Anticipating social acceptance of heating alternatives in Amsterdam

Using value conflicts in an agent-based model

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Executive summary

The municipality of Amsterdam is currently in the middle of a heat transition. The municipality aims to cut down the use of natural gas for space heating in order to reduce its impact on the natural environment. For the Geerdinkhof neighborhood in Amsterdam South-East, the municipality is considering two sustainable heating alternatives: a collective district heating system and a semi-collective all-electric system. District heating systems make use of a collective heat source and rely on underground isolated pipelines to deliver the heat to the end-user. These systems are a significant investment in infrastructure and require adjustments to households before they are suitable for this type of system. The considered semi-collective alternative on the other hand is a heating system in which groups of 5-6 households share a heat pump installation. Heat pumps use electricity to generate heat, and can also be used to cool households during warmer periods. As of now, the municipality aims to transition Geerdinkhof to a more sustainable heating system after 2030.

A heat transition like the one in Geerdinkhof is a significant challenge, as the heating alternatives that are considered are sometimes met with some resistance from households. Households might not always want to switch to a heating alternative for a variety of reasons. The heat transition in Geerdinkhof can therefore become a question of social acceptance. Social acceptance is difficult to accurately define and operationalize, but most people generally have a feeling for what it means. In practice, social acceptance can be understood as a situation where people actively support the roll-out of a technology or conversely a lack of social acceptance is a situation where people act against the roll-out of a technology. Social acceptance can therefore be considered a question of predicting if households are going to make use of this new system or will they resist the implementation. This is of paramount importance to the municipality of Amsterdam, as they wish to supply their citizens with more sustainable space heating that is not resisted.

The difficulty in predicting social acceptance is that relations between the heating system configuration and the associated acceptance are complex. There are many different aspects of a system that can be designed, each with some impact on the household, with which households determine if they would accept the system or not. The systems (investment) cost, efficiency, governance and CO2 emissions influence how a household is affected by it, and in turn influences the social acceptance. The complexity of social acceptance analysis in sustainable heating systems stems from the multitude of relations, the difficulty of the conversion of perceived impact and social acceptance and finally the heterogeneity of households in a neighborhood.

This master thesis is an exploratory study into reasons for social non-acceptance of a new residential heating system in Geerdinkhof, Amsterdam. Given the long life-time of energy systems and large investments necessary, the municipality of Amsterdam is interested in identifying reasons households might not accept a new heating technology. This thesis makes use of the theory on human values, value change and value conflicts to evaluate how households are affected by a heating alternative in their value fulfillment.

Human values are understood as things people consider important or lasting convictions that people should strive for in order to realize a good society. Examples of values with respect to sustainable heating systems could be sustainability, affordability or residential comfort. In this work, social acceptance is said to follow if a heating system fulfills expectations households might have regarding their individual values. If a system does not fulfill a certain value for a household, then this system might enjoy lower social acceptance from this household. Analyzing values using this human values perspective allows for a holistic analysis of issues that might cause lowered social acceptance embedded within the system. Other types of analysis are either focused on a single domain (i.e.

heating technology) or fail to respond to the social effects a new heating system can have.

Values are dynamic and can change over time. The relative importance of values can change over time, and moreover new values can emerge or other values can become unimportant. This dynamic scenery of values is interesting to consider, as two values can also be in conflict. A so-called value conflict is a situation in which two values consider different options as the best choice, when considered in isolation. The reality is that you can only make one choice for a heating system, and that some values might be less fulfilled than desired. This value conflict can therefore indicate a social acceptance issue, and is important for the municipality to consider when they aim to anticipate and improve social acceptance.

In support of social acceptance for a heating system in Geerdinkhof, this study aims to explore what values are relevant for this neighborhood, how they could change and see which value conflicts are embedded in the heating alternatives. These value conflicts can help the municipality in prioritizing system design or policy decisions to overcome the possible social acceptance issues. This is done through combining both qualitative and quantitative elements, with the use of expert interviews and agent-based modelling.

The research is split-up in two parts. In the first part, interviews are held and combined with a literature study to identify the matters households value in a heating system. These values are then used for the second, quantitative, part. In this part, the Geerdinkhof neighborhood is modelled as an agent-based model using Netlogo 6.1.1. This socio-technical system is modelled to explore which value conflicts can be identified. This model is able to explore the effects of different system configurations and value conceptualizations, which is impossible to do in real life. A value conceptualization is simply a different way to interpret the same value. The research is primarily concerned with exploring embedded value conflicts, identifying which households are affected and proposing steps for resolving value conflicts.

After the first part, ten values were identified as relevant for this neighborhood, and five values were used for the modelling exercise: Affordability, Comfort, Inclusion, Freedom of Choice and Sustainability. Additionally, for three of these values different conceptualizations have been tested to consider the effect of different ways to interpret the same values.

Using three different experiments, value conflicts were explored using different heating alternatives and system parameters. Consequently, these value conflicts were considered on their impact on households. Ideally, all conflicts can be resolved but the reality is that some value conflicts have to be prioritized over others as limited resources are available. In this work, value conflicts are considered to have a higher impact if there is a large number of households experiencing this conflict, there is a large average decrease in value fulfillment or if there is a specific group of households affected.

Three groups of conflicts have been identified to have the largest impact: conflicts related to the neighborhood specifics, conflicts with lowered affordability and conflicts with lowered comfort. Additionally it was found that some value conceptualizations are conditions for the emergence of certain value conflicts, indicating that considering a new way to interpret a value is important when exploring all possible conflicts.

Three recommendations are made to the municipality of Amsterdam in support of social acceptance of a new heating alternative in Geerdinkhof: increase the affordability of the system through subsidies, prioritize household insulation for increased thermal comfort and answer to the Geerdinkhof neighborhood characteristics. Geerdinkhof residents generally have the time and means available to participate in the heat transition, and opportunities lie in properly considering how to include households in the process and how to deal with ownership.

This work aimed to make three contributions. Firstly, it is to provide the municipality of

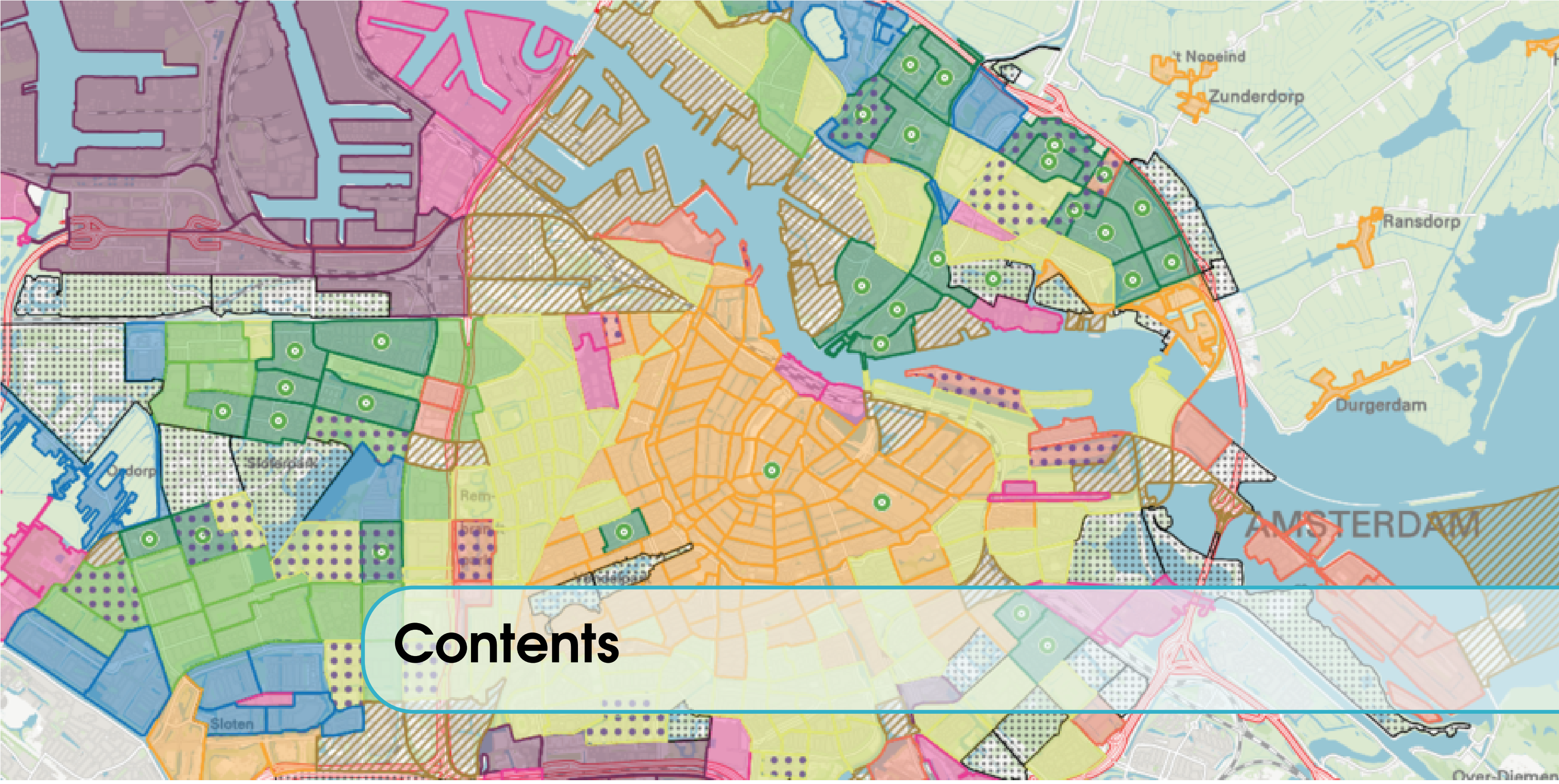
Amsterdam with a new way of considering social acceptance of heating alternatives. We do not argue that this approach has not been done before as it can be considered an extension of De Wildt (2020), but rather that considering human values can give different insights then when only technical specifications are considered. Secondly, this research contributed to the body of literature on the conceptualization of values. As demonstrated, the way a value is interpreted can determine if a value conflict is found or not. Thirdly, contributions are made with regards to value change scenarios and value conflict prioritization.

Acknowledgements

Special thanks goes out to the municipality of Amsterdam for organizing this internship and those who have contributed to the contents of this thesis: the interviewed experts, the AMS institute and the people at the Energie lab Zuidoost.

I would like to thank my two supervisors Tristan and Else for their weekly insights, recommendations and where needed support. Additional thanks goes out to my friends and family who have supported me in this journey that is a Masters thesis.

Enjoy,
Jules
Delft, July 30, 2021



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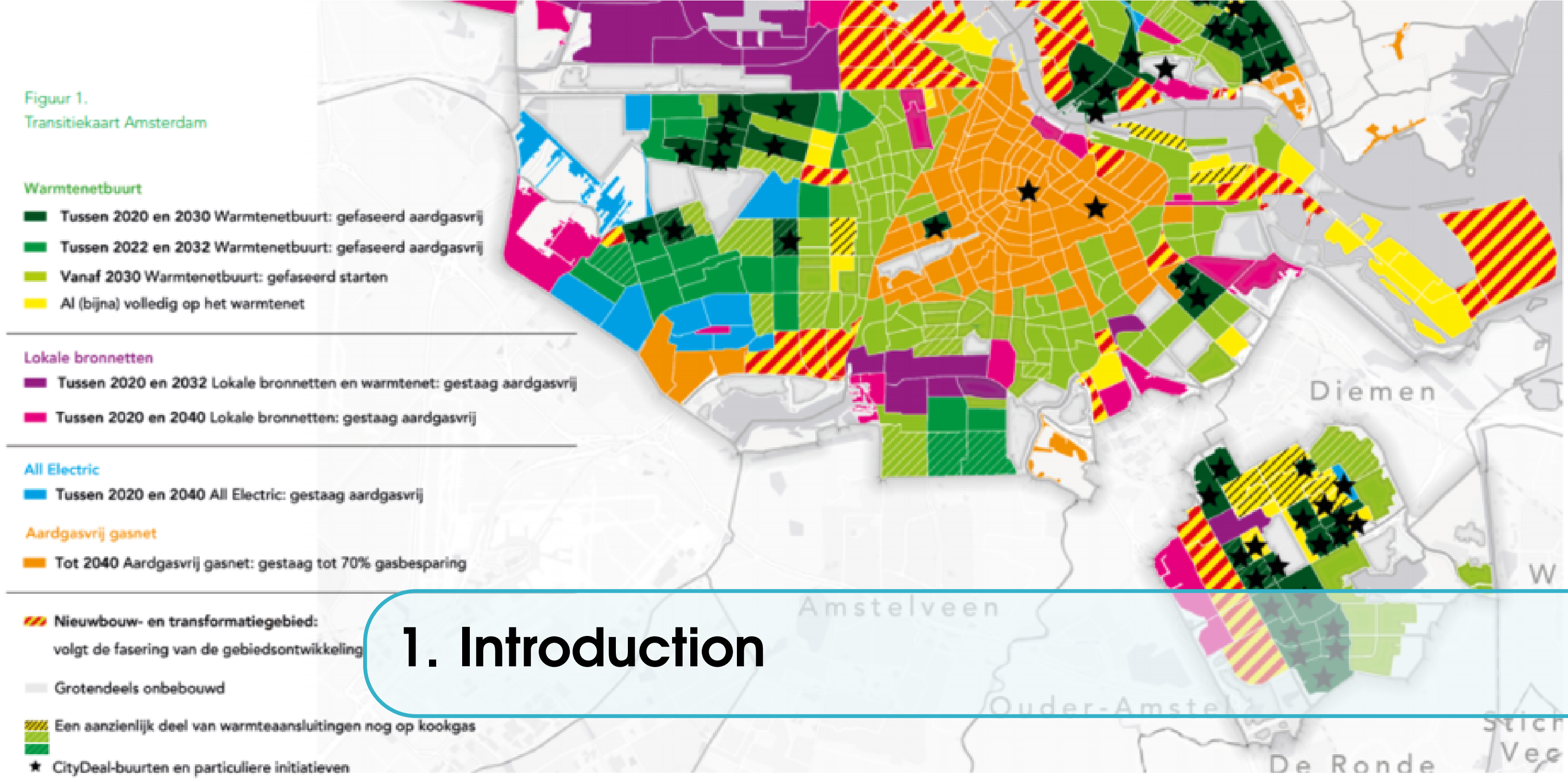


1. Introduction

International treaties such as the Paris Agreement call for large-scale CO2 reduction and climate change mitigation efforts (Falkner, 2016). In the Netherlands, the Climate Agreement describes sustainability goals for sectors as mobility, industry, electricity and the built environment (Rijksoverheid, 2019). Within the the built environment sector, the ambition is to make all residential heating natural gas-free by 2050. The municipality of Amsterdam has developed a vision for this heat transition (Municipality of Amsterdam, 2020b), in which a neighborhood-by-neighborhood approach is proposed (Municipality of Amsterdam, 2020a). The approach describes per neighborhood when and how it is to transition to an alternative heating solution. These alternative heating solutions range from the use of 'sustainable gas', all-electric solutions or District Heating (DH) systems. A district heating system is a system where use is made of '*local fuel or heat resources that would otherwise be wasted, in order to satisfy local customer demands for heating, by using a heat distribution network of pipes as a local market place*' (Werner, 2013). A DH network is typified by the heat source utilized, the thermal energy carrier fluid (usually water) and the carriers temperature (Lake et al., 2017). DH networks are a viable candidate to provide heat in a sustainable manner to households in the near future (Werner, 2017), as use can be made of residual heat that is otherwise lost. For example, the municipality is currently looking into utilizing the waste heat from large data centres for a new generation of DH systems (RVO, 2018). A schematic representation of a DH system using waste heat can be found in Figure 1.1.

