opposition can be prevented (van den Hoven et al., 2015).

However, there is a wider notion to values, in the sense of ‘public values’ or ‘societal values’, which serve the public good (for example (Correljé and Groenewegen, 2009, Demski et al., 2015, Künneke et al., 2015)). This notion is not limited to citizens and (potential) users of technologies. Here, the term value is used more broadly and refers to what can be considered as societally valuable or to "statements about whether certain things or state of affairs are good, i.e. valuable, or bad in a certain respect" (Van de Poel, 2009). Generally, the intersubjective and societal notion of values holds, and thus values are not to be mistaken with individual desires or interests (Van de Poel, 2009). Within this notion, values are not solely indicators of human or moral concerns of citizens or users that need to be considered during the planning phase. Rather, values may be technical and economic as well. They can be explicit goals for design or for driving the design and deployment of technologies rather than solely being considered as social requirements (Tuana, 2015). For example, the value *environmental sustainability* drives the deployment of renewables. *Profitability* is a requirement to ensure that renewable energy technologies are deployed on a larger scale.

Unsatisfied expectations concerning values may eventually lead to social acceptance issues. Wüstenhagen et al. (2007) identify three dimensions of social acceptance: socio-political, community, and market acceptance. Socio-political acceptance relates to the national, political, and policy level. At this level, a technology is typically considered as accepted when it is encouraged by policies, enabled by law, and supported within political debates. Community acceptance refers to the response at local level, by residents and local authorities. The acceptance can be considered as wider when it is at least tolerated by these stakeholders rather than leading to street protests. Market acceptance is an indicator of the adoption of technologies (i.e. whether they are commercially successful) and of the willingness for investors to invest. Values may relate to each of these dimensions. A better consideration of values may lead to a more successful deployment of technologies with respect to these three dimensions (Künneke et al., 2015).

The relationship between value (un)fulfilment and social acceptance is complex. To get a better grasp of the complexity between values and technological use, van de Poel (2016) and Taebi (2016) advocate sharpening the distinction between moral acceptability and social acceptance. Moral acceptability refers to an ethical judgement of a technology, recognising the "moral issues that emerge from its introduction" (Taebi, 2016). Social acceptance refers to whether a technology is accepted or at least tolerated by individuals and organisations. Both notions are complementary. Merely considering the reaction of (groups of) individuals may lead to overlooking underlying moral issues. Similarly, prevailing stakeholders' opinions might be informative for a complete ethical evaluation, or in case moral choices are inescapable.

4.2.2. VALUE CONFLICTS

While a range of values that may potentially influence the acceptance of a technology, it may be difficult to satisfy all values at the same time. This can be due to physical, economic, or regulatory constraints. In some cases, the fulfilment of two values may even be in opposition to each other (Friedman et al., 2008), i.e. conflicting values. According to Van de Poel (2009), "two or more values conflict in a specific situation if, when considered in isolation, they evaluate different options as best".

Conflicting values are widespread in the design of technologies and infrastructures. In information technologies, common conflicts occur between *accountability* and *privacy*, between infrastructure *control* and *democratisation*, and between *security* and *privacy* (Friedman et al., 2008). This last conflict also applies for security technologies of buildings (Davis and Nathan, 2015). In the energy sector, tensions between *safety*, *economic viability*, and *environmental sustainability* play a central role in prioritising different types of power production technologies, for example, in nuclear energy (Taebi and Kloosterman, 2015). In wind power deployment, there is a strong tension between *environmental sustainability* and the use of space (i.e. *landscape authenticity*) (Söderholm and Pettersson, 2011).

The difficulty in coping with value conflicts is explained by the frequent absence of a common measure to compare two alternatives fulfilling two values differently, as well as the seriousness of the choice in terms of societal impact. A common scale for comparison often exists for trade-offs between commodities (products that can be traded) and/or currencies (valuations of commodities) (Beattie and Barlas, 2001). This is where cost-benefit analyses tend to be highly instrumental (Munda, 2004). For choices between non-commodities (non-tradable objects such as emotions or values), alternatives tend to be incommensurable (Beattie and Barlas, 2001, Munda, 2004). For example, in the case of smart meter deployment, how can personal privacy be valued compared to the benefits of smart meters in terms of security of supply? If these non-commodities are values, making a choice means favoring one legitimate and morally defensible vision of the good over another (Martinez-Alier et al., 1998). The literature refers to these as 'tragic choices' (Hsieh, 2016) or choices under 'social incommensurability' (Munda, 2004). A parallel can also be made with moral dilemmas (Van de Poel, 2015). Hence, when choosing a value over another, a morally valuable societal aspect is diminished. Any resulting form of stakeholders' protests that might potentially emerge is both morally legitimate and hardly escapable unless another morally valuable societal aspect is disfavored in return.

Value conflicts may be resolved through innovation. Van de Poel (2015) identifies three main ways to cope with conflicting values: value re-specification, trade-offs, and innovation. Re-specification focuses on clarifying how a design embeds or undermines different values (Van de Poel, 2015), for example, through participatory processes and stakeholder dialog (van der Velden and Mörtberg, 2015). Trade-offs can be made, for example, by using social multi-criteria evaluations (Munda, 2004). Finally, Van de Poel (2015) underlines that, while some values are conceptually in conflict (for example, *confidentiality* and *transparency*), other values conflict only in specific situations. These conflicts may be resolved through innovation. The innovation process broadens the technological and regulatory feasibility set, thereby offering opportunities to resolve conflicting values (Taebi et al., 2014). An example is the design and deployment of storm surge barriers in the Netherlands, which resolved the conflict between flood risk prevention (*safety*) and ecological repercussions (*environment*) (Correljé and Broekhans, 2015).

4.3. METHODS AND APPROACH

4.3.1. METHODS

A difficulty when creating a comprehensive list of value conflicts relates to the interpretation of values. Values tend to be discussed in a latent manner, whether orally or in the literature. This means that often the value in question is not explicitly named, but a broad set of words is used that, to some extent, refers to this value. For example, articles addressing privacy issues may not use this word specifically, but use terms such as 'data protection', 'theft', and 'cybersecurity'. In some cases, articles may also directly refer to technical solutions such as 'encryption' or 'data aggregation', or to the sources of privacy concerns (i.e. 'hackers'). Typically, these sets of words tend to differ depending on the scientific fields from which the article originates. These same words may in some cases have totally different meanings when they are used in a different context. For example, the word 'private' may also be used to express the idea of ownership.

The difficulty to interpret values means that one cannot conclude that a certain value is discussed solely because a certain word has been used. Rather, there is a dependency towards the human mind that is able to capture such complexity. Consequently, existing reviews of value conflicts for a technology are rare and tend to rely on qualitative content analyses (e.g., Milchram et al. (2018a) and Dignum et al. (2016)). However, if a comprehensive list of value conflicts needs to be built, it involves exploring a greater number of documents, preferably originating from multiple types of sources. Christen et al. (2017) use bibliometric analysis and outline a map of conflicting values in cybersecurity. However, the authors encountered problems such as the size of the literature and the difficulty to visualise "contextual aspects of possible conflicts" (Christen et al., 2017).

de Wildt et al. (2018) proposed a computer-aided approach. This approach can be used to make a comprehensive overview of value conflicts. The advantage of such an approach is the number of documents that can be processed, and therefore the diversity of value conflicts that can be found. This approach relies on probabilistic topic models (Blei, 2012) and semantic fields (set of words referring to a common idea) to conclude whether a certain value is discussed within a document. The principle of probabilistic topic models is the following. A topic model algorithm can autonomously identify topics addressed by a set of documents. This is done by passing through the text of multiple articles and observing words that are frequently named together within one article. The algorithm returns a set of topics, each being reported as a distribution over a fixed set of words. The interpretation of topic returned is to be done by the researcher. For example, a topic with high probabilities on words such as 'solar', 'energy' and 'photovoltaics' points to a topic about solar energy. The algorithm also returns how much of each topic a document addresses. Articles referring to a topic of interest can be captured by indicating a minimum percentage of words that have been attributed by the algorithm to this topic.

4.3.2. APPROACH

The approach aims to extract value conflicts in the smart electricity grid by observing a very large body of literature related to this topic. The logic used to identify value conflicts is the following. A large share of the academic literature proposes solutions or approaches (in some form) to address a technological or regulatory challenge (i.e. a trade-off). For example, solutions could be proposed to produce reliable products at lower costs, or to support the diffusion of technologies with the lowest amount of subsidies. In some cases, the trade-off is between two values (i.e. a value conflict). Indeed, as explained by Van de Poel (2015), innovation plays a key role in solving value conflicts (see section 4.2.2). Hence, if two values are observed within an article, and provided the fact that they are in conflict, this article both indicates a value conflict addressed in the literature and an approach to resolve this conflict. Using the approach proposed by de Wildt et al. (2018), this can be done systematically for a large body of literature.

A large set of possible values that may be in some way connected or affected by the deployment of the smart electricity grid with possible conflicts between them may initially be established. Our choice is to concentrate on conflict between a reduced number of seven key values. The first three selected values are the three pillars of the European Union energy policy: *reliability*, *environmental sustainability*, and *competitiveness* (European Commission, 2012). Next, *efficiency* is a key value in engineering design, strongly determining the economic success of a technology. Finally, as the expectation is that conflicting values may relate to technology users and citizens as well, three 'more human' values are chosen: *safety & health*, *justice*, and *privacy*, the latter related to societal discussions about the increased use of information technologies.

In line with the approach proposed by de Wildt et al. (2018), a set of 380,760 articles retrieved from Scopus in March 2018 using the query AUTHKEY(energy) was used. This

Table 4.1: Smart electricity grid topics

Topic 1	Topic 2	Topic 3	Topic 4
electric	algorithm	connected	microgrid
vehicles	optimization	generator	distributed
vehicle	scheduling	inverter	microgrids
charging	optimal	synchronous	resources
hybrid	programming	generators	generation
battery	objective	grid	distribution
forecasting	genetic	tracking	power
management	stochastic	wind	grid
plug	multi	control	storage
strategy	proposed	point	coordination

also holds for the topic model of 100 main topics in the energy literature created and presented by the authors. Since this chapter addresses the smart electricity grid, topics having high probabilities on words referring to this concept were selected. These topics were then verified by manually exploring the content of highly cited articles that were assigned to these topics by the algorithm and evaluating whether they were indeed related to the smart electricity grid. Four topics were finally identified, containing 24,799 articles. Table 4.1 presents the ten most probable words which describe the topics.

To identify articles addressing values, semantic fields (i.e. a set of words referring to a common idea) need to be created in multidisciplinary teams (de Wildt et al., 2018). Five researchers who were all acquainted with the concept of values and all had a strong background in the energy domain together created the semantic fields of values. They originate from various scientific fields such as system engineering, ethics, standardisation, and economics, concerned about the deployment of the smart electricity grid. The creation of semantic fields was done by progressively excluding words from a very large initial set of potentially relevant words. Appendix B shows the semantic fields and the definition of values provided to the researchers during the workshop.

To extract value conflicts from the body of literature, articles in these four topics mentioning at least one word of each of the semantic fields of two values were isolated. The set of related articles was then sorted on number of citations for each combination of two values. For each combination of values, the research concentrated on the 20 articles with the highest number of citations published from 2016 and after. The focus of the search is on recent articles because our interest lies primarily in conflicting values that have not yet been (satisfactorily) resolved and that may require policies or design adjustments to support smart electricity grid acceptance. Value conflicts that are discussed in older literature should still appear in recent articles if they have not been resolved. Section 4.4 presents the results of our analysis.

4.4. RESULTS

The section presents the conflicting values identified in the literature, as well as solutions proposed by this literature to address them. Table 4.2 shows the total number of articles found for each combination of two values. The results show that the smart electricity grid is most frequently addressed from a technical angle. Technical values (e.g. *efficiency*

Table 4.2: Article counts mentioning two or more values found in smart electricity grid topics

	Efficiency	Reliability	Safety & health	Env. sustainability	Justice	Privacy	Competitiveness
Efficiency							
Reliability	8763						
Safety & health	2643	1048					
Env. sustainability	12860	2573	1296				
Justice	695	126	36	219			
Privacy	390	187	59	152	11		
Competitiveness	859	250	101	840	34	21	

Table 4.3: Value conflicts in the smart electricity grid (A: resolves, B: causes)

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	Efficiency	Reliability	Safety and Health	Environmental sustainability	Justice	Privacy	Competitiveness
Efficiency							
Reliability	*B5 - Cons. values vs. competitiveness*						
Safety and Health	*B5 - Cons. values vs. competitiveness*	*B5 - Cons. values vs. competitiveness*					
Environmental sustainability	*A1 - Security of supply vs. renewables*	*A1 - Security of supply vs. renewables*					
Justice	*B3 - Market performance vs. local trading*	*B2 - Ind. access vs. eco. of scale B4 - Spatial distr. vs. system perf.*		*B2 - Ind. access vs. eco. of scale B4 - Spatial distr. vs. system perf.*			
Privacy	*B1 - IT vs. data protection*	*B1 - IT vs. data protection*	*B1 - IT vs. data protection*				
Competitiveness	*B5 - Cons. values vs. competitiveness*	*B5 - Cons. values vs. competitiveness*	*B5 - Cons. values vs. competitiveness*		*B2 - Ind. access vs. eco. of scale B4 - Spatial distr. vs. system perf.*		

and *reliability*) are dominant in the literature, followed by *safety & health*, and *environmental sustainability*. Other social values such as *justice* and *privacy* are not frequently addressed.

Based on the analysis, value conflicts can be divided in two categories: those resolved by the smart electricity grid and new conflicts caused by its deployment and use. Indeed, before introducing new conflicts, the smart grid is a solution to a value conflict in itself. In our analysis, multiple conflicting values are combined if they relate to a similar fundamental design challenge. For example, both environmental sustainability versus efficiency and environmental sustainability versus reliability relate to the incapacity of the electricity grid to efficiently and reliably cope with high voltage fluctuations caused by increasing the share of renewable energy supply. Table 4.3 presents a summary of existing conflicts resolved by the smart electricity grid (category A). These are in blue and are discussed in Section 4.4.1. New conflicts (category B) are in orange and are discussed in Section 4.4.2.

4.4.1. CONFLICTS RESOLVED BY THE SMART ELECTRICITY GRID

CONFLICT A1 - SECURITY OF SUPPLY VERSUS RENEWABLES

Numerous articles address the value conflict between *reliability* and energy *efficiency* on the one hand, and *environmental sustainability* on the other. This value conflict is one motivation for deploying the smart electricity grid. The literature attributes the emergence of this conflict to changing energy policy goals. While, traditionally, reliability and efficiency have always been key values in the energy sector mainly to guarantee economic development and security of supply, environmental sustainability has gained importance lately due to arising environmental concerns and the depletion of coal, gas and oil resources (Yu and Xue, 2016).

These values are conflicting due to the physical limitations of the infrastructure chosen to transport energy (i.e. the electricity grid). Pearson (2011) summarises the three physical realities that largely impact the management of electricity supply: extreme speed of electricity movement, impossibility to delay electricity storage, and high difficulty to direct electricity flows. As a result, grid management needs to be extremely precise and responsive to ensure that supply and demand continuously match. Electricity produced by wind and solar photovoltaics (PV) is however largely unpredictable, thereby threatening this balance (Baghaee et al., 2016). This may lead to an increased number of electricity outages, technical damages, and hence high financial costs. The seriousness of this problem is increased by the fact that power grids are aging in many (developed) countries (Oliver and Sovacool, 2017) and are heavily centralised (Karatayev and Clarke, 2016); the power outage of only a few transmission nodes may switch off electricity in a large share of the country.

The solutions proposed in the literature to address the tension between grid reliability and environmental sustainability relate to the main attributes of the smart electricity grid. As the power produced by wind and solar energy is intermittent, more precise grid data is needed to ensure that supply and demand match. The effect of intermittent power can be reduced by asking consumers to shift electricity demand over time. They can also be resolved at the local level (micro-grids). First, more detailed grid information can be captured by means of "advanced monitoring, control, and communication technologies" (Yu and Xue, 2016). The two-way communication facilitated by smart meters allows a flow of consumption information from seconds to 15-minute intervals (Sharma and Mohan Saini, 2015). System operators can use this information to anticipate consumption and production fluctuation. Additionally, the generation of large amounts of data has led to the use of big data approaches to gain a better understanding of voltage changes in power networks (Hu and Vasilakos, 2016). Second, more detailed consumption information can be used to encourage consumers to provide demand response. This can be done through a range of programs proposed by utility companies (Chen et al., 2017). Households but also commercial and industrial facilities can provide demand response (Samad et al., 2016), which can be triggered by the fluctuation of prices depending on electricity scarcity or excess (Zhou et al., 2016). Third, the tension between grid reliability and environmental sustainability can also be resolved at the local level through the creation of micro-grids. Three types of solutions are proposed by the literature: combination of complementary generation sources, (e.g. wind turbine, PV, and diesel generator) (Haghighat Mamaghani et al., 2016), installation of energy storage systems (Kyriakopoulos and Arabatzis, 2016) and scheduling strategies (Marzband et al., 2017, Nosratabadi et al., 2017, Rastegar et al., 2016, Ren et al., 2016, Sichilalu et al., 2016, Yagcitekin and Uzunoglu, 2016).

By coping with the tension between grid reliability and environmental sustainability, the smart electricity grid also has benefits in terms of cost-efficiency of electricity supply. Fewer investments in capacity, transmission, and distribution limit the increase in electricity prices (Mozafar et al., 2017). Smart meters avoid meter reading costs and reduce electricity theft (Oliver and Sovacool, 2017). Oliver and Sovacool (2017) summarise the contribution of the smart electricity grids by showing that they can help to solve the Energy Trilemma: energy security, energy equity, and environmental sustainability.

4.4.2. CONFLICTS CAUSED BY THE SMART ELECTRICITY GRID

CONFLICT B1 - IT ENABLED SYSTEMS VERSUS DATA PROTECTION

First, the smart electricity grid has caused a value conflict between *privacy* on one hand and *reliability*, *environmental sustainability*, and *efficiency* on the other. Information technologies allow the grid to be more responsive to changes in power production and consumption. Privacy concerns may arise when information is collected and distributed across a network. This is especially a problem when these data are actually meaningful for other parties (whether a Distribution System Operator, a marketing firm, or a hacker).

According to the National Institute of Standards and Technology's 2010 cybersecurity report (The Smart Grid Interoperability Panel Cyber Security Working Group (2010), 2016), Oliver and Sovacool (2017) explain two categories of privacy concerns: concerns about consumption data that reveal personal information about lives of customers and concerns about cybersecurity attacks which may hamper the correct functioning of electricity supply. By accessing the smart meter, other appliances in homes can also be accessed (Brettschneider et al., 2017). Consumption data may include information about socioeconomic status, usage of various appliances, and food consumption patterns (Ahmad et al., 2016). A plug-in electric car, when connected to a home area network (HAN), may reveal its location as well as power injection and life patterns of owners (Akula et al., 2015). These data may not only be used by potential criminals, for example, to verify the absence of home owners (Ahmad et al., 2016), but also by marketing firms interested in using or trading data (Ahmad et al., 2016), or employers wishing to monitor the productivity of employees (Cascone et al., 2017).

In the smart electricity grid, privacy concerns center around information transfer in private and public networks. In household residences, the smart meter acts as a gateway between the wide-area network (WAN), i.e. the network between the system operator and consumers, and the HAN (Sharma and Mohan Saini, 2015). The HAN may connect appliances such as home energy management systems, smart kitchen and cleaning appliances, and plug-in electric cars. As wireless communication is typically used in both WAN and HAN networks, consumption data are more difficult to protect (Ahmad et al., 2016). In a WAN network, a range of appliances tend to be placed in public spaces, thereby making them easily accessible to attackers (Leszczyna, 2018). Other services that are derived from the smart electricity grid, such as cloud services, raise security and privacy issues as well (Yu and Xue, 2016).

The literature proposes four types of solutions to address this conflict: technological innovations, design approaches, organisational approaches, and stakeholder communication. Technical innovations include intrusion detection systems, encryptions, access control systems, anti-malware software or firewalls, and aggregation of data (Leszczyna, 2018). Multiple authors propose packages which combine two or more of these solutions (for example (Martínez et al., 2017, Salinas et al., 2016, Zhang et al., 2016c)). To prove the efficacy of their solutions, these authors demonstrate how their solutions succeed at guaranteeing both privacy and efficiency at the same time. Brown (2014) discusses the concept of 'privacy by design', which aims at taking privacy into account more systematically throughout the entire engineering process of products. Leszczyna (2018) emphasises the importance of using privacy standards in the design of products, as they lead to more reliable solutions and increase the confidence of potential adopters. Organisational approaches include naming an authority within a company or market in charge of safeguarding privacy (Oliver and Sovacool, 2017). Finally, stakeholder communication approaches include improved communication with consumers about the installation process of smart grid appliances, such as the smart meters, as well as about their effects (Oliver and Sovacool, 2017), and a better promotion of other benefits that these appliances may have for consumers (Chen et al., 2017).

CONFLICT B2 - INDIVIDUAL ACCESS VERSUS ECONOMIES OF SCALE

Second, the smart electricity grid has caused a value conflict between justice on the one hand and *reliability*, *competitiveness* and *environmental sustainability* on the other. This conflict relates to inequalities in how individuals or groups are affected, but also whether they may use smart grid developments to their benefit. It is explained by the fact that populations are heterogeneous in terms of income, education, and type of housing. In early phases of deployment, technologies tend to be more expensive and their usage more complex. This raises concerns in terms of accessibility.

The following socioeconomic injustices are discussed in the literature. Chatterton et al. (2016) observe that high income population have more ability to adopt clean and energy efficient technologies, not only due to their stronger financial positions, but also due to housing ownership and the type of residence in which they live. Hence, these populations are more capable of making financial savings. Additionally, the deployment of these distributed technologies is supported through subsidies. Hence, they are paid by all, including poorer consumers (Simpson and Clifton, 2016). Obtaining subsidies for these small-scale technologies is furthermore a privilege, as utility-scale projects may offer similar environmental benefits at far lower costs (Nieto, 2016). Oppenheim (2016) explains that utility regulation has historically been designed based on a compromise between guaranteeing an acceptable return on investments and reasonable electricity costs for all consumers. Distributed generation decreases utility sales but not the costs of maintaining the production and distribution infrastructure. This burden is put on all households, including those without the financial means to participate in smart grid developments.

To address this conflict, approaches proposed by the literature focus on recognising the diversity of individuals and communities. Bednar et al. (2017) explore the relationship between cultural/racial differences in neighborhoods and consumption diversity and show that this can identify efficiency potential and threats of fuel poverty. Botelho et al. (2016) demonstrate the use of the contingent valuation method to estimate local welfare costs of renewable energy development and underline the effectiveness of community-based approaches to support the deployment of energy efficiency measures.

CONFLICT B3 - MARKET PERFORMANCE VERSUS LOCAL TRADING

Third, the smart electricity grid has caused a value conflict between *efficiency* and *justice*. The smart electricity grid supports new organisational models in terms of energy production and storage. For example, these activities may be performed individually or through energy communities, allowing electricity to be traded directly between households. The drawback is that injustices may result from these new organisational models in terms of electricity trading and inequalities in personal involvement and financial investments of individuals within communities. In energy communities, there is a mismatch between overall economic performance of the community and the fair distribution of costs and benefits between individual members. For both shared production units and storage systems, energy costs are reduced when exchanges with the distribution grid are minimised (Parisio et al., 2017). Typically, however, the load profile of each participant is different, meaning that the benefits of using locally produced or stored electricity may not be the equal for all users and may not match how much participants have invested in these (shared) infrastructures (Oh and Son, 2017).

Another issue is typical of markets. As in any markets, issues for market power may arise in energy communities or other forms of organisation models, allowing electricity trading between households. In some cases, entities within the network may react inappropriately to market rules (whether intentionally or not), thereby negatively impacting the reward of others (Zhu et al., 2016). Also, consumption information of participants may be unintentionally shared asymmetrically or used illegally, thereby allowing some participants to exercise market power or obtain unfair financial gains (Mahmoud et al., 2017). Leaked information about how much electricity is injected into the grid by a household can be used as bargaining power for the utility company as it knows that a householder may not be home and has to sell his electricity in any case (Akula et al., 2015).

Solutions proposed by the literature mostly include improved market and distribution allocation schemes that take fairness between participants into account (for example (AlSkaif et al., 2017, Oh and Son, 2017, Parisio et al., 2017, Zhang et al., 2016b). This is done using game-theory (for example (Wu et al., 2017b, Yaagoubi and Mouftah, 2017)), based on Nash bargaining (Wang and Huang, 2016), by comparing different types of allocation schemes (Shapely, the Nucleolus, DP equivalent method, Nash-Harsanyi) (Wu et al., 2017a). Akula et al. (2015) propose a privacy preserving scheme based on an aggregator that groups a set of bids of different storage units proposing to sell electricity, masks these individuals' bids and shares them with the utility. This way, the consumption of information of each community member is masked.

CONFLICT B4 - FAIR SPATIAL DISTRIBUTIONS OF ENERGY SYSTEMS VERSUS SYSTEM PERFORMANCE

Fourth, the smart electricity grid has caused a value conflict between *justice* on one hand, and *reliability*, *competitiveness* and *environmental sustainability* on the other. This conflict relates to inequalities in how different individuals or groups are positively or negatively affected by technologies supported by the smart grid. While these clean technologies have benefits for all, their installation at local level has consequences. Botelho et al. (2016) identify the effects in terms of landscape change, land costs, countryside accessibility, and social consequences as they may change the habits and interactions between individuals in communities. These consequences are not limited to smart electricity grid developments but are of importance for a wide range of energy transition developments in general (Li et al., 2016). As individuals live in different geographical regions, some of them being more appropriate for the installation of e.g. production infrastructures, inequalities in terms of space are created. To address this conflict, Schweizer et al. (2016) propose a "forward-looking model" which assesses the opportunities and risks associated with the deployment of infrastructures and identifies alternative options and how they relate to "plural values, interests, and preferences of those affected by each option". Simpson and Clifton (2016) underline the role of procedural justice in addressing fairness issues.

CONFLICT B5 - CONSUMER VALUES VERSUS COMPETITIVENESS

Fifth, the smart electricity grid has caused a value conflict between *safety & health*, *efficiency*, *competitiveness* and *reliability*. This conflict results from the novelty of the technologies on which the smart electricity grid relies. To be marketable, technologies need to fulfil a range of requirements. However, time is needed before all requirements can be matched satisfactorily. For example, Posada et al. (2017) explain that "for large scale electrochemical storage to be viable, the materials used need to be low cost, devices should be long lasting and operational safety is of utmost importance".

The literature mostly frequently addresses energy storage systems when it comes is technology development issues. Liu et al. (2016) explain that one of the challenges to achieve optimal battery charging includes "various constraints for safe, efficient and reliable operation". Incidents with lithium-ion cells and sodium–sulfur batteries include release of toxic materials (Posada et al., 2017), and the consequences of excessive operational temperatures (Liu et al., 2016). Kyriakopoulos and Arabatzis (2016) compare energy storage systems in terms of reliability. The types of materials used largely influence the reliability of batteries; strategies suggested by these authors include alternative materials (Posada et al., 2017), improved battery charging strategies (Liu et al., 2016), and additional research (Huang et al., 2016b). More generally, the literature addresses the competitiveness of technologies. Jung et al. (2016) perform a survey of social acceptance of renewable energy technologies for buildings. Cost effectiveness is one barrier for the development of these technologies and "could significantly affect the selection of the renovation option by the home owner". This holds for smart electricity grid appliances as well (IqtiyaniIlham et al., 2017).

This value conflict does not only exist for physical appliances, but also for software. Jokar et al. (2016) propose an electricity theft detection system in Advanced Metering Infrastructure (AMI) that is both "robust against non-malicious changes in usage pattern, and provide a high and adjustable performance with a low-sampling rate". Ahmad et al. (2016) discuss robustness in relation to metering equipment. For example, reliability is required to "transfer a high volume of data" and guarantee its accuracy.

To address this conflict, solutions proposed by the literature include both a better understanding of the core mechanism and properties of technologies (or its technological components), improvement of its operation and control rules, and comparison to other such technologies (Fang et al., 2017, Zhang et al., 2016a). The literature also suggests new materials, such as the use of organic materials in energy storage systems (Winsberg et al., 2017), together with new combinations of technologies, e.g. hybrid energy storage systems (for example (Hannan et al., 2017, Zhang et al., 2017, Zuo et al., 2017)). Several studies propose operation and control rules of batteries and charging systems to address the tensions between safety, reliability, and efficiency. This ranges from optimisation methods and programs (Eltamaly et al., 2016), operation rules (Díaz et al., 2017) to full control schemes and management systems (Wang et al., 2016). Generally, these studies emphasise the importance of financial incentives, including tax deductions and investment grants (Jin et al., 2018, Jung et al., 2016). Finally, the literature underlines the importance of trained staff and community education (Dincer and Acar, 2017).

4.5. DISCUSSIONS

4.5.1. PRIORITISATION OF VALUE CONFLICTS

In this research, a comprehensive overview of value conflicts in the smart electricity grid was created. Six groups of value conflicts were identified. The smart electricity grid is seeking to resolve the conflict between grid reliability and environmental sustainability. It has however created five new conflicts: IT enabled systems versus data protection, individual access versus economies of scale, market performance versus local trading, fair spatial distributions of energy systems versus system performance, and consumer values versus competitiveness. This research also identified a range of solutions proposed by the literature to address these conflicts.

An overview of value conflicts is important for policymakers and the industry as it gives an indication of future social acceptance issues that might hamper the successful deployment of the smart electricity grid. An illustration of possible social acceptance issues is proposed in Table 4.4. They have been categorised using the triangle of social acceptance proposed by Wüstenhagen et al. (2007). Possible socio-political acceptance issues include inadequate technology standards, citizen mistrust for governmental institutions and the rejection of legislation by legislative bodies. Community acceptance issues may be perceivable in the form of tensions between citizens, opposition against building permits and resistance from local authorities against national policies. Market acceptance issues encompass limited technology adoption, limited investments by the industry and the lobbying against new legislation.

Resolving value conflicts through technological design or policy arrangements may require resources. From a policy perspective, the question is which value conflict to prioritise. We suggest three factors for the prioritisation of conflicts: severity of resulting acceptance issues, resolvability of conflicts, and resources required for conflict resolution.

SEVERITY OF RESULTING ACCEPTANCE ISSUES

A first factor for the prioritisation of conflicts is the severity of resulting acceptance issues. Factors determining the severity of acceptance issues may include the direct impact on human wellbeing, the importance of the societal goals they are hampering (e.g.

Table 4.4: Illustration of resulting acceptance issues

	Socio-political acceptance issues	Community acceptance issues	Market acceptance issues
B1 - IT enabled systems versus data protection	- Inadequate privacy standards - Rejection of legislation by legislative	- Tensions between individuals - Resistance from local authorities	- Limited consumer adoption - Limited investments by industry
B2 – Individual access versus economies of scale	- Protest movements on national level - Mistrust for governmental institutions - Rivalry between governmental institutions - Inadequate policies for technological development - Lack of political commitment	- Tensions between individuals and communities - Resistance from local authorities	- Limited consumer adoption - Limited investments by industry - Path dependencies leading to socially undesirable technologies
B3 - Market performance versus local trading	- Inadequate technology standards - Mistrust for governmental institutions	- Tensions between individuals - Limited investments by industry	- Limited consumer adoption - Limited investments by industry
B4 - Fair spatial distributions of energy systems versus system performance	- Inadequate special planning - Mistrust for governmental institutions	- Opposition against building permits - Tensions between individuals and communities - Protest movements on local level	- Limited investments by industry - Non-involvement of consumers
B5 - Consumer values versus competitiveness	- Inadequate technology standards - Mistrust for governmental institutions - Inadequate policies for technological development - Rejection of legislation by legislative bodies	- Tensions between individuals and communities	- Limited consumer adoption - Limited investments by industry - Lobbying against new legislation

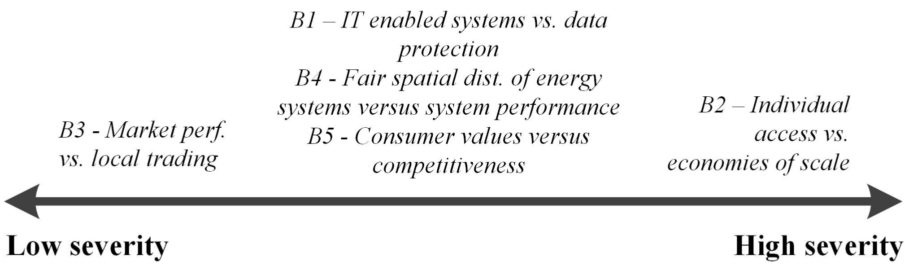

Figure 4.1: Classification of value conflicts by degree of severity of resulting acceptance issues

the energy transition), the size of the movement (number of individuals or firms involved) and their frequency (e.g. recurrent local protests against the installation of wind turbines). An additional factor is time. While Wolsink (2007b) shows that protests against the installation of wind farms often occur during the proposal phase, they could also only appear long after an infrastructure has been installed, for example in the case of natural gas extraction (Voort and Vanclay, 2015).