On the other side, extensive resources are required to transform the heating supply for a neighbourhood from traditional gas supply to a district heating network. Although district heating systems can be competitive in terms of price (Gudmundsson et al., 2013), they still require large-scale investments in infrastructure, household connections and a proper heat source. As these energy systems have a long life-time of up to 40 years (Lund et al., 2010), close attention needs to be paid to issues that can arise during this lifetime. Examples of issues for DH systems are high costs for households (Ekker, 2019; Roos, 2020), inability to choose heat supplier (Van Zoelen, 2020; Ekker, 2019) and loss of thermal comfort (Van Zoelen, 2020; Roos, 2020). Additionally, the sustainability aspect

[1]See Appendix D for explanations and references for the chapter images.

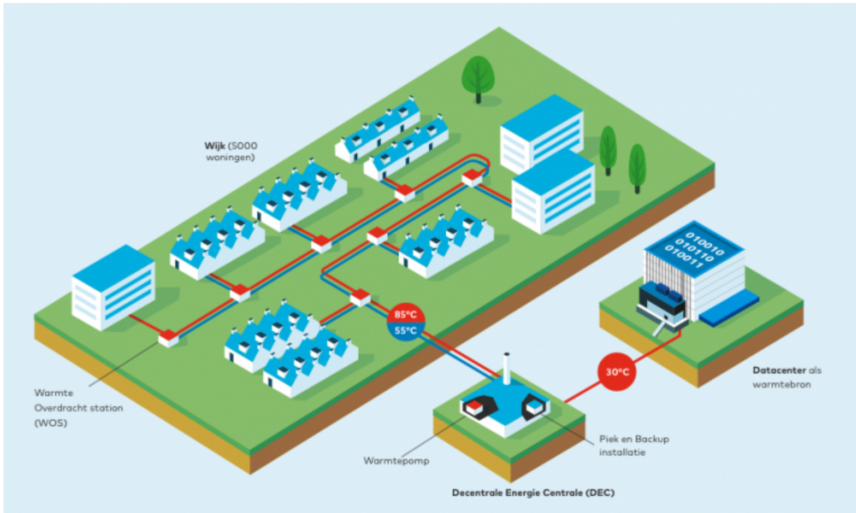


Figure 1.1: Schematic representation of a DH system making use of waste heat from data centres. Low temperature heat is captured from the data center, after which it can be stored in another facility and upgraded to a higher temperature before being transported to households using transfer stations. Image taken from Firan official website (Schiltmans, n.d.)

of DH systems is highly dependent on the heat source utilized (Milieu Centraal, n.d.; ECW, 2020; Werner, 2017) and choice of temperature of the water (ECW, 2020; Wilms, 2019). Additionally, low temperature DH systems are not suitable for all houses, and generally perform better in well-insulated houses with floor heating (Werner, 2017; Fang et al., 2013).

These characteristics of DH systems can give rise to social acceptance issues. Social acceptance issues generally take the shape of resistance against the implementation or low penetration of the system among households. These issues are not as easily anticipated or designed for as a design requirement like the durability of the infrastructure. This can be due to the plethora of interpretations and dimensions of social acceptance (cf. Batel et al. (2013); Wüstenhagen et al. (2007); Fournis & Fortin (2017)), and the difficulty of predicting social acceptance. De Wildt (2020) identified two reasons why social acceptance is difficult to predict: firstly, the impact of new heating systems is difficult to assess as their configuration and suitability is highly dependent on local conditions. Secondly, the way this impact is perceived by households and the following social acceptance is highly unpredictable (De Wildt, 2020, p.100).

In this thesis, possible social acceptance issues for DH systems in Amsterdam are explored from a (human) value perspective. Design of technologies can have impact on human values (such as privacy or inclusion) (Van de Poel, 2016), and if not properly considered, can lead to conflicting values. The notion of conflicting values can be used to anticipate social acceptance issues (De Wildt (2020); De Wildt et al. (2020)). We extend on the work of De Wildt (2020), who addressed social acceptance issues through identifying value conflicts for a neighbourhood in The Hague. A similar approach will be applied to a neighbourhood in Amsterdam, with special attention for value conceptualization and value prioritization.

1.1 Scope

As there is only a limited time of 6 months available for this research, choices have to be made in what is and is not taken into account. Below the scope of this research is described, with first the neighborhood that is to be studied and after that some general scoping.

1.1.1 Neighborhood: Geerdinkhof

In collaboration with the municipality of Amsterdam and the Energie lab Zuidoost, the Geerdinkhof neighborhood was selected as the object of study. Geerdinkhof makes for an interesting case study, and is relevant for the municipality as it is also included in their transition vision *Amsterdam aardgasvrij*[2] (natural gas free). Geerdinkhof is interesting as a case study for two reasons: first it is similar to many other neighborhoods that have to switch to natural gas free heating options in Amsterdam. Geerdinkhof is built around the same time as many other neighborhoods in Amsterdam (e.g. Bullewijk, Kantershof or Holendrecht). Secondly the neighborhood has some characteristics that make it an interesting case study. These are mostly architectural features and the heterogeneity of the people living there. Although it is a relatively affluent neighborhood compared to other neighborhoods in Zuid-Oost, there is a lot of difference between types of houses, insulation and PV installations and difference between education levels, spendable income and age group. This neighborhood was also a practical object of study: it is one of the few neighborhoods in Zuid-Oost that has not started any concrete process towards the heat transition. Other neighborhoods are already a bit further in the realization/negotiating process, and a analysis such as this one could hinder the process.

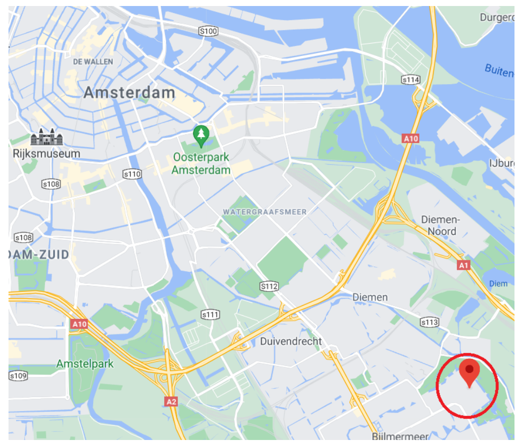


Figure 1.2: Location of the Geerdinkhof neighborhood in Amsterdam South-East. Image taken from Google Maps.

The Geerdinkhof neighborhood has been build in the 1970's and '80's, and consists largely of single-family houses that are meant for private ownership. Houses are on average well-insulated (energy labels A, B or C), but there are also households that are considerably less well insulated. There are 679 addresses carrying the Geerdinkhof name, all being the aforementioned single-family homes. Additionally in the neighborhood is the Garstkamp apartment complex. This complex houses 349 apartments meant for senior residents, and are all under management of the Ymere foundation[3]. Interesting about the neighborhood is that the roads are meandering organically throughout the neighborhood and the houses are built in such a way that the only entrance is through a front garden. Additionally the gardens are walled and the houses are built in such a way that there is little noticing your neighbors. This makes for a relatively child-friendly and expensive neighborhood (sometimes referred to as the gold coast of the Bijlmer).

[2]The interested reader can read more on what the city has published about their neighborhood by neighborhood approach for the heat transition via `https://www.amsterdam.nl/wonen-leefomgeving/duurzaam-amsterdam/aardgasvrij/`

[3]`https://www.ymere.nl/over-ons`

Regarding the demographics of the neighborhood, one of the interviewees (described in Chapter 4) described the people living there as affluent on general, and an entrepreneurial spirit when it comes to collective action. This can perhaps best be illustrated through the Geerdinkhof neighborhood association website[4], where Geerdinkhof residents can find news-updates, information and additionally blog.

In the transition vision by the municipality, Geerdinkhof is to switch to a DH system after 2030 (Municipality of Amsterdam, 2020b). As this is quite far away still, there are little concrete plans on the organizational arrangements or technical specifications like type of heat source. In this research, two heating alternatives are considered for Geerdinkhof: a collective (DH) system and a semi-collective all-electric solution. The collective system can be interpreted as a DH system as described above with to-be-determined specifications. The semi-collective system is a solution in which groups of approximately six households share heat-pumps to provide residential heat.

1.1.2 Other scoping

Next to performing this research on a specific neighborhood, some other choices have been made regarding scoping. This study is primarily concerned with exploring what value conflicts can be observed when switching to a heating alternative. As such, this thesis does not delve too deep into the technical aspects that are associated with realizing such a heating alternative. Feasibility, (societal) cost, availability of a suitable heat source and institutional aspects as investments or operational organization are left outside the scope of this research. This partly due to the time limitations a master thesis poses, and partly due to the desire to focus the analysis on underlying human values rather than technical details.

To add to this, also the realization process of a new heating process is not considered too closely. Rather, it is assumed that the municipality of Amsterdam will initiate a reasonable process that has as primary goal to increase the liveability for Geerdinkhof residents at a lower environmental impact. This implies a certain due diligence with regards to process design. Design of a fair heat transition process should get the attention of a separate study, and studying it in little detail in this thesis would not do it justice.

Additionally, it is explicitly not the goal to predict household decision-making. This work is intended to explore value conflicts, and not to serve as a tool to predict what choices households make under certain conditions. This choice is made as it is interesting to consider what embedded value conflicts certain heating systems bring, as it can tell more than for example a technical analysis alone. Additionally, predicting household decision-making can be done with more suitable means as discrete choice experiments, household surveys or other methods.

1.2 Thesis organization

The thesis work is supported by the Energy Lab Zuidoost[5]. Energy Lab Zuidoost is an initiative to connect science to practice to support the energy transition in Amsterdam South-East. The Energy Lab is a collaboration between the City of Amsterdam, the Amsterdam Institute for Advanced Metropolitan Solutions (AMS institute[6]), the Urban Energy Institute of the TU Delft[7], the University

[4] https://geerdinkhof.nl/
[5] https://www.energielabzuidoost.nl/
[6] https://www.ams-institute.org/
[7] https://www.tudelft.nl/urbanenergy

of Amsterdam (UvA) and the Applied University of Amsterdam (HvA). The assignment is structured as a paid internship at the City of Amsterdam. The City of Amsterdam acts as the problem owner.

The involved supervisors are Tristan de Wildt and Else Veldman. Tristan de Wildt, the daily supervisor, is a post-doctoral researcher on value change and social acceptance of energy systems at the faculty of Technology, Policy and Management of the TU Delft. Else Veldman, the external supervisor from the AMS Institute, is program lead of the Energy Lab Zuidoost. This ecosystem of the Energy Lab provided some of the interviewees and gave welcome insights during periodic updates on the thesis work.

1.3 List of concepts and abbreviations

Readers may come across concepts or abbreviations used in this thesis that are unfamiliar to them. Also, readers may refer back to this section if they are unsure what is meant with certain concepts.

List of concepts

- Agent-based Modelling (ABM): a type of modelling technique in which individual agents can interact with each other, see Section 3.2.3.
- District Heating (DH): a network of insulated pipes carrying heated water from a heat source to residential areas, for heating purposes.
- Social acceptance: a system is said to be socially accepted if its deployment is not resisted (passive interpretation) or if its deployment is supported (active interpretation), see (Batel et al., 2013). For a more extensive discussion on social acceptance, see section 3.1.1 or the dimensions of social acceptance proposed by (Wüstenhagen et al., 2007) or (Fournis & Fortin, 2017).
- Value: "*lasting convictions or matters that people feel should be strived for in general and not just for themselves to be able to lead a good life or realize a good society*" (Van de Poel & Royakkers, 2011, p. 72).
- Value conflict: when the realization of a value inhibits or otherwise limits the realization of another value, or more specifically "*two or more values conflict in a specific situation if, when considered in isolation, they evaluate different options as best.* (Van de Poel, 2009).
- Value change: a change of the relative importance of certain values over time. See (Van de Poel, 2018) for a more critical taxonomy of value change.
- Value change scenario: a coherent story-line or narrative in which a likely shift in prioritization of values is observed.
- Value conceptualization: A conceptualization is interpreted as a way of defining or interpreting a value. Two different value conceptualizations can cover different aspects of the same value (See section 4.4)

List of Abbreviations

- ABM: Agent-Based Modelling
- DH: District Heating
- FOC: Freedom of Choice
- RET: Renewable Energy Technologies
- SAS: Storyline-and-Simulation (research approach)
- STS: Socio-Technical System

1.3.1 Reading guide

In Chapter 2 the research problem is described and the research questions are posed. Following that, Chapter 3 describes the theory and methodology used in the following chapters. The research is thereafter split in a qualitative part (Chapter 4) and a quantitative part (Chapter 5). In the qualitative part, interviews and literature are used to identify what values are important to accept a heating alternative in Geerdinkhof. In the quantitative part, an Agent-Based Model is constructed to explore possible value conflicts for the heating alternatives considered. In the final chapter, the findings are synthesised and used to formulate recommendations for the municipality of Amsterdam after which the conclusions and discussion are given.

2. Problem definition

In this Chapter, the research problem is formulated, the knowledge gap is described and the relevance is demonstrated.

2.1 Research problem

The research problem follows from a combination of the long life-time of DH systems and phenomena that might cause social acceptance issues. In an ideal world, phenomena that might lower the social acceptance of a DH system can be predicted and anticipated for before they have any real impact. The reality is different however, as there is a plethora of reasons why a household does not accept the DH system. These reasons can include technical specification of the systems (type of heat source), institutional aspects (price, organization) or perceptions about the possible impact (loss of independence for example). Given the long life-time of this type of systems, new reasons for non-acceptance can emerge or other reasons can become more prominent over time. This can be problematic for the municipality of Amsterdam, as they would like to supply their citizens with a heating alternative that helps the heat transition and enjoys social acceptance.

As social acceptance can play a great role in decision-making processes for renewable technologies (Roddis et al., 2018), it can offer great value for policy-makers to know *ex ante* which social acceptance issues can be anticipated, and how social acceptance can be supported through system design. As the neighbourhoods in Amsterdam are quite heterogeneous in terms of types of houses and citizens, the municipality is interested in what social acceptance issues it could anticipate in the (near) future and what measures it can take to support social acceptance based on neighborhood characteristics.

The research problem is maybe best formulated in the main research question: "*How can social acceptance of residential heating alternatives in Amsterdam Geerdinkhof be anticipated using a value conflict and agent-based modelling approach?*"

Research placement
There are different routes available to analyze a social acceptance problem such as the one in this thesis. The DH system can be considered from a technical point of view for example, considering the design specifications (such as the heat source or water temperature) and how that might affect the perception of the system by the households. One can also take a route that focuses more on the economical characteristics (price, economic feasibility, etc.) or institutional characteristics (ownership, contracts, etc.). Every route can give additional insight into how this system can become more socially accepted through design, given the complex interplay of system design, institutional rules, social perceptions or policy.

The premise of this research is found in energy justice. Energy justice could be considered as a collection of frameworks with which the 'fairness' of production and consumption of energy can be assessed. Sovacool & Dworkin (2015) write: "*... an energy-just world would be one that promotes happiness, welfare, freedom, equity, and due process for both producers and consumers. It would distribute the environmental and social hazards associated with energy production and use without discrimination. It would ensure that access to energy systems and services is equitable. It would guarantee that energy procedures are fair and that stakeholders have access to information and participation in energy decision-making*". Jenkins et al. (2016) describe that energy justice "*evaluates (a) where injustices emerge, (b) which affected sections of society are ignored, (c) which processes exist for their remediation in order to (i) reveal, and (ii) reduce such injustices*".

It is not within the scope of this work to critically discuss energy justice, but rather we follow Jenkins et al. (2016) and dissect energy justice into three 'tenets': Distributional justice, recognition and procedural justice. Distributional justice concerns the fair distribution of cost and benefits associated with energy production and consumption, and is aimed at investigating which injustices occur. Recognition concerns identifying which societal groups are affected by these injustices and finally procedural justice concerns identifying proper equitable procedures that engage all stakeholders in a non-discriminatory way (Jenkins et al., 2016). The discussion on justice is in essence a philosophical one, but is especially important to consider when designing technologies or policies that can translate accepted values to a household or individual level (Jenkins et al., 2017). In this case, the accepted value could be 'sustainability', as the heat transition is undertaken to mitigate climate change. Starting from energy justice, this research aims to explore which possible injustices occur when a neighborhood in Amsterdam Zuid-Oost switches to a more sustainable heating alternative. The question is which sections of society are affected, and how these injustices could be addressed through procedural justice or policy.

This research follows the route of (human) values. This route allows for a more holistic analysis of the problem at hand that can also include ethical considerations, rather than confining the analysis to a technological, economical, or institutional analysis alone. Ethics describe the field of study of what is morally right and what is not[1] , and the field of Ethics of Technology can thus provide guidelines on how technology can be used in an ethical manner (Luppicini, 2010, p.26). Technology, like a DH system, is designed to serve a function (i.e. provide residential heat) and as illustrated through Albrechtslund's discussion of Langdon Winners classic article "Do Artifacts have Politics?" [2], technology can also have ethical implications (Albrechtslund, 2007). This is in line with Kroes &

[1]From the Cambridge dictionary for 'ethic'

[2]In this article, the design of a New York city bridge is discussed. This bridge wouldn't allow busses to cross it, which caused less affluent people who often relied on public transit busses for transportation to be unable to reach the beaches of Long Island. This was less of a problem for the wealthier people, who owned cars that could cross the bridge. The bridge design therefore had ethical implications. See (Winner, 2010)

Van de Poel (2015), who argue that engineering practices are inherently value-laden and normative. To account for these ethical implications of technological design, the research is placed within Value Sensitive Design (VSD, cf. Friedman (1996)). VSD is a design approach that is "*a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process*" (Friedman et al., 2002). Human values are especially important when design choices can have negative consequences. As S. H. Schwartz (2012) put it: "*Values enter awareness when the actions or judgements one is considering have conflicting implications for different values one cherishes*" (S. H. Schwartz, 2012, p.12).

A more elaborate discussion on human values is given in Chapter 3. Placing the research within the context of VSD allows for analysis of the ethical implications of a DH system in Amsterdam Zuid-Oost. These ethical implications can take the form of value conflicts, which consequently influences the social acceptance of the DH system.

2.1.1 Knowledge gap

The knowledge gap this thesis aims to fill is threefold. Firstly, the work is an addition to the work of De Wildt (2020). This means that the premise of the research is to explore possible value conflicts in anticipation of social acceptance issues. Social acceptance issues can be caused by a plethora of factors, which makes them difficult to anticipate or design for. This is partly due to the different understandings of what social acceptance is (cf. Batel et al., 2013, Wüstenhagen et al., 2007, Fournis & Fortin, 2017), and the difficulty of predicting social acceptance (De Wildt, 2020, p.100). To overcome these difficulties, we follow the approach by De Wildt (2020), who used embedded value conflicts in energy systems to anticipate social acceptance issues for a neighborhood in The Hague (De Vruchtenbuurt). Analysis of value conflicts are suitable to support social acceptance because it does not rely on the prediction of stakeholder opinions and decision-making and additionally this type of analysis allows for a wider range of concerns that may lead to lowered social acceptance (De Wildt, 2020, p.5). The first part of the knowledge gap is therefore how this approach would translate to a different neighborhood. The question is if similar findings can be found if a neighborhood with different characteristics is used, and if different relevant values can be found through empirical research. The second and third part of the knowledge gap are found in De Wildt (2020)'s research agenda: to incorporate conceptualization of values and future research on the prioritisation of value conflicts.

Value conceptualizations can best be understood as different ways to interpret the same value[3]. Conceptualizations of values are especially interesting to consider, as stakeholders can understand certain values differently which can lead to conflicts (Taebi & Kloosterman, 2015). How such a value should be conceptualized is however a difficulty to find in literature (De Wildt, 2020, p.128), and as such De Wildt (2020) used the Capability Approach for their conceptualizations. There is however a described weak link between this approach and the analysis of energy systems (De Wildt, 2020, p.128), and a different method of conceptualizing values can prove an addition. De Wildt (2020)'s research agenda of incorporating multiple conceptualisations of values is therefore part of the research. We aim to add to the body of literature concerning the conceptualization of values as there is currently a lack of such literature, and to explore the conflicts following the use of multiple conceptualizations.

[3] One could interpret the value *Sustainability* as minimizing CO2 emissions, but another interpretation could be *Sustainability* as ensuring that no damage is done to local wildlife. Although one could argue that less CO2 emissions means less damage to wildlife, they can be considered different interpretations of the same value.

Within the same research agenda, De Wildt (2020) identified the need for future research on prioritization of value conflicts. He calls for a more systemic approach to identify which value conflicts can be considered more severe and require more priority in resolving. The question is how one can judge the severity or impact of an explored value conflict, and how these conflicts relate to each other such that a prioritization can be made.

2.2 Research questions and approach

In this section the research questions are posed and the research approach is described. The research questions divide the research in different parts and the approach guides the search for answers.

2.2.1 Research questions

This research aims to formulate an answer to the following question:

"*How can social acceptance of residential heating alternatives in Amsterdam Geerdinkhof be anticipated using a value conflict and agent-based modelling approach?*"

Next to the main research question, four sub-questions are posed to divide the research in smaller, manageable, parts.

1. What are the relevant values and what are their conceptualizations for heating alternatives in Geerdinkhof (Amsterdam Zuid-Oost)?

The first question mostly relates to the first part of the knowledge gap described above. In translating the approach by De Wildt (2020) to another neighborhood, more exhaustive empirical research is needed to elicit the values households find important in accepting a new heating alternative. In order to answer this research question, an overview of relevant values for this neighborhood has to be sought after. Additionally, here a closer look is taken at how some of these values might be interpreted different ways, leading to conceptualizations of the same value.

2. How can the Agent-Based Modelling approach from (De Wildt, 2020) be translated to the case of Amsterdam to identify value conflicts in anticipation of social acceptance?

After constructing an overview of the relevant values and their conceptualizations, a closer look at the modelling part of the approach is taken. Answering this sub-question will lead to an ABM that is adjusted to the neighborhood in Amsterdam and is able to evaluate different conceptualizations of values. This could mean adjust the existing model, or construct a new one all-together from a similar value conflict starting point.

3. What value conflicts can be observed in the neighborhood of Geerdinkhof and what is their relative impact?

This research question aims to combine the efforts made in the prior two questions. The selected relevant values and their conceptualizations and the suitable ABM are used to see what value conflicts can be observed, and how much impact these conflicts have. Here, also the effects of different conceptualizations is observed and a closer look at recognition justice is taken. It is of course interesting to see where certain conflicts concentrate.

4. How can social acceptance be supported by the use of the identified value conflicts?

The final research question is used to make recommendations to the municipality of Amsterdam. This means taking a close look at the results from the third sub-question, to see which conflicts should be prioritized over others. Additionally, a look at procedural justice is taken to see how these value conflicts could be resolved, in support of social acceptance.

2.2.2 Research approach

Due to the qualitative nature of human values and the importance to provide a substantiated discussion on social acceptance, choice was made to make use of the Storyline-and-Simulation approach (Alcamo, 2008). This approach aims to combine the strengths of qualitative research with quantitative modelling, while addressing possible weaknesses. A more detailed explanation of this approach can be found in Section 3.0.1

2.2.3 Relevance

Other than the previously described knowledge gap this research aims to fill and associated scientific relevance, it can also be considered of relevance for society.

Scientific relevance

The scientific relevance mostly relates back to the knowledge gap, but is in the basis an exploration of how value change and value conflict theory can be used in combination with ABM in support of social acceptance of energy systems. As this is perhaps not the most easy thing to explain to colleagues at the coffee-machine, the relevance is is divided in three parts.

The first part of the scientific relevance is the combination of computer models in the evaluation of moral issues related to the social acceptance of energy systems. The use of ABM can help make cognitively demanding analyses of complex relations between values and social acceptance more doable and allow a more informed discussion. Rather than basing a policy decision or design requirement on a hypothesized relation between value conflict and stakeholder acceptance, the discussion can be substantiated with model results and 'what-if?'-scenarios[4]. Using ABM and human values, a more holistic approach in support of social acceptance can be taken. The analysis is not confined to a technological or institutional analysis alone, but rather allows for a normative analysis of the underlying moral issues caused by a new energy system. By relating moral issues of energy systems to their social acceptance, policy-makers can better consider the moral implications of a new energy system.

Secondly, the use of conceptualizations of values is of scientific relevance. Investigating the effects different value conceptualizations can have on model outcomes can give valuable insights. These insights are not only related to how a certain value can be interpreted in different ways, but also how certain conflicts can arise when two stakeholders have different conceptions about what a certain value means. This forces the researcher to think of the many ways the same value can be interpreted, and what the effects are.

Finally, the use of value prioritizations is scientifically relevant. Prioritizing one value over another is often a subjective matter, and can change from stakeholder to stakeholder. The scientific

[4]These scenarios allow to experiment with the system, something that is considerably harder to do in real-life. In the model, you can see what happens when the system becomes cheaper or what happens if you consider different values.

relevance is then in how one can prioritize one value over the other on a more objective basis. This is especially relevant for policymakers, which is described in more detail below.

Societal relevance

Regarding societal relevance, this thesis aims to provide the municipality of Amsterdam with a new point of view to consider social acceptance issues from. Zaunbrecher et al. (2016) found in their study of German DH systems a need for integrating the citizens perspective into technical modelling of heating scenarios, stating it is a "critical issue" in the decision process. The citizens perspective is considered in this thesis by taking a look at *their* values, and for example not the values of the municipality or heat supplier. This value perspective is maybe more holistic as it considers not specific reasons for non-acceptance, but rather looks at the underlying human values. If underlying values are insufficiently met by the new system, the municipality can take action to better address these values. This is especially useful when done *ex ante*, as it is easier to change design requirements and policies before than after implementation.