Figure 4.1 proposes a classification of value conflicts based on the severity of resulting acceptance. The conflict between market performance and local trading has low severity since it is expected to be limited to frustrations between market participants and low production adoption. The conflicts between IT enabled systems and data protection may lead to political discussions in the national level, and therefore has medium severity. The conflict between fair spatial distribution of energy systems and system performance is frequent but tends to remain a local issue with limited severe impact on well-being. The effect of the conflict between consumer values and competitiveness is limited in terms of direct impact on well-being. However, a fast diffusion of green technologies is needed to support the energy transition (e.g. energy storage systems). Finally, the conflict between individual access and economies of scale has high severity. Raising socioeconomic inequalities may have a profound effect on societal cohesion and lead to social unrest on the national level. An example is the so-called 'gilets jaunes' movement in France which reveals a tension between socioeconomic equality and the energy transition (Mehling, 2018).

RESOLVABILITY OF THE CONFLICT

A second factor for the prioritisation of conflicts is their degree of resolvability, hence the extent to which they are expected to be resolved in the future. Factors influencing the resolvability of a conflict may include the inherency of the conflict, the availability of measures needed to resolve the conflict, and the degree to which resolution depends on other factors, for example, technological development.

Figure 4.2 shows a classification of value conflicts based on their degree of resolvability. The conflicts related to IT, market performance, and spatial distribution of energy systems are all inherent conflicts. Information technologies require (consumption) data. Any form of trading may create issues of fairness between those who have better access, attributes, or skills to get the best of an existing market. Infrastructures require space. Solutions found in the literature are limited to mitigation efforts. The conflict

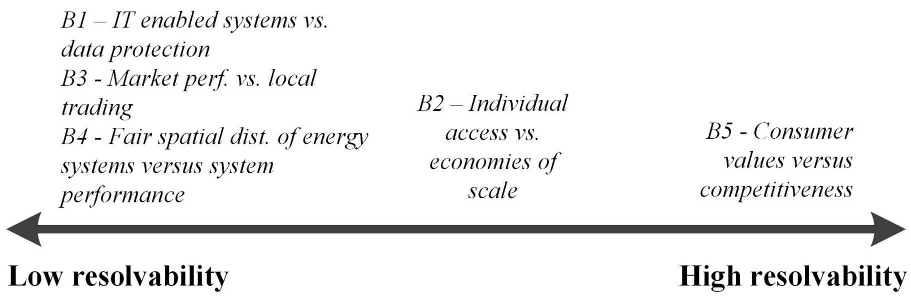

Figure 4.2: Classification of value conflicts by degree of resolvability

Table 4.5: Types of resources required to resolve conflicts

	Resources
B1 - IT enabled systems versus data protection	- Organizations supervising the adequacy of technology standards - Governmental support schemes for technology and regulatory development addressing privacy issues - Communication strategy with involved stakeholders (producers and consumers)
B2 – Individual access versus economies of scale	- Financial support schemes to support technology access
B3 - Market performance versus local trading	- Organizations supervising the adequacy of technology standards - Governmental support schemes for regulatory development improving market design and rules
B4 - Fair spatial distributions of energy systems versus system performance	- Improved spatial planning regulation - Compensation mechanisms between negatively and positively affected areas - Communication strategy with involved stakeholders (producers and consumers)
B5 - Consumer values versus competitiveness	- Organizations supervising the adequacy of technology standards - Governmental support schemes for technology development

between individual access and economies of scale has medium resolvability. It can be addressed through financial support schemes (although at high costs), but its resolution depends on the speed of technological development impacting the accessibility of the technology. Finally, the conflict between consumer values versus competeveness has high resolvability. This conflict is typically solved as a result of market competition and various forms of governmental support schemes.

REQUIRED RESOURCES FOR CONFLICT RESOLUTION

A third factor for the prioritisation of conflicts is the level of resources required to resolve a conflict. Besides actual costs, other factors may include the distribution of costs over time (one-time only or continuous), the uncertainty associated with future costs and economic spin-offs generated by the resource. Table 4.5 provides an illustration of types of resources required to (partially) solve value conflicts.

Figure 4.3 classifies value conflicts based on the level of resources required. The con-

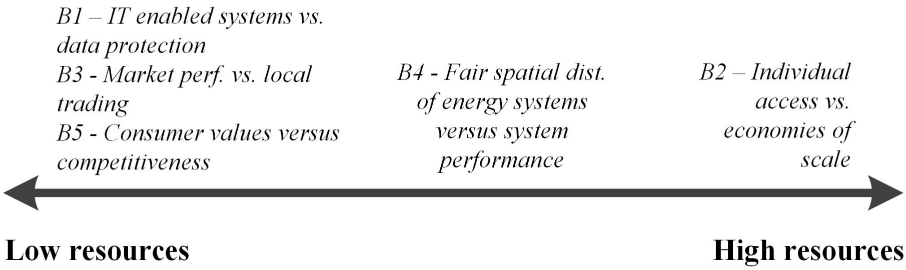

Figure 4.3: Classification of value conflicts by required resources for their resolution

flicts between IT enabled systems and data protection, market performance and local trading and consumer values and competitiveness require relatively limited resources. Typical measures are in the form of support schemes for technological development. These measures tend to generate economic spin-offs. The conflicts between fair spatial distribution of energy systems and system performance, and individual access and economies of scale require higher resources. They involve forms of compensation for which positive economic repercussions are more uncertain. They differ by the number of individuals requiring compensation.

4.5.2. REFLECTING ON THE CURRENT PRIORITISATION OF VALUE CONFLICTS

Looking at the classifications of value conflicts made in section 4.5.1, some appear more concerning than other. The conflict between consumer values and competitiveness is generally well-covered through technology standards and various support schemes. Still, the smart electricity grid faces big technological challenges, for example in the case of energy storage systems. The conflict between market performance and local trading cannot be solved structurally, but the impact on human well-being is limited. More concerning conflicts are the ones between the fair spatial distribution of energy systems versus system performance, IT enabled systems versus data protection and individual access versus economies of scale.

The conflict between the fair spatial distribution of energy systems and system performance has largely been addressed by the literature (e.g Bidwell (2013), Devine-Wright and Howes (2010), Haggett (2011), Wolsink (2007a). Nevertheless, oppositions against the installation of renewable power plants are recurrent (Ferraro and Geraint, 2016). The inherency of underlying value conflict (*justice* vs. *efficiency*) may explain the persistence of resistances (see section 4.4.2). To address injustices, approaches that give individuals more power in decision-making might be effective. This includes participatory decision-making (Wolsink, 2007b) and citizen ownership of energy systems (Koirala et al., 2016).

The conflict between IT enabled systems and data protection in the smart electricity grid has largely been addressed by legislation. At European level, for example, regulation EU-2016/679 and Directive 95/46/EC apply. Different tasks force are involved in this topic such as Expert Group 2 of the European Commission Smart Grids Task Force on privacy, data protection and cyber-security and the Energy Expert Cyber Security Platform. Critics against privacy issues in smart meters are however recurrent and have an impact on the success of their deployment (for example Cuijpers and Koops (2012), Faure and Schleich (2018)). The fact that underlying values are inherently in conflict means that these critics cannot be completely discredited. One approach may be to increase trust between energy utilities and consumers, for example by making the design of platforms more transparent (e.g. (Turèl and van Alphen, 2016)).

The most concerning conflict is probably the one between individual access and economies of scale. Several authors have already described possible negative impacts of the energy transition in terms of socioeconomic inequalities (e.g. Healy and Barry (2017), Mullen and Marsden (2016), Sonnberger and Ruddat (2017)). This is not different for the smart electricity grid. While early adopters have a critical role in the diffusion of technologies, these typically more privileged populations are also the ones receiving public money through financial incentives and other support schemes. Technologies in the smart electricity grid also allow these populations to make financial savings. Finding the right balance between sustainability and socioeconomic equality is difficult (e.g. Mehling (2018)) and the impact of not succeeding may be large for future generations.

4.5.3. CONTRIBUTIONS AND FUTURE WORK

This work offers four main contributions.

1. This work anticipates potential acceptance issues that might emerge during the deployment and operation phase of the smart electricity grid. This is done by identifying underlying value conflicts. This work is particularly important for policymakers and the industry to identify potential actions required to increase the chances that the technology gains acceptance.

2. This work provides an overview of the state of research in addressing value conflicts. Using the approach proposed by de Wildt et al. (2018), this work identifies both latent value conflicts and solutions proposed across multiple scientific communities.

3. This work contributes to conceptualising the notion of value conflicts by suggesting three factors for their prioritisation: severity of resulting acceptance issues, resolvability, and required resources for the resolution of conflicts. This contributes to making the notion of value conflicts more tangible and hence more useful for policy-making.

4. This work reflects on current approaches in addressing value conflicts. The conflict between individual access and economies of scale is probably the most concerning as it directly affects the success of crucial sustainability efforts as well as societal cohesion on a national level.

Future work includes the analysis of a wider range of values, possibly related to other infrastructures. In this chapter, seven values and potential conflicts between them were included. Other relevant values for the smart electricity grid may include autonomy, which is strongly supported by the deployment of the smart electricity grid, and trust, which is often discussed in the deployment of energy infrastructures. Further research using the same approach could explore how these values conflict with others, and examine solutions proposed by the literature to address them. The same approach could also be used to study other infrastructures, the deployment and use of which are expected to raise acceptance issues too.

The need to further clarify the relationship between value fulfilment and social acceptance is essential. As explained in Section 4.2.1, this relationship is complex. The fact that an innovation (partially) resolves a value conflict and hence supports a better fulfilment of values is meaningful with regard to its 'acceptability', i.e. the extent to which it is considered morally just. Additional factors however come into play which determine its 'acceptance', i.e. whether it is actually accepted within society (van de Poel, 2016). This includes norms, beliefs, and history between stakeholders. Insights from additional fields e.g. innovation management, adoption of innovation literature, and social psychology are needed to determine the acceptance of technologies. The Technology Acceptance Model (Davis, 1991) and the Value-Belief-Norms model (Stern et al., 1999) are considered evident next steps. These models may be combined with simulation methods that are able to represent to complexity of individual decision-making in social environments, such as agent-based modeling (Epstein and Axtell, 1996).

Finally, a more dynamic approach to ethics of technology is advocated. Within this field, analyses of the morality of technologies tend to be conducted in a static manner. However, the fact that innovations can resolve but also create new conflicts shows that a more dynamic approach to ethics of technology is required. As values change over time and are an integral part of the design and deployment of technologies, the morality of these artefacts may change over time as well. Hence, different trade-offs may be preferred at different moments in time. An increased consideration of the notion of 'Evolutionary Account of Morality' (Ruse, 1986) as well as of 'complex adaptive systems' (Holland, 2006) in ethics of technology is essential. Doing so may lead to better design and policy recommendations to support the morality of technologies facing a wide range of uncertain future scenarios.

5

Conflicted by decarbonisation: five types of conflict at the nexus of capabilities and decentralised energy systems

This chapter explores capability conflicts in the deployment of decentralised energy systems and identifies the affected population. These systems have positive societal impacts in terms of sustainability and consumer empowerment, but they are not accessible to all and their deployment may increase socioeconomic inequalities. The societal impacts of decentralised energy systems can be understood in terms of conflicting capabilities; for some citizens capabilities may increase, whereas for others they may decrease. While problematic, capability conflicts may not be inherent. They may only occur in certain neighbourhoods, for example, where both affluent and less affluent populations coexist. By understanding why these capability conflicts occur, we may be able to anticipate whether these decentralised energy projects could result in societal problems. We use agent-based modelling and the scenario discovery technique to identify capability conflicts and the populations that may be affected. We distinguish five classes of conflicts, which can be used to anticipate social acceptance issues. Affected populations can be involved in the decision-making process to foster acceptance of decentralised energy systems. This work contributes to the growing political and scientific debate on issues of energy justice and inclusiveness related to the energy transition. Additionally, we contribute to the operational-

This chapter is based on the work published in the peer-reviewed international journal Energy Research & Social Science (de Wildt et al., 2020b). The first author conceptualised and performed the research. The other authors have performed an advisory role

isation of such capabilities, as this is one of the first attempts to formalise the Capability Approach using an agent-based model.

5.1. INTRODUCTION

Decentralised energy systems have positive and negative impacts on societal well-being. Decentralised energy systems are energy installations that are installed close to the consumption site and aim to meet local energy needs (Kaundinya et al., 2009). Examples of decentralised energy systems include household solar panels, micro-grids, local energy communities and district heating systems (Yaqoot et al., 2016). The benefits of these systems include consumer sustainability and autonomy (Orehounig et al., 2015). Renewable energy sources or waste energy are typically used for energy generation (Perry et al., 2008). Brisbois (2019) explains how the emergence of decentralised energy systems, whether controlled by individuals, communities or cooperatives, alters the political power of traditional energy companies. There are however concerns that these systems could increase socioeconomic inequalities. For example, decentralised energy supply tends to be expensive and is therefore not accessible for all (Walker, 2008). Those who can afford to purchase it may be able to make savings, as this can be a cheaper option than the energy supplied from traditional energy providers. Also, the quality of traditional communal energy supply and services might decrease as more affluent populations opt for decentralised forms of energy production (Sovacool et al., 2019). Ultimately, the deployment of decentralised energy systems may generate societal tensions such as citizen protests and a growing mistrust of governmental institutions. The 'yellow vests' movement in France is an example of how the deployment of energy transition measures may eventually lead to social discontent (Mehling, 2018). These tensions may jeopardise the successful deployment of decentralised energy systems and the achievement of sustainability targets.

Positive and negative impacts of decentralised energy systems on well-being can be understood in terms of context- and system specific conflicting capabilities. Capabilities refer to "opportunities to achieve (...) 'beings' and 'doings'" (Robeyns, 2011). Examples include the ability to live a healthy life, to have attachments to other human beings and to decide upon one's life (Nussbaum, 2006). The fulfilment of capabilities supports at least a 'partial and minimal account of social justice' (Nussbaum, 2006). From a design perspective, the difficulty is that multiple capabilities may be in conflict. Hence, it may not be possible to fulfil all capabilities at the same time. This is also referred to as 'capability conflicts' (Holland, 2008). Capability conflicts may have moral consequences. For example, the deployment of decentralised energy systems may both enable individuals to increase their control over their energy consumption (i.e. capability: *Control*) and exclude others who are unable to access these technologies (i.e. capability: *Affiliation*). Capabilities may conflict, but only in specific circumstances. For example, a conflict between the capabilities of *Control* and *Affiliation* may only occur when a share of the population does not have sufficient income or suitable housing to participate in these energy systems. Identifying the circumstances in which capabilities conflict is essential for understanding potential moral issues that may occur in different types of neighbourhoods and for anticipating possible resulting issues of social acceptance (see de Wildt et al. (2019), Wüstenhagen et al. (2007)).

This chapter aims to identify conflicting capabilities in the deployment of decentralised energy systems and who are affected by them. This is done using an exploratory modelling approach. We develop an agent-based model (Epstein and Axtell, 1996) to simulate the effect of different neighbourhoods on the occurrence of capability conflicts. Scenario discovery (Bryant and Lempert, 2010) is used to classify in which types of neighbourhoods (combinations of model input parameters) capability conflicts occur. This work contributes to the conceptualisation of capabilities. To the best of our knowledge this is the first time that the Capability Approach has been formalised into an agent-based model. This work is also in line with the core tenets of energy justice: identify injustice, identify the affected population and create an appropriate decision-making process (Jenkins et al., 2016).

This chapter is structured as follows. Section 5.2 discusses the literature on decentralised energy systems and explains why the occurrence of capability conflicts is difficult to anticipate. Section 5.3 introduces the methods used to identify capability conflicts: agent-based modelling and scenario discovery. Section 5.4 describes the conceptualisation of capabilities, the resulting model, assumptions on which it is based and the experimental setup. Section 5.5 presents the model results and identifies five classes of conflicts and the populations that are affected by these conflicts. Section 5.6 discusses the model results and the implications for the technology and regulatory design of various types of decentralised energy systems. The contributions of this work, limitations and suggestions for future work are also addressed in this section.

5.2. THEORY

5.2.1. DECENTRALISED ENERGY SYSTEMS

Decentralised energy systems are forms of electricity or heat supply placed close to their point of consumption (Devine-Wright and Wiersma, 2013, Little, 1999). Walker and Cass (2007) identify four degrees of spatiality for the implementation of energy systems: macro, meso, micro and pico levels. The macro level refers to centralised energy systems. Decentralised energy systems cover all levels from meso (areas) to micro (buildings) and pico (devices). They are typically formed by a set of hardware (production, storage and network technologies) and software (energy management schemes) (Giotitsas et al., 2015, Hiremath et al., 2007, Orehounig et al., 2015). Examples of technologies include solar water heating, solar photovoltaics, micro-wind and micro-CHP (Allen et al., 2012). Decentralised energy systems may remain connected to the national energy grid or used as stand-alone systems (Little, 1999). Two main forms of ownership exist: individual and community ownership. An individual owner is often referred to as a 'prosumer' (Jacobs, 2017). Energy communities are typically initiated by a group of individuals within a specific local geographical location (Klein and Coffey, 2016). A wider range of actors (i.e. private, public, public-private and civic actors) may be involved to carry out these projects (Devine-Wright and Wiersma, 2013, Lammers and Hoppe, 2018).

The benefits of decentralised energy systems for users include sustainability, empowerment, education, affiliation and autonomy. These systems contribute to a more carbon-neutral energy mix (Allen et al., 2012, Goldthau, 2014, Koirala et al., 2016) as they often involve the use of renewables. They also support the use of democratic innovation and decision-making processes (Pesch et al., 2019, Smith and Stirling, 2016). Decentralised energy systems also provide opportunities for users to learn about energy supply and its societal impact (Walker et al., 2007). Their deployment requires the creation of solutions that are adapted to local contexts, for example housing characteristics and living patterns of involved citizens (Goldthau, 2014, Gupta and Ivanova, 2009). They also have benefits in terms of affiliation and trust within a community. This is referred to as 'social capital' (Putnam, 1995). Hence, they foster social interactions between residents as well as a sense of identity (Devine-Wright and Wiersma, 2013, Hoffman and High-Pippert, 2005, Pesch et al., 2019, Rogers et al., 2008). Finally, decentralised energy systems enable users to be more autonomous in case of grid failure (Giotitsas et al., 2015, Schleicher-Tappeser, 2012).

The drawbacks of decentralised energy systems include the injustices that may be generated by their deployment. Most justice and fairness issues related to decentralised energy systems discussed in the academic literature refer to distribution of costs and benefits among community participants (e.g. Chun Zhang et al. (2012), Koirala et al. (2016), Wu et al. (2017b)). Few studies have addressed injustices for populations who are not able or not willing to participate in such developments. Purchasing decentralised energy systems (individually or in communities) typically requires high upfront payments and a certain level of understanding of technologies (Walker, 2008). Also, the installation of these systems is more difficult (insufficient space) or even impossible if housing is not owned but rented. Low-income and less educated societal groups may well be excluded from owning decentralised energy systems. Additionally, as more affluent households move towards decentralised energy production, the quality of traditional energy supply and services might decrease (Allan et al., 2015, Sovacool et al., 2019). This could increase the vulnerability of less affluent households (Bouzarovski and Petrova, 2015). Finally, the deployment of decentralised energy systems is often supported by public subsidies and other forms of support mechanisms paid by all. This includes less affluent households. Concluding, the deployment of decentralised energy systems may thus contribute to a transfer of wealth from low to high income populations (Catney et al., 2014, Sovacool et al., 2019).

5.2.2. CAPABILITY CONFLICTS

We employ the Capability Approach of Sen (1992) and Nussbaum (2011) as a value theory that points to different (possibly conflicting) aspects of human well-being. The Capability Approach is a conceptual framework used to assess individual well-being and evaluate social arrangements and design policies with high social impact (Robeyns, 2011). It states that 'the freedom to achieve well-being is of primary moral importance' and the 'freedom to achieve well-being is to be understood in terms of people's capabilities' (Robeyns, 2011). Nussbaum (2006) suggests ten basic capabilities, ranging from *Bodily health* to *Emotions*, *Affiliation* and *Control over one's environment*. A 'partial and minimal account of social justice' (Nussbaum, 2006) is provided when any of these capabilities are fulfilled above a certain threshold. The Capability Approach has been applied in developing countries but is now increasingly used in western countries too. Examples include the assessment of energy poverty and justice in Europe (e.g. Day et al. (2016) and Bartiaux et al. (2018)). Nussbaum's capabilities have been illustrated in the context of energy systems by Hillerbrand and Goldammer (2018). Table 5.1 provides an overview of these capabilities. This list of capabilities will be used to conceptualise the model in Section 5.4.2.

Table 5.1: Energy capabilities (adapted from Hillerbrand and Goldammer (2018))

Energy capabilities	Application to energy systems
Life and bodily integrity	Ability to live free from accidents and long-term negative side-effects generated by energy systems (e.g. emissions).
Emotions	Ability to enjoy a safe and enjoyable life due to the availability of energy supply and the absence of emotional pain caused by the presence of energy infrastructures
Senses, imagination, and thought	Ability to educate oneself due to the availability of energy supply and the absence of taboos related to electricity production
Trust	Ability to live in a stable and reliable environment
Practical reason, or the imagination of goodness	Ability to consume electricity in line of one's perception of the good
Affiliation	Ability to identify with others and to share the (financial and non-financial) costs and benefits of energy supply
Ecological connectivity	Ability to live free from climate change and the direct negative impacts of energy infrastructure on nature
Play	Ability to have a more relaxed life due to the availability of energy supply and the absence of alteration of leisure space by energy infrastructure
Control over one's environment, Part A: weak separateness	Ability to be more self-sufficient in energy supply
Control over one's environment, Part B: strong separateness	Ability to participate and shape forms of energy supply

Besides providing a range of energy capabilities, the Capability Approach is used in this work to identify the factors leading to the occurrence of different conflicts. Central to this approach is the acknowledgement of human diversity. Whether capabilities are fulfilled for individuals depend both on the resources they have (e.g. income) and the conversion factors that they have to convert resources in capabilities (Sen, 1992). Three types of conversion factors exist: personal (e.g. education), social (e.g. social norms) and environmental (e.g. housing properties). These factors affect the fulfilment of capabilities, but also the occurrence of capability conflicts. In the case of decentralised energy systems, forming a local energy community allows neighbours to gain autonomy (*Control over one's environment*) in comparison to traditional energy supply. A sense of community can be created in the neighbourhood (*Affiliation*). Both capabilities are therefore aligned. However, forming energy communities may not be feasible for households living in impoverished neighbourhoods because they may lack the financial means or education required to form these kinds of communities. In this case, the formation of an energy community might involve higher risks in terms of finance and comfort, leading to more stress for participants. As a result, there may be a conflict between *Control* and *Emotions*.

5.2.3. ANTICIPATING CAPABILITY CONFLICTS

Policy interventions, which typically require resources and commitment, might be needed to resolve capability conflicts. For example, subsidies can be used to make renewable energy technologies available to less affluent groups and offer them a higher degree of autonomy over their energy consumption. It is therefore essential to assess whether underlying moral issues may occur in a specific neighbourhood or district and whether the use of policy interventions is required. However, it is difficult to anticipate whether the properties of a neighbourhood with regard to inhabitants, housing and existing infrastructures may lead to capability conflicts. We identify two reasons why this is the case.

First, the fulfilment of capabilities may depend on a wide range of intertwined factors which might be too much to evaluate using simple human cognition. Koirala et al. (2018) show that 'environmental concern, renewables acceptance, energy independence, community trust, community resistance, education, energy related education and awareness' all contribute to community energy system participation. Next to these socio-psychological factors, households may also be limited by their financial situation and whether they actually own their property. Geographical factors may also play a role with regard to *Affiliation*. In some cases, it might be the diversity of households with regard to this factor that explain the occurrence of capability conflicts. For example, only the more affluent population in a neighbourhood may be able to purchase decentralised energy systems. The more affluent group becomes more autonomous whereas the poorer group is less able to identify themselves with their neighbours. Here, the capabilities *Control* and *Affiliation* are in conflict.

Second, it is difficult for the human mind to fully comprehend all possible impacts that the realisation of some capabilities may have on the capabilities of other households. A capability conflicts with another when fulfilling one capability is at the expense of another. If some households decide to form an energy community to become more sustainable and autonomous, other households may be excluded based on their socioeconomic characteristics and housing conditions. As a result, their capability of social affiliation might be affected. Also, a conflict is only real if households have no other reasonable opportunities to change their electricity supply to regain the same level of well-being. These opportunities need to be included in the analysis to be able to conclude that two capabilities are in conflict. Furthermore, the change in electricity supply to regain the same level of well-being may affect other households in new ways. To be able to anticipate capability conflicts, we require methods that can recreate the circumstances for such conflicts to occur. This can be achieved by using agent-based models and the scenario discovery technique.

5.3. METHODS

This section introduces agent-based modelling and scenario discovery. An agent-based model is used in this work to simulate the potential occurrence of capability conflicts between households in one type of neighbourhood, for example, one in which households are highly educated or where there is a high diversity in education levels. The scenario discovery technique is used to run the agent-based model numerous times, each time for a different type of neighbourhoods (i.e. a different combination of household properties and spatial distribution of these characteristics over the population). This approach allows us to map the occurrence of capability conflicts between households in different types of neighbourhoods. The conceptualisation of the agent-based model and the experimental setup are further described in Section 5.4.

5.3.1. AGENT-BASED MODELLING

We use an agent-based model (Epstein and Axtell, 1996) to evaluate the occurrence of capability conflicts between households in different neighbourhoods. A neighbourhood is defined as a specific combination of household properties and spatial distribution of these characteristics over the population. A simulation model is required due to the multiplicity of (heterogeneous) factors that can influence capability conflicts and the difficulty to understand how the fulfilment of some capabilities by certain households affects the fulfilment of capabilities of others (agency). Agent-based modelling originates from the fields of complexity and generative science (Bankes et al., 2002). These models are well suited to study systems in which heterogeneity, spatial distribution and interactions between entities impact overall system behaviour (Rahmandad and Sterman, 2008). In a typical agent-based model, a set of agents is asked to pursue individual goals by performing a set of actions. This is done sequentially and repeatedly. As agents are given heterogeneous properties and their behaviours influence each other, we can observe emergent system patterns (e.g. capability conflicts) that are not directly inscribed in the model conceptualisation.

5.3.2. SCENARIO DISCOVERY

Scenario discovery is used to classify which capability conflicts between households occur in which types of neighbourhoods. Scenario discovery consists of two steps. First, Exploratory Modelling and Analysis (EMA) (Bankes, 1993, Kwakkel et al., 2013) is used to generate a high number of scenarios. This is done by running a simulation model (in this case the agent-based model) multiple times using different combinations of input parameters (e.g. average resources of agents, distribution of resources across the population, hence neighbourhood). Second, the set of scenarios is explored using the Patient Rule Induction Method (PRIM) (Friedman and Fisher, 1999). This method is useful to find combinations of input parameters that have led to a certain outcome of interest (i.e. a conflict between capabilities). For example, we may find a conflict between *Affiliation* and *Control* (of energy production) in neighbourhoods where the population is highly heterogeneous in terms of resources and the degree of spatial clustering is low.

5.4. MODEL DESCRIPTION AND ASSUMPTIONS

This section explains the application of agent-based modelling and scenario discovery for this work. We evaluate whether the model is 'fit-for-purpose' and identify to what the requirements the model should comply (5.4.1). Next, we describe the model conceptualisation, the model agents, the capabilities and explain how capability conflicts are identified in the model (5.4.2). We then describe our experimental settings (5.4.3) and validate the model (5.4.4). Appendix C.1 provides a model description using the ODD+D protocol (Müller et al., 2013). The model and python code used to generate visualisations can be found online[1].

5.4.1. SIMULATION GOAL AND REQUIREMENTS FOR MODEL VALIDATION

The aim of the simulation experiment is to identify which capabilities could conflict in which types of neighbourhoods when decentralised energy systems are deployed. Additionally, we want to know which type of population is affected by these conflicts, both positively and negatively. Our simulation model should therefore comply to the following three requirements. First, the model should allow us to test a variety of neighbourhoods regarding household properties and their spatial distribution. Second, it should be able to measure the fulfilment of various capabilities as a result of different choices with regard to the level of decentralisation. Third, it should show the conflicts between capabilities for different types of populations. At the end of each model run, we should be able to measure whether a capability has increased for a certain population (e.g. an affluent population) but has decreased another capability for another population (e.g. a less affluent population).

We underline that the simulation goal is not to predict human or household behaviour and interaction. Rather, our simulation comprises a large number of illustrative 'what if' analyses, where we systematically examine whether an action taken by household A to increase one capability leads to the decrease of another capability for the same household or for household B. This is done for a large variety of types of neighbourhoods (different initial properties of households and distribution of properties over the population). Capability conflicts emerge from the chosen conceptualisation of capabilities (based on the illustration for energy systems provided by Hillerbrand and Goldammer (2018), and households' heterogeneous characteristics.

[1] *https://github.com/tristandewildt/Capability_Conflicts*

Table 5.2: Properties of agents

Agent properties	Distributions over the agent population
Resources	Normal distribution with a mean varying each model run between [0-10], with a standard deviation varying between 0.5 and 3. 0 is set as an absolute minimum for the level of resources of agents and 10 as absolute maximum.
Personal conversion factors (PCF)	Normal distribution with a mean varying each model run between [0-10], with a standard deviation varying between 0.5 and 3. 0 is set as an absolute minimum for the level of PCF of agents and 10 as absolute maximum.
Social conversion factors (SCF)	Spatial clustering of agents in the model. A degree of clustering can be varied from highly clustered to randomly placed. Clustering can be based on resources, on PCFs and resources and on ECFs and resources.
Environmental conversion factors (ECF)	Normal distribution with a mean varying each model run between [0-10], with a standard deviation varying between 0.5 and 3. 0 is set as an absolute minimum for the level of ECF of agents and 10 as absolute maximum.

5.4.2. MODEL CONCEPTUALISATION

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TYPES OF NEIGHBOURHOODS: AGENT PROPERTIES AND SPATIAL DISTRIBUTION

The first requirement is that the model should allow us to test a variety of neighbourhoods in which capability conflicts might occur. Different neighbourhoods are characterised in this work by different combinations of household properties and spatial distribution of these properties over households.

In line with the CA, both resources and conversion factors (personal, social and environmental) play a role in determining the level of capabilities. In the model, an agent represents a household. Each agent is given a certain level of resources, a personal conversion factor (PCF) and an environmental conversion factor (ECF). These parameters are assigned to the population using a normal distribution of which the mean and standard deviation vary each model run (see Table 5.2). Social conversion factors (SCFs) are conceptualised as a measure of agent clustering. The higher the clustering value, the more agents with similar levels of resources, PCFs and ECFs are placed close to each other in the model. The lower the clustering value, the more random the distribution of agents over the model space. Figure 5.1 shows an example of a population with high resources and one with low resources, both highly clustered. The level of resources and conversion factors of agents will eventually determine their level of capability fulfilment and the choices they make to maximise them.

CONCEPTUALISATION OF CAPABILITIES

The second requirement is the ability to measure the fulfilment of capabilities. This section explains the conceptualisation of capabilities in the model. As discussed in Section 5.2.2, Nussbaum (2011) suggested ten basic capabilities. These capabilities have been illustrated in the context of energy supply by Hillerbrand and Goldammer (2018). In this work, we concentrate on capabilities that are affected by the introduction of decentralised energy systems compared to centralised energy supply. The theory however gives freedom on how to conceptualise capabilities. We have chosen a conceptualisation that fits within the illustration provided by Hillerbrand and Goldammer (2018) and concentrate on exploring all possible conflicts that might occur within this conceptualisation.