Often times, new energy systems are considered using a societal cost and benefit analysis. These compare the cost of developing a new energy system, and what benefits in terms of cost reduction or CO2 savings this could deliver. Problematically however is that there is a need for a common comparing scale, which usually boils down to translating all costs and benefits to some monetary value and compare that. Normative elements and moral issues can be lost in this translation, which can make that some things are neglected in the consideration or some things are given too much attention. By looking at embedded value conflicts for the heating alternatives, these normative elements are at the basis of the analysis.

3. Theory and Methodology

Within this chapter, the theoretical background for this thesis is described. The chapter begins with elaborating on the Storyline-and-Simulation approach, after which theory on social (non-)acceptance, values, value change, value conflicts and participation is discussed. After that, the used methods are described.

3.0.1 Storyline and Simulation approach

The answers to the posed research questions are sought after through a combination of methods. From the range of research questions it is clear that both use of qualitative and quantitative methods is required. Through identification of relevant values and scenarios of value change, the modelling approach can help identify what the impact is of different value change scenarios and help policy-makers anticipate social acceptance.

The research approach should make use of the strengths qualitative scenarios and quantitative modelling can offer, and provide a coherent basis for analysis. Qualitative scenarios are useful in synthesising expert views into possible future developments, but often face problems with reproducibility and can sometimes be considered "unscientific" (Alcamo, 2008). Underlying expert assumptions are not always explicit, making it hard to reproduce the same results with different experts. Quantitative methods on the other hand are practical in the sense that they provide numerical results (Alcamo, 2008). This makes underlying assumptions explicit as they are conceptualized in the model (Alcamo, 2008), which poses challenges when cause-effect relations are not fully known which is often the case in socio-technological systems (Bogdan, 2019).

To combine strengths of qualitative and quantitative methods, while addressing the challenges these methods bring, the approach draws from the Storyline-and-Simulation (SAS) approach (Alcamo, 2008). This approach provides a general method to construct credible scenarios together with stakeholders, the use of models to produce quantitative results and harmonizing the findings from both parts. The SAS approach is devised to promote openness of the analysis process and to incorporate many different points of view. The following analyses are said to be more credible as more information is synthesized from both qualitative and quantitative methods, as well as being more relevant and creative due to the amount of views taken into account (Alcamo, 2008). The SAS approach has one drawback next to the reproducibility problem inherent to qualitative methods: that of conversion. As quantitative and qualitative information has to be converted back and forth, some information can be lost and attention needs to be paid on how to minimize information conversion losses (Alcamo, 2008).

This thesis draws from this approach in two regards. Firstly, close attention is paid to situations where conversions between qualitative and quantitative information and vice versa take place. Additionally to the conversion problem, the reproducibility problem is considered by closely documenting all assumptions made and acknowledging the effect expert interviews have on outcomes. Selecting different experts can give different relevant values or relations. Secondly, room for creativity is left in the first qualitative part of the research. Allowing for flexibility in this part of the research means that the sometimes unexpected inputs from experts can add to the overall creativity and legitimacy of the findings.

We do not argue that this approach is vastly different or innovative from a normal modelling exercise that makes use of expert interviews. Arguably, the same thought processes are used whether you call it SAS or not. It is however beneficial to acknowledge the advantages and drawbacks, adding to the awareness of why certain choices are made in this research.

3.1 Theory

Below is a description of theoretical background and theory used in this thesis.

3.1.1 Social (non-)acceptance and moral acceptability

As is the case with many latent topics, also social acceptance of energy technologies can be understood in a variety of ways. Everybody generally has a feel for what social acceptance could mean: the technology at hand is on average perceived as a positive change, has no major public concerns or does not have strong opposition. Overall, the people are better off with the technology than without. Adoption of innovations, creation of favorable policies and absence of citizen protests can be considered as forms of social acceptance (De Wildt, 2020, p.13; Wüstenhagen et al., 2007). In this section, a closer look is taken at what is meant with ‘social acceptance’, what the difference is between social acceptance and moral acceptability and why this is relevant for this thesis.

To define social acceptance

To properly discuss what social acceptance is, one must also acknowledge the difficulty of defining it. Although it is often used in literature, clear definitions are rarely given for “social acceptance” (Wüstenhagen et al., 2007). Devine-Wright (2008) described a lack of a widely accepted understanding of social acceptance. For starters, the phenomenon of social acceptance is interchangeable referred to by different disciplines as: social acceptance, public acceptance, local acceptance or inversely as social, public, or local opposition (Cohen et al., 2014). Additionally, “acceptance” and “acceptability” are also used interchangeably (Fournis & Fortin, 2017). Generally speaking, social acceptance of renewable energy technologies (RET) can be interpreted actively and passively. Active social acceptance is characterized by support, which in this case would mean there is clear supportive behavior for the DH system and it is actively promoted and adopted. This could take the shape of energy cooperations willing to realize a DH system or households willing to become co-owner of the network. Passive social acceptance can best be described as a “tolerance” for the system, as there is no active countermovement against the adoption of the DH system (like citizen protests) but also no active supportive behavior (Von Wirth et al., 2018). If there is little social acceptance (either active or passive), we enter the domain of non-acceptance. Examples of non-acceptance can be seen in the public resistance or stakeholder protests against for example siting decisions of nuclear plants, or when people simply do not use or adopt a new technology (Van de Poel, 2016). Reasons for non-acceptance may be lack of information, (un)justified fears, selfishness or indicate the moral unacceptability of a technology (Van de Poel, 2016).

Ideally, a potential lack of social acceptance of a new energy structure can be predicted and addressed before finalization of the DH system. This can be done for example by specifying design requirements or policy guidelines that address the source of lowered social acceptance (De Wildt, 2020, p.100). In reality however, social acceptance is hard to predict. (De Wildt, 2020, p.100) identified two reasons: firstly, it is difficult to assess the exact impact a DH system has on a specific household as it is very much dependent on the local conditions (type of housing, location, existing infrastructure). Secondly, even if this impact could be assessed perfectly, the way this impact is perceived by the households and the following social acceptance is highly unpredictable (De Wildt, 2020, p.100).

(Von Wirth et al., 2018, p.2619) stated: "*Energy-technologies acceptance may be defined as an affirmative reply or a positive attitude toward a technology or measure that is likely to lead to supporting behavior for the respective technology if necessary or requested*". This positive attitude is also seen back in in the discussion of the word 'acceptance' in low carbon energy literature (Batel et al., 2013). Additionally, they call for a more critical attitude towards the use of 'acceptance', as the lack of consistency and transparency in the use of the concept constraints the understanding of public responses to energy infrastructures. These not only include acceptance or support, but also resistance, apathy and uncertainty (Batel et al., 2013).

When taking a closer look at what constitutes social acceptance, there are different approaches possible. Different conceptual frameworks have been developed for social acceptance (cf. Devine-Wright, 2008; Bronfman et al., 2012; Wolsink, 2007a; Devine-Wright, 2009), but below two are discussed to demonstrate the range in approaches possible. In an influential article, Wüstenhagen et al. (2007) introduced three dimensions of social acceptance: socio-political, community and market acceptance. Socio-political acceptance is acceptance on the most general level, and constitutes acceptance of both policies and technologies by the public, key stakeholders and policy makers (Wüstenhagen et al., 2007). Community acceptance in turn refers to the specific acceptance of siting decisions and renewable energy projects by local stakeholders (Wüstenhagen et al., 2007). Community acceptance has a time dimension, and typically the community acceptance follows a U-shape pattern: going from high acceptance to low acceptance during the siting phase, and back up again once the project is up and running (Wüstenhagen et al., 2007). Finally, market acceptance relates to the process of market adoption of an innovation. This dimension relates not only to consumers adopting to green energy, but also to investors willing to 'accept' new technologies into their portfolio and intra-firm acceptance of renewable innovations (Wüstenhagen et al., 2007).

Another approach to what constitutes social acceptance is in the interpretation by Cohen et al. (2014). They formulate a definition that draws from economic utility and welfare theories, and stated "*Social acceptance of new infrastructure occurs when the welfare decreasing aspects of the project are balanced by welfare increasing aspects of the project to leave each agent at worst welfare neutral and indifferent to the completion of the project, or better off and supportive of the project.*" (Cohen et al., 2014, p.5). Welfare decreasing aspects can be understood as procedural injustice, safety concerns, pollution, reduced property values and others, while welfare increasing aspects can be understood as those that are seen as 'good': economic development, security of supply, compensation etc. (Cohen et al., 2014).

A final note on the definition of social acceptance is that scoping can matter. As illustrated by (Wolsink, 2007a), social acceptance has a time dimension. As local acceptance follows a U-shape curve, it can make a difference if you consider the social acceptance before, during or after the realization of a project (Wolsink, 2007a; Wüstenhagen et al., 2007). Additionally, scope regarding scale can also be important. The general acceptance of for example wind energy projects can be good when looking at a national scale, but when scoping down to a regional or community level the acceptance can be different, and usually lower (Fournis & Fortin, 2017).

Acceptance and acceptability

As said before, social acceptance and social acceptability are used interchangeably (Fournis & Fortin, 2017), but can be used to mean two conceptually different things. Social acceptance as described above is usually a descriptive assessment whether a technology is accepted by stakeholders. Social acceptability on the other hand identifies moral issues caused by technology (De Wildt, 2020, p.12). By making the distinction between these two concepts, different types of assessment are possible. Assessments of social acceptance are focused on anticipating stakeholder opposition (or lack of support), based on empirical data or descriptive analysis and usually on the level of stakeholders (De Wildt, 2020, p.13). Assessments on the social acceptability on the other hand are based on a value theory in a societal level of analysis, to evaluate moral issues caused by a technology (De Wildt, 2020, p.13). Acceptability thus concerns whether or not a technology is 'good' for society and ought to be strived for. In that respect, a technology can be considered better if it sufficiently considers a range of moral values (De Wildt, 2020, p.13; Friedman et al., 2008). Although the distinction between descriptive and normative is nice and neat, acceptance and acceptability can also be considered as thick concepts, which means they both have descriptive and normative contents (Van de Poel, 2016).

In Van de Poel (2016)'s discussion on the relation between social acceptance and moral acceptability of technology, social acceptance is found to be often framed as a problem to be overcome (Van de Poel, 2016). This frame is however problematic, as this can lead to a one-sided approach in which measures are taken to increase acceptance of the technology without considering this lack of acceptance to be a sign of non-acceptability of a technology (Van de Poel, 2016). According to Van de Poel (2016), by framing acceptance as a constraint to overcome, the moral issues that might lead to (non-)acceptance might be lost in the analysis (Van de Poel, 2016).

Social acceptance in this thesis

The scope is set at a household level, and the analysis makes use of empirical data and modelling. Although the importance of the moral dimension in an analysis such as the one in this thesis is underlined, it is not explicitly used. This is due to the fact that a normative acceptability analysis is less suitable for use in a technical modelling analysis[1]. The interest lies in anticipating when households experience what type of value conflicts, which are seen for underlying reasons for lowered social acceptance. This could give reasons for lowered social acceptability, but due to the household scope and combination of different data types choice is made for this thesis to use the descriptive operationalization of social acceptance.

[1] One of the requirements for this thesis for it to be a valid completion of this Msc degree is that there is a substantive engineering or modelling element.

3.1.2 Values, value conflicts and value change

Now that a workable interpretation of social acceptance has been formulated, it is worthwhile to look into what values are, how they can be considered dynamic and what happens when two values are in conflict.

Values

Values, sometimes referred to as human, personal or moral values in literature, can be most generally described as something people consider important (Friedman et al., 2002). A more detailed description is found in Van de Poel & Royakkers (2011): "*lasting convictions or matters that people feel should be strived for in general and not just for themselves to be able to lead a good life or realize a good society*" (Van de Poel & Royakkers, 2011, p.72). Examples of values can be found in Schwarts' overview of human values and include values like security, self-direction or hedonism (S. H. Schwartz, 2006). Examples of relevant values for DH systems are for example sustainability, affordability or flexibility and will be further discussed in Chapter 4. Schwartz described 6 features of values that are often implied in value-related literature (S. H. Schwartz, 2012):

1. **Values are beliefs**, and when activated they become infused with feeling.
2. **Values refer to desirable goals** that motivate action
3. **Values transcend specific actions and situations**. This distinguishes values from norms or attitudes, as these usually refer to specific actions or situations.
4. **Values serve as standards**. They can be used to evaluate actions, people or policies.
5. **Values can be ordered by importance relative to each other**. People are characterized as individuals through their own prioritization of values.
6. **The relative importance of multiple values guide action**, when they are relevant for the situation and important for the actor.

Values are important to consider when looking at social acceptance of technologies. Values can say something about the societal expectations of a technology (Tuana, 2015), and can help shape design requirements regarding efficiency, affordability or sustainability. Social acceptance of technologies can be supported and potential social opposition can be minimized if the relevant values are more carefully considered during the design phase (De Wildt, 2020, p.49; Van den Hoven et al., 2015). Similarly, social acceptance issues can be caused by unsatisfied expectations concerning values (Grunwald, 2015; Wüstenhagen et al., 2007). The underlying relation between social acceptance and value fulfillment can be considered complex (De Wildt, 2020, p.48), and the difficulty in resolving acceptance issues can be explained by value conflicts (Van de Poel, 2009).