Table 5.3: Conceptualisation of capabilities

Capabilities	Conceptualisation in the model
Emotions	A measure of the difference between the level of resources and the agent's PCF, and the minimum level of resources and the PCF required to participate in a production group. If the level of resources and the PCF are insufficient, the level of Emotions is 0. The level of Emotions then increases as the distance between the level of resources and the agent's PCF and the minimum required level increases.
Trust	A measure of the extent to which the size of a production group of an agent matches the size of production groups of its neighbours. The level of Trust is high if all agents are in individual production groups or if all agents are in large groups. If some agents are in small production group and their neighbours in large groups, the level of Trust of those agents will be low.
Senses, Imagination, and Thought	A measure of both the size of the production group to which the agent belongs (the smaller, the more there is to learn) and the diversity of that production group in terms of ECF (the more diverse the group in terms of housing characteristics, the more complex the required solution, and therefore the more they can learn).
Affiliation	A measure of the extent to which the level of capabilities of agents matches the level of capabilities of their neighbours. The more similar the level of capabilities, the higher the level of Affiliation (even if the level of capabilities is low).
Control over one's Environment	A measure of the size of the production group to which the agent belongs; the smaller the group, the higher the level of Control.

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Table 5.3 shows the six capabilities and explains their conceptualisation in the model. A more detailed conceptualisation of capabilities in the model can be found in the ODD+D description in Appendix C.1. Control over one's environment, Part A and B are combined into one capability.

We include six capabilities. We include *Emotions* since different forms of organisational modes may affect levels of security of supply [2]. The insecurity of being able to access or afford electricity may lead to stress for households. This is especially a problem for less affluent populations (i.e. low income and low education). The introduction of decentralised energy systems may change the social dynamics within a neighbourhood, for example, by creating new groups among individuals and excluding others. This affects the extent to which households may consider their environment as stable and *Trustworthy*. We include *Senses, imagination and thought* since smaller scale electricity production places more responsibility on households, thereby encouraging them to increase their understanding of electricity supply and its impacts. *Affiliation* is affected since the deployment of new forms of organisational modes may change household well-being unequally, thereby impacting the extent to which households can identify with others. Decentralised energy systems allow households to be more autonomous (*Control over one's environment, Part A*). By forming energy communities, these households have the opportunity to have more influence on the way the electricity sector is shaped (*Control over one's environment, Part B*). Control over one's environment Part A and B are com-

[2] While we acknowledge the literature on values and emotions, we do not use the term 'emotions' in a substantive sense. Rather we refer to Nussbaum's notion of emotions as a capability.

bined.

We exclude four capabilities. We exclude the capability *Life and bodily integrity* because we assume that in western countries the deployment of decentralised energy supply is sufficiently regulated through quality standards. We assume that all households have access to electricity. Therefore, the benefits of electricity supply in terms of *Practical reason, or the imagination of goodness* are not affected. The deployment of a decentralised electricity supply does not particularly change nature at the local level (*Ecological connectivity*), but could make a change on global scale. Also, in most western countries, biomass is not used as a new solution for decentralised energy supply. Finally, leisure opportunities are not affected since the space required by decentralised energy systems is usually limited (*Play*).

EXPLORING THE OCCURRENCE OF CONFLICTS

The third requirement is the ability to identify which conflicts occur in which types of neighbourhoods and who is affected by these conflicts. Hence, we need to identify when the increase of one capability leads to the decrease of another capability, and for which type of population. In this section, we first explain how a conflict can be observed in one model run. We then describe how we can identify the types of neighbourhoods in which two capabilities are in conflict and the affected population.

Occurrence of conflicts in one model run In the model, agents aim to maximise the fulfilment of their own capabilities. To do so, they can associate or dissociate themselves to form smaller or larger production groups. The smaller the production group, the more decentralised its production. Agents in the model continuously evaluate the following options and their effects on their own level of capabilities: (1) switch to another production group, (2) form a new production group (i.e. produce individually) or (3) remain in the current production group. Agents choose the option that scores the highest for all capabilities, provided it is a feasible option for them (i.e. they have sufficient resources and conversion factors for this particular option). If none of the options are feasible, they choose the option that is closest to a feasible solution. The model stops when no agents are able to further maximise their level of capabilities.

The agents' level of resources and conversion factors influences their preferred level of decentralisation. For example, agents with low resources may prefer to be in a large production group to ensure a sufficient level of *Emotions* (i.e. more affordable energy due to economies of scale). This low level of resources might not allow them to produce themselves (i.e. be in an individual production group). In contrast, agents with high resources may prefer an individual or a small production group because this could increase their level of *Control*.

However, the choices of some agents with regard to a certain level of decentralisation may influence the fulfilment of capabilities of others. By moving to an individual production group, agents can increase their capability of *Control*, but this reduces the size of the initial production group to which they belonged. As a result, the level of *Emotions* of remaining agents in this group decreases, while the minimum level of resources and PCFs required to belong to this group increases. In this case, there is a conflict between *Emotions* and *Control*.

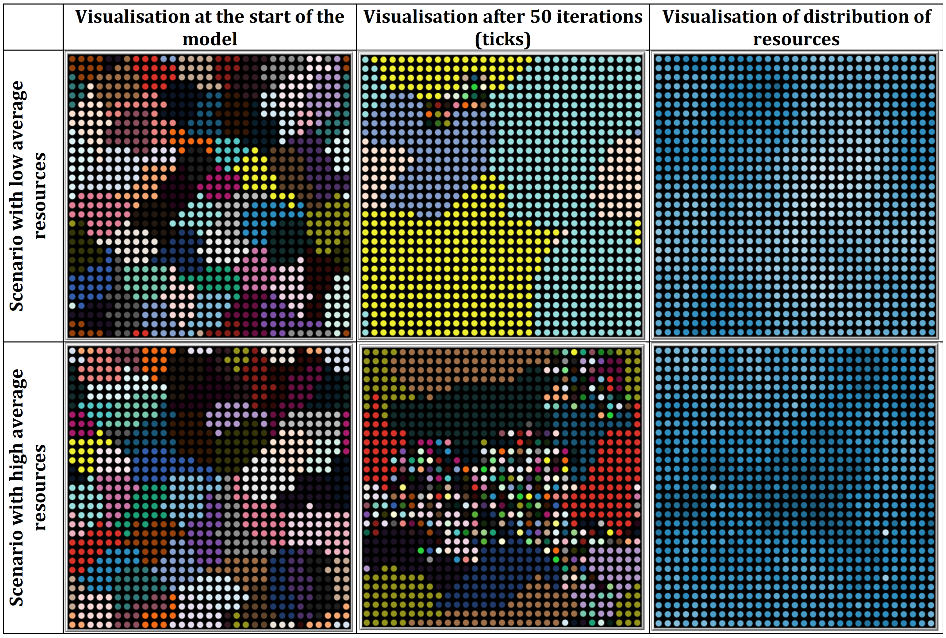

Figure 5.1: Model visualisations with low and high average levels of resources of agents

Identifying neighbourhoods where capabilities conflict and the affected population
Different distributions of properties over a set of households (i.e. the type of neighbourhood) may lead to different levels of decentralisation chosen by agents. This impacts whether a conflict between two capabilities occurs or not. The model output with low and high average resources for agents is compared in Figure 5.1. The first picture for each scenario is the model visualisation at the start of the model run, the second is the visualisation after 50 iterations (ticks) of agents choosing to form and switch between production groups. The third picture for each scenario is an overview of the level of resources of agents. In each picture, one dot represents one agent. In the first and second pictures, each production group has a colour. In the first picture of each scenario, agents are divided among roughly 50 production groups. In the two second pictures, agents have formed new production groups. The number of production groups is low if the average resources of agents was initially set to low, and high if the average resources of agents was initially set to high. In the scenario with low average resources, only few agents (those with the highest resources) have formed individual production groups. Many more decided to unite in large production groups. In the scenario with high average resources, the number of individual production groups is clearly higher. The third picture for each scenario shows the initial distribution of resources among agents in each of these two model runs. The darker the dot, the higher the agent's level of resources. Since the second scenario is a neighbourhood with a high average level of resources, the third picture is darker than the one for the first scenario.

As different average levels of resources influence agents' choices, a conflict that may

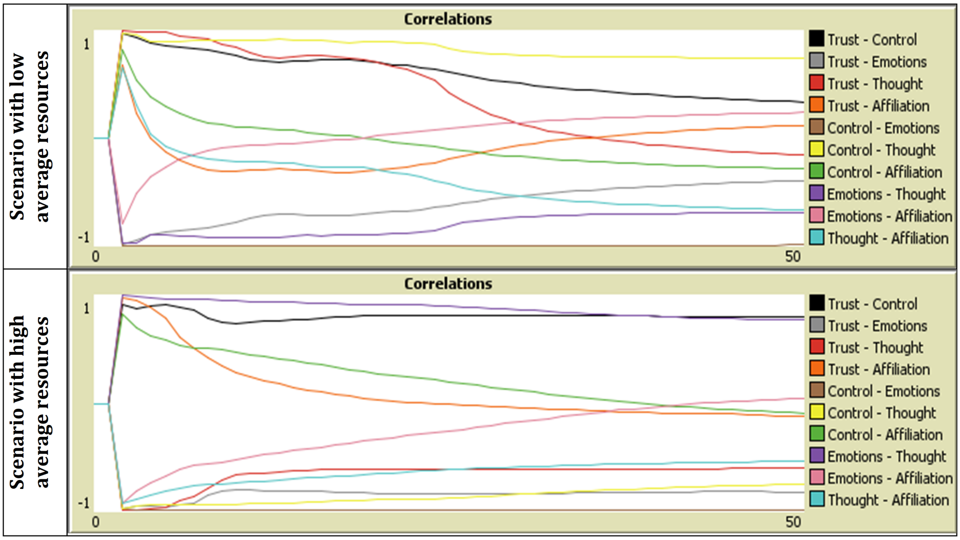

Figure 5.2: Conflicts with low and high average levels of resources of agents

occur in the first model run may not happen in the second and vice versa. Figure 5.2 shows the evolution of the correlations between different capabilities from the start of the model run until after 50 iterations (ticks), when the agents' average level of resources is low and high, respectively. The figure shows that *Control* and *Emotions* (in brown) are in conflict in both cases. This is different for *Emotions* and *Thought* (in purple). In the scenario with low average resources, agents with a low level of resources choose low levels of decentralisation to ensure they can afford energy. Low levels of decentralisation are however less favourable to encourage individuals to think about electricity (*Thought*, see conceptualisation in 5.4.2). Hence, both capabilities are in conflict. In the scenario with high average resources, agents have high levels of resources, meaning that *Emotions* can also be fulfilled with high levels of decentralisation. Hence, both capabilities are aligned.

5.4.3. EXPERIMENTAL SETTINGS

This section presents the experimental settings used for the scenario discovery experiment. For each model run, a different combination of values of model input parameters (see 5.4.3) is selected using Latin Hypercube sampling (Kwakkel et al., 2013). After all model runs are performed, we evaluate which combination of parameters leads to the occurrence of capability conflicts and present the visualisations used to report circumstances in which capabilities conflict (see 5.4.3).

EXPERIMENT

The simulation model was run 2000 times, using a different combination of input parameters each time (see 5.4.3). Different combinations of input parameters mimic different types of neighbourhoods, for example, in terms of level of income and education. We found that performing additional model runs did not change the number or types of

Table 5.4: Variations of model input parameters

Input parameters sweep	Description	Range
mean_resource_population	Average resource level of the entire population	[0-10]
mean_Pcf_population	Average PCF level of the entire population	[0-10]
mean_Ecf_population	Average ECF level of the entire population	[0-10]
std_dev_resource_population	Standard deviation around the mean of resources	[0.5-3]
std_dev_Pcf_population	Standard deviation around the mean of PCFs	[0.5-3]
std_dev_Ecf_population	Standard deviation around the mean of ECFs	[0.5-3]
clustering_resource	Geographical clustering based on resource levels	[0-1]
correlation_Pcf_resource	Correlation between resource and PCF level per agent	[0-1]
correlation_Ecf_resource	Correlation between resource and ECF level per agent	[0-1]

classes of capability conflicts. The total number of model iterations is set to 50 ticks. In almost all cases, the agents' levels of capabilities had stabilised by that point, meaning that an equilibrium was reached.

VARIATIONS OF MODEL INPUT PARAMETERS

Table 5.4 presents the model input parameters and the ranges of values used to mimic different types of neighbourhoods. The *mean_resource_population* variable determines the average level of resources (e.g. average income) of the neighbourhood in a model run. A value of 8 means that the neighbourhood is predominately affluent. The *std_dev_resource_populatio* variable determines the standard deviation of the distribution of resources among the population. The higher this value, the more diverse agents are in terms of resources. Similar variables are created for PCFs (e.g. level of education) and for ECFs (e.g. suitable housing for decentralised energy production).

The variable *clustering_resource* determines the extent to which agents with similar levels of resources are geographically clustered. A value of 1 means that agents with similar levels of resources are placed close to each other. A value of 0 means that they are randomly distributed of the population. The variables *correlation_PCF_resource* and *correlation_ECF_resource* determine whether agents with high resources also have the highest PCFs and ECFs (i.e. they are highly educated and have suitable housing for decentralised energy production). These variables represent agents' SCFs.

MODEL OUTPUTS

We now present the visualisations used to show in which types of neighbourhoods capability conflicts between households occur and which population groups are affected. We introduce these visualisations by using the conflict between *Trust* and *Thought* as an example. Hence, following our conceptualisation of capabilities, the conflict entails that the possibility of belonging to a production group of the same size as that of the neighbours (i.e. a similar form of energy supply) is in conflict with the possibility to learn from electricity production, for oneself and for other agents.

When analysing a conflict, we first need to identify in which type of neighbourhood this conflict might occur. Figure 5.3 is a PRIM visualisation (Patient Rule Induction Method, see Section 5.3.2) which shows the ranges of initial model parameters (the blue line) when a conflict is observed. In Figure 5.3, the conflict between *Trust* and *Thought* mostly occurs when the variables *mean_Ecf_population*, *mean_Pcf_population*, *correlation_Ecf_resources*, *std_dev_resource_population* and *clustering_resource* are between

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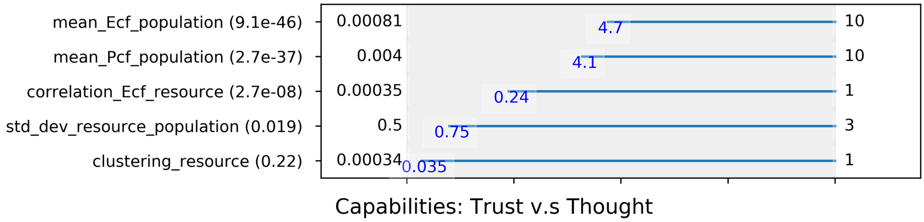

Figure 5.3: PRIM visualisation showing ranges of initial model parameters leading to capability conflicts

4.7 and 10, 4.1 and 10, 0.24 and 1, 0.75 and 3, and 0.035 and 1, respectively. We see that *Trust* is in conflict with *Thought* in neighbourhoods where houses tend to be suitable for decentralised energy production, and where agents have rather high education levels. There is also a positive correlation between agents with high resources and houses suitable for decentralised energy production. The diversity in suitability of these types of houses is also higher. As the range found for geographical clustering based on resource levels practically matches the full initial range of the input variable, this variable does not play a large role in determining the occurrence of the conflict. All other variables do not strongly contribute to the occurrence of this conflict as they do not appear in this visualisation.

Second, we need to identify when a conflict between *Trust* and *Thought* occurs (i.e. which levels of decentralisation are chosen by different categories of agents leading to the occurrence of this specific conflict). This is shown in Figure 5.4. The boxplot shows the categories of agents and their levels of decentralisation when *Trust* and *Thought* are in conflict. The two capabilities are in conflict when agents with high resources, PCFs and ECFs choose high levels of decentralisation.

Third, we need to identify which categories of agents are affected by the conflict between *Trust* and *Thought*, either positively or negatively. Figure 5.5 shows which types of agents are involved in the conflict between *Trust* and *Thought*. The diagram is divided in three sections: resources, PCFs and ECFs. Each section is divided in three groups. For example, the section resources is divided between agents with high resources, medium resources and low resources. A chord between two groups indicates that a conflict exists between these two populations. The size of a chord is a measure of how often this conflict has occurred in the total amount of model runs. The colours indicate the degree of centralisation when the conflict occurs: blue when centralised, yellow when mid-centralised and red when decentralised. Figure 5.5 thus shows that the conflict between *Trust* and *Thought* is between agents with high resources and the rest of the population. The conflict is almost never between agents with medium resources and low resources. The same observations can be made with regard to PCF and ECF categories.

5.4.4. MODEL VALIDATION

We verified and validated our model using the Evaludation method described in Augusiak et al. (2014). This method comprises six steps: data evaluation, conceptual model evaluation, implementation verification, model output verification, model analysis and

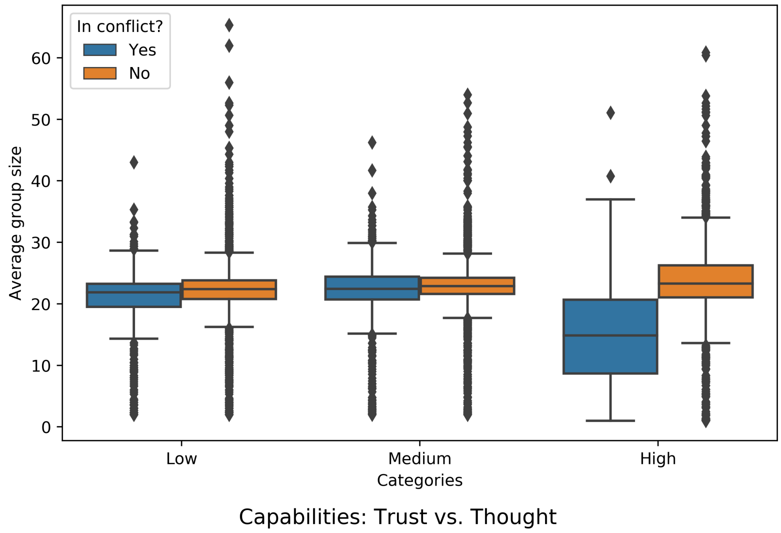

Figure 5.4: Levels of decentralisation when *Trust* and *Thought* are in conflict

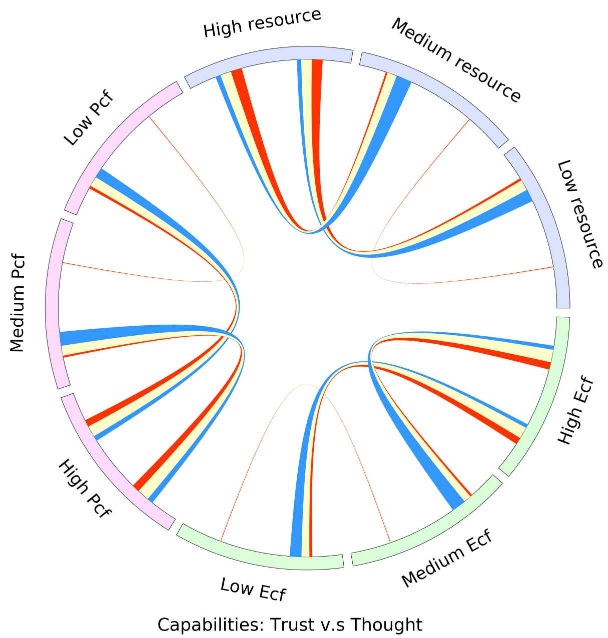

Figure 5.5: Types of population groups affected by conflict between *Trust* and *Thought*

model output corroboration.

The data is a translation of the operationalisation of the Capability Approach in the context of decentralised energy systems. We conducted sensitivity analyses to verify that variation of curve parameters did not influence our conclusions in terms of the classes of conflicts identified in Section 5.5. The conceptual model evaluation and model output verification steps are challenging in our case as we were unable to find other models in which the Capability Approach is conceptualised in the literature. We performed a series of logical tests to verify that the model adequately matches the core ideas of the Capability Approach, for example, that both resources and conversion factors influence the fulfilment of capabilities. We used four tests proposed by Van Dam et al. (2013) for the implementation verification: recording and tracking of agent behaviour, single-agent verification, minimal model interaction verification and multi-agent verification. Model output corroboration was conducted by verifying that model outputs could be related to cases of energy injustices observed in the real world.

5.5. MODEL RESULTS

In this section, we present capability conflicts identified by means of the model and approach described in Section 5.4. Capability conflicts are grouped into five classes of conflicts, based on the types of neighbourhoods where they could occur and the affected population:

- Class 1: Conflicts in centralised energy systems for all populations
- Class 2: Conflicts in centralised energy systems for affluent populations
- Class 3: Conflicts in (partially) decentralised energy systems for less affluent populations
- Class 4: Conflicts when only affluent populations choose decentralised energy systems
- Class 5: Conflicts in decentralised energy systems

The five classes of conflicts are further described in Section 5.5.1 through Section 5.5.5. For each class of conflict, we present the figures of only one conflict observed in this class. This is because the circumstances leading to other conflicts in this class are similar, hence also the figures (see Appendix C.2). Figure 5.6 visualises the five classes of conflicts where each conflict class is represented by a red line. A dot on a line indicates that this class refers to a specific population, e.g. with low resources and medium decentralisation (Class 3). The arrow side means 'the rest of the population'. Hence, a line with both a point and an arrow indicates that the conflict involves one specific group of agents and the rest of the agent population.

5.5.1. CLASS 1: CONFLICTS IN CENTRALISED ENERGY SYSTEMS FOR ALL POPULATIONS

Figure 5.7 shows that a first class of conflicts occurs when the average level of resources of the population is low to medium (see PRIM visualisation). Here, all agents choose large production groups (see boxplot). These conflicts are frequent in all model runs

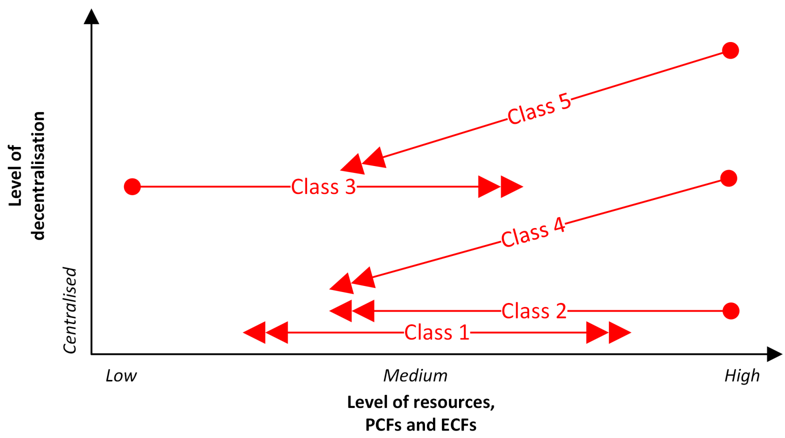

Figure 5.6: Summary of classes of conflicts

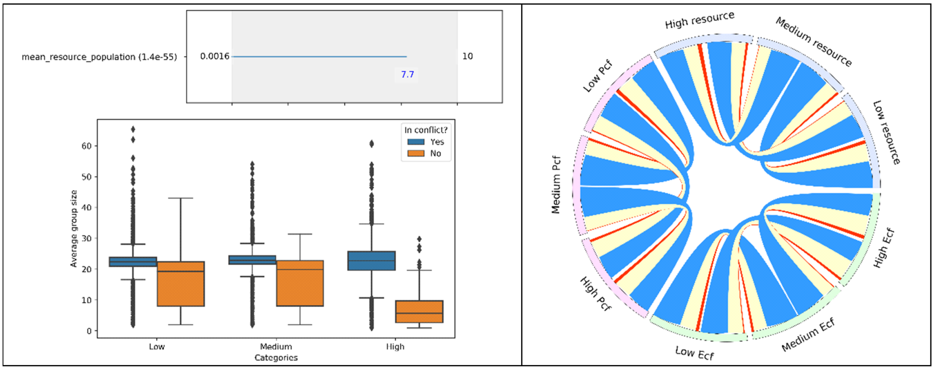

Figure 5.7: Description of class 1 conflicts

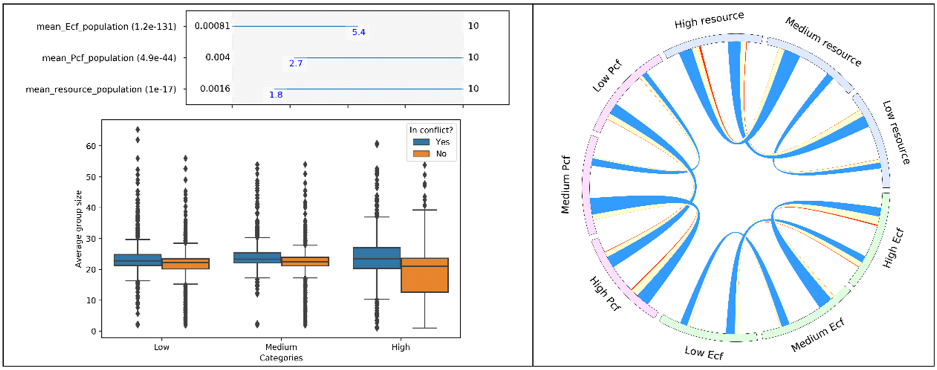

Figure 5.8: Description of class 2 conflicts

and between every population categories (see chord diagram). Conflicts occurring in this class are:

- *Control-Emotions*;
- *Emotions-Thought*.

The explanation is the following. In less affluent neighbourhoods, levels of income (i.e. resources) and education (i.e. PCFs) of households tend to be lower. A highly centralised system contributes to economies of scale, thereby making energy more affordable. As a result of this choice, the level of *Emotions* of households increases. However, following the conceptualisation of capabilities and the choices made here by agents, their levels of *Control* and *Thought* decrease.

5.5.2. CLASS 2: CONFLICTS IN CENTRALISED ENERGY SYSTEMS FOR AFFLUENT POPULATIONS

Figure 5.8 shows that a second class of conflicts occurs when there is a discrepancy between resources and PCFs (high), and ECFs (low). Here, all agents choose relatively large production groups, with similar circumstances as those observed in Class 1 conflicts. They however affect populations with high levels of resources, PCFs and ECFs more. Conflicts occurring in this class are:

- *Affiliation-Control*;
- *Affiliation-Thought*;
- *Trust-Emotions*.

In neighbourhoods where houses tend to be inadequate for decentralised energy installations (i.e. low ECFs), households are forced to keep using traditional (centralised) energy supply. The problem in terms of capabilities is particularly for households with high income (i.e. resources) and education (i.e. PCFs), since they would normally tend to choose more decentralised forms of energy production. As a result, their levels of *Control* and *Trust* decrease. The overall levels of *Affiliation* and *Trust* however increase, as all populations make similar consumption choices that are also largely affordable.

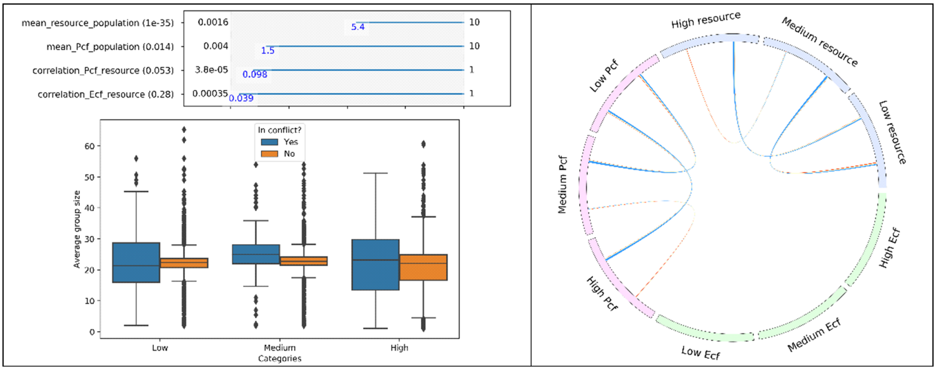

Figure 5.9: Description of class 3 conflicts

5.5.3. CLASS 3: CONFLICTS IN (PARTIALLY) DECENTRALISED ENERGY SYSTEMS FOR LESS AFFLUENT POPULATIONS

Figure 5.9 shows that a third class of conflicts occurs when the average levels of resources and PCFs of the population are high. Here, agents tend to choose relatively medium sized production groups. These conflicts affect populations with low resources and PCFs. Conflicts occurring in this class are:

- *Affiliation-Trust*;
- *Affiliation-Affiliation*.

In relatively affluent neighbourhoods, the population is inclined to choose higher levels of decentralisation. This creates a problem for populations with lower income and education. To increase their level of *Trust*, these households would be tempted to choose decentralised means of production too. This would however come at high costs in terms of the other capabilities that they have (*Affiliation*). In these cases, while decentralisation has a positive impact on *Affiliation* for affluent populations, it has a negative impact on the *Affiliation* of the less affluent ones.

5.5.4. CLASS 4: CONFLICTS WHEN ONLY AFFLUENT POPULATIONS CHOOSE DECENTRALISED ENERGY SYSTEMS

Figure 5.10 shows that a fourth class of conflict occurs when the average level of PCFs and ECFs is high, and the correlation between ECF and resources is high. Here, only agents with high levels of resources choose decentralised energy production. The conflicts are between this category of agents and the rest of the population. Conflicts occurring in this class are:

- *Control-Trust*;
- *Thought-Trust*;
- *Emotions-Affiliation*.

In affluent neighbourhoods, households may end up choosing very decentralised means of energy production (i.e. produce individually). As a result, their levels of *Control* and

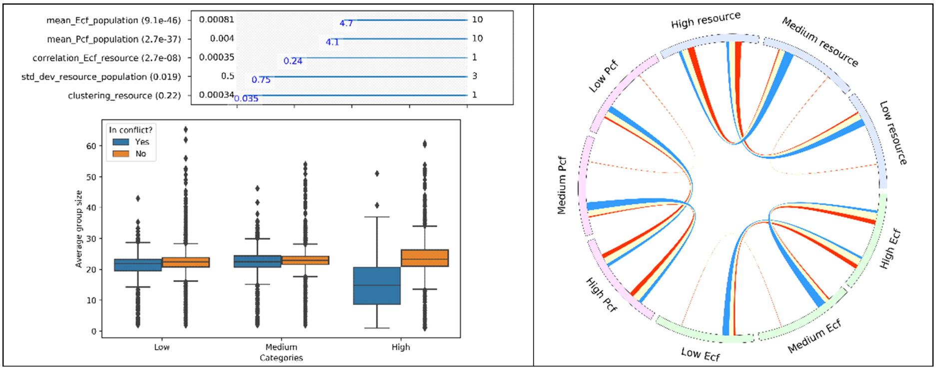

Figure 5.10: Description of class 4 conflicts

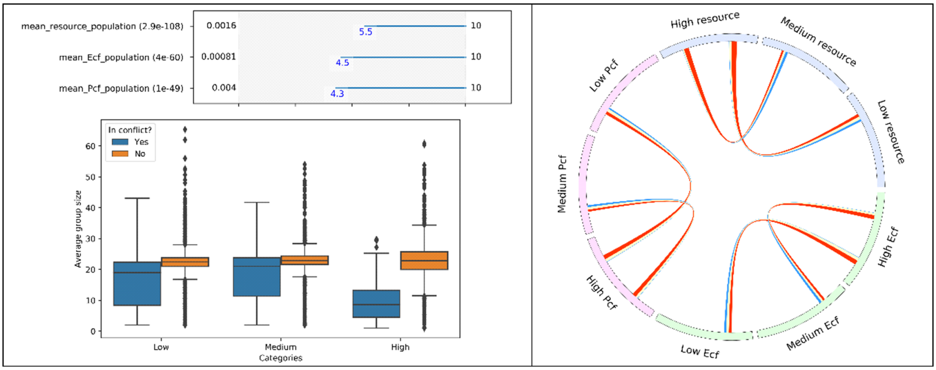

Figure 5.11: Description of class 5 conflicts

Thought increase strongly. Consequently, the entire population faces a decrease of *Trust*. This is because the diversity with regard to the chosen means of energy production is large. Households are less certain that they have made the appropriate choice. The diversity of choices also has impacts in terms of *Affiliation* and pushes households to make decisions that may not be favourable in terms of their *Emotions*.