Value conflicts

Values are said to conflict if, when considered in isolation, they evaluate different options as best (Van de Poel, 2009). A well-documented value conflict in renewable energy systems is that between landscape authenticity and sustainability with respect to wind turbines (Wolsink, 2007b; Roddis et al., 2018; Firestone et al., 2012). Wind turbines offer a promising way to generate renewable energy, but also imply the construction of large monopiles in the landscape. Local residents generally value an unobstructed view of their natural landscape over the generation of green power as favored by government or energy companies and as such a trade-off between the two values has to be made by policymakers. Trading-off one value for another is often a reality in realizing technological or regulatory designs of energy systems (Van den Hoven et al., 2015). In residential heating, when only looking at the value sustainability, the best heating option might be to insulate the household very well and install a heat pump powered by solar panels. This is however a costly endeavor, and when considering the best heating option from an affordability perspective, it might be best to heat the household using cheap, less sustainable, natural gas. One can see that through the realization of one value, the realization of another value can be inhibited (Van de Poel, 2009).

The difficulty in value conflicts is in overcoming them. As values often have no common measure for comparison, it is challenging to compare design alternatives that fulfill two values in a different way (Van de Poel, 2009; De Wildt, 2020, p.50). Additionally, trade-offs between different value fulfillments for design alternatives can have serious societal impacts (De Wildt, 2020, p.50). Van den Hoven et al. (2015) proposed three ways to overcome value conflicts: through re-specification, trade-offs and innovation (Van den Hoven et al., 2015).

Value change

Although the definition by Van de Poel & Royakkers (2011) described values as lasting convictions, they are not necessarily static over time. Rather, they may be subject to change during the lifetime of a system (Van de Poel, 2018), so-called value change. This is especially important to consider for products or systems with long lifetimes (Van de Poel, 2018), including DH systems which can have a lifetime of up to 40 years (Lund et al., 2010). When designing a DH system that is to be socially accepted, not only the values that are relevant during the design phase should be taken into account, but also the values resulting from value change. Van de Poel (2018) distinguishes 5 different kinds of value change:

1. **The emergence of new values**
2. **Changes in what values are relevant for a certain technology**
3. **Changes in the relative importance or prioritization of values**
4. **Changes in the conceptualization of values**
5. **Changes in the specification of values into norms and design requirements**

Value conflicts and value change in this thesis

Values can change over time, and can give rise to different value conflicts over time. We follow the narrative of De Wildt et al. (2020), where value conflicts are said to lower social acceptance and are therefore important for the municipality to consider. Both the possible value conflicts now, as the conflicts that can emerge over time. How these values change over time is not necessarily important, rather we look at which values could conflict in the future if values were to change (for any given reason).

3.1.3 Participation

Another subject that is important to cover in this theory section is that of participation. Participation is often mentioned in grey literature as a means to involve the households in the process of the heat transition, and is generally displayed as a good practice for increasing social acceptance of DH systems. Consider for example the report by Platform31[2], that states that without active participation by civilians the heat transition cannot take place (Buitelaar & Heeger, 2018). Another example is

[2] A knowledge organization aimed at connecting policy, practice and academia such that policy-makers can address the current problems of the Utrecht region.

the report by NPBO[3], that describes participation as empowering civilians in undertaking action in light of the energy transition themselves, as a mean to increase acceptance related to the energy transition in the neighborhood (Woudstra et al., 2018, p.5). In a study done by the Rijksuniversiteit Groningen for a neighbourhood in Groningen, several means of having the households participate in the heat transition process were found to increase the social acceptance of a possible DH system (Perlaviciute et al., 2019). Arnstein (1969) said the following about participation: "*The idea of citizen participation is a little like eating spinach: no one is against it in principle because it is good for you. Participation of the governed in their government is, in theory, the cornerstone of democracy -a revered idea that is vigorously applauded by virtually everyone.*". Participation is discussed below because it will be included in the modelling exercise.

The difficulty with discussing participation is that the boundary for meaningful participation is not the same for every household. Some households may feel they have adequately participated in the process when they can have decision-making power or form a partnership for shared ownership for example, whereas others might feel they have participated after completing a survey concerning their opinion of a DH system. Anything ranging from tokenism[4] participation to full citizen power can be called participation. Sherry Arnstein provided a typology for different levels of participation: the ladder of participation (Arnstein, 1969).

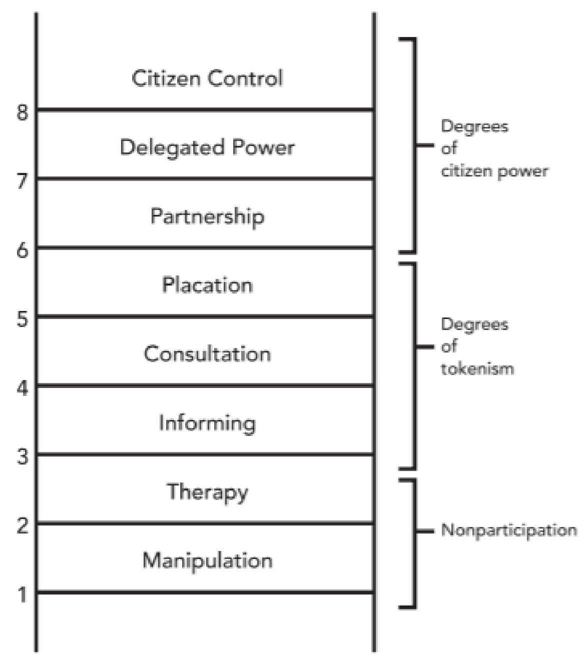


Figure 3.1: Arnstein's ladder of participation, from (Arnstein, 2019)

In Arnstein's ladder of participation, she describes 8 levels (rungs in a ladder) possible for citizen participation. In Figure 3.1 the ladder is shown, where each rung represents the extent to which citizens have power in determining the end product (Arnstein, 1969). Arnstein identifies three modes of participation: nonparticipation, tokenism and citizen power.

Within nonparticipation there is manipulation and therapy. These levels of participation enable powerholders to 'educate' or 'cure' participants, and can be considered as contrived by powerholders to substitute genuine participation (Arnstein, 1969).

After nonparticipation there are various degrees of tokenism: informing, consultation and placation. These rungs of participation allow citizens to hear and have a voice in the process, but there is little obligation for powerholders to do somethings with the views presented to them. Placation here is a special form of tokenism where 'have-nots' are given positions of influence (in the Advisory Board, Planning Committee, ..) but due to little community organization and technical

[3]NPBO stands for Dutch Platform Civilian Participation and Government Policy (Nederlands platform burgerparticipatie en overheidsbeleid)

[4]The Oxford English dictionary defines tokenism as: The practice of making only a perfunctory or symbolic effort to do a particular thing, especially by recruiting a small number of people from underrepresented groups in order to give the appearance of sexual or racial equality within a workforce.

assistance supporting that position, there is often no real influence (Arnstein, 1969)

After tokenism we move into the realm of citizen power. Arnstein (1969) writes: "*Citizens can enter into a (6) Partnership that enables them to negotiate and engage in trade-offs with traditional powerholders. At the topmost rungs, (7) Delegated Power and (8) Citizen Control, have-not citizens obtain the majority of decision-making seats, or full managerial power. Obviously, the eight-rung ladder is a simplification, but it helps to illustrate the point that so many have missed -that there are significant gradations of citizen participation.*".

Within the modelling exercise that is later described, Arnstein's ladder of participation will be used to typify different levels of participation meant in the model. Different ways of discussing or typifying participation can be thought of, but as Arnsteins ladder proved an influential typification, choice is made to make use of her work.

3.2 Methodology

Within this section, the methods used in later parts of this report are described. As said in the introduction, this thesis aims to combine a qualitative with a quantitative modelling element. The methods described in this section are qualitative interviews and scenario-making, Agent-Based Modelling and Modelling of Socio-Technical Systems.

3.2.1 Qualitative interviews

In order to identify relevant values for a DH system in Geerdinkhof, qualitative expert interviews were conducted. Turner (2010)'s *practical guide for novice investigators* was used to structure the organizational parts of the interviews. Additionally, inspiration was drawn from Rawluk et al. (2018) for eliciting values from interviews.

For the interviews choice was made to make use of what Turner (2010) calls *standardized open-ended interviews*. These type of interviews are characterized by a strong structuring in wording of the questions. All interviewees are asked exactly the same, open-ended questions. These open-ended questions allow interviewees to provide as much detail as they can, and this type of interview also allows for probing and follow-up questions. This is especially useful when dealing with latent topics such as values, where follow-up questions can be used to ensure interviewer and interviewee are on the same page. Next to selecting the appropriate type of interview, Turner (2010) gives suggestions for preparation of the interview, participant selection, pilot testing, questions and data interpretation.

For the preparation of the interviews a topic guide was written. This guide contains an introduction to be read to interviewees, the interview questions and the structure of the interview. In the introduction the interviewees are given background information about the thesis, practical information (duration of interview and confidentiality/ data processing agreement) and there is room for questions before the interview starts. The topic guide can be found in Appendix A[5].

Participants were selected on basis of employment and expertise. In the end, 5 participants were selected that cover a range from municipality employees to academics and had previous experience with social acceptance, district heating or household perceptions on the heat transition. Interviewees are described in more detail in Section 4.2.

The interview was pilot tested before the first interview with an acquaintance of the researcher, to smooth out the structure of the interview and gain some prior experience.

[5]Note that it is in Dutch, as all participating interviewees spoke Dutch.

As for the questions posed, Turner (2010) encourages the use of questions that allow the researcher to dig deep into the knowledge and experience of the interviewee. For this purpose, questions should be open-ended, be as neutrally posed as possible and make use of clear wording. For the exact phrasing of the questions, advice from prof. dr. ir. Ibo van de Poel[6] was sought after. The questions can be found in the Topic Guide, Appendix A.

For the interpretation of data use was made of an online posterboard[7] tool. As the interviews were held online, an online environment with sticky notes helped making the input visual for both parties. Data was later interpreted using the sticky notes and interview recordings. The findings of the interviews can be found in Section 4.3.

3.2.2 Scenario-making

For later prioritization of value conflicts, use is made of scenarios. These scenarios give insight in how values can change over time, and which values could become more important in the future. We draw on the work of Rawluk et al. (2018), who used value-based scenario planning in their case study of bush wildfires in Australia. In their work, scenarios are made using a participatory process and tensions between important values. Using these scenarios and value tensions, different solutions per subject in wildfire management (prevention, education, communication, ...) are proposed based on how they fulfill a certain value.

We will not follow their exact methodology, but rather combine the theory on value change with value-based scenario planning. Values can change over time, and as Rawluk et al. (2018) showed tension between conflicts can be used to consider future actions with. Using the expert interviews described in Chapter 4, future prioritizations of values are elicited. Possible ways to prioritize values can be considered scenarios[8], and these scenarios are used to see which value conflicts can become more prominent over time. If a value is said to be more important in the future in a certain scenario, then in that scenario it is wise to resolve conflicts with that value before others. Scenarios in this thesis will therefore take the shape of narratives in which different prioritizations of values can arise, and these will be used to see which conflicts should be prioritized in resolving over others.

3.2.3 Agent-based Modelling

Agent-Based Modelling (ABM) (Epstein & Axtell, 1996) is used to study the heat transition of Geerdinkhof as a socio-technical system (STS). A simulation model is a suitable method to investigate a large variety of parameters assumed to be of importance (De Wildt, 2020, p.76), and allows to study the system in isolation which is often not possible in real world systems (Van Dam et al., 2012, p.55). ABM originates from complexity and generative science (Bankes et al., 2002), and is especially useful to increase understanding of the STS (Van Dam et al., 2012, p.5) and study emergent properties or anticipation of the future (Nava Guerrero et al., 2019).

An agent represents an autonomous software entity that has both a state (a collection of parameters defining the agent (Wooldridge & Jennings, 1995)) and a set of rules governing how an agent responds to its environment, other agents or own state. Additionally, the agents are placed in an environment that can have influence on the agents or vice versa. In this thesis, the autonomous entities are households, and their state can consist of things like income, home energy label, their

[6]Next to being the chairman of the graduation committee, Ibo is Antoni van Leeuwenhoek Professor in Ethics and Technology and head of the Department Values, Technology & Innovation of the School of Technology, Policy and Management at Delft University of Technology.

[7]Use was made of `https://ideaflip.com/`, but many online tools can be found for this purpose.

[8]Note that the Cambridge dictionary entry for 'scenario' is *a description of possible actions or events in the future*

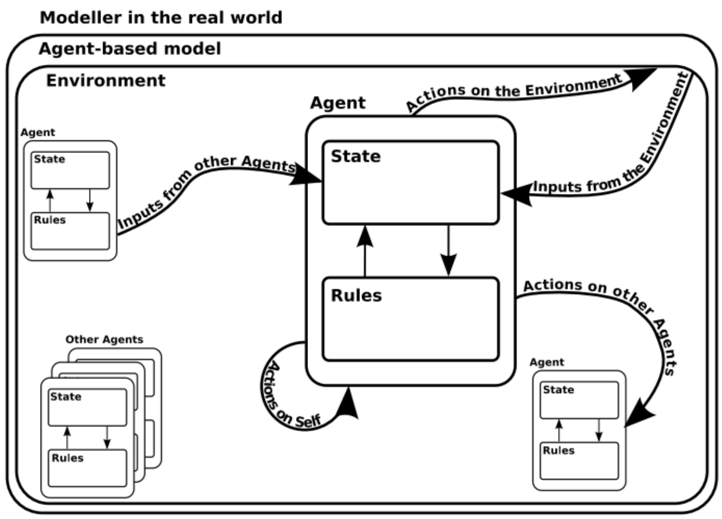


Figure 3.2: Basic anatomy of an ABM, image taken from (Van Dam et al., 2012, p.58)

heating cost and how happy they are with their heating system for example. Every household has a state like this, and households can interact with each other (to see what heating system their neighbors have perhaps?). The environment, consisting of exogenous variables like the DH system offered to the households, influences what actions the households take which in turn has influence on other households. This way, behavior can emerge that was not explicitly put in the model as a behavior rule, but can give valuable insight in the real world system of study.