5.5.5. CLASS 5: CONFLICTS IN DECENTRALISED ENERGY SYSTEMS

Figure 5.11 shows that a fifth class of conflicts occurs when the average level of resources, PCFs and ECFs is very high. All agents choose rather small production groups, with agents with high resources choosing even smaller ones (i.e. individual production). These conflicts are between agents with high resources, PCFs and ECFs, and the rest of the population. Conflicts occurring in this class are:

- *Emotions-Emotions*;
- *Thought-Thought*;
- *Control-Thought*;
- *Control-Control*.

In affluent neighbourhoods, a competition for *Control* might occur. The most affluent population is typically able to produce individually and therefore gain high levels of *Thought* and *Control*. Less affluent populations might however need to rely on the first category of households to be able to establish relatively small production groups such as energy cooperatives. The possible choice of the most affluent population to produce individually has therefore negative consequences in terms of *Control* and *Thought* for the rest of the population. An advantage for the latter population is however that their level of *Emotions* increases.

5.6. CONCLUSIONS AND DISCUSSION

5.6.1. CONCLUSIONS

This chapter identified conflicting capabilities in the deployment of decentralised energy systems in neighbourhoods using an agent-based model and scenario discovery. Five classes of capability conflicts were identified:

- Class 1: Conflicts in centralised energy systems for all populations
- Class 2: Conflicts in centralised energy systems for affluent populations
- Class 3: Conflicts in (partially) decentralised energy systems for less affluent populations
- Class 4: Conflicts when only affluent populations choose decentralised energy systems
- Class 5: Conflicts in decentralised energy systems for all populations

These classes of conflicts affect the social acceptance of decentralised energy systems differently. Capability conflicts can eventually result in social acceptance issues (de Wildt et al., 2019, van den Hoven et al., 2015, Wüstenhagen et al., 2007). How conflicts affect a population is indicative for the types of moral problems that are created and hence the types of acceptance issues that could emerge. By analysing the five classes of conflicts, we identified three types of moral issues: those inherent to a technical or organisational choice, personal dilemmas and conflicts between population groups.

First, capability conflicts can affect all populations, independently of the characteristics of households. This can be seen in Class 1 and Class 5 conflicts. In these cases, conflicts are inherent to a technical or organisational choice. Centralised energy systems are beneficial in terms of affordability (*Emotions*), due to economies of scale. This however conflicts with consumer empowerment (*Control*). Consumers depend on the initiative of (often large) energy suppliers to have access to their preferred source of energy production (e.g. more sustainable ones). Decentralised energy systems may create a competition for *Control*. As they are not affordable for all, less affluent households are dependent on the willingness of others to engage in energy cooperatives and gain higher levels of *Control* and *Thought*. In these cases, related capability conflicts can only be solved by choosing a different form of electricity supply. This new form of electricity supply may however have capability conflicts of its own.

Second, conflicts can be specific to a type of population. This can be seen in Class 2 and Class 3 conflicts. In Class 2 conflicts, affluent populations may choose more decentralised production. This enables them to have more *Control* over their energy consumption and to learn about energy supply. From the point of view of *Affiliation*, the drawback is however that their levels of well-being will increase significantly compared to other groups. They might become more socially isolated, for example, because of jealousy between groups of citizens. In Class 3 conflicts, less affluent populations may choose to participate in more decentralised forms of energy production too. This enables them to feel more socially included. However, compared to other groups, this might negatively affect their level of well-being due to higher costs of decentralised production. Both Class 2 and Class 3 conflicts relate to some form of personal dilemma. However, in Class 3 conflicts this is triggered by the choices of other population groups.

Third, conflicts can occur between population groups. This can be seen for Class 2, 4 and 5 conflicts. In Class 2 and 4 conflicts, the fact that affluent populations choose higher levels of decentralisation will both decrease their level of *Affiliation* and *Trust*, and those of less affluent populations. In Class 5 conflicts, the fact that affluent populations choose highly decentralised production enables them to achieve a high level of *Control* over their energy production. However, a less affluent population is dependent on a more affluent population to provide sufficient levels of resources and knowledge to form decentralised production groups. By choosing highly decentralised production groups (e.g. individual production), affluent populations exclude others from the opportunity to adopt more decentralised forms of energy production. These groups can have high levels of *Control* over their electricity production and more opportunities to educate themselves, at the cost of less affluent populations.

The classes of capability conflicts identified in this work can be used to anticipate future social acceptance issues and deploy adequate policies. As suggested by Van de Poel (2015), innovation could be an approach to solve value conflicts. The author explains that technical innovations can 'ease value conflict' as it 'enlarges the feasibility set'. For example, the smart electricity meter eases the tension between grid reliability and sustainability facing the deployment of intermitted renewable energy sources (Sharma and Mohan Saini, 2015). The challenge is thus to find innovations that can address these issues. Other approaches include cost-benefit analysis or direct trade-offs (Van de Poel, 2015). A list is also suggested by Thacher and Rein (2004). For example, organisations could share responsibility for conflicting values so that value conflicts are institutionalised as a constant tension between two or more organisations.

5.6.2. IMPLICATIONS OF IDENTIFIED CONFLICTS FOR THE DESIGN OF DECENTRALISED ENERGY SYSTEMS

This work contributes to the emerging scientific and political debate on inclusiveness issues generated by the energy transition. Green energy technologies offer multiple advantages, including increased consumer autonomy and sustainability. These technologies are however more accessible for affluent populations and may therefore create issues of distributive justice. This research shows that decentralised energy systems are not different in this respect. This work has three implications for the design of decentralised energy systems.

First, this work shows that the design of decentralised energy systems needs to be adjusted based on the characteristics and diversity of households that reside in the area of interest. This includes those related to their financial situation, to their housing properties, but also to more social and psychological characteristics. Specific capability conflicts only occur in certain types of neighbourhoods. Competition for *Control* (Class 5 conflicts) occurs when the population is affluent and lives in conditions that are particularly suitable for the deployment of decentralised energy systems (e.g. households have a lot of space). Regulation can be put in place to support the deployment of energy communities. However, this could fail if a affluent population can achieve energy consumption goals individually, without having to rely on neighbour participation.

Second, although no negative societal responses were perceived during the deployment phase of a decentralised energy system, this does not mean that it will be free of social acceptance issues in the future. The distinction between moral acceptability and social acceptance (see (Taebi, 2016, van de Poel, 2016) shows that technological and organisational choices might still bear underlying moral issues even though this might not be observed through political debates or citizen protests. The consequence of these conflicts might only appear in certain circumstances, for example, because of a change in the (implicit) societal prioritisation of capabilities (or values). Class 1 conflicts have always been an underlying issue due to past choices to concentrate on energy provision through centralised energy systems. Only later did these conflicts enter the 'societal cognitive domain', mainly due to the growing mistrust of citizens of the ability of large energy firms to make more sustainable choices. Class 3 conflicts may be a serious reason for concern. They may not be visible, now or in the future, because less affluent groups are too small in rich countries or they are not sufficiently represented by political parties. Furthermore, their impact on the well-being of less affluent populations can be severe.

Third, certain types of conflicts have more severe effects than others and might therefore need to be prioritised. Resolving capability conflicts requires resources. Hence, it is necessary to prioritise the resolution of conflicts by evaluating their potential impact. de Wildt et al. (2019) suggest three factors: the severity of resulting acceptance issues, the extent to which conflicts are resolvable, and the resources required to resolve them. With this in mind, the discussion on capability thresholds is highly relevant. In her work, Nussbaum (2006) argues for the specification of capability thresholds. The fulfilment of each capability above these thresholds would guarantee a minimum level of social justice. Holland (2008) however states that guaranteeing social justice is a matter of trade-offs among capabilities. Therefore, establishing capability ceilings would allow us to limit the amount of resources spent on capabilities that are in conflict.

With regard to this work, the fact that capabilities are in conflict is not inherently problematic with regard to social justice. Rather, it is a problem when conflicts lead to the fulfilment of some capabilities falling under these thresholds, and when these capabilities cannot be fulfilled by other infrastructures and organisational systems as a replacement. Conflicts occurring in decentralised energy systems (Class 5 conflicts) lead to a decrease of the capability *Emotions* for affluent populations. However this conflict does not seem to be problematic as these populations tend to have sufficient resources to cope with less affordable energy. Conflicts in centralised energy systems for more affluent populations (Class 2 conflicts) are more problematic. The capabilities of *Thought* and *Control* are linked to the practice of democracy. This is critical currently, since the fulfilment of these capabilities encourages a transition to a more sustainable form of energy supply. However, *Thought* and *Control* can be fulfilled by other initiatives, for example, through new political movements. Finally, conflicts occurring in (partially) decentralised energy systems for less affluent populations (Class 3 conflicts) are critical. Here, *Affiliation* (i.e. the overall level of well-being) may significantly decrease for less affluent populations. Also, this fulfilment of this capability cannot easily be adjusted due to the amount of resources required for compensation. This class of conflicts may therefore be highly problematic with regard to the level of the social justice provided by decentralised energy systems and to potential future issues of social acceptance.

5.6.3. CONTRIBUTIONS, LIMITATIONS, AND FUTURE WORK

This work aims to classify capability conflicts that might occur in the different types of neighbourhoods and to identify the type of population affected by these conflicts by using agent-based modelling and scenario discovery.
This work offers three main contributions.

1. It contributes to the ability to anticipate potential problems of social acceptance and social justice in various neighbourhoods during the deployment of decentralised energy systems. We have identified the type of population affected by these conflicts. This is essential for policymakers to adjust the technological and regulatory design ex ante to solve potential problems that might emerge in a later stage of deployment. Also, this indicates which types of citizens and societal actors need be involved in the decision-making process to increase the chances of successful deployment.

2. It contributes to the overall debate on the inclusiveness of the energy transition. Particularly, this work is in line with the emerging literature on energy justice (see (Jenkins et al., 2016)). The exploration of capability conflicts contributes to distributional justice, and the identification of affected populations to recognitional justice. Both can then be used to design fairer decision-making processes.

3. It is, to our knowledge, the first in which the Capability Approach is explicitly formalised into an agent-based model. By focusing largely on the individual, the Capability Approach and agent-based models are largely compatible in a conceptual sense. We have introduced a new way in which the Capability Approach can contribute to addressing issues of inequality and well-being. We also contribute to further exploring and conceptualising the notion of capability conflicts. While recurrently acknowledged in the Capability Approach literature (e.g. (Holland, 2008, Martha C. Nussbaum, 2000, Peeters et al., 2013), the consequences of capability conflicts on the feasibility of such a conceptual framework of well-being have not yet been systematically explored.

A first limitation of this work is the application of the Capability Approach to a specific technology, in this case decentralised energy systems. Other (coexistent) systems to these technologies may play a role in the fulfilment of capabilities and as such may also solve some of the conflicts identified by the model. For example, we might question whether the need for *Control*, *Thought* and *Affiliation* should necessarily be solved by decentralised energy systems. Different social projects may achieve similar effects.

Results from the model should therefore be interpreted by taking the wider context of energy decentralisation into account.

A second limitation is the conceptualisation of capabilities, which is highly dependent on the case modelled and specific technical and organisational details. A large range of possible conceptualisations for one capability may be valid. In this work, we have chosen to concentrate on one conceptualisation that fits within the illustration provided by Hillerbrand and Goldammer (2018) and explore capability conflicts that might occur between groups, within groups and within individuals in a systematic and rich manner.

Methodologically, future work includes the application of this modelling approach to an empirical case. The use of qualitative data in the form of functions describing the relationship between resources, conversion factors and the achievement of capabilities was sufficient to identify multiple classes of capability conflicts. It may however be beneficial to evaluate model results with richer data.

Future work for the deployment of decentralised energy systems could include participatory methods to involve citizen groups affected by specific capability conflicts. A promising method is the Participatory Value Evaluation methodology (Mouter et al., 2017), which could include citizens' moral considerations in the policy-making process.

6

EX ANTE ASSESSMENT OF THE SOCIAL ACCEPTANCE OF SUSTAINABLE HEATING SYSTEMS

This chapter demonstrates an approach to assess, ex ante, the social acceptance of sustainable heating systems in city districts. More sustainable heating systems are required in city districts to reduce greenhouse gas emissions. However, these systems may lack social acceptance as they often require significant adjustments to homes and may lead to a noticeable loss of in-home thermal comfort. Predicting social acceptance is often difficult due to the long-term planning horizon for energy systems. It is therefore unclear which design requirements and policy guidelines need to be specified ex ante. We suggest an approach to anticipate social acceptance by identifying value conflicts embedded in sustainable heating systems. Due to value change, embedded value conflicts might cause a lack of social acceptance over time. We demonstrate this approach using a case of community-driven heating initiative in The Hague, the Netherlands. We identify value conflicts embedded in various sustainable heating systems using an agent-based model. We formulate scenarios of value change to understand the severity of resulting social acceptance issues and discuss suitable heating systems for the city district. The approach can be used to support the decision-making process of policymakers at the local level, even in situations of limited local expertise.

This chapter is based on the work submitted in the peer-reviewed international Energy Policy (de Wildt et al., 2020a). The first author conceptualised the research, built the agent-based model and performed the experiments. The second author collected the data. The other authors have performed an advisory role.

6.1. INTRODUCTION

The deployment and operation of sustainable heating systems for city districts may lack social acceptance. In 2019, the Netherlands had the fifth-highest greenhouse gas emission (GHG) per inhabitant in the European Union (Statistics Netherlands, 2019). Residential heating largely accounts for these high figures, with approximately 10% of Dutch GHG emissions (PBL, 2019). A vast majority of households currently rely on natural gas for residential heating (Gerdes et al., 2016). Multiple sustainable heating systems are available to replace current natural gas heating. These include hydrogen networks (Klip, 2017), combinations of photovoltaics, batteries, and heat pumps in houses (Litjens et al., 2018), and sustainable district heating (Persson and Werner, 2011). However, it is unclear whether these systems are socially acceptable. Most sustainable heating systems may require significant financial efforts from households (Hers et al., 2018) and sacrifices in terms of in-home thermal comfort. It is uncertain whether households in city districts will be willing to commit to such investments and purchase heat above the market price.

The social acceptance of sustainable heating systems for city districts is difficult to assess ex ante but can be addressed by specifying design requirements and policy guidelines to cope with households' concerns in the city district. These design requirements and policy guidelines should preferably be specified during the planning phase (i.e. ex ante) (Künneke et al., 2015, Taebi et al., 2014). Later changes, such as replacing parts of the existing physical infrastructure or renegotiating contracts with suppliers and consumers, may result in significant additional costs. However, a potential future lack of social acceptance is difficult to anticipate. Future household decisions to protest or not to support the sustainable heating system are difficult to predict as they result from partial information sets and interactions with social networks (Rai and Robinson, 2015). As a result, there is often a mismatch between the perceived social acceptance during the planning phase and the actual social acceptance during the deployment and operational phases (Hai et al., 2017, Wolsink, 2007a).

This chapter introduces an approach to assess, ex ante, the social acceptance of sustainable heating systems in city districts by addressing value conflicts embedded in heating systems. These value conflicts can be addressed in the planning phase before they materialise into a lack of social acceptance. Our approach consists of two steps. First, we identify value conflicts embedded in sustainable heating systems using an agent-based model (Epstein and Axtell, 1996). Such a model is well suited to simulate the effects of heterogeneous characteristics of households and housing on emergent system features (i.e. value conflicts) (Rahmandad and Sterman, 2008). Second, we evaluate the impact of identified value conflicts on social acceptance by identifying scenarios of value change (van de Poel, 2018b). Value change could lead to a mismatch between values prioritised in sustainable heating systems and those prioritised in society. This mismatch may result in a lack of social acceptance. Our research question is the following: *How can we assess ex ante the social acceptance of household sustainable heating systems at the city district level by addressing value conflicts?*

This chapter is structured as follows. Section 6.2 describes the challenges of assessing the social acceptance of sustainable heating systems for city districts. In Section 6.3, we suggest an approach to anticipate social acceptance by addressing value conflicts embedded in sustainable heating systems. In Section 6.4, we describe the methods, case and the model used to identify value conflicts in sustainable heating systems. Section 6.4.5 presents model results and evaluates which sustainable heating systems would be more suitable with regard to social acceptance. Conclusions, policy implications, and suggestions for future research are discussed in Section 6.5.

6.2. THEORY: SUSTAINABLE HEATING SYSTEMS AND SOCIAL ACCEPTANCE

Multiple sustainable systems exist to replace residential natural gas heating in the Netherlands. These systems rely on renewable energy sources or waste heat. Renewable sources include renewable gas (Jensen et al., 2020), solar collectors (Perez-Mora et al., 2018), geothermal heat (Self et al., 2013), and green electricity (Poppi et al., 2018). Combinations of different sources are often used to ensure a better match between heat supply and demand (e.g. Emmi et al. (2017), Khalid et al. (2016), Litjens et al. (2018)). Waste heat can be extracted from industries using high temperature processes and producing large energy outputs, such has electricity power plants and waste incinerators (Klinghoffer and Castaldi, 2013, Sarkar and Bhattacharyya, 2012, Werner, 2017). Sustainable heating systems can be implemented at various levels. At the national level, hydrogen produced using renewable electricity could replace natural gas supply (Kampman, 2019, Meibom and Karlsson, 2010). At the city district level, district heating systems can be built. Such systems (re-)use local heat resources to serve local heating demand (Werner, 2017). At the household level, households can complement existing heat supply with residential heat pumps (Petrović and Karlsson, 2016). Depending on the level of implementation, ownership, and control may vary among private and public companies, public organisations, individual households, and community cooperatives and collectives (Warbroek et al., 2019, Zeman and Werner, 2004).

Multiple challenges exist in replacing residential natural gas heating with more sustainable systems. At the technical level, the current heating infrastructure may require considerable adjustments (Li et al., 2017, Lund et al., 2014, Werner, 2017). At the regulatory level, existing regulations regarding heat trading and pricing often need to be adjusted to accommodate for new governance models (Schilling et al., 2017, Warbroek et al., 2019). At the financial level, arrangements are needed to cope with the typically high sunk costs of new heating infrastructures (Blom, 2017). An additional challenge is the potential lack of social acceptance of sustainable heating systems by households.

Social acceptance conveys both the more passive notion of accepting the technology (i.e. not resisting its deployment) and the more active notion in terms of support and adoption of technologies (Batel et al., 2013). Sustainable heating systems may have significant drawbacks for households, which may result in a lack of social acceptance. In the Netherlands, the replacement of natural gas heating by CO2 neutral systems will add on average €1000 of heating costs per household per year (Hers et al., 2018). Sustainable heating systems may change levels of in-home thermal comfort (insufficient radiant heat and humidity issues), mostly for households living in older houses (Hernández, 2015). Social tensions may arise, for example between households having access to lower heating costs and others without this access (Hers et al., 2018). Due to these drawbacks, households may decide not to purchase or not to use the required heating appliances

(Sauter and Watson, 2007, Sovacool et al., 2019). They may also decide to compensate for the loss of thermal comfort in a non-sustainable manner (Aydin et al., 2017, Hong et al., 2006, Seebauer, 2018). Ultimately, overall heating costs may increase, and issues of energy poverty may appear (Hast et al., 2018, Reames, 2016b).

The potential lack of social acceptance of sustainable heating systems can be addressed by specifying design requirements and policy guidelines ex ante. For example, subsidies can be provided to make heating appliances more affordable (Hers et al., 2018). Heating systems can be chosen that offer a better balance between environmental sustainability and in-home thermal comfort in city districts with poorly thermally insulated houses. Specifying design requirements and policy guidelines to support social acceptance requires anticipating future households' decisions not to accept sustainable heating systems. This information can be used to adjust the system adequately.

The difficulty is that households' decisions not to accept sustainable heating systems are highly uncertain and difficult to predict. We identify two reasons why social acceptance is difficult to predict. First, it is often difficult to assess the exact impact of sustainable heating systems on households. The suitability of these systems is dependent on the "geographical assemblage of networked materialities and socioeconomic relations" (Harrison and Popke, 2011) that characterises city districts. Effective technical solutions depend on local characteristics in terms of housing, geographic location, and existing infrastructure (Millar et al., 2019, Reames, 2016b, Schilling et al., 2019, Werner, 2017). Second, even if project developers were to know the exact impact of sustainable heating systems, the perception of these impacts by households and therefore their acceptance is often highly unpredictable. Household perception depends on a range of intertwined factors. These include psychological factors such as awareness, motivation, knowledge, and social networks (Huijts et al., 2012, Niamir et al., 2018, Rai and Robinson, 2015, Stigka et al., 2014). Perception might change over time as households learn from using the heating system (Niamir et al., 2018) but also due to other exogenous societal changes (e.g. economic, social, and technological developments).

The difficulty of anticipating social acceptance means that there is often a discrepancy between the perceived social acceptance during the planning phase and the revealed social acceptance during the deployment and operation phases of energy systems (Eltham et al., 2008, Wolsink, 2007b). As a result, specified design requirements and policy guidelines to support social acceptance are not effective.

6.3. PROPOSED APPROACH

In this section, we propose an alternative approach to anticipate the social acceptance of sustainable heating systems. The approach entails identifying value conflicts embedded in heating systems (i.e. risks or a future lack of social acceptance) and understanding which scenarios of value change could result in a lack of social acceptance.

Designing regulatory and technological systems often requires coping with value conflicts. Values can be defined as "lasting convictions or matters that people feel should be strived for in general and not just for themselves to be able to lead a good life or realise a good society" (van de Poel and Royakkers, 2011). Examples of values are *privacy*, *autonomy* (Friedman et al., 2006), and *security* (Schwartz, 2012). Technologies are 'value-laden' (Verbeek, 2011, Winner, 1980): they are often designed to achieve certain values, but the realisation of these values often jeopardise the realisation of others. For example, the smart meter was deployed to achieve *reliability* in electricity supply (Jackson, 2014). However, *reliability* is supported by using household consumption data, which means this value is in conflict with the value *privacy*. Another example of a value conflict in energy systems is *environmental sustainability* versus *landscape authenticity* in the deployment of industrial wind farms (Söderholm and Pettersson, 2011) where the general public is prioritised over local communities (Wüstenhagen et al., 2007).

The fact that regulatory and technological systems embed value conflicts means that they are prone to a lack of social acceptance. When two values are in conflict for the realisation of a system, its deployment inherently requires balancing the values, which often means favouring one value over the other (for example, *reliability* was favoured over *privacy* in the case of the smart meter). At different moments during the planning, deployment, and operation phase of these systems, societal groups that feel negatively affected by disfavoured values may undertake actions in defence of their values. This includes public protests, political movements, or a lack of adoption of technologies. During the planning phase, local communities may, for example, voice their concerns during public consultation procedures (Wolsink, 2007a). During the deployment and operational phase, consumers may refuse to invest in or use appliances on which the system depends (Sauter and Watson, 2007). Besides a lack of fulfilment of values, factors contributing to a (perceivable) lack of social acceptance include perceived usefulness, perceived ease of use, attitudes and intentions (Davis, 1989).

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The consequences of value conflicts on a future lack of social acceptance can be anticipated by identifying scenarios of value change. Value change refers to changing prioritisations among values over time (van de Poel, 2018b). While the deployment of the system inherently crystallises a prioritisation between two conflicting values, the societal desired prioritisation of values may change over time. An example is *environmental sustainability* versus *affordability* in the current energy transition (Rösch et al., 2017, Shortall and Davidsdottir, 2017). Although consumers may initially have agreed to pay higher heating prices (*affordability*) to support sustainable initiatives (*environmental sustainability*), preferences could change as a result of an economic recession. An economic recession is an example of a scenario of value change that could result in a lack of social acceptance. Others include technological innovations and political movements. The occurrence of such scenarios of value change may endanger the financial viability of sustainable heating systems.

The proposed approach is different than a typical one which aims to predict households' decisions (see Section 6.2). Factors related to household decision-making (e.g. attitudes, intentions, availability of information) are not included in our analysis. Rather, we assess conflicting opportunities for households to realise their values. More affluent households, for example, could choose to invest in sustainable heating systems and become more *environmentally sustainable*, but this decision might affect the *inclusiveness* of the less affluent ones. Factors affecting these opportunities are the socioeconomic and housing characteristics of households (i.e. their living conditions).

Although addressing value conflicts might not allow us to exactly predict future acceptance (which is challenging in the case of sustainable heating systems in any approach), it can help to identify potential risks and understand when these risks can become problematic. This information will help to further specify design requirements and policy guidelines ex ante in support of future social acceptance.

6.4. METHODS, CASE, AND MODEL DESCRIPTION

This section presents the methods, the case, and the model used to identify value conflicts embedded in sustainable heating systems for city districts. Section 6.4.1 presents the two methods used to identify value conflicts embedded in heating systems: agent-based modelling and the scenario discovery technique. Section 6.4.2 introduces the community-driven heating initiative in 'de Vruchtenbuurt' which is used as a case. Section 6.4.3 explains the model conceptualisation and Section 6.4.4 describes the model specification.

6.4.1. METHODS

We use agent-based modelling and the scenario discovery technique to identify value conflicts in sustainable heating systems for city districts. We introduce both methods in Section 6.4.1 and Section 6.4.1 respectively, and argue why they were selected given the research objective.

AGENT-BASED MODELLING (ABM)

ABM is a simulation technique originating from the field of complexity science (Bankes et al., 2002). It is used to capture emergent phenomena in social systems (Bonabeau, 2002). In an ABM, entities that are part of the social system (e.g. individuals, households) are modelled as a set of heterogeneous and autonomous software agents who pursue predefined individual goals by performing a set of actions. The fact that agents are interdependent in the achievement of their goals means that they act and react to each other. The sequence of actions performed by agents can lead to an emergent system behaviour that is not explicitly engraved in the conceptualisation of the model.

We use ABM to identify value conflicts embedded in heating systems. Multiple techniques exist to simulate the behaviour of social systems. These include computable general equilibrium (Ronald W. Jones, 1965), system dynamics (Forrester, 1958), discrete event simulation (Gordon, 1981), and agent-based modelling (Epstein and Axtell, 1996). ABM is a suitable technique to identify value conflicts because they are emergent phenomena that result from the heterogeneous characteristics and interactions between households. For example, a conflict between the values environmental sustainability and inclusiveness occurs when there is a group of households that can afford the sustainable heating system and can become more sustainable, and a group that cannot (heterogeneity). This conflict occurs as a result of actions from some households (e.g. the decision to opt for sustainable heating systems), which in turn affects other households (interactions).

THE SCENARIO DISCOVERY TECHNIQUE

Different sustainable heating systems may embed various value conflicts. For example, some sustainable heating systems may be more affordable, and therefore there is no conflict between *affordability* and *environmental sustainability*. These systems might be more suitable in poorer city districts. Other designs might be less *affordable* but perform better in terms of *environmental sustainability*. These systems could be suitable in wealthier city districts. By comparing sustainable heating systems based on their embedded value conflicts, we can evaluate which systems are suitable for a specific city district in terms of social acceptance.

The scenario discovery technique is useful in combination with the agent-based model to systematically classify which value conflicts are embedded in different sustainable heating systems. The scenario discovery technique (Bryant and Lempert, 2010) is an application of Exploratory Modelling and Analysis (Bankes, 1993) and is instrumental in classifying value conflicts that are embedded in sustainable heating systems. It can systematically classify which combination of model input parameters (scenarios) in a series of model runs leads to a particular outcome (Kwakkel et al., 2013). In our work, combinations of model input parameters are sustainable heating systems. The outcomes of interest are the value conflicts that the agent-based model can find.

6.4.2. INTRODUCTION TO THE COMMUNITY DRIVEN HEATING INITIATIVE IN 'DE VRUCHTENBUURT'

We demonstrate the approach to assess, ex ante, the social acceptance of heating systems by using a case of community driven heating initiative in a city district named 'de Vruchtenbuurt' (in English 'the fruit neighbourhood') in The Hague, the Netherlands. The use of a case is needed because the occurrence of value conflicts in city districts is not generic but results from the characteristics in terms of households and housing (de Wildt et al., 2020b).

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In 'de Vruchtenbuurt', the majority of houses are currently heated by natural gas from the national grid. In 2015, a group of citizens created an initiative named 'Warm in de Wijk' (Coöperatie Duurzame Vruchtenbuurt U.A., 2017) to find and deploy a more sustainable system than natural gas heating. The citizens' initiative is considering multiple sustainable heating systems, which are described in Section 6.4.4. It is however unclear which systems are more suitable given the characteristics of the city district in terms of households and housing.

We choose this case for two reasons. First, there is a societal need for research since members of the heating initiative are currently discussing different heating systems. Long term commitment from participating households is essential but can be uncertain over time. Second, the case is typical for many city districts in the Netherlands in terms of city district characteristics and feasible heating systems. A high percentage of houses were built post-1945 (IF Technology, 2018). Most houses in this city district are poorly, or not, thermally insulated (EnergieAtlas, 2019). 80.2% of households are home-owners (The Hague, 2019).

6.4.3. MODEL CONCEPTUALISATION

In this work, we build on the model published by de Wildt et al. (2020b). This model showed how capability conflicts can be identified using an agent-based model. We extend and refine the model to identify value conflicts in a spatially explicit model, with realistic (non-random) heterogenous households. This newly created agent-based model visualises 'de Vruchtenbuurt' and its households. The households are modelled as 'agents'.

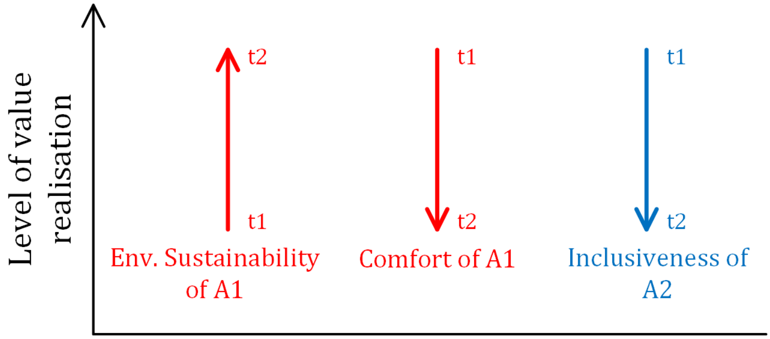

Figure 6.1: Example of value conflicts created as a result of switching to sustainable heating by household A1 on itself and on household A2

They have characteristics including annual disposable income, heat consumption, type of household, energy label, and housing surface area.

To identify embedded value conflicts, households in the model make choices to satisfy their values[1]. These choices are: (1) use (or continue to use) the sustainable heating option evaluated in the model or (2) use (or continue to use) traditional natural gas heating. For example, choosing traditional natural gas heating might be more beneficial in terms of *affordability*. This might not be the case for every household. The realisation of some values may conflict with other values. An example is provided in Figure 6.1. To realise *environmental sustainability*, household A1 might decide to switch from natural gas to sustainable heating. This decision might lead to a loss in-home *thermal comfort* if the house is poorly insulated. Hence, *environmental sustainability* and thermal comfort are in conflict for this household. Moreover, the realisation of *environmental sustainability* by household A1 may affect household A2. Household A2 might not have sufficient income to switch to sustainable heating. If most of A2's neighbours switch to sustainable heating, household A2's *inclusiveness* could decrease. The realisation of *environmental sustainability* by household A1 is therefore in conflict with the realisation of *inclusiveness* by household A2.

The model runs until an equilibrium is reached. This means that no agents are able to realise their values further. At the end of the model run, we identify whether a particular value increases or decreases for each agent.

The model was implemented in Netlogo (Wilensky, 1999) and is available using the following link (*link will be disclosed after review*). The full model description can be found in Appendix D.5, following the ODD+D (Overview, Design Concepts and Details + Decision) protocol (Müller et al., 2013). We use the 'evaludation method' of Augusiak et al. (2014) to verify and validate the model. The scenario discovery experiment is performed using PyNetLogo (Jaxa-Rozen and Kwakkel, 2018). Section 6.4.4 describes the model specifications.

[1] This is a way to identify value conflicts in the agent-based model. We do not claim that this is what households actually do.

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6.4.4. MODEL SPECIFICATION

The data collected for the case introduced in Section 6.4.2 consist of (1) values and their conceptualisation for 'de Vruchtenbuurt', (2) the sustainable heating systems considered by the community-driven heating initiative, and (3) the housing and household data in 'de Vruchtenbuurt'. In this section, we present this data and explain how it was collected.

VALUES

We conducted expert interviews to identify relevant values and their conceptualisation for the city district. Our rationale for performing expert interviews instead of household surveys is that we need to anticipate potential negative impacts of sustainable heating systems ex ante. Households may have limited knowledge about the characteristics of different heating options. Therefore, the importance of some values may only become apparent when households actually face specific negative impacts. Experts with different backgrounds and with specific knowledge about the city district have a clearer understanding of these systems and can provide a richer overview of the risks associated with heating systems even if they are not perceivable yet.

Appendix D.1 gives a detailed overview of our interviewees. We interviewed experts from a range of organisations: the Dutch Ministry of Economic Affairs and Climate Policy, the municipality of The Hague, the Netherlands Enterprise Agency, TNO, the Netherlands Organisation for applied scientific research, Stedin, the local distribution network operator, and 'Warm in de Wijk', a citizens' initiative. These interviews provided a complete overview of the suitability of the heating systems, the social aspects related to their deployment and utilisation, and the specific characteristics of 'de Vruchtenbuurt' in terms of households and housing.

Interviews were conducted in two rounds. First, we made a list of values based on five articles addressing values in the energy sector (Demski et al., 2015, Künneke et al., 2015, Ligtvoet et al., 2015, Milchram et al., 2018a, 2019). We discussed this list with the interviewees and asked them to select the values they thought should be taken into account when switching to a new heating system in 'de Vruchtenbuurt'. We also asked them which characteristics of households and housing could influence the realisation of these values taking into consideration the specific characteristics of the heating systems. The first round resulted in a list of relevant values for 'de Vruchtenbuurt' with a definition for each value and a corresponding empirical conceptualisation. These were verified in a second round with four policymakers specialised in energy at the ministerial level and one local initiator of the project in 'de Vruchtenbuurt'. Appendix D.2 includes the list of interview questions.

We identified the following five values: *thermal comfort*, *affordability*, *environmental sustainability*, *autonomy*, and *inclusiveness* (see Table 6.1). The conceptualisation of these values can be found in the ODD+D (Müller et al., 2013) model description in Appendix D.5.

SUSTAINABLE HEATING SYSTEMS

The sustainable heating systems considered were obtained by consulting documents shared by the 'Duurzame Vruchtenbuurt U.A.' cooperative, the initiators of the project. Further technical data (e.g. efficiency of various technologies) and financial data for

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Table 6.1: Values identified for 'de Vruchtenbuurt' case

Values	Definition
Comfort	The extent to which households receive the appropriate level of heating to ensure sufficient well-being. well-being.
Affordability	The extent to which households spend a reasonable amount of their disposable income on the heating and the purchase of heating related appliances.
Environmental sustainability	The extent to which households have a limited impact on the ecosystem.
Autonomy	The extent to which households can choose their preferred heating consumption.
Inclusiveness	The extent to which households can engage in common activities.

these systems and thermal insulation were taken from a range of reports from research institutions (Appendix D.4).

Table 6.2 lists the sustainable heating systems considered by the initiative. These systems were developed by the citizens' initiative and an engineering company named IF Technology. The first type is a 70°C district heating system. Possible heat sources are waste heat from industries located in the port of Rotterdam or collective thermal heat (55°C heat) from a geothermal plant and a collective heat pump. However, this would mean installing a new heat network in the district. A heat exchanger would replace gas boilers in households. Improved housing thermal insulation is not strictly required but advised to maintain similar levels of thermal comfort. The second type, a 40°C district heating system, is similar and could use the same geothermal plant. However, this would require significant adjustments to homes. Individual heat pumps or electric boilers would be needed to top up the heat to 60°C. Standard radiators would have to be replaced by low-temperature ones or by floor heating. Houses would have to be thermally insulated (i.e. floor, roof, HR++ windows). The third type, the all-electric system, leaves more room for individual preferences: heat pumps, electric boilers, or a combination of heat sources. However, it would also require major adjustments to homes, similar to those mentioned above.

HOUSEHOLD AND HOUSING DATA

The characteristics of households and housing influence the suitability of heating systems. Housing data include the energy label, and the type and square meter surface of the housing. We collected energy labels from the Dutch National Energy Atlas website (EnergieAtlas, 2019). We identified three types of housing (single-family houses, duplexes, and flats) using Google Maps. The surface of houses was taken from a feasibility study for city district heating made by IF Technology (IF Technology, 2018).

Household data includes annual disposable income, the type of household, the type of electricity consumed (green or grey), the type of ownership, and heat consumption. This data is only available at the city district and city level on the statistics website 'Den Haag in Cijfers' (The Hague, 2019), Statistics Netherlands (CBS, 2019), and the Dutch Authority for Consumers & Markets (ACM, 2017). We distributed this data over individual households by using correlations between these attributes in the literature (MBZK, 2019). In case no correlations were found, we distributed the data randomly. Using the scenario discovery technique (see Section 6.4.1), we ran the model multiple times

Table 6.2: Sustainable heating systems considered in 'de Vruchtenbuurt', The Hague

Type of heating system	Subtype	Central / common heat source	Heat transport	Individual heat source	Additional house adjustments
70°C district heating system	1.1	Waste heat	New heat network		- Heat exchanger - Thermal insulation to energy label C
	1.2	Collective geothermal heat	New heat network	Collective heat pumps	- Heat exchanger - Thermal insulation to energy label C
40°C district heating system	2.1	Collective geothermal heat	New heat network	Individual heat pumps	- Heat exchanger - Replacement of radiators or floor heating - Thermal insulation to energy label A
	2.2	Collective geothermal heat	New heat network	Electric boilers	- Heat exchanger - Thermal insulation to energy label A
All-electric heating system	3.1			Individual heat pumps	- Replacement of radiators or floor heating - Thermal insulation to energy label A
	3.2			Electric boilers	- Thermal insulation to energy label A
	3.3			Individual heat pumps and electric boilers	- Thermal insulation to energy label C

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to compensate for this randomness.

Appendix D.4 provides a detailed overview of household and housing data, including the sources of these data. Appendix D.5 gives an overview of how these data relate to the realisation of values by households in the ODD+D model.

6.4.5. RESULTS

Table 6.3 gives an overview of the identified value conflicts embedded in the heating systems. The columns show the system types and subtypes, and the rows show all combinations between two values. We test different funding options for each type of system on their ability to resolve value conflicts. We test two common financial instruments for energy efficiency measures (zero-interest loans (L) and subsidies (S)). These two financial instruments were selected because they are commonly used to support the adoption of energy-efficient technologies (Hesselink and Chappin, 2019). Systems without financial support are also tested (no support (N)). The data and colours at the intersections between heating systems and the combination of two values are indicators of whether these values conflict. For each type of system, the model was run multiple times due to stochastic uncertainty resulting from the order of actions between agents (see Briggs et al. (2012). A '0' (green) means that the combination of two values was never found to be in conflict in any of the model runs made in the scenario discovery experiment. '0.7' (orange) means that the combination of two values was found to be in conflict in 70% of model runs. In this section, we discuss value conflicts identified per system type. Due to their high number, we have combined value conflicts in groups if they affected the same types of households.

70°C DISTRICT HEATING SYSTEMS

Group 1 conflict: Environmental Sustainability and Autonomy vs. Thermal Comfort (with an increase in thermal comfort for some households)

This group of value conflicts is embedded in the 70°C district heating system. It occurs in geothermal systems combined with heat pumps (1.2). Households can become more *sustainable* and *autonomous* by choosing this system, but their *thermal comfort* might decrease due to the use of heat pumps. The maximum temperature that can be generated is limited if these pumps are not combined with a high-temperature heat source (e.g. an electric boiler). This would affect the lowest income households and those living in houses with low energy labels who may not be able to afford thermal insulation (see Table 6.4).

Group 2 conflict: Environmental Sustainability and Autonomy vs. Affordability (with an increase in affordability for some households)

This group of value conflicts occurs in the 70°C district heating system, both with waste heat (1.1) and in geothermal systems combined with collective heat pumps (1.2). *Affordability* may decrease for lower-income households switching to these systems (see Table 6.5) as adjustments to housing (changes to the heating system and thermal insulation) may not be affordable. *Affordability* also decreases in households with low heat consumption, such as single-person households but increases in high-income households and those with high heat demand (couples with children and those living in houses). For

Table 6.3: Overview of value conflicts per system type and subtype (abbreviations are described in the legend)

Sustainable heating systems			70°C district heating																	
Subtype			*1.1*									*1.2*								
Heat source 1			**Waste heat**									**Collective goethermal heat**								
Ownership			External party									External party								
Financial support			N									N								
Heat source 2												**Collective heat pumps**								
Ownership												Cooperative								
Financial support												S	S	S	L	L	L	N	N	N
Required changes in houses			**Heat exchanger**									**Heat exchanger**								
Financial support			S	S	S	L	L	L	N	N	N	S	S	S	L	L	L	N	N	N
Advised thermal insulation			**Energy label C**									**Energy label C**								
Financial support			S	L	N	S	L	N	S	L	N	S	L	N	S	L	N	S	L	N
Comfort	vs.	Comfort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Comfort	vs.	Affordability	0.3	0	0.8	0.2	0	0.8	0.5	0	0.8	0.3	0.1	0.4	0.4	0.1	0.6	0.3	0.2	0.4
Comfort	vs.	Env. Sustainability	0	0	0	0	0	0	0	0	0	0.3	0.1	0.4	0.4	0.1	0.6	0.3	0.2	0.4
Comfort	vs.	Autonomy	0.1	0.1	0.3	0.3	0.1	0.2	0.3	0.2	0.1	0	0	0	0	0	0	0	0	0
Comfort	vs.	Inclusiveness	1	0.9	0.9	1	1	0.9	0.9	0.9	0.9	0.3	0.1	0.4	0.3	0.1	0.6	0.3	0.1	0.4
Affordability	vs.	Affordability	0.3	0	0.8	0.2	0	0.8	0.5	0	0.8	0.4	0.1	0.7	0.2	0.1	0.7	0.5	0.1	0.6
Affordability	vs.	Env. Sustainability	0.3	0	0.8	0.2	0	0.8	0.5	0	0.9	0.4	0.1	0.8	0.3	0.1	0.7	0.6	0.3	0.8
Affordability	vs.	Autonomy	0.1	0.1	0.3	0.3	0.1	0.2	0.3	0.3	0.2	0.1	0.3	0.2	0.1	0.1	0.3	0.2	0.1	0.1
Affordability	vs.	Inclusiveness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Env. Sustainability	vs.	Env. Sustainability	0	0	0	0	0	0	0	0	0	0.1	0	0.1	0	0	0	0.1	0.1	0.2
Env. Sustainability	vs.	Autonomy	0.1	0.1	0.3	0.3	0.1	0.2	0.3	0.3	0.2	0.1	0.3	0.2	0.1	0.1	0.3	0.2	0.1	0.1
Env. Sustainability	vs.	Inclusiveness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Autonomy	vs.	Autonomy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Autonomy	vs.	Inclusiveness	0.1	0.1	0.3	0.3	0.1	0.2	0.3	0.3	0.2	0.1	0.3	0.2	0.1	0.1	0.3	0.2	0.1	0.1
Inclusiveness	vs.	Inclusiveness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Sustainable heating systems			40°C district heating																	
Subtype			*2.1*									*2.2*								
Heat source 1			**Collective goethermal heat**									**Collective goethermal heat**								
Ownership			External party									External party								
Financial support			N									N								
Heat source 2			**Individual heat pumps**									**Electric boiler**								
Ownership			Individual households									Individual households								
Financial support			S	S	S	L	L	L	N	N	N	S	S	S	L	L	L	N	N	N
Required changes in houses			**Heat exch. + rad. + fl. heating**									**Heat exchanger**								
Financial support			S	S	S	L	L	L	N	N	N	S	S	S	L	L	L	N	N	N
Advised thermal insulation			**Energy label A**									**Energy label A**								
Financial support			S	L	N	S	L	N	S	L	N	S	L	N	S	L	N	S	L	N
Comfort	vs.	Comfort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Comfort	vs.	Affordability	0.1	0	0.2	0.1	0	0.3	0	0	0.1	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.5	0.3
Comfort	vs.	Env. Sustainability	0.1	0	0.4	0.2	0	0.4	0.1	0	0.2	0.1	0.1	0.1	0.1	0.1	0	0.1	0.1	0
Comfort	vs.	Autonomy	0.1	0	0	0	0	0.1	0	0	0	0.2	0.1	0.2	0.2	0.3	0.2	0.1	0.1	0.1
Comfort	vs.	Inclusiveness	0.1	0	0.3	0.1	0	0.4	0.1	0	0.2	0.5	0.7	0.4	0.6	0.7	0.4	0.5	0.6	0.3
Affordability	vs.	Affordability	0.3	0.5	0.1	0.4	0.1	0.1	0.2	0.5	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Affordability	vs.	Env. Sustainability	0.6	0.6	0.8	0.6	0.2	0.9	0.8	0.8	0.9	0.8	0.9	0.9	0.9	0.9	0.8	0.8	0.9	0.8
Affordability	vs.	Autonomy	0.2	0.3	0.1	0.1	0.3	0.1	0.1	0.2	0.1	0.2	0	0.1	0.2	0.2	0.2	0.2	0.1	0.2
Affordability	vs.	Inclusiveness	0.9	1	0.9	1	0.9	1	0.8	0.9	0.9	0.6	0.7	0.5	0.7	0.8	0.6	0.6	0.7	0.5
Env. Sustainability	vs.	Env. Sustainability	0.2	0.1	0.3	0.1	0.1	0.2	0.3	0.3	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Env. Sustainability	vs.	Autonomy	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.4	0.3	0.1	0.2	0.3	0.4	0.3	0.2	0.1	0.2
Env. Sustainability	vs.	Inclusiveness	1	1	1	1	1	1	0.9	1	0.9	0.8	0.9	0.9	0.9	0.9	0.8	0.8	0.9	0.8
Autonomy	vs.	Autonomy	0.1	0.1	0	0	0.1	0	0.1	0.1	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	0	0.2
Autonomy	vs.	Inclusiveness	0.4	0.3	0.2	0.2	0.4	0.3	0.2	0.2	0.4	0.3	0.1	0.2	0.3	0.4	0.3	0.3	0.2	0.2
Inclusiveness	vs.	Inclusiveness	1	1	0.9	1	1	0.9	0.9	0.9	0.9	0.6	0.7	0.5	0.7	0.8	0.6	0.6	0.7	0.5

Sustainable heating systems			All electric																									
Subtype			*3.1*									*3.2*									*3.3*								
Heat source 1			**Individual heat pump**									**Electric boiler**									**Individual heat pump**								
Ownership			Individual households									Individual households									Individual households								
Financial support			S	L	N	S	L	N	S	L	N	S	L	N	S	L	N	S	L	N	S	L	N	S	L	N	S	L	N
Heat source 2																					**Electric boiler**								
Ownership																					Individual households								
Financial support																					S	L	N	S	L	N	S	L	N
Required changes in houses			**Radiators + floor heating**																										
Financial support			S	L	N	S	L	N	S	L	N																		
Advised thermal insulation			**Energy label A**									**Energy label A**									**Energy label C**								
Financial support			S	L	N	N	S	L	L	N	S	S	L	N	N	S	L	L	N	S	S	L	N	N	S	L	L	N	S
Comfort	vs.	Comfort	0.2	0.2	0.1	0.1	0.3	0.2	0.2	0.1	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Comfort	vs.	Affordability	0.2	0.2	0.1	0.1	0.3	0.2	0.2	0.1	0.3	0	0.1	0	0	0	0.1	0	0	0	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.2
Comfort	vs.	Env. Sustainability	0.8	0.9	0.8	0.7	0.9	0.8	0.9	0.8	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Comfort	vs.	Autonomy	0.3	0.2	0.1	0.3	0.3	0.2	0.2	0.3	0.3	0	0	0	0	0	0	0	0	0	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1
Comfort	vs.	Inclusiveness	0.5	0.4	0.3	0.3	0.6	0.4	0.5	0.3	0.4	0	0.1	0	0	0	0.1	0	0	0	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.2
Affordability	vs.	Affordability	0.1	0.1	0.1	0.1	0	0.1	0.1	0.1	0.1	0	0.1	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Affordability	vs.	Env. Sustainability	0.8	0.9	0.8	0.7	0.9	0.8	0.9	0.8	0.8	0.5	0.7	0.6	0.6	0.5	0.7	0.5	0.6	0.6	0.8	0.8	0.6	0.8	0.8	0.7	0.8	0.7	0.7
Affordability	vs.	Autonomy	0.3	0.2	0.1	0.2	0.3	0.1	0.1	0.2	0.3	0.2	0.1	0.2	0.3	0.1	0.2	0.3	0.3	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.3	0.1	0.1
Affordability	vs.	Inclusiveness	0.5	0.4	0.3	0.3	0.6	0.4	0.4	0.3	0.4	0.1	0.3	0.1	0.2	0.2	0.3	0.2	0.2	0.2	0.4	0.5	0.4	0.4	0.5	0.5	0.4	0.4	0.4
Env. Sustainability	vs.	Env. Sustainability	0.2	0.2	0.1	0.2	0.3	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Env. Sustainability	vs.	Autonomy	0.3	0.3	0.1	0.2	0.4	0.1	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.1	0.2	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.1	0.4	0.3	0.1	0.2
Env. Sustainability	vs.	Inclusiveness	0.8	0.9	0.8	0.7	0.9	0.8	0.9	0.8	0.8	0.5	0.7	0.6	0.6	0.5	0.7	0.5	0.6	0.6	0.8	0.8	0.6	0.8	0.8	0.7	0.8	0.7	0.7
Autonomy	vs.	Autonomy	0.1	0.1	0	0.1	0.2	0	0.1	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Autonomy	vs.	Inclusiveness	0.4	0.3	0.1	0.3	0.5	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.1	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.4	0.4	0.2	0.2
Inclusiveness	vs.	Inclusiveness	0.5	0.4	0.3	0.3	0.6	0.4	0.4	0.3	0.4	0.1	0.3	0.1	0.2	0.2	0.3	0.2	0.2	0.2	0.4	0.5	0.4	0.4	0.5	0.5	0.4	0.4	0.4

Legend

Financial support

S = Subsidy
L = Zero percent loan
N = No support

Frequency of conflicts

0 Conflict found in 0% of model runs

0.5 Conflict found in 50% of model runs

1 Conflict found in 100% of model runs

Table 6.4: Environmental Sustainability and Autonomy vs. Thermal Comfort

Values in conflict	Households positively affected	Households negatively affected
- Environmental Sustainability **- Autonomy**	- Middle and high income - Middle and high demand - Living in single-family houses and duplexes	
	vs.	
- Thermal Comfort	- High income - Middle and high heat demand - Living in single-family houses	- Low and middle income - Low energy labels - Living in duplexes and flats - Often poorer households located close to richer households

Table 6.5: Environmental Sustainability and Autonomy vs. Affordability

Values in conflict	Households positively affected	Households negatively affected
- Environmental Sustainability **- Autonomy**	- Middle and high income - Middle and high heat demand - Living in single-family houses and duplexes	
	vs.	
- Affordability	- Middle and high income - Middle heat demand - Couples with children - Living in single-family houses	- Low and middle income - Low heat demand - Low energy label - Single-person households

Table 6.6: Thermal Comfort vs. Affordability

Values in conflict	Households positively affected	Households negatively affected
- Thermal Comfort	- High heat demand - Low energy label	
	vs.	
- Affordability	- High income - Living in single-family houses - Couples with children	- Low income - Low heat demand

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these households, new heating systems can substantially reduce heat consumption and thus energy costs.

Group 3 conflict: Thermal Comfort vs. Affordability (with an increase in affordability for some households)

This group of value conflicts exists in the 70°C district heating system, more specifically in geothermal systems combined with heat pumps (1.2). Switching to this type of heating improves thermal insulation, making houses more *comfortable*. However, these systems may be expensive. *Affordability* decreases for low-income households with low heat demand (see Table 6.6).

Group 4 conflict: Environmental Sustainability and Affordability vs. Inclusiveness (inclusiveness issues for lower-income households)

This group of value conflicts occurs in the 70°C district heating system, both in systems with waste heat (1.1) and in geothermal systems combined with collective heat pumps (1.2) and may create *inclusiveness* issues. Lower-income households may not be able to afford all the required appliances and thermal insulation. This is also the case for tenants who are dependent on landlords and housing corporations to change their heating system.

Figure 6.2 shows where issues of *inclusiveness* are concentrated in the 70°C district heating system. These occur in areas in the city district where some households switched to sustainable heating systems, whereas others, especially those with lower-incomes, still rely on natural gas heating due to either *affordability* issues or because they are tenants (see Table 6.7).

Distribution of households	**Inclusiveness issues**
Households with 70°C district heating systems = yellow dots *Households with natural gas heating = white dots*	*Households with high inclusiveness = green* *Households with medium inclusiveness = white* *Households with low inclusiveness = red*

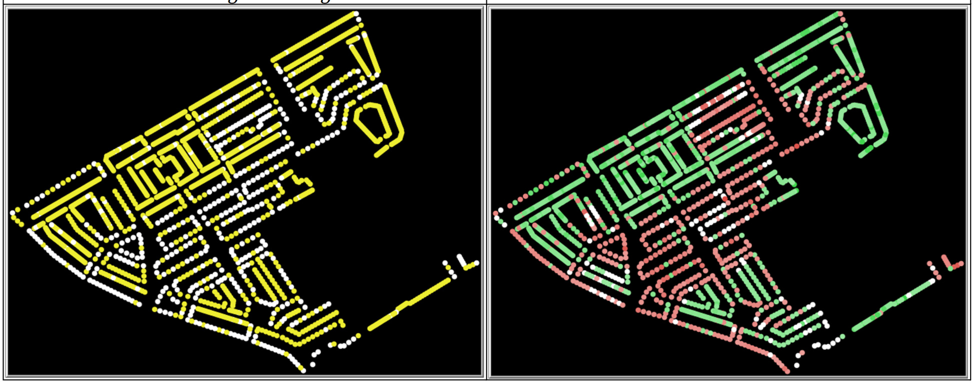

Figure 6.2: Household inclusiveness with 70°C district heating systems

Table 6.7: Environmental Sustainability and Autonomy vs. Inclusiveness

Values in conflict	**Households positively affected**	**Households negatively affected**
- Environmental Sustainability **- Affordability**	- Middle and high income - Middle and high demand - Living in single-family houses and duplexes	
	vs.	
- Inclusiveness	- Middle and high income - Middle and high heat demand - Living in single-family houses - Low and middle energy label	- Low and middle income - Low heat demand - Living in duplexes and flats - Tenants

Table 6.8: Environmental Sustainability and Autonomy vs. Affordability

Values in conflict	Households positively affected	Households negatively affected
- Environmental Sustainability **- Autonomy**	- Middle and high income - Low and middle demand - Middle and high energy label - Living in single-family houses	
	vs.	
- Affordability		- Middle and high income - Low and middle heat demand - Middle and high energy label - Living in single-family houses

40°C DISTRICT HEATING SYSTEMS

All groups of value conflicts found in the 70°C district heating system were also found in the 40°C district heating system. We identified a value conflict between *environmental sustainability* and *autonomy* versus *thermal comfort* (Group 1) in 2.1, due to the use of individual heat pumps. However, in these heating systems, the loss of *thermal comfort* is even greater than in the 70°C district heating systems. The value conflict between *environmental sustainability* and *autonomy* versus *affordability* (Group 2) also occurs in 2.1. Some households are negatively affected in terms of *affordability*, whereas others are positively affected. We also identified a value conflict between *thermal comfort* and *affordability* (Group 3). While *thermal comfort* may increase, heat *affordability* tends to decrease for lower-income households with low heat demand. We identified a value conflict between *environmental sustainability* and *autonomy* versus *inclusiveness* (Group 4). *Inclusiveness* issues are similar to those in the 70°C district heating system. An additional value conflict was found between *environmental sustainability* and *autonomy* versus *affordability* for the option with electric boilers (2.2) where households were affected differently.

Group 5 conflict: Environmental Sustainability and Autonomy vs. Affordability (no increase in affordability)

This group of value conflicts is embedded in 40°C district heating systems. While in Group 2 conflicts, some households have gains in terms of *affordability*, this is not the case here. Heating costs are higher due to the use of electric boilers. Hence, only high-income households, typically those living in single houses, tend to choose 40°C district heating systems (see Table 6.8). Although their *thermal comfort* increases due to better home thermal insulation, *affordability* decreases. Zero-interest loans and subsidies for thermal insulation can reduce *affordability* for houses with low energy labels.

ALL-ELECTRIC HEATING SYSTEMS

In the all-electric system, we found a value conflict between *environmental sustainability* and *autonomy* versus *affordability* (Group 5). These systems are relatively expensive and therefore only accessible for higher-income households. Although *thermal comfort* increases due to better insulation, heat *affordability* decreases. The following three new groups of value conflicts were found.

Group 6 conflicts: Environmental Sustainability and Autonomy vs. Thermal Comfort

Table 6.9: Environmental Sustainability and Autonomy vs. Thermal Comfort

Values in conflict	Households positively affected	Households negatively affected
- Environmental Sustainability - Autonomy	- High income - Middle and high demand - Living in single-family houses	
	vs.	
- Thermal Comfort		- High income - Middle and high heat demand - Living in single-family houses

Table 6.10: Thermal Comfort vs. Affordability

Values in conflict	Households positively affected	Households negatively affected
- Thermal Comfort	- Middle and high income - Middle and high heat demand - Low energy label	
	vs.	
- Affordability		- Middle and high income - Low and middle heat demand

(no increase in thermal comfort)

This group of value conflicts is embedded in electric heating systems with individual heat pumps (3.1). While in Group 1 conflicts, some households benefit in terms of *thermal comfort*, this is not the case here (see Table 6.9). Heating costs are relatively high, which explains why mostly high-income households choose this option. These households tend to live in single-family houses rather than in duplexes and flats.

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Group 7 conflicts: Thermal Comfort vs. Affordability (no increase in affordability)

This group of value conflicts is embedded in electric heating systems for households who rely on individual heat pumps and electric boilers (3.3). *Thermal comfort* increases due to the use of electric boilers and better thermal insulation. Compared to Group 3 conflicts, however, no households gain in terms of heat *affordability* (see Table 6.10).

Group 8 conflicts: Environmental Sustainability and Affordability vs. Inclusiveness (inclusiveness issues for higher-income households)

This group of value conflicts occurs in electric systems. Compared to Group 4 value conflicts, *inclusiveness* issues apply to higher instead of lower-income households (see Table 6.11). This is due to the relatively high costs of these systems, and hence their lack of *affordability*. *Inclusiveness* issues are concentrated in other areas in the city district (see Figure 6.3).

SUMMARY OF GROUPS OF VALUE CONFLICTS FOR THE THREE SUSTAINABLE HEATING SYSTEMS

In Table 6.12, we provide a summary of groups of value conflicts embedded in each heating option using the agent-based models. If a group of value conflicts was found to be embedded in a certain heating option, the corresponding cell is coloured red. In Section 6.4.6, value conflicts are analysed to evaluate their impact in terms of social acceptance.

Distribution of households	**Inclusiveness issues**
Households with electric heating systems = yellow dots *Households with natural gas heating systems = white dots*	*Households with high inclusiveness = green* *Households with medium inclusiveness = white* *Households with low inclusiveness = red*

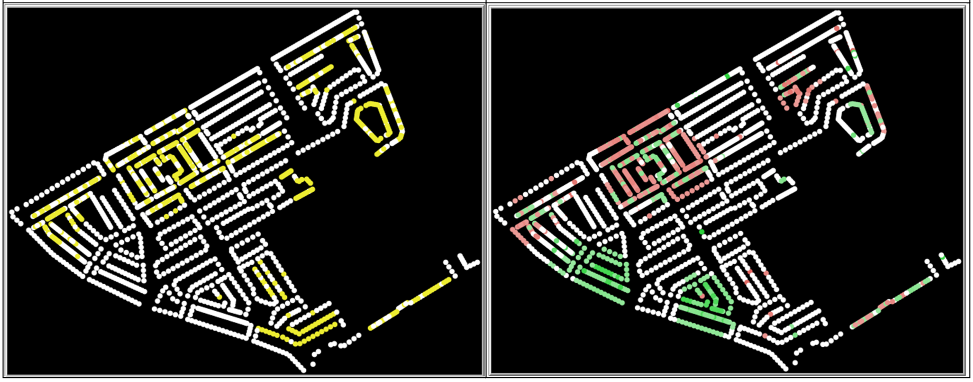

Figure 6.3: Inclusiveness issues in all-electric heating systems

Table 6.11: Environmental Sustainability and Autonomy vs. Inclusiveness

Values in conflict	Households positively affected	Households negatively affected
- Environmental Sustainability **- Affordability**	- Middle and high income - Middle and high heat demand - Middle and high energy label - Living in single-family houses and duplexes	
	vs.	
- Inclusiveness	- Middle and high income - Low and middle heat demand - Living in single-family houses	- Middle and high heat demand - Low and middle energy label

Table 6.12: Summary of value conflicts embedded in different heating systems (in red)

	Types of heating systems						
	70°C district heating systems		**40°C district heating systems**		**All electric heating systems**		
Subtypes	*1.1*	*1.2*	*2.1*	*2.2*	*3.1*	*3.2*	*3.3*
Group 1: *Environmental Sustainability* and *Autonomy* vs. *Comfort* (with increase in comfort for some households)							
Group 2: *Environmental Sustainability* and *Autonomy* vs. *Affordability* (with increase in affordability for some households)							
Group 3: *Comfort* vs. *Affordability* (with increase in affordability for some households)							
Group 4: *Environmental Sustainability* and *Affordability* vs. *Inclusiveness* (inclusiveness issues for lower income households)							
Group 5: *Environmental Sustainability* and *Autonomy* vs. *Affordability* (no increase in affordability)							
Group 6: *Environmental Sustainability* and *Autonomy* vs. *Comfort* (no increase in comfort)							
Group 7: *Comfort* vs. *Affordability* (no increase in affordability)							
Group 8: *Environmental Sustainability* and *Affordability* vs. *Inclusiveness* (inclusiveness issues for higher income households)							

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6.4.6. EVALUATION OF SUITABLE DISTRICT HEATING SYSTEMS FOR 'DE VRUCHTENBUURT'

In this section, we evaluate which sustainable heating systems are most suitable for 'de Vruchtenbuurt' with regard to social acceptance. To understand the impact of embedded value conflicts, we identify potential scenarios of value change that could result in a lack of social acceptance (see Section 6.3). This list of scenarios is illustrative and was developed with co-authors. Both scenarios of value change and resulting social acceptance issues are informative to estimate the severity of social acceptance issues.

Table 6.13 presents an overview of scenarios of value change that could lead to a lack of social acceptance for each group of value conflicts. In Group 1 and Group 6 value conflicts, households may realise over time that the loss of *thermal comfort* is greater than they initially expected. This may lead to protests against public authorities or to households choosing to top up their current heating with less sustainable heating sources (e.g. electric heaters powered by grey electricity). In Group 2 and Group 5 value conflicts, increasing electricity and heat prices may have serious consequences for low-income households that have switched to sustainable heating systems. Ultimately, socioeconomic inequalities may increase. For Group 3 and Group 5 value conflicts, investments to improve the energy labels of houses may not be reflected in house prices. Switching to sustainable heating systems may therefore involve significant financial risks. In Group 4 value conflicts, growing socioeconomic inequalities may further segregate income groups in city districts and result in tensions between households. In Group 8 value conflicts, households that have switched to sustainable heating systems may conclude that they are making too many sacrifices compared to the rest of the population.