ABM has seen many applications in many different fields including economics, sociology, anthropology, political science, and game theory (Bankes et al., 2002). ABM is also a proven method for investigating value conflicts in heating systems (de Wildt et al., 2021, De Wildt et al., 2020, De Wildt, 2020) or the heat transition in general (Nava Guerrero et al., 2019, Hansen et al., 2021, Busch et al., 2017, Remondino, 2007). Of course, ABM is not the only model family suitable to study a STS. Consider for example the use of system dynamics (Forrester, 2009) or discrete event simulation (Gordon, 1978). Choice is made for ABM because it is especially suitable to study emergent phenomena. Emergent phenomena are a type of model behavior that is not explicitly formalized in the model, but something that comes into existence when heterogeneous agents interact with each other. In this thesis, the emergent phenomena are the value conflicts: we do not tell the agents what value conflicts to look for, rather they interact with their heterogeneous environment such that value conflicts emerge.

3.2.4 Agent-Based Modelling of socio-technical systems

In order to formalize, verify, test and validate the ABM in a structured manner, the ten step approach by Van Dam et al. (2012) is used. In their book, *Agent-Based Modelling of Socio-Technical Systems*, Van Dam et al. (2012) describe the theory on systems thinking, complexity theory and ABM modelling practices. In Chapter 5, the steps are followed in more detail but a short overview is given here (Van Dam et al., 2012, p.73-136):

1. **Problem formulation and actor identification:** What are you trying to model and research, and who is involved?

2. **System identification and decomposition:** Here you decompose the real world system into preliminary elements for the formal model.
3. **Concept formalisation:** Here you look at data structures and the ontology.
4. **Model Formalisation:** Here you develop a qualitative account of what the model does and take the first step towards software implementation.
5. **Software implementation:** Here you translate previous steps to a suitable modelling environment.
6. **Model verification:** Here you verify that the computer model is an accurate translation of the formal model.
7. **Experimentation:** Now the model can be used to conduct experiments and generate data.
8. **Data analysis:** The data can be visualized, interpreted and explained.
9. **Model Validation:** This steps concerns checking if the constructed model answers the questions it was intended for.
10. **Model use:** The final step concerns presentation of findings and stakeholder engagement.

4. Part 1: Qualitative interviews

In the first, qualitative, part of the thesis the relevant values for a DH system in Geerdinkhof are sought after. This is done through combining a literature search with semi-structured expert interviews. After this section, 5 values with different conceptualizations are selected to be used in the modelling part.

4.1 Literature study relevant values

A literature study was undertaken to identify relevant values prior to the interviews. An initial search into the scientific literature concerning DH systems, renewable heating alternatives and policy documents regarding residential heating created an initial overview of values. This initial overview was used as a basis for the discussion on and selection of relevant values for the case of Geerdinkhof.

Making use of the Google Scholar search engine in standard settings, literature was sought after from the last decade in the aforementioned topics. Individual articles were selected on publication date, amount of citations and whether they bring a new relevant value to light. The result is Table 4.1, with an initial overview of values that could be relevant for Geerdinkhof. As is the case with the previous discussion on defining social acceptance, few articles had exactly similar interpretations of the same value. Often times, the argument can be made that one value is part of another value, or that a constituent of a value could be considered a stand-alone value. The distinction between one value and another is not always clear-cut. Elements of values can overlap or be shared among values. To come to this overview however, articles have been grouped under the same value if they mentioned a single-worded value and described what elements they considered for that value or grouped if elements the authors deemed important for a heating system could be considered part of a value.

To give the reader a feeling of what is generally meant with these values, a general description is proposed. Note that these are only short, general, descriptions. These descriptions might not do full justice to their philosophical conceptions, which is beyond the scope of this section. Rather, Table 4.1 represents an initial exploration into what values could be relevant for a new heating system and what elements they are comprised of.

Table 4.1: Literature review of relevant values

Value	Literature	General description
Affordability	Bouw (2017), Cohen et al. (2014), De Wildt (2020), Jansma et al. (2020), Krikser et al. (2020), Mouter et al. (2021), Van Aalderen et al. (2021), Perlaviciute & Steg (2014), Sayegh et al. (2017), Sun (2020), Zaunbrecher et al. (2016)	Affordability relates to how reasonable the price is for the heat provided. This affordability can be seen as a price comparison between existing heat options, the investment required to switch from traditional heating to a DH system or other related costs.
Comfort	Bouw (2017), De Wildt (2020), Demski et al. (2015), Devine-Wright et al. (2014), Jansma et al. (2020), Van Aalderen et al. (2021), Nava Guerrero et al. (2019), Perlaviciute & Steg (2014), Sun (2020), Zaunbrecher et al. (2016)	Comfort can be interpreted as the benefit or possible nuisances following using a heating option. (Thermal) comfort follows when household receive the appropriate level of heat in a safely and reliable manner, without being confronted with maintenance or consistency issues.
Flexibility	Bouw (2017), Demski et al. (2015), Fournis & Fortin (2017), Jansma et al. (2020), Nava Guerrero et al. (2019), Sayegh et al. (2017), Sun (2020), Von Wirth et al. (2018), Wüstenhagen et al. (2007)	Flexibility implies a certain adaptability and robustness. Households can value if they can be flexible in which heat supplier they choose, a certain modularity when it comes to when certain households are connected to the system and a system that is adaptive to future developments such as new heat sources, stakeholders or other.
Freedom of choice	Demski et al. (2015), Mouter et al. (2021), Van Aalderen et al. (2021), Sun (2020), Zaunbrecher et al. (2016)	Freedom of choice relates to the agency or autonomy of households, in the sense that they should be able to make the choices they want to. This could be in choosing to join in or opt out of the DH system, to choose their desired heat supplier, level of participation or even level of ownership in the system.
Inclusion	Bronfman et al. (2012), De Wildt (2020), Demski et al. (2015), Wüstenhagen et al. (2007), Zaunbrecher et al. (2016)	Inclusion relates to making households feel connected with their community and represented in this heat transition. This entails enabling households in making their desired choices in relation to their environment, enabling a sense of community and giving households control over the process.
Locality	Bouw (2017), Krikser et al. (2020), Perlaviciute & Steg (2014), Sayegh et al. (2017)	Locality is the collection of characterizations referring to the local community. Locality means strengthening the local economy through local jobs and keeping capital within the community, making the distinction between insiders and outsiders and finding optimal solutions for the local conditions.
Participation	Demski et al. (2015), Mouter et al. (2021), Van Aalderen et al. (2021), Nava Guerrero et al. (2019), Sayegh et al. (2017), Von Wirth et al. (2018)	Participation relates to allowing households to take part in and contribute to the realization process. Different levels of participation exist, and range from informing households to households having control over the process or even forms of co-ownership of the system.
Sustainability	Bouw (2017), Cohen et al. (2014), De Wildt (2020), Demski et al. (2015), Devine-Wright (2011), Jansma et al. (2020), Krikser et al. (2020), Mouter et al. (2021), Van Aalderen et al. (2021), Perlaviciute & Steg (2014), Sayegh et al. (2017), Sun (2020), Zaunbrecher et al. (2016)	Sustainability is interpreted as being an environmentally 'good' solution, now and in the future. This relates to minimizing impact on the natural environment, reducing CO_2 emissions, mitigating climate change effects and contributing to the energy transition overall.
Transparency	Bouw (2017), Bronfman et al. (2012), Cohen et al. (2014), De Wildt (2020), Demski et al. (2015), Devine-Wright (2007), Krikser et al. (2020), Van Aalderen et al. (2021), Raven et al. (2009), Von Wirth et al. (2018), Sun (2020), Wüstenhagen et al. (2007), Zaunbrecher et al. (2016)	To openly share conditions, requirements and details of the process with all participating. Often relates to why and how the realization process will go, and requires transparency in communication, truthful information, clarity on price construction, addressing perceptions and emotions and represent all interests.
Trust	Bronfman et al. (2012), Van Aalderen et al. (2021), Perlaviciute & Steg (2014), Perlaviciute et al. (2019), Wüstenhagen et al. (2007)	The ability to have faith in a beneficial outcome of the process, the benevolence of the orchestrating members (government, municipality, heat supplier, etc.), honesty of communication and stability in safeguarding current and future interests.

4.2 Description interviews and interviewees

5 Expert interviews have been performed for the identification of relevant values for Geerdinkhof specifically, different conceptualizations and future states of these values. The selection of interviewees covers a variety of organizations and expertise, to ensure as many as possible different points of view are taken into account during this exploratory phase. Interviewees included employees from the municipality, an umbrella organization for energy cooperatives, an information foundation and an academic. Although this research is on the social acceptance of households, no interviews with households in the neighborhood have been performed. Due to the ongoing Covid-19 pandemic and the heterogeneity of households, choice was made to not interview residents in the Geerdinkhof area. Instead, some interviewees were selected as they could represent households in the area because of past work experience. The interviewees are described below:

1. Municipal researcher on energy transition Amsterdam Zuid-Oost, looked at economic, social and business perspective of the heat transition.
2. Associate professor on environmental geography, with an expertise in social acceptance of renewable energy systems.
3. Employee national umbrella organization for local energy cooperatives, specialized in community heating.
4. Municipal project manager and energy commissioner.
5. Liveability researcher and natural gas free team member for independent foundation for information and advice on rental housing, home-ownership, energy, organization and participation.

Structure of the interviews

The interviews were split-up in two parts. The first part was shaped as a brainstorm to come up with as many relevant values and conceptualizations as possible. Interviewees were asked what they thought households would deem important for accepting a DH system in the Geerdinkhof area. When values were mentioned directly, interviewees were asked how they would describe these values or what different conceptualizations they could identify. If, on the other hand, something was mentioned that did not fall directly under a value, interviewees were asked to place it under a to-be named value. This was often the case for anecdotal examples.

In the second part, interviewees were asked two questions. They were asked whether they could identify scenarios for future value change and what value conflicts they expect. To be considered a scenario, interviewees had to come up with a prioritization of values and under what conditions such a prioritization could come about. The second part was used to come to a final selection of values for the model.

A full description of the interview structure can be found in Appendix A. Here, the topic guide (in Dutch) is given that was used to structure the interviews with.

4.3 Outcome interviews

The outcomes of the interview will be discussed in three parts: the first part concerns the different identified values and conceptualizations, the second part discusses future developments of these values, and finally the selection of values with their conceptualizations is described.

Identified Values and conceptualizations

The answers to the question of what interviewees think households find important for accepting a DH system were aggregated into a single overview. This created a web of values with different conceptualizations, together with relations between values (like trust being the derivative of inclusion). As it is challenging to accurately describe a value, individual characteristics for a certain value could in some cases be argued to be a whole new value. This is for example the case with participation. Participation can be interpreted as some form of inclusion or freedom of choice for example, but also as a value on its own. As there is no exact way to say when a characteristic is a new conceptualization of an existing value or a new value altogether, the distinction was made on the basis of input from the interviews. If interviewees described explicitly a certain characterization that had little conceptual overlap with other values or characterizations, choice was made to note it down as a new value. This was the case for the values flexibility and locality. Consequently, some characterizations did not necessarily fit the identified values or characterizations, but were identified as important properties for social acceptance of DH systems. This is the case for different elements of justice (climate justice, procedural justice, energy justice), having control or say in the process (in contrast to participation) and freedom of choice (of participation, of being connected to the system, of heat supplier). A graphical representation of the input from the interviews can be found in Figure 4.1. This is discussed in more detail in Section 4.4.

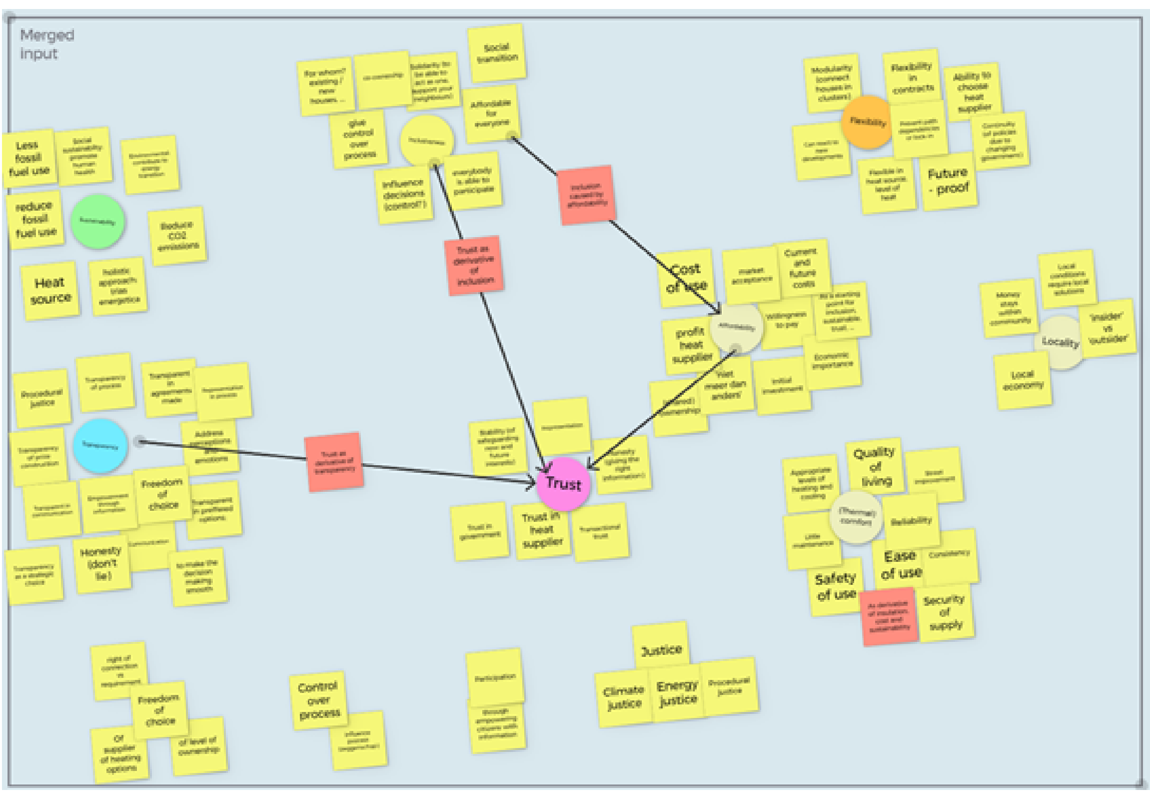


Figure 4.1: Merged input from the interviews. Round post-its are specifically mentioned individual values, yellow notes indicate characteristics for certain values, arrows with red notes indicate relations between values. Note that some characteristics did not fall under a specific value. The merged input can be viewed in more detail using `https://ideaflip.com/view/9c6twpi8jv9k/eULcAsNGSh5i`

4.3.1 Expected value conflicts and scenarios

Interviewees were also asked which conflicts between values they expect, and whether certain values could become more important in the (near) future. Note that not all interviewees identified conflicts or scenarios, as time did not always allow for that or interviewees were unable to think of future prioritizations or conflicts. These expected value conflicts were used for validation purposes of the model.