In the 70°C district heating system, waste heat as the central heat source is more suitable as it involves the least amount of loss of in-home *thermal comfort*. Group 1 and Group 3 value conflicts do not occur for this subtype of heat system. Two value conflicts remain in this system. The conflict between *environmental sustainability* and *autonomy* versus *affordability* may be severe. For some households, costs related to thermal insulation and the purchase of new appliances may represent a high and risky investment. These households are also vulnerable to changing regulation on heat taxation. It is uncertain how dedicated households will remain if the costs of using this heating system increase. This conflict could be addressed by subsidies and other means of financial support, although costs for public organisations may be high. Financial support could be directed towards the more vulnerable households (low-income families living in poorly insulated houses). The value conflict between *environmental sustainability* and *affordability* versus *inclusiveness* (Group 4) is less severe because *affordability* issues are essentially for higher income populations. Still, the fact that only these populations are able to afford sustainable heating might contribute to a general feeling of growing socioeconomic segregation at the national level. Various social activities in support of social inclusion could be organised at the city district level, but it is unclear to what extent they can contribute to the *inclusiveness* of the energy transition.

The 40°C district heating system is clearly riskier in terms of in-home *thermal comfort* in 'de Vruchtenbuurt'. This is due to the relatively poor thermal insulation of houses. The use of electric boilers is more suitable as it can top up water heat to the same level as gas boilers. Three value conflicts exist in this system. The value conflict between

Table 6.13: Scenarios of value change and possible social acceptance issues

Groups of value conflicts	Possible scenarios leading to value change	Possible acceptance issues
Group 1: Environmental Sustainability and Autonomy vs. Thermal comfort (with an increase in thermal comfort for some households)	-Hype of switching to sustainable heating systems is over. People doubt whether the loss in thermal comfort was worth it. -Winters are colder than usual. -Planned thermal insulation work is more complicated than expected or even infeasible due to the characteristics of (old) houses.	-Lower home temperatures, leading to societal unrest and complaints to public authorities. -People look for alternative solutions: e.g. electric heaters, which are less sustainable if they use grey electricity. Grid might not be able to comply, leading to issues of security of supply. -Tensions between households that experience a loss of thermal comfort and those that do not.
Group 2: Environmental Sustainability and Autonomy vs. Affordability (with an increase in affordability for some households)	-Energy (heat or electricity) prices increase. -Heat is taxed at the same level as natural gas and electricity. -An economic recession occurs.	-Electricity bills increase, leading to societal unrest. -Socioeconomic inequalities in the city district increase. -Tensions between households that experience a loss of heating affordability and those that do not.
Group 3: Thermal comfort vs. Affordability (with an increase in affordability for some households)	-Real estate prices do not reflect investments in thermal insulation and other heating appliances. -An economic recession occurs.	-Houses become less attractive for potential buyers; sellers lose money. -The financial situation of poorer households worsens.
Group 4: Environmental Sustainability and Affordability vs. Inclusiveness (inclusiveness issues for lower income households)	-Growing socioeconomic inequalities -Deployment of other technologies (e.g. electric cars) further segregate high- & low-income households.	-Tensions between households living in single-family houses and those living in apartments in the city district.
Group 5: Environmental Sustainability and Autonomy vs. Affordability (no increase in affordability)	-Energy (heat or electricity) prices increase. -Heat is taxed at the same level as natural gas and electricity. -An economic recession occurs.	-Electricity bills increase, leading to societal unrest. -The overall wealth of the city district declines.
Group 6: Environmental Sustainability and Autonomy vs. Thermal comfort (no increase in thermal comfort)	-The hype of switching to sustainable heating options is over. People start to doubt that the loss in thermal comfort was worth it. -The winter is colder than usual. -Planned thermal insulation work appears to be more complicated than expected or even unfeasible due to characteristics of (old) house.	-Lower home temperatures, leading to societal unrest and complaints to public authorities. -People look for alternative solutions: e.g. electric heaters which are less sustainable if they use grey electricity. Grid might not be able to comply, leading to issues of security of supply.
Group 7: Thermal comfort vs. Affordability (no increase in affordability)	-House selling prices do not reflect investments in thermal insulation and other heating appliances. -An economic recession occurs	-Houses become less attractive for potential buyers; sellers lose money. -The wealth of the city district declines.
Group 8: Environmental Sustainability and Affordability vs. Inclusiveness (inclusiveness issues for higher income households)	-Households that have switched to sustainable heating systems feel they are make too much effort compared to rest of population.	-Households switch back to traditional forms of heating.

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thermal comfort and *affordability* (Group 3) is significant because this system requires households to purchase a large number of appliances and apply thorough thermal insulation. While insulation contributes to greater *thermal comfort*, costs may be high. However, this mostly concerns higher-income households since this heating system is probably not affordable for others. Similar to the 70°C district heating system, this heating system may lead to *inclusiveness* issues (Group 4). In addition to social activities, regulation could be changed to allow for inter-household sharing of heat and heating appliances. This could allow more households to have access to sustainable heating. The value conflicts between *environmental sustainability* and *autonomy* versus *affordability* mostly affects small households with relatively high incomes. Similar to Group 3 value conflicts, they can be addressed through subsidies. Information campaigns could provide information to households about investment risks.

In electric heating systems, using electric boilers is more suitable since it involves the fewest changes to houses besides thermal insulation. Electric boilers can also reach same heat levels as natural gas boilers. Two value conflicts exist in this system. The value conflict between *environmental sustainability* and *autonomy* versus *affordability* (Group 4) only affects high-income households. Changes in houses are limited to thermal insulation and the purchase of electric boilers. However, heating costs may increase considerably due to higher electricity consumption. Subsidies could support the thermal insulation of houses. The value conflict between *environmental sustainability* and *affordability* versus *inclusiveness* (Group 8) also mostly affects higher-income households. Policy measures could include the promotion of environmental benefits of electric boilers usage powered by green electricity. This could encourage households to pursue their efforts despite *inclusiveness* issues.

6.5. CONCLUSIONS AND POLICY IMPLICATIONS

6.5.1. CONCLUSIONS

This chapter answered the following research question: *How can we assess ex ante the social acceptance of household sustainable heating systems at the city district level by addressing value conflicts?* We took a two-step approach. First, we identified value conflicts embedded in sustainable heating systems using an agent-based model. Next, we identified scenarios of value change that could lead to a lack of social acceptance and evaluated the severity of resulting acceptance issues. This approach is useful for policymakers to select sustainable heating systems for city districts and to specify additional design requirements and policy guidelines. We demonstrated this approach using a case of community driven heating initiative in the city district 'de Vruchtenbuurt', in The Hague, the Netherlands.

The advantage of the approach proposed in this chapter is that we are able to identify the risks of future social acceptance in specific city districts even if the duration and complexity of the heating system project does not allow prediction of household (non-)acceptance. The agent-based model is capable of taking the specific characteristics of households in the city district into account and evaluate how these could affect future social acceptance. For example, in 'de Vruchtenbuurt', the relative geographical clustering in terms of income and type of housing is responsible for value conflicts involving *inclusiveness* (Groups 4 and 8). Taking specific characteristics of households into account is necessary because social acceptance of sustainable heating systems in other city districts does not necessarily guarantee social acceptance in 'de Vruchtenbuurt'.

Our work has three limitations. First, we do not address all possible sources of social acceptance. As indicated in Section 6.3, factors related to household decision-making (e.g. attitudes, intentions, availability of information) are not included in our analysis. These cannot be accurately predicted for the entire lifetime of installed sustainable heating systems. However, the impact of these factors is that social acceptance issues could occur even if no value conflicts exist, or inversely. Public participation procedures exist to address these factors in support of social acceptance (Pidgeon et al., 2014). Second, while the aim of this work is to support social acceptance, value conflicts also have implications in terms of social justice and fairness. Some of these issues may not result in a lack of social acceptance but might still be important for selecting more sustainable heating systems in city districts. Third, we did not identify value conflicts that can also occur between city districts. Issues of *inclusiveness* could occur between more or less affluent city districts, or because some sustainable heating systems are not suitable everywhere.

6.5.2. SCIENTIFIC CONTRIBUTIONS

We contribute to the academic literature on energy policy by demonstrating an approach to robustly support the social acceptance of energy systems in an uncertain future. The literature on the social appraisal of technologies can be divided among social psychology and behavioural science on one side, and ethics of technology on the other. The first tends to concentrate on the immediate appraisal of infrastructures by individuals. For example, the Technology Acceptance Model (Davis, 1989) considers the impact of perceived usefulness and perceived ease-of-use. While this could be sufficient to support social acceptance in the short term, this may not be sufficient for systems that are installed for several decades. This is because households may only be confronted with potential negative effects after the system is deployed, and their preferences can be affected by other exogenous societal changes over time. The second tends to concentrates on broader societal impacts of technologies, even if they may not immediately result in a lack of social acceptance. Therefore, such analyses can point to potential future acceptance issues, even if they are not immediately revealed by households. The literature on ethics of technology is generally not concerned with the causality between a better consideration of values and social acceptance (Oosterlaken, 2014). By identifying value conflicts and scenarios of value change, we show how this relationship can be conceptualised. Agent-based modelling and the scenario discovery technique are two effective and efficient methods to carry out this approach.

6.5.3. POLICY IMPLICATIONS

This work addresses part of the challenge to switch from traditional natural gas heating systems to sustainable heating systems. While there is a sense of urgency in deploying more sustainable heating systems, their deployment may have serious future effects on the well-being of households (e.g. in-home thermal comfort, financial situation, social inclusion). Choices that are made today may create a lock-in effect and limit options of future inhabitants or generations to act upon their well-being. For example, choosing the 70°C district heating system could limit possibilities to deploy more sustainable systems in the future, when 40°C district heating technology becomes cheaper.

In the light of this work, we identify three key implications for policy. First, appropriate regulation is required to guide the planning and deployment of sustainable heating systems initiated by community initiatives. While such initiatives may contribute in terms of environmental sustainability, they may also have serious negative consequences on human well-being in the short and long term. Regulation is required to balance the values to which sustainable heating systems should comply and ensure social cohesion and well-being. Second, tailor-made policy instruments at the level of city districts are required to adjust sustainable heating systems to city district characteristics. This work shows that the characteristics of city districts in terms of housing and households affect the suitability of heating systems and hence their social acceptance. Third, sustainable heating systems should be designed to account for value change (van de Poel, 2018b). Even if heating systems may seem to be accepted initially, economic, technological, and social changes may affect the suitability of sustainable heating systems over time. This might result in significant additional costs to replace parts of the existing system. The approach demonstrated in this chapter can be useful for policymakers in charge of planning sustainable heating systems in city districts. It can be used to identify the lack of social acceptance resulting from the deployment of various heating systems. Design requirements and policy guidelines can be specified to account for value change in support of social acceptance.

6.5.4. FUTURE RESEARCH

We have two suggestions for future research. First, the approach proposed in this work could be tested for other cases. This includes other energy infrastructures, such as the deployment of the smart electricity grid. It would also be informative to test our approach in city districts that are less heterogeneous in terms of housing and households than 'de Vruchtenbuurt'. For these other cases, empirical research to identify important values and their conceptualisation for different households could be more exhaustive. This could be done by means of in-depth interviews, surveys, and participant observations. Second, the approach proposed in this chapter could be complemented with participatory methods. While value conflicts in this research are analysed in terms of social acceptance issues, they also have implications for fairness and social justice. Stakeholders could be involved to identify the preferred balance between values, as ultimately trade-offs are inevitable. Participatory methods such as the Participatory Value Evaluation method (Mouter et al., 2019) are particularly interesting as they create more understanding for stakeholders about the impact of their choices and the trade-offs that they involve.

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TOWARDS SOCIALLY ACCEPTED ENERGY SYSTEMS

7.1. CONCLUSIONS AND DISCUSSION

Conclusions from this work are provided in section 7.1.1. Key research choices are then discussed in section 7.1.2.

7.1.1. CONCLUSIONS

The aim of this thesis was to support the design of socially accepted energy systems by means of a methodological contribution. This thesis answered the following central research question:

- **How can value conflicts embedded in energy systems be addressed in support of social acceptance?**

We demonstrated an approach to support the social acceptance of energy systems through a normative analysis of moral issues. Identifying value conflicts embedded in energy systems can help to anticipate a lack of social acceptance. The decision to deploy energy systems that embed value conflicts inevitably entails a prioritisation of some societal groups over others. Disfavoured societal groups may decide to take actions in support of these values, for example by opposing the deployment of these systems. This may occur during the planning phase, or at a later phase as a result of value change. The exploration of scenarios of value change can used to evaluate the plausibility of resulting stakeholder oppositions or lack of support. Value conflicts embedded in energy systems can be addressed by identifying existing tactics in the academic literature. These tactics can be used to specify design requirements and policy guidelines in support of the social acceptance of energy systems.

Approaches to address value conflicts embedded in energy systems are limited. Although the academic literature proposes tactics to address value conflicts, they often discuss values in a latent manner. The relevant literature cannot be accurately captured using traditional keyword searches. Additionally, it is difficult to identify which value conflicts are embedded in energy system designs. This is because a wide range of intertwined factors specific to designs or to the geographical locations where they are deployed may explain the embeddedness of value conflicts. To address these research gaps, we formulated four research questions. These questions are answered in this section.

RQ1: How can multidisciplinary literature addressing values be systematically explored? We developed an approach, based on probabilistic topic modelling and semantic fields, to capture and explore the academic literature addressing values. Starting with a very wide range of scientific articles potentially addressing values, we used probabilistic topic models to isolate the relevant literature iteratively. Semantic fields of values were used in case the resulting set of articles still contains a number of non-relevant articles.

The approach was tested for the value *justice* in the energy literature. This resulted in a more complete overview of the types of justice issues addressed by the academic literature in comparison to traditional keyword searches. Especially the literature on the smart electricity grid and electricity markets frequently addresses the value justice without naming this value explicitly.

RQ2: How are value conflicts embedded in energy systems currently addressed? We identified and explored tactics to address value conflicts embedded in the smart electricity grid. Value conflicts addressed by the academic literature have been clustered into six groups.

A first group of value conflicts is between *reliability* and *energy efficiency* on the one hand, and *environmental sustainability* on the other. Electricity produced by renewables tends to be intermittent and could endanger the reliability of the electricity grid. Tactics include intrusion detection systems and encryptions systems.

A second group of value conflicts is between *privacy* on the one hand and *reliability*, *environmental sustainability*, and *efficiency* on the other. A wide range of metering technologies can be used to monitor the state of the electricity grid. This may however result into privacy issues for consumers. Tactics suggested by the literature include intrusion detection systems and encryptions systems.

A third group of value conflicts is between *justice* on the one hand and *reliability*, *competitiveness* and *environmental sustainability* on the other. The smart electricity grid may enable households to come more sustainable and make financial savings. This might however not be the case for all households, for example those with lower incomes. Tactics suggested by the literature include procedures to account for user cultural and economic diversity.

A fourth group of value conflicts is between *efficiency* and *justice*. The smart electricity grid may enable consumers to participate more actively in electricity markets. Market rules may however need to be adjusted to avoid resulting justice and fairness issues. Tactics suggested by the literature include market and distribution allocation schemes are suggested by the literature.

A fifth group of value conflicts is between *justice* on the one hand, and *reliability*, *competitiveness* and *environmental sustainability* on the other. The smart electricity grid may allow the deployment of new renewable energy production plants. Local communities may however be affected. Tactics suggested aim to identify better the local impacts of energy systems.

A sixth group of value conflicts is between all following values: *safety & health*, *efficiency*, *competitiveness* and *reliability*. As any other products, the development of smart grid technologies is a constant battle between the values just mentioned. Tactics focus on technology standards to ensure sufficient safety & health and reliability.

RQ3: How can a simulation model be conceptualised and specified to identify value conflicts embedded in energy systems? We developed an approach to identify value conflicts embedded in energy systems. This approach relies on the capability approach, agent-based modelling, and the scenario discovery technique. As in most city districts, households in the model (i.e. 'agents') are heterogeneous with regard to their levels of resources (e.g. income) and conversion factors (e.g. education or type of housing). To visualise value conflicts embedded in energy systems, agents attempt to each realise their capabilities. They do so by choosing the energy system design that maximises their own capabilities. The realisation of capabilities by some agents may however restrict capabilities of other agents. Hence, some capabilities will be in conflict. Using the scenario discovery technique, the approach identifies capability conflicts in energy system designs and in the city districts they occur.

We tested this approach for the deployment of decentralised energy systems and identified three main types of capability conflicts. First, some capability conflicts may be inherent to technological choices. Decentralised energy systems may provide more *control* over household energy consumption. However, individual investments is such systems may be riskier than relying on traditional energy supply (*emotions*). Second, capability conflicts may occur within one type of population. Using decentralised energy systems may allow households to be more *environmentally sustainable*. However, this may lead to inclusiveness issues (*affiliation*) for neighbours who are not able to participate. Third, capability conflicts may occur between different types of populations. While higher income groups can switch to decentralised energy systems and become more *environmentally sustainable*, the reliability of the national energy supply used by lower income populations may decrease (*emotions*).

RQ4: How can we assess ex ante the social acceptance of household sustainable heating systems at the city district level by addressing value conflicts? We addressed value conflicts embedded in sustainable heating systems for city districts. This was done using a real-world case of community driven heating initiative in The Hague, the Netherlands. Three sustainable heating systems were considered by the initiative: 70°C district heating, 40°C district heating and all-electric heating. Each system consists of a range of alternatives with regard to the type of heat source used (collective or individual) and the level of thermal insulation required in houses. We identified the value conflicts embedded in each district heating system and evaluated them based on their consequences in terms of social acceptance. Design requirements and policy guidelines were suggested to cope with embedded value conflicts.

For the 70°C district heating system, we found that the alternative with waste heat is preferable with regard to embedded value conflicts. A first group of value conflicts embedded is between *environmental sustainability* and *autonomy* on the one hand, and *affordability* on the other. Subsidies for housing thermal insulation could be used to make this alternative more affordable. A second group of value conflicts is between environmental sustainability and autonomy on the one hand, and inclusiveness on the other. Different activities in support of social inclusion could be organised to ensure that households with lowest incomes and tenants still feel included in the city district.

For the 40°C district heating system, we found that the alternative combined with electric boilers is preferable. A first group of value conflicts is between *comfort* and *affordability*. A possible measure could be to encourage a better consideration of energy labels in the value of houses, for example through tax incentives. A second group of value conflicts is between *environmental sustainability* and *autonomy* on the one hand, and *inclusiveness* on the other. Here also, this group of value conflicts could be addressed by organising social activities at the city district level. A third group of value conflicts is between *environmental sustainability* and *autonomy* on the one hand and *affordability* on the other. Next to subsidies, information campaigns could be used to help households to cope with investment risks.

For the all-electric heating system, we found that the alternative with electric boilers is preferable. A first group of value conflicts is between *environmental sustainability* and *autonomy* on the one hand, and *affordability* on the other. Subsidies could be used to help the renovation of houses. A second group of value conflicts is between *environmental sustainability* and *affordability* on the one hand, and *inclusiveness* on the other. The environmental benefits of electric boilers powered by green electricity could be promoted to ensure that household do not switch back to less sustainable means of heat production.

7.1.2. Discussion

This thesis demonstrates an approach to support the social acceptance of energy systems through a normative analysis of moral issues. This is done by addressing embedded value conflicts. In this section, we discuss the implications of our choice to concentrate on moral issues to support social acceptance, and of our methodological choices.

Normative analysis of moral issues caused by energy systems

Normative analysis of moral issues and uncertainty. An advantage of using a normative analyses of moral issues is that we can account more adequately with the uncertainties that characterise the occurrence of a lack of social acceptance during the long-term planning horizon for energy systems. Two types of uncertainties need to be addressed when predicting social acceptance (see Figure 7.1). The first is the current and future impact of the infrastructure. What social, economic, and technological changes might occur during the long-term planning horizon for infrastructures? This can influence how stakeholders are affected by the infrastructure over time. The second is stakeholder decision-making. Given this negative impact, how are stakeholders going to respond? This depends on their perception, opportunity, and aspiration. By trying to predict stakeholder opposition and lack of support, social acceptance assessments inherently comprise both types of uncertainties. However, predicting stakeholder oppo-

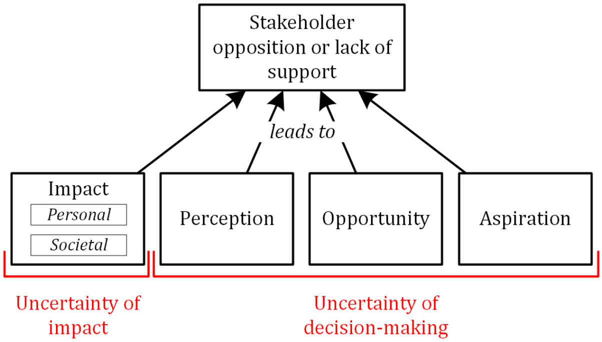

Figure 7.1: Uncertainty characterising a potential future lack of social acceptance

sition or lack of support and coping with the uncertainty of decision-making over such a time span might be too far-fetched. Since we focus on moral issues (i.e. impact) rather than on the predication of stakeholder behaviour, the approach chosen in this thesis does not involve coping with the uncertainty of decision-making. Rather, it allows us to study how this impact might change over time. Although it does not allow us to predict a lack of social acceptance, an analysis of embedded value conflicts indicates underlying concerns that are riskier in terms of acceptance and under which conditions they may become problematic. Such an analysis may be helpful to specify adequate design requirements and policy guidelines.

Normative and descriptive analyses to support social acceptance. In chapter 2, we sketched a rather polarised view of moral acceptability and social acceptance assessments. In theory, the first relies solely on normative analyses whereas the second relies on descriptive analyses. A strict separation between moral acceptability and social acceptance is referred to as the "separatist view" (van de Poel, 2016). Descriptive and normative analyses can however complement each other. As explained in chapter 2, normative analyses can point to a wider range of underlying concerns that could lead to a lack of social acceptance in the future. Descriptive analyses can be used to identify stakeholder preferences and indicate underlying concerns that should be addressed as priority. This more integrated outlook is referred to as the "coherentist view" of moral acceptability and social acceptance (van de Poel, 2016). The exploration of such a coherentist view of energy systems could help strengthen research in support of their social acceptance.

TYPES OF CONFLICTS FOUND USING PROBABILISTIC TOPIC MODELLING AND AGENT-BASED MODELS

In this thesis, we used two approaches to explore value conflicts. In chapters 3 and 4, the approach based on probabilistic topic modelling identifies value conflicts only if they have been discussed in the literature. This is a significant limitation for an ex ante support of the social acceptance of energy systems. In chapters 5 and 6, we used agent-based modelling to identify embedded value conflicts. Agent-based models are less suitable for identifying conflicts involving values that relate more to character traits than to actions (such as empathy or calmness). The consequences of values can only be found in an agent-based model if they result in actions by agents. While both approaches are complementary, remaining value conflicts might exist that have not been addressed by the literature and are not the result of stakeholders actions.

PROBABILISTIC TOPIC MODELLING TO CAPTURE VALUES

Probabilistic topic models were used to capture and classify scientific articles addressing (latent) value conflicts. We found two limitations to this use of probabilistic topic models. First, current implementations of probabilistic topic modelling are poorly equipped to identify small topics of interest. Most common implementations are unsupervised. This means that the algorithm typically finds the most important and distinguishable topics in a corpus of documents, but this might not necessarily include the topics (i.e. values) of interest. In chapter 3, we proposed an approach based on semantic fields to cope with this limitation. This approach could however be improved using supervised topic modelling. In an iterative process, words can be 'fed' into supervised topic models to create topics specific to values. Second, the use of probabilistic topic models currently requires knowledge of programming languages. Although the required level of programming skills is limited, it might still represent a barrier for researchers with no programming experience.

USING AGENT-BASED MODELLING IN ETHICS OF TECHNOLOGY

We used agent-based models to identify value conflicts in energy systems and to identify the affected population. However, we encountered three difficulties.

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The first is the absence of literature on the conceptualisation of values. In chapter 5 and 6, we chose to conceptualised values as capabilities for pragmatic reasons. Besides the capability approach (Nussbaum, 2011, Sen, 1992), we were unable to find literature on how to conceptualise values so that value conflicts in socio-technical systems can be tested. Our choice has two drawbacks. First, the link between capabilities and energy systems is fairly weak. Capabilities aim to evaluate human well-being, which is influenced by much more than just the energy system in question. In this sense, the notion of 'energy capabilities' introduced by Hillerbrand and Goldammer (2018) can be criticised as well. Second, capabilities evaluate well-being from the perspective of individuals. The concept of values covers a broader perspective of what goodness entails.

The second difficulty relates to the abstractness of values. Philosophical concepts (like values) are quite abstract. This abstractness is purposeful since they need to reflect lasting convictions or matters that are separate from specific objects. However, evaluating design choices in socio-technical systems requires their conceptualisation to be more specific. This is especially the case when being integrated into a simulation model, since eventually values need to be translated into code. Simulation models are useful for understanding the implications of design choices on values. However, inevitable choices concerning the conceptualisation of values may not always do full justice to their original philosophical conception.

The third difficulty is the trade-off between choosing to conceptualise the model based on existing theoretical frameworks or aiming for an accurate representation of reality. On one hand, it is preferable to conceptualise simulation models based on existing theoretical frameworks (such as the Capability Approach). This makes the model more accessible for peers (which is a frequent challenge in the field of modelling), thereby encouraging discussions and feedback. On the other hand, it is preferable to conceptualise the model as close as possible to reality. Reality may however be highly complex (such as what different values entail). Besides feasibility issues concerning coding, this approach can make it almost impossible for peers but also for modellers to understand the model and make proper sense of its outcomes.

In section 7.3, we argue for the need of a notion of values that is applicable to design choices in energy systems. Such a notion could help to conceptualise values in simulation models in such a way that it is more in line to what an evaluation of moral acceptability entails.

7.2. CONTRIBUTIONS

Scientific contributions are provided in section 7.2.1. This is followed by societal contributions in section 7.2.2.

7.2.1. SCIENTIFIC CONTRIBUTIONS

We have contributed to the field of social acceptance by demonstrating how to anticipate long-term social acceptance based on a normative analysis of moral issues caused by energy systems. As explained by Oosterlaken (2014), the causality between moral issues caused by technologies and their acceptance by stakeholders is often a hypothesis for researchers. This is because stakeholder decision-making is complex, difficult to predict, and also depends on other factors than solely values (see section 2.2). Relating moral issues to social acceptance is however critical as it shows more clearly how a better consideration of moral considerations can be instrumental for policy-making. By addressing value conflicts, we focused on identifying broad futures (scenarios of value change) that might give stakeholders a reason not to accept energy systems. Such an approach contributes to understanding the problems that can be created by the deployment and operation of energy systems and helps to select design requirements and policy guidelines in support of social acceptance.

We have contributed to the field of ethics of technology by showing the promises of computer assisted methods for ethics of technology. While this thesis aims to support social acceptance, it uses values as the level of analysis. We were unable to find text mining methods that can address values in written documents. Appling agent-based modelling to ethics is still unusual (Lasquety-Reyes, 2018). This thesis has shown the potential of such methods in at least three ways. Computer assisted methods can help to perform tasks that are cognitively demanding, i.e. to evaluate the feasibility and impact of ethical frameworks to technical and regulatory designs. They can also help to process a large set of information and provide insights about how to improve the moral acceptability of technologies. While critical, such empirical tools are rare in the ethics of technology. Finally, they can provide a platform to discuss and test the implication of concepts that are typically difficult to define and communicate (e.g. values).

7.2.2. SOCIETAL CONTRIBUTIONS

This thesis has provided two main societal contributions. First, we have shown the societal risks that come with the energy transition. The energy transition is urgent. It is however one societal goal that competes with other important considerations, such as economic development and social equality. Although the energy transition can be seen as a priority for some citizens, this might not be the case for all. This might be due to different opinions, but also because some citizens live in more difficult socioeconomic conditions than others. Imposing sustainability policies and technologies might backfire and result in a lack of social acceptance if other societal considerations are not taken into account. Our approach helps analysists to include stakeholder perspectives (i.e. values) that may not seem to play a role on social acceptance now but could lead to a lack of social acceptance in the future. This includes the values of typically vulnerable populations who may not always have the means to defend their interests.

Second, we have provided a systematic and practical approach to integrate human values in the regulatory and technical design of infrastructures. Project managers may be reluctant to integrate human values and involve local stakeholders in design making. Stakeholders opinions may seen as irrational or difficult to predict. By focusing on embedded value conflicts, we make abstraction of the complex stakeholder decision-making process. Rather, we focus on identifying socioeconomic conditions that could lead to stakeholder oppositions or lack of support. By identifying value conflicts, we also visualise how and when human aspects are in tension with more technical and economic aspects. This can be used to discuss whether the right priorities are made in energy system designs.

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7.3. RESEARCH AGENDA TOWARDS SOCIALLY ACCEPTED ENERGY SYSTEMS

In this section, we suggest five areas of research towards value robust energy systems: probabilistic topic modelling, agent-based modelling, research on prioritisation of conflicts, governance of value conflicts in energy systems and modelling social mechanisms leading to a lack of social acceptance.

Probabilistic topic modelling. Approaches to capture scientific articles addressing values using probabilistic topic models should be further developed. As explained in section 7.1.2, unsupervised topic models are limited in finding small topics. Hence, it may be difficult to capture values that are only addressed to a limited extent by the literature. Supervised topic models enable the modellers to provide input and hence guide the identification of topics of interest (Blei and McAuliffe, 2007). Words can be fed to the model to help the creation of topics specific to values. This can be used to capture the literature of interest, even if related values are addressed only to a limited extent.

Agent-based modelling and conceptualisation of values. The agent-based modelling approach used to identify value conflicts can be further developed in three ways. First, the model needs to be tested in other city districts, in different energy systems, and in different infrastructures besides energy. This would identify more model limitations and could lead to model improvement. Second, the model could be used to explore conflicts between multiple conceptualisations of values. As indicated by Taebi et al. (2020), conflicts could exist because stakeholders do not have the same understanding of what a value entail. Third, the development of the model should go hand in hand with the development of a notion of values that is applicable to design choices in socio-technical systems. As explained in section 7.1.2, the concept of values is theoretically rather abstract. More precise conceptualisations are needed for their use in simulation models and for the design of more acceptable and accepted socio-technical systems. A direction for search is to make the conceptualisation of values emergent from the moral problems that it aims to address (cf. van de Poel (2018a)).

Prioritisation of value conflicts. Further research is needed on how to prioritise design options based on embedded value conflicts. In this work, we identified scenarios of value change to evaluate the plausibility and severity of value conflicts on resulting lack of social acceptance. We identified scenarios in a rather illustrative manner. A more systematic approach could be the use of scenario tools. An example is Cross-impact Balances (Weimer-Jehle, 2006). This scenario tool is well equipped to explore socioeconomic futures and hence to evaluate how the relative importance of multiple values may change over time.

Governance of value conflicts embedded in energy systems. Further research is required on how to govern value conflicts embedded in energy systems. Once preferable energy system designs are selected, remaining value conflicts need to be governed. Various authors have suggested methods to govern value conflicts. Thacher and Rein (2004) suggested seven approaches to govern value conflicts. This includes separating responsibilities for values among institutions and giving the responsibility for making trade-offs between value conflicts at higher organisational levels. Dietz et al. (2003) proposed five strategies to govern complex systems. These include designing institutions in such a way that they can adapt to value change and providing trustworthy information for decision-making. This literature could be used to identify regulations to govern value conflicts embedded in energy systems.

Modelling social mechanisms leading to a lack of social acceptance. Research is required to model social mechanisms that lead to a lack of social acceptance when values are not sufficiently addressed. In this thesis, agent-based modelling is being used to identify value conflicts embedded in energy systems. While we have illustrated potential impacts in term of social acceptance throughout this thesis (e.g. in chapter 4 and 6), the modelling of underlying social mechanisms falls outside of the scope of the thesis. Future research could aim at conceptualising the relationship between embedded value conflicts and social acceptance. Agent-based modelling could be used for this purpose as the occurrence of a lack of social acceptance is typically influenced by interactions between heterogeneous societal actors (c.f. Davis (1989), Friedkin and Johnsen (1999), Rogers (1962)).

APPENDICES

APPENDIX A

This section corresponds to the appendices of chapter 3.

APPENDIX A.1: SAMPLE OF EXCLUDED AND REMAINING ARTICLES BASED ON OUTCOMES OF THE FIRST TOPIC MODEL

Title	**Authors**	**Journal / Conference / Book**
Remaining articles		
– "Flexible control for small power generation employing renewable energy source used in isolated communities"	Barara et al. (2015)	56th International Scientific Conference on Power and Electrical Engineering of Riga Technical University, RTUCON 2015
– "Profiling energy profilers"	Jagroep et al. (2015)	Proceedings of the ACM Symposium on Applied Computing
– "Marginal abatement cost curves for policy recommendation - A method for energy system analysis"	Tomaschek (2015)	Energy Policy
– "Can you take the heat? - Geothermal energy in mining"	Preene and Younger (2014)	Transactions of the Institutions of Mining and Metallurgy, Section A: Mining Technology
– "The energy-saving potential and countermeasures of the medium and large cities in Jilin Province"	Li and Zhao (2014)	Applied Mechanics and Materials
– "Dissemination of nuclear energy applications"	de Siqueira et al. (2013)	22nd International Conference on Production Research, ICPR 2013
– "The integrated solid waste management system: its implementation and impacts towards the environment "	Norazli et al. (2013)	Causes, Impacts and Solutions to Global Warming
– "Document Containerless Solidification of Magnetic Materials Using the ISAS/JAXA 26-Meter Drop Tube"	Ozawa (2012)	Solidification of Containerless Undercooled Melts
– "Analysis of energy strategies to halve CO2 emissions by the year 2050 with a regionally disaggregated world energy model"	Hosoya and Fujii (2011)	Energy Procedia
– "Modeling of water spray evaporation: Application to passive cooling of buildings"	Belarbi et al. (2006)	Solar Energy
Excluded articles		
– "Linking recovery and recrystallization through triple junction motion in aluminum cold rolled to a large strain"	Yu et al. (2013)	Acta Materialia
– "Color control in coaxial two-luminophore nanowires"	Garreau et al. (2013)	ACS Nano
– "Near-infrared emission and energy transfer mechanism of Tm 3+/Yb 3+ codoped tellurite glasses"	XU et al. (2012)	Guangzi Xuebao/Acta Photonica Sinica
– "Drying kinetics of olive pomace in a fluidized bed dryer"	Meziane (2011)	Energy Conversion and Management
– "Two-photon absorption coefficient in relation to the typical pulse models of laser"	Zhao et al. (2010)	Optics Communications
– "An energy-balancing unequal clustering protocol for wireless sensor networks"	Yang T (2009)	Information Technology Journal
– "The integrated Sachs-Wolfe effect in unified dark matter scalar field cosmologies: An analytical approach"	Bertacca and Bartolo (2007)	Journal of Cosmology and Astroparticle Physics
– "Energy efficiency evaluation of wireless LAN over bursty error channel"	Yin et al. (2005)	GLOBECOM - IEEE Global Telecommunications Conference
– "Measurement of linear energy transfer distribution at CERN-EU high-energy reference field facility with real-time radiation monitoring device III and its comparison with dosimetric telescope"	Doke et al. (2004)	Japanese Journal of Applied Physics, Part 1: Regular Papers and Short Notes and Review Papers
– "Multicompartment model for mechanics and energetics of fibrillating ventricle"	Yaku et al. (1991)	American Journal of Physiology - Heart and Circulatory Physiology

APPENDIX A.2: LIST OF TOPICS FOUND IN THE SECOND TOPIC MODEL

Technologies

Topic #	*Topic titles*	*Distr.*
2	Smart energy management systems	3
5	Inverters	2,5
7	Wind turbines	2
8	Micro-grids	1,9
9	Heat storage	1,9
11	Heat pump systems	1,5
13	Solar energy systems	1,5
19	Combustion engines	1,3
20	Hydraulic systems	1,3
23	DC converters	1,2
25	Combined heat and power	1,2
26	Hydro and wave energy	1,1
27	Flywheels	1,1
28	Smart grids	1,1
30	Desalination plants	1,1
32	Cooling systems	1
37	Geothermal energy	1
42	Nuclear energy	0,9
44	Digital control of technologies	0,9
45	Transmission grids	0,9
47	(wireless) sensors	0,9
49	Phase Change Materials	0,9
51	Wave energy	0,9
54	Electrical power technologies	0,8
55	Lithium batteries	0,8
57	Tidal power	0,8
58	Smart homes	0,8
59	Compressed air energy storage	0,8
61	Micro safety systems	0,8
62	Energy system failures	0,8
66	Lighting	0,7
68	Energy storage capacitors	0,7
71	Monitoring and communication platforms	0,7
73	Solar cell efficiency	0,7
74	Doubly fed induction machines	0,7
76	Mobile systems and appliances	0,6
77	Urban sustainable infrastructures	0,6
78	Magnetic energy systems	0,6
79	Traffic	0,6
80	Deployment of decentralized systems	0,6
89	Sodium reactors	0,5
91	Air conditioning	0,5
93	Macrotidal ecosystems	0,5
97	Energy appliances in buildings	0,4
99	Flyback converters	0,4
100	Carbon capture and storage	0,4

Energy inputs and outputs

Topic #	*Topic titles*	*Distr.*
1	Carbon emissions	3,7
4	Energy consumption of buildings	2,7
12	Biomass and hydrogen production	1,5
15	Fossil fuels	1,4
16	Combustion exhausts	1,4
21	Energy wastes	1,3
29	Energy for food production	1,1
39	Modeling of networks	0,9
52	Clean energy	0,9
65	Residential energy consumption	0,8
83	Waste water treatment	0,6
84	Biofuels	0,5
98	Voltages	0,4

Energy governance

Topic #	*Topic titles*	*Distr.*
6	Energy policies	2,1
10	Energy and economic development	1,6
33	Energy policy options	1
34	Energy education	1
35	Energy economics	1
41	Financial and security assessments	0,9
43	EU energy policy	0,9
48	UK energy industry	0,9
50	(wind) Potential and investments	0.9
69	Energy poverty	0,7
72	Humans and the environment	0,7
75	Economic growth	0,6
87	Agriculture	0,5
92	Russian energy policy	0,5
94	Energy regulation	0,5
95	Environmental protection	0,4
96	Degradation of energy systems	0,4

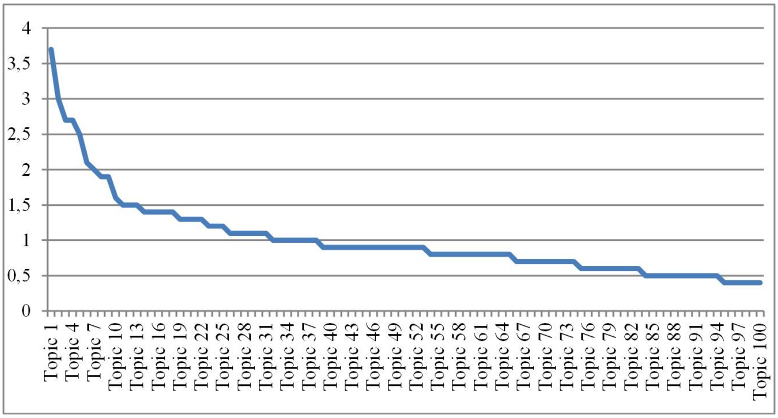
Geographical area's

Topic #	*Topic titles*	*Distr.*
22	Cities	1,3
24	Communities	1,2
38	Districts	1
64	Geographical locations of energy systems	0,8

Methods

Topic #	*Topic titles*	*Distr.*
3	Scheduling algorithms	2,7
14	Spatial optimization	1,4
17	Load management	1,4
31	(fuzzy) multi-objective decision-making	1,1
39	Modeling of networks	0,9
46	Short term scheduling of energy systems	0,9
53	Exergy analysis	0,9
56	Grid stability assesmments	0,8
60	Algorithms in smart energy systems	0,8
63	Energy and exergy analyses	0,8
67	Buiding energy systems evaluations	0,7
70	Energy management and safety of vehicles	0,7
81	Buiding refurbishment	0,6
82	Pricing and markets	0,6
85	Energy physics	0,5
86	Retrofitting	0,5
88	Sparse transition estimations	0,5
90	Energy saving mechanisms	0,5

APPENDIX A.3: MARGINAL DISTRIBUTION OF TOPICS FOUND IN THE SECOND TOPIC MODEL



APPENDIX A.4: SUMMARY OF SOURCES OF INJUSTICES, AFFECTED STAKEHOLDERS AND APPROACHES FOR REMEDIATION IDENTIFIED BASED ON THE SEARCH APPROACH PROPOSED IN CHAPTER 3

Sources of injustices	**Affected stakeholders**	**Approaches for remediation**
1. Historical disparities between countries in carbon emissions and impacts of climate change	Developing countries, socioeconomic groups	Measurement of historical inequalities in CO2 emissions (Raupach et al., 2007); Support of sustainable development (Toklu et al., 2010); Usage of Energy Justice Metric for energy policy decision-making (Heffron et al., 2015); Investigation of disparities between countries of the ratio CO2 emitted/ consumed (Davis and Caldeira, 2010)
2. Inequality of access to newer and cleaner energy technology and sources	Economic regions, poorer citizens	Empirical study to evaluate inequalities between regions based using the concept of meta-frontier (Wang et al., 2013); Usage of the concept of energy justice (Jenkins et al., 2016); Review of challenges of biofuel deployment (Sagar and Kartha, 2007); Performance of a SWOT analysis (Liu et al., 2011), Environmental Kuznets Curve approach (Bilgili et al., 2016), Single-Resource-Separate-Production-Reference (SRSPR) allocation method (Beretta et al., 2014), Increase of bioenergy competitiveness (Souza et al., 2017), Investigation of energy poverty Nothern Ireland (Walker et al., 2014)
3. Inequalities in faculties to support the costs of environmental measures	Low income households, economic regions, developing countries	Evaluation of conditions when (carbon) taxes lead to more inequity (Speck, 1999); Identification of necessary changes to energy policy models to take specificities of developing countries into account (Pandey, 2002); Usage of the concept of polycentrism for energy governance (Sovacool, 2011); Usage of the concept of energy justice (Heffron and McCauley, 2014, Jenkins et al., 2016)
4. Disparities between benefits and burdens of energy production in terms of health and safety risks	Local communities, future generations	Deployment of renewables and energy efficiency measures (Löfquist, 2015); Proposal for an improved design framework for local production systems (Leung Pah Hang et al., 2016); Review of the EURATOM legal framework (Kilb, 2015), Usage of the concept of energy justice (Sovacool and Scarpaci, 2016), Concept of environmental justice (Stretesky and Lynch, 2011)
5. Disparities between benefits and burdens of energy production in terms of cultural and aesthetic impacts	Local communities	Performance of a case study evaluating equity perceptions of wind farms (Aitken, 2010); Usage of the concept of energy justice (Jenkins et al., 2016); Evaluation of more effective and just approaches to resolving inequities (Cowell et al., 2011); Proposal for a comprehensive framework of energy technology acceptance allowing to understand reasons for renewable technology acceptance or rejection (Huijts et al., 2012), Usage of the concept of energy justice (Reames, 2016a)
6. Inequalities between users in conditions of access to the grid	Electric vehicle users	Proposal for a fair Use Policy-based Offered Energy Calculation (Paul and Aisu, 2012); Proposal for a satisfaction metric of EV user (Aswantara et al., 2013)

Sources of injustices	Affected stakeholders	Approaches for remediation
7. Inequalities in usage of devices and revenues attributed to smart grid users	Users of energy harvesting devices, wholesale energy market participants, electricity consumers	Proposal for improvements to nanogrids power distribution rules (Nordman and Christensen, 2013); Proposal for improved scheduling algorithms for utilization of dispersed energy storage systems (Xin et al., 2013); Proposal for a cost allocation method based on LMP sensitivity (Negash et al., 2015); Proposal for a two-stage mechanism for electricity cost sharing (Mhanna et al., 2014); Proposal for a load allocation approach (Hong et al., 2015), Nash bargaining framework (Zhao et al., 2013), Multiagent minority-game (MG)-based demand-response management (Huang et al., 2016a)
8. Inequalities between investments by community members and resulting benefits of local energy infrastructures (e.g. micro-grids)	Energy communities	Proposal for a fair cost sharing methods which is based on Nash bargaining (Wang and Huang, 2016)
9. Lack of fairness between competitors in electricity markets	Market participants	Institutional redisign of the Chinese retail electricity market (Bai et al., 2015)

APPENDIX A.5: SUMMARY OF SOURCES OF INJUSTICES, AFFECTED STAKEHOLDERS AND APPROACHES FOR REMEDIATION IDENTIFIED BASED ON A KEYWORD-BASED SEARCH USING THE WORD 'JUSTICE'

Sources of injustices	**Affected stakeholders**	**Approaches for remediation**
1. Historical disparities between countries in carbon emissions and impacts of climate change	Population of developing countries, future generations	Review of the EU's external governance (Lavenex, 2004); Review of guidelines of sustainable development (Ferrè et al., 2002); Proposal for an Energy Justice Metric to be used for energy policy decision-making (Heffron et al., 2015); Evaluation of the perception of climate change by citizens (Manzo, 2010); Review of the role of cities in climate change inequities (Rees and Wackernagel, 2008); Evaluation of the potential and limits of renewable energy (Trainer, 2013); Introduction of the SCORE index allowing the evaluation of environmental prudence (Sovacool and Bulan, 2013); Support of sustainable development (Weinberg, 1985); Proposal for an 'equal burden' formula for CO2 emissions (Benestad, 1994)
2. Inequality of access to newer and cleaner energy technology and sources	Poorer populations	Review of sources of inequalities in access to energy (Hornborg, 1998); Usage of the concept of energy justice (Heffron and McCauley, 2014, Jenkins et al., 2016); Review and comparison of the concepts of energy justice and ethical consumption (Hall, 2013); Review of equity aspects of energy poverty (Csiba et al., 2011); Review of the Warm Front Program aiming at reducing fuel poverty (Sovacool, 2015); Identification of energy uses critical to households from a perspective of energy justice (Walker et al., 2016); Evaluation of differences in energy consumption practices between generations (Shirani et al., 2013); Performance of a regional study to identify market potential of pelletised wood fuel (Illsley et al., 2007); Evaluation of the effects of energy infrastructures in terms of fuel poverty (Harrison, 2013); Evaluation of the relationship between fuel poverty, disabled people, and policy changes in England (Snell et al., 2015)
3. Inequalities in faculties to support the costs of environmental measures	Low income households, economic regions, developing countries	Usage of concept of energy justice (Jenkins et al., 2016, Sovacool and Dworkin, 2015); Review of the social dimension of the energy transition (Miller et al., 2013); Review of procedural and distributional aspects of the energy transition (Newell and Mulvaney, 2013); Performance of case studies to understand how stakeholders frame justice (Fuller and McCauley, 2016); Evaluation of success factors of energy efficiency measures (Galvin, 2015)
4. Disparities between benefits and burdens of energy production in terms of health and safety risks	Local communities	Proposal for an environmental justice framework allowing the evaluation of the health impact of oil production and use (O'Rourke and Connolly, 2003); Evaluation of disparities using the concept of environmental justice (Stretesky and Lynch, 2011); Review of cases where environmental justice was successfully applied (Schelly and Stretesky, 2009); Review of justice claims of business, government and civil society related to energy infrastructural development in the Arctic (McCauley et al., 2016); Exploration of novel approaches supporting the achievement of justice in nuclear energy policy (Ash, 2010); Review of a failed initiative to 'strand' petrolium assets to improve policy advice (Sovacool and Scarpaci, 2016); Development of a three-level framework supporting morally responsible risk communication (Fahlquist and Roeser, 2015)

Sources of injustices	Affected stakeholders	Approaches for remediation
5. Disparities between benefits and burdens of energy production in terms of cultural and aesthetic impacts	Local communities	Evaluation of more effective and just approaches to resolving inequities (Cowell et al., 2011); Usage of the concept of energy justice (Jenkins et al., 2016, Sovacool and Dworkin, 2015); Usage of the concept of environmental justice (Keir et al., 2014); Proposal for a community knowledge networks approach allowing the recognition of cultural characteristics of social groups (Catney et al., 2013); Performance of a survey describing how general attitudes and project characteristics of wind energy projects are influencing local acceptance (Walter, 2014); Identification of value clusters for energy system change (Demski et al., 2015); Performance of a case study to evaluate project success factors (Magnani, 2012); Performance of case studies of failures to take procedural justice into account (Yenneti and Day, 2015, 2016); Proposal for a conceptual framework for social sustainability which is based on a process of community group priorization and visioning (Whitton et al., 2015); Survey on project perception by stakeholders (Simcock, 2014); Review of the local impacts of solar energy deployment (Mulvaney, 2013); Analysis of wind energy projects in terms of procedural justice (Ottinger et al., 2014); Identification of the contribution of legislation on climate policy to sustainable development (Rietig, 2013); Evaluation of the potential of shared ownership of renewable energy projects (Goedkoop and Devine-Wright, 2016)
6. Inequalities between users in conditions of access to the grid		
7. Inequalities in usage of devices and revenues attributed to smart grid users		
8. Inequalities between investments by community members and resulting benefits of local energy infrastructures (e.g. micro-grids)		
9. Lack of fairness between competitors in electricity markets		

APPENDIX A.6: SUMMARY OF SOURCES OF INJUSTICES, AFFECTED STAKEHOLDERS AND APPROACHES FOR REMEDIATION IDENTIFIED BASED ON A KEYWORD-BASED SEARCH USING THE SEMANTIC FIELD OF JUSTICE

Sources of injustices	**Affected stakeholders**	**Approaches for remediation**
1. Historical disparities between countries in carbon emissions and impacts of climate change	Developing countries, population of developing countries, future generations	Measurement of historical inequalities in CO2 emissions (Raupach et al., 2007); Identification of disparities between countries of the ratio CO2 emitted and CO2 consumed (Davis and Caldeira, 2010);Review of vulnerabilities of urban populations in developing countries in terms of health (Campbell-Lendrum and Corvalán, 2007); Empirical evaluation of the impacts of carbon taxes on competitiveness and distribution of income (Zhang and Baranzini, 2004); Support of sustainable development (Clift, 2007, Stambouli, 2011, Toklu et al., 2010); Review of guidelines of sustainable development (Ferrè et al., 2002)
2. Inequality of access to newer and cleaner energy technology and sources	Poorer populations, economic regions	Evaluation of the usefulness of energy poverty indicators (Kemmler and Spreng, 2007); Introduction of a MARKAL optimization model allowing the evaluation of preferable local energy systems (Howells et al., 2005); Performance of a multi-part, split-sample contingent valuation method and fair share survey, which allows to research the willingness to pay for renewable energy source (Solomon and Johnson, 2009); Review of challenges of biofuel deployment (Sagar and Kartha, 2007); Empirical study to evaluate inequalities between regions using the concept of meta-frontier (Wang et al., 2013); Review of competitive fairness aspects of heat markets (Grohnheit and Gram Mortensen, 2003); Performance of case studies allowing the evaluation of fuel choices of households in Zimbabwe (Campbell et al., 2003); Proposal for remote sensing-based indicators that evaluates equity issues in access to water (Ahmad et al., 2009); Review of sources of energy for pumping groundwater (Mukherji, 2007); Usage of the concept of energy justice (Jenkins et al., 2016, Sovacool and Dworkin, 2015); Review of current distribution of energy consumption (Roberts, 2008); Introduction of the concept of 'just' grids (Welsch et al., 2013); Usage of the water-energy-food nexus (Biggs et al., 2015); Performance of a SWOT analysis (Liu et al., 2011)
3. Inequalities in faculties to support the costs of environmental measures	Low income households, economic regions, developing countries	Usage of the concept of polycentrism for energy governance (Sovacool, 2011); Identification of how energy policy models should be changed to take specificities of developing countries into account (Pandey, 2002); Usage of Lorenz curves of cumulative electricity consumption and Gini coefficients to be used as metrics of energy distribution and equity (Jacobson et al., 2005); Evaluation of conditions when (carbon) taxes lead to more inequity (Speck, 1999); Analysis of the conventional energy efficiency rating system for existing residential buildings (Koo et al., 2014); Reviews of the social dimension of the energy transition (Miller et al., 2013); Support of stakeholder engagement, the fair distribution of costs and benefits of mitigation policies, as well as interregional agreements (Peterson and Rose, 2006); Evaluation of renewable electricity policy mechanisms (Sovacool, 2010); Review of procedural and distributional aspects of the energy transition (Newell and Mulvaney, 2013); Proposal for public-Private Partnership to share investments risks (Zanon and Verones, 2013); Proposal for a dynamical multicriterion method for fair allocation of emission rights (Vaillancourt and Waaub, 2004); Evaluation of the impact of carbon taxes (Alton et al., 2014)

Sources of injustices	Affected stakeholders	Approaches for remediation
4. Disparities between benefits and burdens of energy production in terms of health and safety risks	Local communities	Review of the literature that discusses equity issues of biofuels (Solomon, 2010); Usage of the environmental justice framework allowing the evaluation of the health impact of oil production and use (O'Rourke and Connolly, 2003); Performance of empirical research to identify public attitudes related to biofuels technologies and policy (Delshad et al., 2010); Review of experts perspectives on managing climate change (Lowe and Lorenzoni, 2007)
5. Disparities between benefits and burdens of energy production in terms of cultural and aesthetic impacts	Local communities	Proposal for a comprehensive framework of energy technology acceptance allowing the understand reasons for renewable technology acceptance or rejection (Huijts et al., 2012); Review of the social dimensions of biomass power plants (Upreti, 2004); Evaluation of more effective and just approaches to resolving inequities (Cowell et al., 2011); Performance of a case study to evaluate equity perception of wind farms (Aitken, 2010); Usage of an explanatory framework for addressing public responses to the deployment of wind energy (Bell et al., 2013)
6. Inequalities between users in conditions of access to the grid	Renewable energy producers	Identification of success factors of renewable energy deployment, including fair access to the grid (Reiche and Bechberger, 2004)
7. Inequalities in usage of devices and revenues attributed to smart grid users	Users of energy harvesting devices, Wholesale energy market participants, electricity consumers	Proposal for an improved allocation algorithms (Gorlatova et al., 2011, 2013); Identification of equity issues by reviewing the demand response literature (Gyamfi et al., 2013); Usage of reciprocal fair energy management schemes (Koutitas, 2012)
8. Inequalities between investments by community members and resulting benefits of local energy infrastructures (e.g. micro-grids)		
9. Lack of fairness between competitors in electricity markets		

APPENDIX B

This section corresponds to the appendices of chapter 4.

APPENDIX B.1: DEFINITIONS OF VALUES AND SEMANTIC FIELDS USED TO CAPTURE RELEVANT ARTICLES IN CHAPTER 4

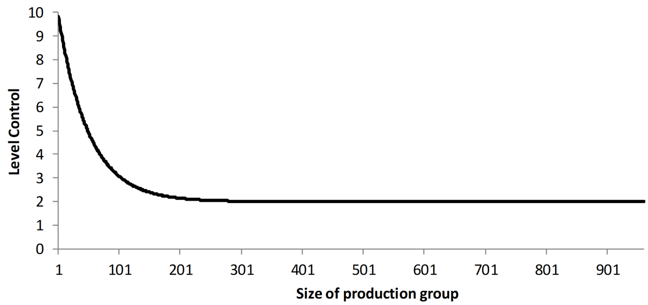
Values	Definitions	Semantic fields
Efficiency	The system has high effective operation as measured by a comparison of production and cost (as in energy, time, and money).	effectiveness, efficacy, ineffectiveness, inefficiency, productivity, performance, efficiency, efficient
Reliability	The system is capable of performing without failure under a wide range of conditions.	fitness, resilience, strength, unbreakable, adaptability, integrity, breakable, collapse, failure, reliability, maintainability, resiliency
Safety and Health	The system does not harm people.	safeness, danger, distress, endangerment, imperilment, jeopardy, peril, healthiness, illness, sickness, unhealthiness, dreadful, hazard, wellbeing, safe, harmful, health
Environmental sustainability	The system does not burden ecosystems, so that the needs of current generations do not hinder future generations.	unsustainable, sustainability, sustainable, natural, ecological, eco-friendly, nature-friendly, environmentally-friendly, intergenerational, renewable, environmental, climate, sustainability, sustainability
Justice	The system is just, impartial, or fair.	equity, fair, inequity, injustice, just, impartial, unfair, unbiased, justice, objectivity, equality, lawful, egalitarian, distributive
Privacy	The system allows people to determine which information about the need to control is used and communicated.	hack, hacker, cybersecurity, cyber, internet of things, data protection, privacy
Competitiveness	The system offers an economic advantage.	competitor, contestant, rival, noncompetitor, market structure, barriers to entry, monopoly, oligopoly, competition, contestability, strategic behavior, competition, complementary assets, competitive, advantage, stakeholders, competitiveness, stakeholders, competitiveness

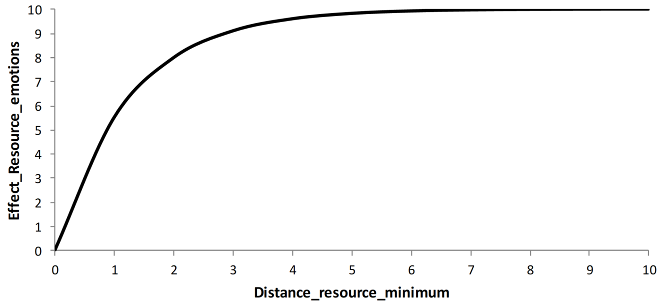
APPENDIX C

This section corresponds to the appendices of chapter 5.

APPENDIX C.1: ODD+D MODEL DESCRIPTION

Overview	
Purpose	- To identify capability conflicts in socio-demographic and housing conditions for different kinds of populations.
State variables and scales	-The agents have properties of households, conceptualised based on the Capability Approach: — Resources — Personal Conversion Factors (PCFs). — Social Conversion Factors (SCFs). — Environmental Conversion Factors (ECFs). - Resources, PCFs and ECFs are values between 0 and 10. The SCF is a variable of spatial clustering of agents with similar resources, PCFs and ECFs. The value of SCF can be set between 0 and 1. A SCF of 0 means that characteristics are randomly distributed over agents. A SCF of 1 means that agents with e.g. high resources, PCFs and ECFs are placed close to each other. - The values of resources, PCFs, SCFs and ECFs of agents do not change over time in the model. Indeed, the goal is solely to identify how different levels and configurations of these characteristics impact the occurrence of capability conflicts.
Process overview and scheduling	- Setup: — The levels of resources, PCFs and ECFs are distributed over agents. — Agents are randomly placed in a number production groups. — A level of SCF (clustering of agents among properties) is set between 0 and 1. - Go: — Agents try to increase the sum of the five levels of capabilities. This is done by switching, creating new production groups, joining existing production groups or remaining in their current production groups. — The model runs until all agents have no further opportunities to increase their levels of capabilities (approx. 50 ticks).
Design concepts	
Theoretical and empirical background	-The Capability Approach (Nussbaum, 2011, Sen, 1992). We use two key elements from this approach: — The list of ten capabilities suggested by Nussbaum (2011) and illustrated in the context of energy systems by Hillerbrand and Goldammer (2018). We retain six capabilities, as they are most affected by the deployment of decentralised energy systems. Control part A and B are integrated into one capability. — The fulfilment of capabilities is evaluated by considering both the resources and conversion factors that individuals have in order to transform resources into capabilities.
Individual decision making	- Each ticks, agents aim to increase their overall level of capabilities (sum of all five levels of capabilities): — Capabilities are *Trust*, *Control*, *Emotions*, *Thought* and *Affiliation*. The level of a capability is a value between 0 and 10, 10 being a capability completely fulfilled. - Agents evaluate which of the following options increase their overall level of capabilities most: 1. Stay in the current production group. 2. Start a new production group (individual). 3. Join an neighbouring production group. - Agents calculate the best feasible option (i.e. whether their level of resources, PCFs and ECFs is sufficient for this option). - Agents choose the option that increases their overall level of capabilities most, provided that this option is feasible. If no option is feasible, they choose the most feasible option.
Learning	- None

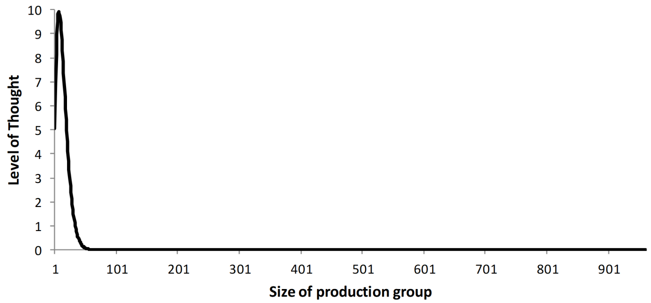
Individual sensing	- Agents look at their surroundings at two stages: — To evaluate *Trust*, they look at the size of production groups of their direct neighbours. — To evaluate *Affiliation*, they look at the fulfilment of the other four capabilities of their direct neighbours.
Individual prediction	- None
Interaction	- There is no specific interaction in the sense that that agents ask each other information. Rather they look at the characteristics of their neighbours (see individual sensing).
Collectives	- Agents belong to energy production groups. Their sizes can vary between 1 (individual production group) to 961 agents (total of agents in the model).
Heterogeneity	- Agents are heterogeneous with regard to their levels of resources, PCFs and ECFs.
Stochasticity	- The following elements are stochastic in the model: — The initial placement of agents in production groups. — Randomised agent iteration. — Properties of agents with regard to resources, PCFs and ECFs are distributed over the population of agents with a mean and a standard deviation around that mean.
Observation	- The model provides the following output: — Level of fulfilment of each capability of agents. — Correlation between capabilities for different groups of agents (e.g. those with low, medium and high resources).
Details	
Implementation details	- The model is implemented in Netlogo. - The following functions are used: **Fulfilment of capabilities** *Trust* Trust = 1.25 –((abs (size of production group – size of production group of neighbour) / 961) * 1.25) * number of neighbours *Control* Control = (exp(–ax + ln(1 * b)) + b) * mult , where a = 0.02, b = 0.2, mult = 10, x = size of the production group  *Emotions* Effect of level of resources on *Emotions*: — Distance_resource_minimum = resource –minimum required resource — If Distance_resource_minimum <= 0, effect_resources_Emotions = 0 — If Distance_resource_minimum >0 — effect_resources_Emotions = 10 –(exp(–ax + ln(1 * b)) + b) * mult , where a = 0.8, b = 0, mult = 10, x = Distance_resource_minimum



Effect of level of PCFs on *Emotions*: Similar as for resources
Level of Emotions = Min(level of Emotions for resources; level of Emotions for PCFs)

Thought
variance_Ecf_group = variance (Sum(ECF of agents in production group))
effect_of_size_community = (k / l) * (x / l)^(k – 1) * exp(-1 * (x / l)^(k)) * mult, where:
k = 1.5, l = 15, mult = 200, x = size of the production group

Implementation details

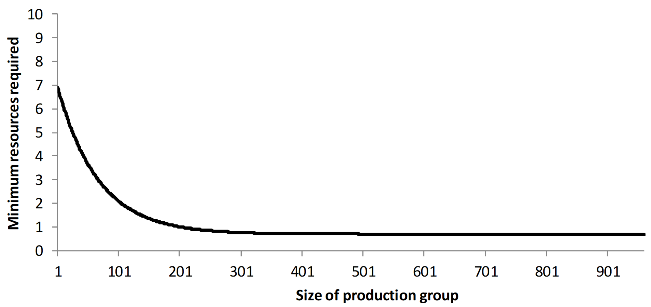


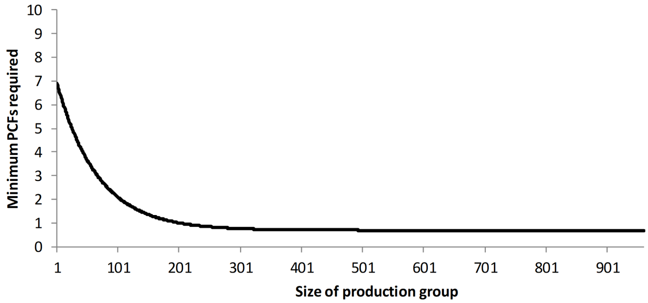
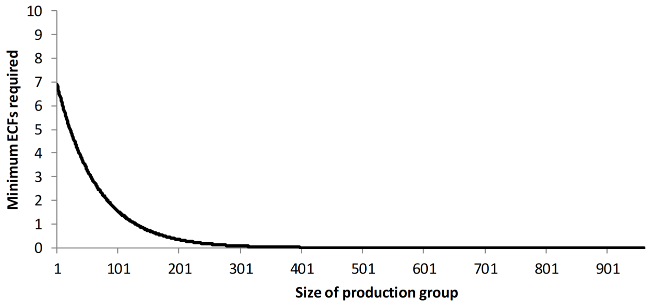
Thought = variance_Ecf_group / 10 * effect_of_size_community