Value conflicts
Below is a short overview of value conflicts identified. The number in brackets corresponds to the interviewee who identified the value conflict, and the value conceptualizations used in Table 4.1 can be assumed.

- **Transparency – transparency (1)**: There is a conflict between the transparency desired by parties on the one hand, and transparency that other parties are able or willing to give. For example, a heat supplier might not be able to be fully transparent about their CO2 emissions or profitability as it might weaken their strategic position.
- **Sustainability – flexibility (2)**: There is a trade-off in being flexible with regards to mitigating climate change effects now and remaining flexible in responding to future developments. Taking sustainability-related actions could also create path dependencies that would reduce future flexibility.
- **Locality - Participation/inclusion (3)**: Locality in the sense of strengthening the local economy, creating job opportunities and other positive local externalities cannot be realized without facilitating participation through co-ownership, control over the process or otherwise including the local community.
- **Affordability – Transparency (3)**: Transparency about profitability cannot always be given, which impacts the affordability. Transparency can be a strategic matter, and being too transparent can have a negative effect on the strategic market position.
- **Inclusion – Affordability (3)**: Being unable to afford for example the initial investment for household to join the DH system can lead to it being less inclusive.
- **Affordability – sustainability - flexibility (3)**: Technical solutions that have less impact on the natural environment are more often than not also less affordable than more impactful solutions. Hence, a trade-off between how much a solution costs and how much impact it has on the environment can be identified. When also accounting for remaining flexible towards possible future developments, this trade-off becomes more challenging.
- **Comfort and sustainability (3)**: Reaching the desired level of heat in a household in the most comfortable way (in terms of how long it takes to heat up, how easy it is to reach that level, account for heat losses) is not necessarily the most sustainable way of heating.

Value change scenarios
Following the question about value conflicts, interviewees were asked if they could identify a trajectory in which these values could develop. These trajectories can give insight into which values might become more important in the future relative to each other, and how these trajectories come into existence through a qualitative narrative. These trajectories or storylines are used in the impact analysis in Section 5.10.1. There, the identified value conflicts are analysed for their impact. If a value that is identified below to have a possible high priority in the future, conflicts with this value are considered to have more impact.

Below is a short overview of such trajectories, with value prioritizations given from high to low and which interviewee proposed the trajectory.

1. **Local optimum**
    - **Trajectory:** A DH system design should be as close to the local optimum as possible. This means designing on a case-by-case basis, and paying close attention to the local resources available, remaining flexible to future developments such as new heat sources, including your citizens in the transition in the new system through offering an affordable alternative and ensuring every household is able to join.
    - **Value prioritization**: Locality, Flexibility, Affordability, Inclusion
    - **Proposed by:** Interviewee 1
2. **Future proof**
    - **Trajectory**: A DH system design should first and foremost be a good solution now, and in the future. This implies firstly that the system has a minimal impact on the natural environment, and additionally being 'fair': the system offers a convincing business-case and is affordable to households. Finally, this system should be realized in a transparent manner, such that households are properly informed and all interests are adequately addressed.
    - **Value prioritization**: Sustainability, Affordability, Transparency
    - **Proposed by**: Interviewee 1
3. **Social heat transition**
    - **Trajectory**: This trajectory considers the new DH system from the social perspective of the household. Households should not be negatively affected by the system, and be able to contribute in a way they see fit. The households should share in the benefits of the heat transition, be able to participate in a transparent process while in the end working towards a more sustainable way of residential heating.
    - **Value prioritization**: Affordability, Inclusion, Participation, Transparency, Sustainability
    - **Proposed by**: Interviewee 2
4. **Residential comfort**
    - **Trajectory**: This trajectory considers the new DH system from the physical perspective of the household. First and foremost is the importance of increasing the quality of life of the households, ensuring appropriate heat levels in the household in a reliable and safe manner.
    - **Value prioritization**: Comfort, Affordability, Inclusion
    - **Proposed by**: Interviewee 1

4.4 Selection relevant values and scenarios

After the creation of this overview, a total of 10 distinct values was identified. These values were comparable to those identified in literature, however some characterizations given by interviewees proved an addition to the literature. This was especially the case for the values trust, locality and participation. Interviewees found trust often to be a derivative value of affordability or inclusion, and by fulfilling these values trust would follow. For locality, interviews expanded on the local distinctiveness as described by Devine-Wright (2011) with notions of local economy, insider versus outsider and a general sense of community. Also important to consider were the discussions on what participation meant for the interviewees and the links between inclusion and participation.

In Table 4.2, the 5 selected values are displayed together with their conceptualizations. Each conceptualization describes one specific aspect of that value that is to be modelled later on.

Discussion on values inside the selection

The five values that are selected for the modelling exercised are discussed here, with their corresponding conceptualizations, per value.

Affordability was one of the most prominent values, and was selected as it was mentioned by a great deal of literature and all experts. Choice was made for two conceptualizations: initial investment and comparability of cost. Especially the expert interviewees made the distinction between how the initial investment sum is perceived and how a new heating system compares to an existing system in terms of monthly operating cost.

Freedom of Choice (FOC) is selected with two conceptualizations: ability to choose heat supplier and ability to choose level of ownership. These conceptualizations are maybe a little less straight-forward than those of affordability, as the basis of FOC (do I have the ability to make the choice I want?) is not explicitly taken into account. This was done on basis of the scoping done in Section 1.1.2, and it is assumed households are always free to choice if they want the new heating alternative rather than being forced to choose. During the interviews, experts identified two possible consequences of switching to a heating alternative that can negatively affect the FOC: unable to choose witch heat supplier you want and unable to choose if and how you want to be owner of your heating system. Collective heating systems often have only one heat supplier, and, if connected, gives little choice in terms of heat supplier. The same goes for ownership, households hold the power over the choice if they want to fully own their heating system or maybe rent it. For collective systems, these possibilities are often limited.

Inclusion was selected, but maybe not under the best fitting name. Again, there are two conceptualizations: the first looks at if everybody is able to make the same decision and the second whether a household can have say over the process if they want to. Inclusion here is therefore maybe not interpreted as feeling part of the community as described as in Table 4.1, but rather as either an equality principle in which no-one is excluded in making a similar choice and inclusion as participation or representation. The choice for these conceptualizations was made, as the interviewees often described feeling included means no households are *excluded* from the system or being represented in the decision-making process.

Sustainability should not come as a surprise as a selected value. The premise of a new heating system is that it is more sustainable than the existing one. The interpretation of sustainability is different however, as the interviewees had different views on what sustainability is and how to reach it. Choice was made to only look at CO2 emissions associated with the heat used. This was the most often mentioned characteristic of sustainability, and makes modelling more straight-forward.

Comfort finally was selected to represent the group of characteristics associated with the perception of the system within the household. These characteristics are the appropriate level of heat in the household, the safety of use (consider for example gas leaks in individual heating units), ease of use and the burden of maintenance. These characteristics are important to consider as they make up the core of a heating system: providing heat to a household.

Discussion on values outside the selection

Five values have not been selected for the model for a variety of reasons: Flexibility, Locality, Participation, Trust and Transparency. Ideally, all values are taken into account but due to the limited

Table 4.2: Overview of selected values with conceptualizations.

Values	Conceptualization	Description
Affordability	C1 Initial investment	Relates to how much a household needs to invest to be able to join in the DH system. The higher the initial investment, the lower the social acceptance.
	C2 comparability of costs	Relates to the comparison of heat costs between district heating and traditional heating. The more a household needs to pay for heat in comparison, the lower the social acceptance.
Freedom of Choice	C1 Ability to choose heat supplier	Relates to how much households want to and are able to choose their preferred heat supplier. The social acceptance is higher if they can make their preferred choice.
	C2 Ability to choose level of ownership	Relates to how much households want to and are able to be owner of their heating system. If households can reach their desired level of ownership, the social acceptance is higher.
Inclusion	C1 Everyone is able to make the same decision	Relates to be able to make the same decision as your surroundings if you want to. If a household is unable to make the choice they want, the acceptance is lower.
	C2 Everyone can have say in the process	Relates to comparison of level of participation desired and level of participation offered. The larger the difference, the lower the acceptance.
Sustainability	C1 Less CO2 emissions	Relates to how much CO2 emissions are associated with meeting the heat demand. Less CO2 emissions saved means a lower social acceptance.
Comfort	C1 Ease of use	Relates to how easy it is for household to reach their desired heat level, how much maintenance is involved and associated safety. The easier the heating system is to use, the higher the social acceptance.

time available some values are outside the scope of the modelling exercise. Below is a discussion on why these values have not been selected for the modelling exercise.

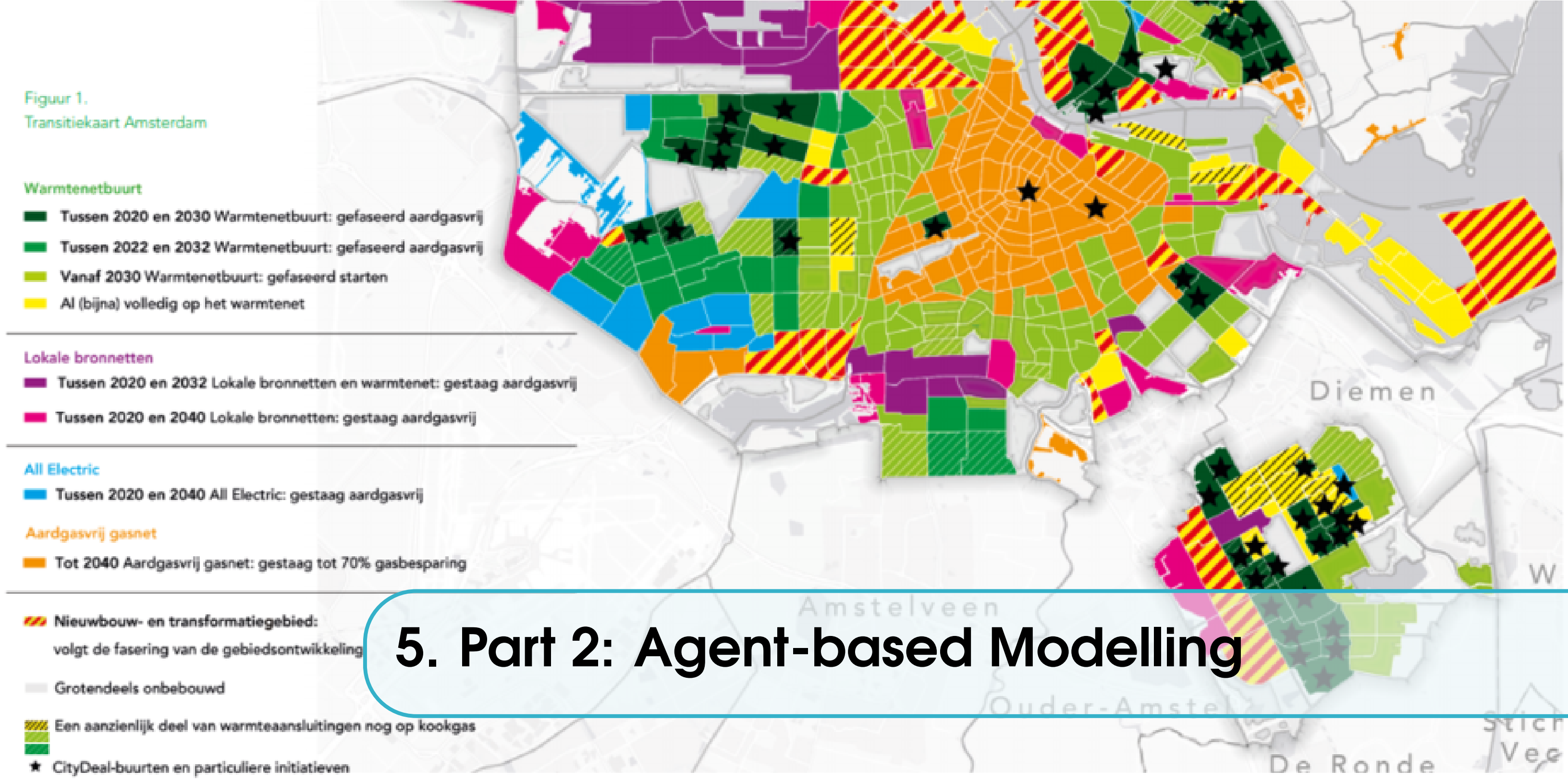
Flexibility, as described before, mostly relates to the technical design of the system. A flexible system is a system that can adapt to future contingencies or developments. For example, the system should be able to incorporate new (sustainable) heat sources when they present themselves, make use of new algorithms to further optimize the flow of heat or be accommodating for households that want to join at a later time. Although flexibility is described as one of the ways to deal with value change, together with adaptability and robustness (Van de Poel, 2018), flexibility in its description here is almost a contingency plan and relates mostly to the technical and institutional design of the system. The value flexibility is not selected for two reasons. Firstly, households might have difficulty in assessing how much this system fulfills their flexibility demand. They might not observe how flexible the system is, and evaluate if this would increase or decrease their acceptance of the system. Secondly, flexibility has a less direct impact on the households than for example affordability or comfort.