Affiliation
Level of affiliation gained per capability = 2.5 – ((abs (mean capability of neighbors – capability) /10) * 2.5)
Affiliation = Sum of all Level of affiliation gained per capability

Minimum level of resources, PCFs and ECFs to join a production group

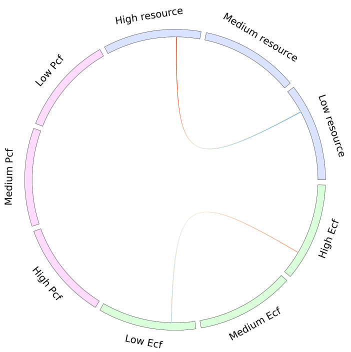
Resources
Min_resources_required = (exp(–ax + ln(1 * b)) + b) * mult , where: a = 0.015, b = 0.1, mult = 7, x = size of the production group



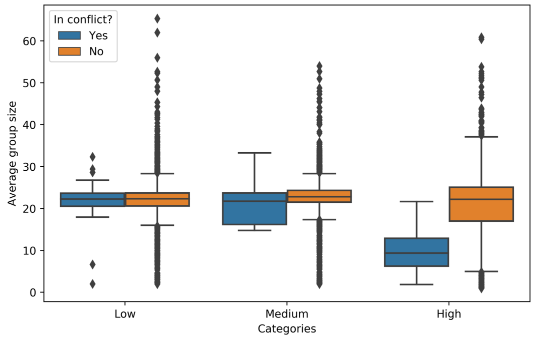
Implementation details	*PCFs* $\text{Min\_PCFs\_required} = (\exp(-ax + \ln(1 * b)) + b) * \text{mult}$, where: $a = 0.015$, $b = 0.1$, $\text{mult} = 7$, x = size of the production group  *ECFs* $\text{Min\_ECFs\_required} = (\exp(-ax + \ln(1 * b)) + b) * \text{mult}$, where: $a = 0.015$, $b = 0.1$, $\text{mult} = 7$, x = size of the production group 
Initialization	- Agents are randomly divided into 50 production groups. - Agent properties with regard to resources, PCFs and ECFs are distributed over the population.
Input	- Distribution of resources, PCFs and ECFs over the population. - Degree of clustering of agents with similar properties with regard to resources, PCFs and ECFs over the population.
Submodels	- No submodels

APPENDIX C.2: VISUALIZATIONS OF CAPABILITY CONFLICTS FOUND IN CHAPTER 5

Capability conflict Trust-Trust

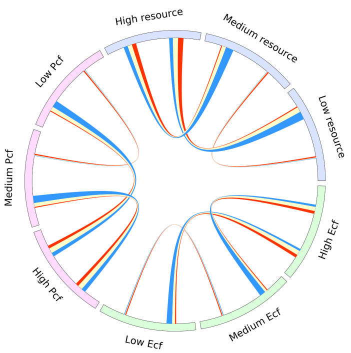


Capabilities: Trust v.s Trust

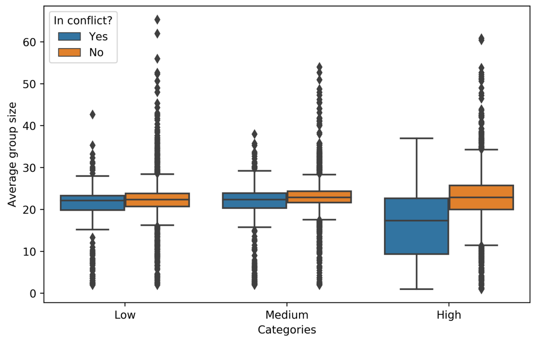


Capabilities: Trust vs. Trust

Capability conflict Trust-Control

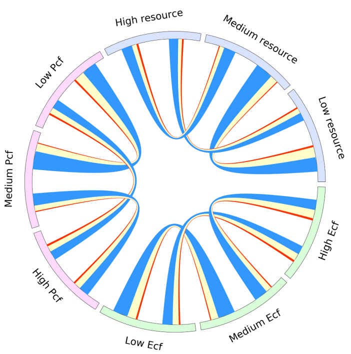


Capabilities: Trust v.s Control

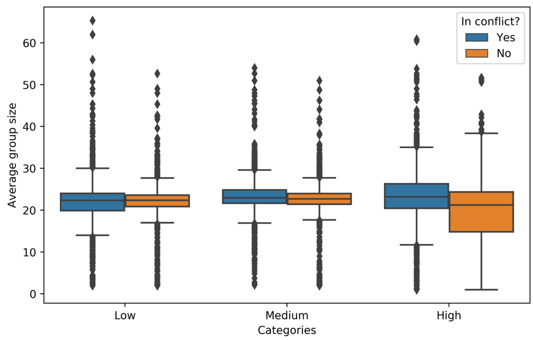


Capabilities: Trust vs. Control

Capability conflict Trust-Emotions

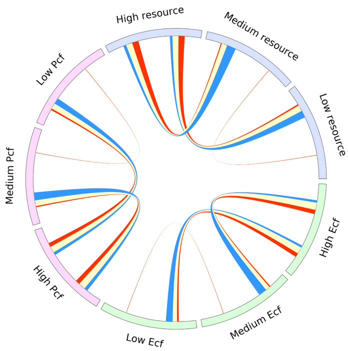


Capabilities: Trust v.s Emotions

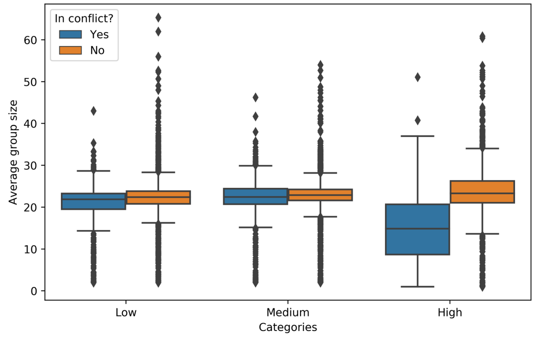


Capabilities: Trust vs. Emotions

Capability conflict Trust-Thought

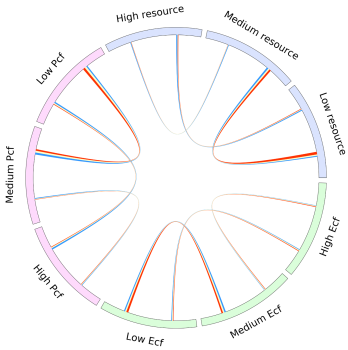


Capabilities: Trust v.s Thought

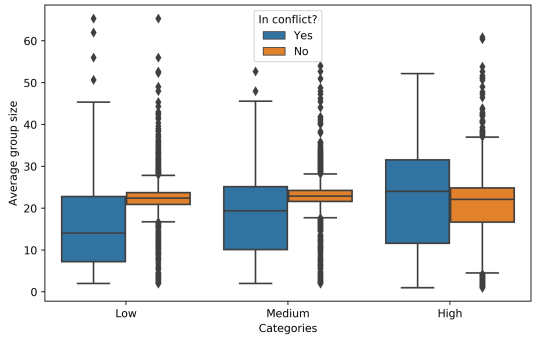


Capabilities: Trust vs. Thought

Capability conflict Trust-Affiliation

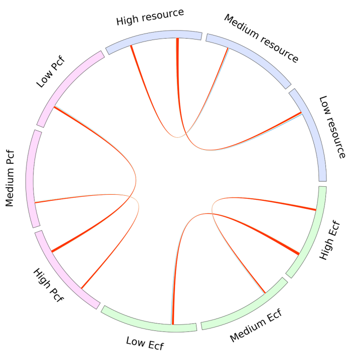


Capabilities: Trust v.s Affiliation

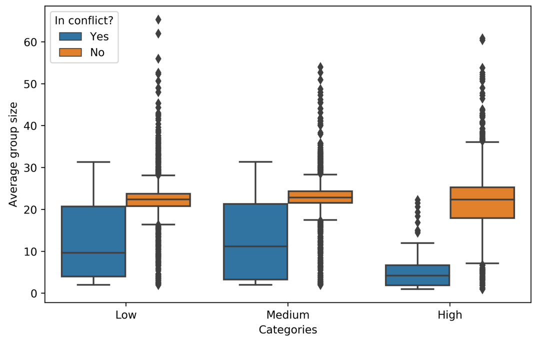


Capabilities: Trust vs. Affiliation

Capability conflict Control-Control

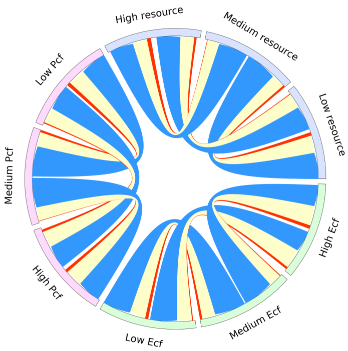


Capabilities: Control v.s Control

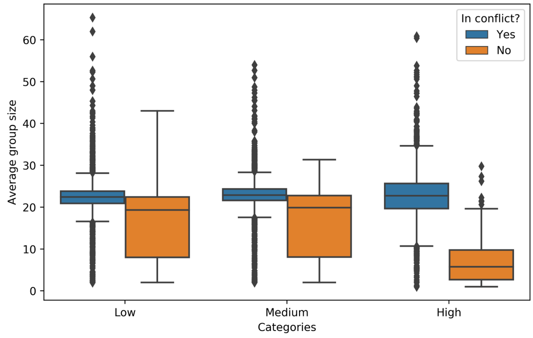


Capabilities: Control vs. Control

Capability conflict Control-Emotions

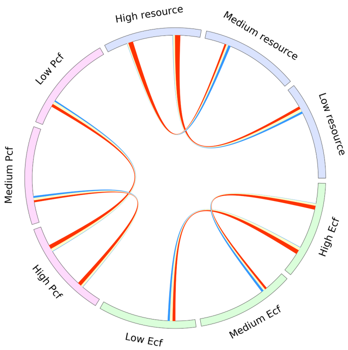


Capabilities: Control v.s Emotions

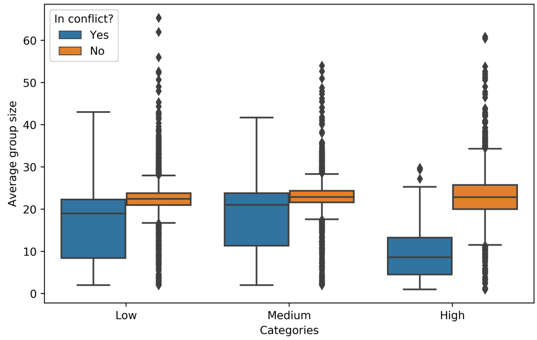


Capabilities: Control vs. Emotions

Capability conflict Control-Thought

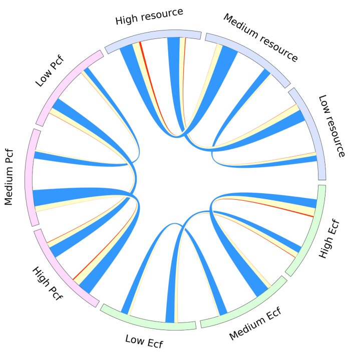


Capabilities: Control v.s Thought

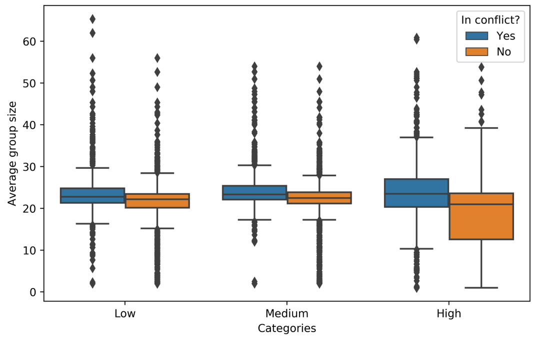


Capabilities: Control vs. Thought

Capability conflict Control-Affiliation

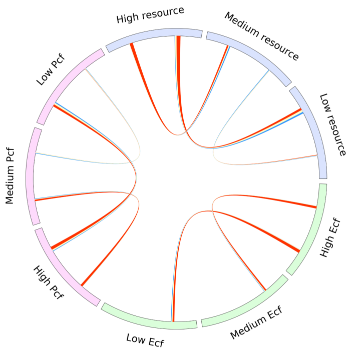


Capabilities: Control v.s Affiliation

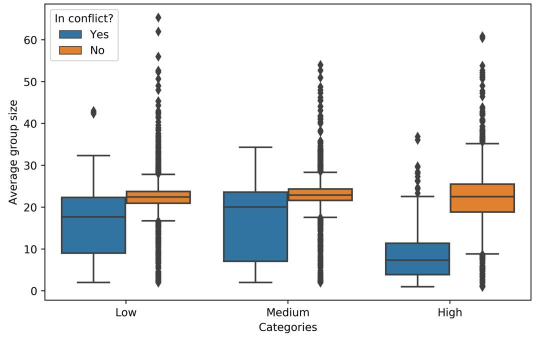


Capabilities: Control vs. Affiliation

Capability conflict Emotions-Emotions

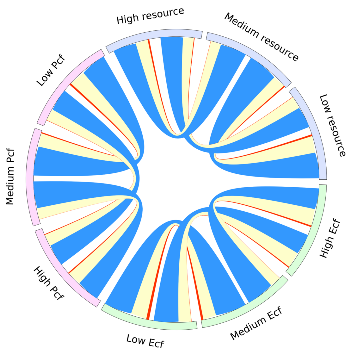


Capabilities: Emotions v.s Emotions

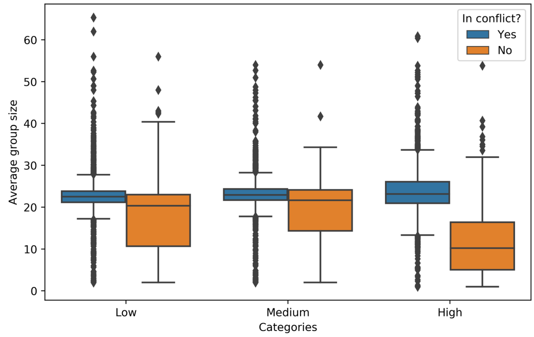


Capabilities: Emotions vs. Emotions

Capability conflict Emotions-Thought

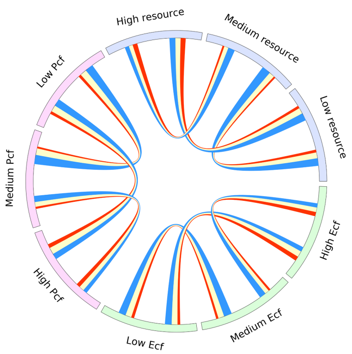


Capabilities: Emotions v.s Thought

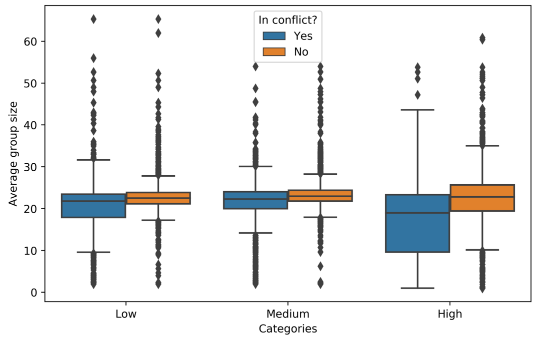


Capabilities: Emotions vs. Thought

Capability conflict Emotions-Affiliation

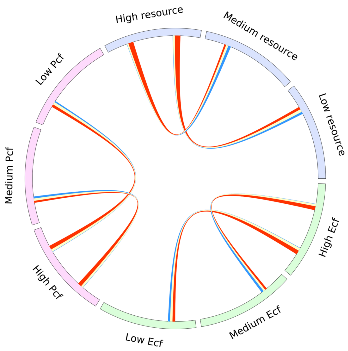


Capabilities: Emotions v.s Affiliation

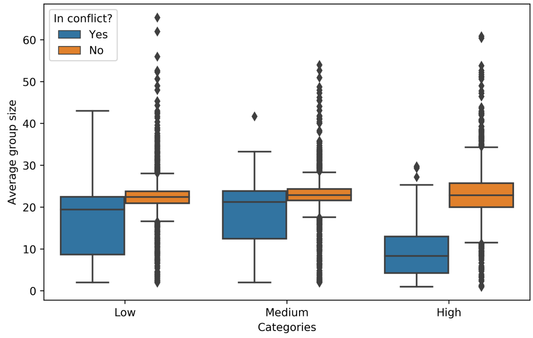


Capabilities: Emotions vs. Affiliation

Capability conflict Thought-Thought

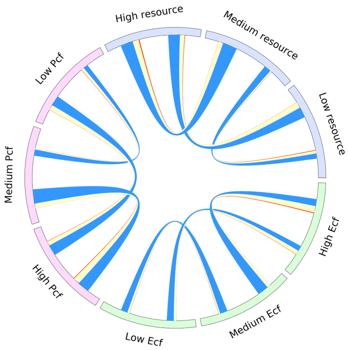


Capabilities: Thought v.s Thought

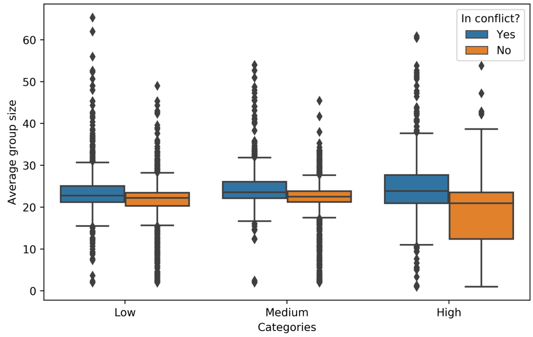


Capabilities: Thought vs. Thought

Capability conflict Thought-Affiliation

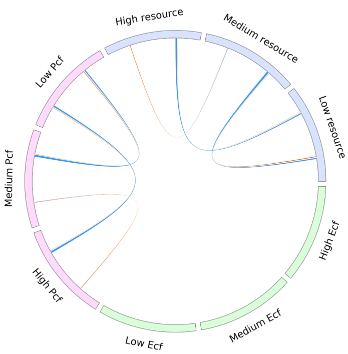


Capabilities: Thought v.s Affiliation

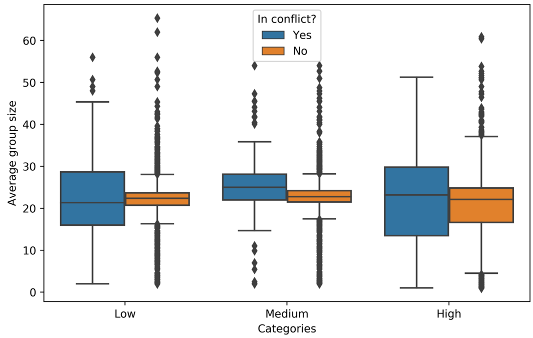


Capabilities: Thought vs. Affiliation

Capability conflict Affiliation-Affiliation



Capabilities: Affiliation v.s Affiliation



Capabilities: Affiliation vs. Affiliation

APPENDIX D

This section corresponds to the appendices of chapter 6.

APPENDIX D.1: OVERVIEW OF PERSONS INTERVIEWED TO IDENTIFY VALUES AND THEIR CONCEPTUALISATION IN 'DE VRUCHTENBUURT'

Interviewee	**Organisation**	**Expertise**
Senior policy advisor	Ministry of Economic Affairs and Climate Policy	Integration of new energy systems (social, governance and technical)
Senior policy advisor	Ministry of Economic Affairs and Climate Policy	Energy markets
Head of Energy Markets and Innovation	Ministry of Economic Affairs and Climate Policy	Energy markets
Senior policy advisor	Ministry of Economic Affairs and Climate Policy	Acceptance of new energy systems
Policy advisor	Ministry of Economic Affairs and Climate Policy	Heat transition in city districts
Policy officer	Ministry of Economic Affairs and Climate Policy	Acceptance of energy transition on regional level
Research manager Energy Transition Studies	ECN part of TNO	Smart grids, smart energy systems and all-electric districts
Advisor Energy Research and Development	Netherlands Enterprise Agency (RVO)	Pilot projects with smart grids and decentralised energy systems in the built environment
Strategy manager transition	Netbeheer Nederland	Social aspects of the energy
Regional coordinator for the Energy Transition	Stedin	Process management in energy infrastructure
Active initiator in 'De Vruchtenbuurt' district	/	Local expertise
Active board member of Warm in de Wijk' in the 'De Vruchtenbuurt'district	/	Local expertise
Senior policy advisor Energy Transition	Municipality of The Hague	Local expertise

APPENDIX D.2: INTERVIEW QUESTIONS

Round 1	- What is your role in the energy transition? - What other parties are you working with? What other parties are critical in this problem? - What is your link to decentralised heating systems? - What is your link to 'De Vruchtenbuurt'? - What would you describe as remarkable aspects of this city district? - What aspects (values) should be considered during the transition to a decentralised heating system? - What specific household characteristics should be considered during the transition to a decentralised heating system? - How do you think these characteristics influence values? - What do you expect to be the biggest obstacle in the transition to a decentralised heating system? - Which governance and technologies do you expect to have much potential? - What do you expect from bottom-up initiatives? Is there enough support for these initiatives? - Do you expect that a general approach for city districts to change to a decentralised heating system can be identified?
Round 2	- What is your role in the energy transition? - With what other parties are you working together? What other parties are critical in this problem? - What is your link to decentralised heating systems? - What is your link to 'De Vruchtenbuurt'? - Do you agree with the chosen values? Are any important values missing? - Do you agree with the chosen conversion factors? Are any important conversion factors missing? - Do you agree with the chosen governance models and technical designs? Are any models or designs missing?

APPENDIX D.3: HOUSEHOLD AND HOUSING DATA IN 'DE VRUCHTENBUURT'

Type of data	Data	Distribution to individual households	Source
Annual disposable income	- Distribution of annual disposable income for the Hague applied to 'de Vruchtenbuurt'	- Distributed to individual households depending on the type of housing: households living in single-family houses have the highest income, followed by those in duplexes and those in flats. - A normal distribution over each annual disposable income to compensate for the fact that the relationship between income and type of housing is not completely linear.	CBS data (CBS, 2019)
Ownership	- Owners: 80.2% - Tenants: 19.8%	- Percentages of ownership per type of housing (MBZK, 2019)	Data The Hague 'in cijfers' (The Hague, 2019)
Type of household	- Single-person household: 35.4% - Couples without children: 26.2% -Couples with children: 29.2% - One parent with children household: 9.2%	- Percentages of type of household per type of housing (MBZK, 2019)	Data The Hague 'in cijfers' (The Hague, 2019)
Energy label	- Data taken from map	- For houses with an unknown energy label, we assign labels using a normal distribution over the average energy label of that type of housing in 'de Vruchtenbuurt'.	Nationale EnergieAtlas (EnergieAtlas, 2019)
Type of housing	- Taken from Google Maps	\	Google Maps
Surface per type of housing	- Taken from the IF Technology report	\	IF Technology (IF Technology, 2018)
Heat consumption per house	- A function of the energy label, size and type of house	\	Thesis Dasa Majcen (Daša Majcen, 2016)
Green electricity	- Percentage of households using green electricity: 69% - Percentage of households using grey electricity: 31%	- Randomly distributed over households	Energiemonitor 2017 (ACM, 2017)

APPENDIX D.4: TECHNOLOGICAL DATA OF HEATING SYSTEMS CONSIDERED IN 'DE VRUCHTENBUURT'

Costs

	Purchase and installation costs	Maintenance costs per year	Connection costs	Consumption costs	Sources
Individual heat pump	6500 EUR	150 EUR	/	0.022 EUR /MJ	(Milieu Centraal, 2019a) (Stedin, 2019)
Collective heat pump	250 EUR /kW	7.5 EUR /kW	200 EUR	0.015 EUR /MJ	(Milieu Centraal, 2019a) (Stedin, 2019)
Collective geothermal heat	Apartments: 8000 EUR Houses: 12000 EUR	/	200 EUR	0.003 EUR /MJ	(In't Groen et al., 2018) (Schilling et al., 2017)
Individual electric boiler	2000 EUR	20 EUR	/	0.056 EUR /MJ	(Milieu Centraal, 2019a)
Waste heat	Apartments: 8000 EUR Houses: 12000 EUR	/	200 EUR	0.00745 EUR /MJ	(Hers et al., 2018) (Schilling et al., 2017) (van Vliet et al., 2016)
Gas boiler	1600 EUR	70 EUR	171.97 EUR	0.025 EUR /MJ	(Milieu Centraal, 2019a) (Stedin, 2019)
Thermal Insulation	Data per m2 and energy label	/	/	/	(Hers et al., 2018) (Schilling et al., 2017)

Costs of thermal insulation of apartments to a higher energy label (EUR/m2, adapted from Hers et al. (2018))

	A+	A	B	C	D	E	F	G
Currently G	441	141	116	102	80	57	30	0
Currently F	337	138	107	89	61	30	0	-
Currently E	337	132	96	75	43	0	-	-
Currently D	253	160	80	34	0	-	-	-
Currently C	267	157	72	0	-	-	-	-
Currently B	119	84	0	-	-	-	-	-
Currently A	64	0	-	-	-	-	-	-
Currently A+	0	-	-	-	-	-	-	-

Costs of thermal insulation of single-family houses to a higher energy label (EUR/m2, adapted from Hers et al. (2018))

	A+	A	B	C	D	E	F	G
Currently G	303	170	140	123	96	66	33	0
Currently F	277	166	128	106	72	35	0	-
Currently E	232	147	107	85	49	0	-	-
Currently D	198	122	76	49	0	-	-	-
Currently C	218	185	69	0	-	-	-	-
Currently B	82	70	0	-	-	-	-	-
Currently A	31	0	-	-	-	-	-	-
Currently A+	0	-	-	-	-	-	-	-

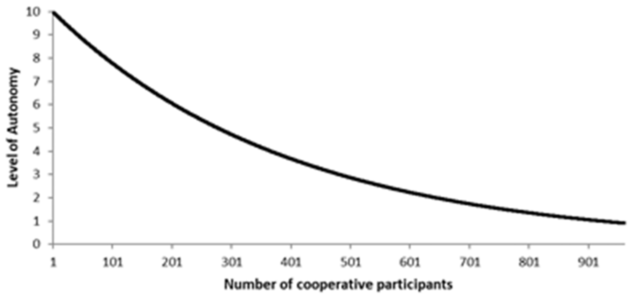
CO2 emissions (adapted from Milieu Centraal (2019b))

	kg CO2 per MJ	Efficiency energy source to heat	kg CO2 per used MJ
Heat pump	0.1147	2.5	0.04588
Collective geothermal	0.1147	4	0.02868
Electric boiler	0.1147	1	0.1147
Waste heat	0	0.9	0
Gas boiler	0.0537	0.85	0.0632

APPENDIX D.5: ODD+D MODEL DESCRIPTION

Overview	
Purpose	- To identify value conflicts in underlying sustainable heating systems
State variables and scales	- The agents have characteristics of households (annual disposable income, heat demand, housing ownership, type of electricity consumed (green or grey) and type of household) and housing (energy label, surface, and type of building). - All households and housing data remain the same for the entire duration of the model run. The goal of the model is to identify how these data affect the occurrence of value conflicts. - Various sustainable heating systems are tested. Each system is associated to purchase, installation and consumptions costs, CO2 emissions, ownership (individual, community initiative or private company), and financing (subsidy, zero-interest loan, or no public support).
Process overview and scheduling	- Setup: — 15% of agents are asked to join the community initiative, the others continue to use natural gas. — All agents evaluate the initial fulfilment of their values. - Go: — Agents try to increase the fulfilment of their individual values. At every tick, agents decide to join or exit the community initiative according to what maximises the sum of the fulfilment of their values most. All households have the same values. The fulfilment of their values might however differ depending on the household and housing characteristics and the heat consumption choice they made. — The model runs until all agents have no further opportunities to increase the fulfilment of their values (approx. 10 ticks).
Design concepts	
Theoretical and empirical background	- Value Sensitive Design (Friedman, 1996): technologies are not value neutral but are value-laden. - Ethics of Technology and value conflicts (Van de Poel, 2015): the realisation of some values may affect others.
Individual decision-making	- At every tick, agents aim to increase their overall level of value fulfilment (sum of all five levels of fulfilment of values). — Values are Thermal comfort, Affordability, Environmental Sustainability, Autonomy and Inclusiveness. Their fulfilment is a number between 0 (not fulfilled) and 1 (completely fulfilled). - Agents evaluate which of the following options increase their overall level of value fulfilment most: 1. Join (or stay in) the community initiative. 2. Quit (or stay out of) the community initiative and rely on natural gas consumption for heating. - Agents calculate the best feasible option. The option is feasible if they have sufficient income to afford it. The best option is the one that maximises the level of value fulfilment most. If no option is feasible, they choose natural gas consumption.

Learning	- None
Individual sensing	- Agents look at their surroundings to evaluate the value inclusiveness: the more neighbours that have made the same choice for heating (whether in or out the community initiative), the more they feel included.
Individual prediction	- None
Interaction	- Occurs in the model when agents evaluate the value inclusiveness.
Collectives	- Agents belong or do not belong to the community initiative. This means that they use the same technologies for heating. The level of insulation of houses might change.
Heterogeneity	- Agents are heterogeneous with regard to annual disposable income, heat demand, and housing ownership, type of electricity consumed, type of households, energy label, housing surface and type of building.
Stochasticity	- The following elements are stochastic in the model: — Randomised agent iteration. — Correlation between agent parameters (household and housing characteristics) if data for a specific household in the city district are unknown. This is essentially the case for household data: annual disposable income, heat demand, housing ownership, type of electricity consumed, type of household.
Observation	- The model provides the correlation between the evolutions of value fulfilment for different groups of agents. Two values are in conflict if the fulfilment of value 1 increases for one group and the fulfilment of value 2 decreases for another group, these.
Details	
Implementation details	- The model is implemented in Netlogo - The following functions are used: **Fulfilment of value** *Thermal comfort* We use a point system: — Individual heat pump: 0.45 — Collective heat pump: 0.45 — Collective geothermal heat: 0.55 — Electric boiler: 0.80 — Waste heat: 0.70 — Gas boiler: 0.80 Points are attributed based on the max temperature that each technology or source can provide. A good house insulation increases the level of points (max up to 1). *Affordability* We first calculate the sum of the following total costs per year: — NPV of purchase, installation and network costs (including subsidy and loans) — NPV of insulation costs — Consumption costs Then the willingness to pay: annual disposable income * 'U2_threshold_disposable_income_to_affordability' Affordability is a function of the willingness to pay and the total costs per year. Affordability is 0 if costs are higher than the willingness to pay and 1 when energy costs are less than 1% of the annual disposable income. *Environmental sustainability* This is the sum of the CO_2 emissions of heating consumption compared to systems with the lowest and highest CO_2 emissions for this household. Environmental sustainability is 1 if the sum is the same as the lowest CO_2 emission possible and 0 if the sum is same as the highest CO_2 emission possible.

Implementation details	*Autonomy* Autonomy = e−ax+ln(1−b)+b * mult , where: a = U2_slope_autonomy_size_community b = 0 mult = 10 x = Number of community initiative participants  *Inclusiveness* Percentage of neighbours having made the same choice for heating consumption (either in or out the community initiative)
Initialisation	- 15% of agents are asked to join the community initiative, the others continue to use natural gas
Input	- Household data: annual disposable income, heat demand, housing ownership, type of electricity consumed (green or grey) and type of household. - Housing data: energy label, surface, and type of building. - Heating option: costs and CO2 emissions.
Submodels	- No submodels

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Curriculum Vitæ

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List of Publications

Reviewed journal papers

1. **de Wildt T. E.**, Chappin E. J., van de Kaa G., Herder P. M., *A comprehensive approach to reviewing latent topics addressed by literature across multiple disciplines*, Applied Energy **228**, 2111–28 (2018).

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4. **de Wildt T. E.**, Boijmans A. R., Chappin E. J., Herder P. M., 2020. Ex ante assessment of the social acceptance of sustainable heating systems; An agent-based modelling approach. Manuscript in review.

Conference contributions

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