Locality was left out as it would significantly increase the workload of the modelling and could also be considered to be largely fulfilled if opted for the semi-collective design alternative. The semi-collective design alternative would already meet many of the characterizations given by interviewees. There would be little insider versus outsider discussion as the heating is done together with your neighbours, there is no capital flowing out of the community as there are no payments made to outside of the community and a local economy is incentivized. Additionally, adding in the distinction between insider and outsider parties, an associated flow of capital between these parties and a conceptualization of local economy / employment opportunities would make an interesting addition to the model but was left for future research due to time constraints.

Participation was not taken into account as a separate value for overlap reasons, as participation can be argued to be a constituent of the inclusion value. Where participation relates to including household in the process (ranging from informing to co-deciding), inclusion relates both to feeling part of the community you reside in and being represented in the process. The overlap here is between the representation in the process and how much people can partake in this process. Although a semantic difference can be identified between the two, both indicate a range of possibilities for households to be heard during and have control over the process. As such, in the modelling exercise participation is used as a system configuration parameter, which has an effect on the fulfillment of the inclusion value.

Trust was not considered as a separate value, as several interviewees found that trust follows from the fulfillment of other values. Although no interviewee denied the importance of trust, trust could be reached by fulfilling values of affordability, transparency and inclusion. By offering a more affordable system, trust in those executing the process follows. The same applies for being open and honest in your communication about your goals and intentions, and including everyone in the way they want to.

Transparency is the last value not to be explicitly included as value. Transparency fulfillment can be hard to perceive for households, as only perceived lack of transparency can lead to lower acceptance. Transparency, as described before, demands a certain level of honesty and openly sharing of information (of the process, heat price or implications). Without full and truthful information households are less able to evaluate how a new system would impact them, and in turn decide to fully support a new heating system. This way, transparency could perhaps even be considered as a condition for social acceptance, as without it households might not be able to evaluate how the system fulfills their values, and decide whether to support or protest against the system. Transparency was often mentioned by interviews to be a strategic matter, as for example heat suppliers might not want to be fully transparent in how their prices are constructed, possible giving a way profit margins. On the other hand, transparency could also be demanded by for example the municipality in their tenders or contracts, ensuring everyone has access to the right information.



5. Part 2: Agent-based Modelling

Within this chapter, the modelling part of the thesis is described. The methodology from Van Dam et al. (2012) as described in Chapter 3 is followed and used to describe the construction of the model. Additionally, practices from Galán et al. (2009) are used to prevent introducing errors and unwanted artefacts into the model.

5.1 Step 1: Problem formulation

The first step in the methodology is that of problem formulation and actor identification (Van Dam et al., 2012). Within this step, the researcher has to make explicit what exactly is the problem he is investigating, what lack of insight is to be addressed and what actors are involved. The problem definition can be found in more detail in Section 2.1, but is shortly described below for clarity reasons:

The implementation of a heating alternative in Geerdinkhof can have influence in how certain values of households are fulfilled, and can lead to value conflicts. In order to support social acceptance of a new heating alternative, these value conflicts need to be explored in order to rise to the challenges of energy justice: to identify injustices, identify those affected and finally try to remedy these injustices.

The problem owner, the municipality of Amsterdam, is interested in which values households find important for a new heating alternative, and how values could be compromised in a new heating system. Consequently, the municipality could use the to-be identified value conflicts to alleviate some of the social acceptance issues. This could be in the shape of re-specified design requirements or adjusted policies. New design requirements dictate the technical configuration of the system, and if that does not address the value conflicts properly policies can be put in place to do this.

5.2 Step 2: System identification and decomposition

Now that the research problem is formulated, the next step is to decompose the real-world system into its internal structure. This structure helps the researcher in making assumptions and data explicit and translate this into a formalised model. System decomposition is done in three phases: *Inventory*, *Structuring* and *Formalisation* (Van Dam et al., 2012, p.77). In the *Inventory* phase, the physical and social entities of the system and links between them are made explicit. This generates an overview of relevant concepts, actors, behaviors and interactions. In the *Structuring* phase, the entities identified before are grouped in agents and interactions. Note that this phase is also used to re-iterate over the *Inventory* phase, if elements have been overlooked or incorrectly included in the model.

Inventory and Structuring

Firstly, input on the relation between the system and the problem at hand needs to be gathered. This is done to create an overview of relevant elements, issues, factors, worries or other explanations (Van Dam et al., 2012), which is used in further formalisation of the model. These interviews are described in Chapter 4, and additional household data is described in Appendix C.1.

Secondly, choosing the correct time frame for the model is important. As this thesis aims to explore value conflicts embedded in the system, the time frame should be long enough to make sure new conflicts do not emerge after the time frame has ended. This would imply that we are only looking at the system for the coming 20 years for examply, while a certain conflict would only become evident after 30 years. As the goal is to explore all the relevant value conflicts in the system, the time frame is chosen such that no new conflicts emerge after the time-frame. This means that the model will be run until equilibrium, i.e. no new conflicts emerge.

Finally in the *Inventory* phase, is to specifically identify the relevant concepts, actors, behaviors, interactions and properties (Van Dam et al., 2012, p.78). In below overview, the *Inventory* phase is combined with the *Structuring* phase, in order to present a structured overview that has already included all iterations between the two phases. This overview is adjusted from (Van Dam et al., 2012, p.79), and note that for some items it is also included if they do not change over the course of a simulation (static), or if they are subject to change during the simulation (dynamic). Additionally, the *Structuring* phase also includes a description of the external world.

1. **Relevant concepts**:
    - Rational decision making: households make choices based on full information availability and maximization of value fulfillment.
    - Heating system considered: either a collective or semi-collective system is considered.
    - System parameters: the heating system considered is characterized by certain parameters: initial investment cost, participation level (Section 3.1.3), ownership level and freedom of heat supplier choice level.
    - Willingness to Pay: Household characteristic describing how willing a household is to pay for a new heating alternative.
    - Willingness to Choose: Household characteristic describing how important a household finds the ability to choose heat supplier.
    - Willingness to Participate: Household characteristic describing which level of participation is desired by the household.
    - Willingness to Own: Household characteristic describing how important a households finds the ability to be owner of the heating alternative.
    - Value conflict: A value conflict is defined as a value vs another value, in which the first value is increased in fulfillment and the second decreased. The value conflict *Comfort vs Inclusion* of size X means that the Inclusion fulfillments decreases with X when Comfort is increased.

2. **Actors**
   - The only actors in this model will be the households themselves. The amount of households and individual characteristics are static.
3. **Interactions or flows:** These describe possible interactions between the households or the system.
   - Interactions between households take place in two ways: when assessing what their heating cost would be for different heating alternatives (static) and when assessing how included they will feel if they use a particular heating option (dynamic).
   - Interaction between an individual household and the DH system considered. The parameters (i.e. cost, associated CO2 emissions, ...) of the system (dynamic) will have influence how certain values are fulfilled for a household (dynamic).
4. **States or properties:** These describe and specify the agents (households).
   - Part of the system: This state of the household describes if the household would be part of the system considered if realized (dynamic).
   - Installations: This state indicates if there are solar PV panels present on the household roof (static).
   - Ownership: This state indicates if households own the property or live there as tenants (static).
   - Household properties: each household has several individual characteristics (static): annual spendable income (EUR), insulation level as an energylabel (A,B,C,...), heat demand (GJ/yr) and heating cost (EUR/yr) for each considered heating alternative.
   - Value fulfillments: These states describe for each household how each value is fulfilled, both by means of individual heating or the DH system at hand.
5. **Relevant Behaviors:** Behaviors are changes in household states caused by interactions, or changes in household states caused by other changes in states.
   - Value fulfillment: Each household has a set of values that it deems important and wants to have fulfilled. Household will choose for the heating system that better fulfills their values (dynamic).
   - Economies of scale: DH systems are subject to economies of scale, i.e. when more households decide to join the system, the learning costs and infrastructure investments are shared over a larger number of connections, thus lowering the cost per connection (dynamic).
   - Neighbor influence: the choices and characteristics of the households surrounding another household will influence if certain heating options are feasible (static), and how included the household feels with respect to their direct environment (dynamic).

Identifying the external world

The external world describes that which is outside the sphere of influence of components within the model. The external world has two parts in this model: the first part is the geographical restriction of the neighborhood. Only the households in Geerdinkhof are considered, and interactions with households or other actors outside this geographical scope are not part of the model. The second part could be called the exogenous variables, which in this case describe the system parameters (initial investment, participation, choice and ownership levels offered) of the heating system considered and which value conceptualizations are used.

5.3 Step 3: Concept formalisation

In previous steps the relevant components for the model have been identified and described in natural language. However, to make this model workable for computers, it needs to be formalised. (Van Dam et al., 2012, p.82) state "*The main reason for formalisation is that even though the identified concepts may seem well-defined to the stakeholders, they may be far more context dependent or specific than the stakeholders realise and computers are ill-equipped to deal with ambiguity and context dependency.*" In below section, the decision-making model of the households is formalised, together with the concept of time and value conflicts. After that an overview is given of other necessary formalisations in a format described by Van Dam et al. (2012).

Rational decision-making

Household decision-making is formalized in the model. Although the primary aim of the model is explicitly not to predict what choices households will make (but rather explore which value conflicts are possible), choices have an influence on the model outcomes. It is important to understand how decision-making is formalized in the model, as it forms the basis of the emergent phenomena that are later on analyzed. As it is nearly impossible to perfectly model human decision-making, choice is made to make use of rational choice theory.

Rational choice theory (Morgenstern & Von Neumann, 1953) assumes people are rational choosers, have prioritized preferences, have complete information on the choice at hand and are independent of perceptions and emotions (Green, 2002). Assumed also is that rational choosers compare choice options and maximize for perceived utility or values (B. Schwartz et al., 2002). These assumptions have historically determined the sciences of economics (B. Schwartz et al., 2002), but the reality is that humans are not always rational decision-makers[1]. Full information is often not available and the perceptions and emotions surrounding the choice can also have an influence.

Herbert Simon proposed an alternative to the assumption of maximization (Simon, 1956), recognizing that it is not always realizable in real life due to the complexity of the real world and limitations in how humans process information (B. Schwartz et al., 2002). He proposed humans "satisfice"[2], rather than maximize. As B. Schwartz et al. (2002) put it: "*To satisfice, people need only to be able to place goods on some scale in terms of the degree of satisfaction they will afford, and to have a threshold of acceptability. A satisficer simply encounters and evaluates goods until one is encountered that exceeds the acceptability threshold. That good is chosen.*"

In the model, use is made of rational choice theory as a decision-making model. Households are assumed to have all the information they need to assess how a heating alternative would satisfy their values. Households will choose for the heating alternatives with the highest combined value fulfillments. Perceptions, emotions or non-availability of information are therefore not taken into account in order to keep the modelling exercise executable in the allotted time.

Time

The model aims to identify value conflicts, and those that could possibly emerge over time. As such, it is important to consider how the passing of time is formalized. 'Time' in real-life could be considered a continuous flow, which is sometimes difficult to translate to a computer model as they

[1]The works of Amos Tversky and Daniel Kahneman (for example (Kahneman et al., 1982), (Tversky & Kahneman, 1981)) illustrate this well, and have been condensed into the international best-seller *Thinking fast and slow* (Kahneman, 2011), an approachable introduction into heuristics and bias in human decisions.

[2]A combination of satisfy and suffice (Simon, 1956)

often work with discrete computing steps. The difficulty is then in relating how computing steps relate to real-world time: is one cycle of decisions analogous to a day, a year or a decade?

To overcome this difficulty, time (hours, days, years) is not explicitly modelled. Rather, choice is made to run the model until equilibrium. When equilibrium is reached, no new value conflicts are emerging anymore. This equilibrium is assumed to be sufficiently far in the future of the heating alternative, and can reasonably be assumed to cover its entire lifespan. This overcomes the difficulty of formalizing time, but has a possible drawback in the fact that the identified value conflicts cannot be traced back to when they happen. As described in Section 3.1.1, the time dimension can matter in assessing social acceptance.

Value conflict formalisation

Following decision-making and time, the formalisation of a 'value conflict' is also necessary. Values were said to conflict if, when considered in isolation, they evaluate different options as best (Van de Poel, 2009). Together with the rational decision-making described before, value conflicts are formalized as follows.

A value conflict is denoted when an increase in value fulfillment is associated with a decrease in value fulfillment of another value. This means that the value conflicts are denoted following a certain choice. Value fulfillments are determined before and after this choice, and after that a household can determine how these fulfillments relate to each other.

Two additional remarks are given on this formalization. Firstly, the choice households make. As this research considers the transition from traditional heating to a new heating system, households will compare value fulfillments prior to the transition to a new heating system, and after. This means comparing the value fulfillment when making use of an individual heating system (often time a gas-fired boiler) with that of a new heating system (either a collective DH system or an all-electric semi-collective system for Geerdinkhof).

Secondly, as decreases or increases of two different value fulfillments are compared, value conflicts are always a combination of two values. A value conflict will take the shape of *Value 1 vs Value 2*. A hypothetical example of a value conflict is given in Figure 5.3 later on to give the reader a better feeling for this formalisation.

Computer-understandable formalisation

Below is a formalisation of the earlier described concepts in computer-understandable language, using the software data structures approach as described in (Van Dam et al., 2012, p.83). This approach converts the concepts previously identified in computer understandable analogues. Most agent properties or characteristics are numbers instead of for example strings or booleans, as this will help increase the mathematical tractability and make the verification step easier to perform (Galán et al., 2009).

1. Objects
   - Households: contain decision-making capabilities and data describing their states and properties
2. Numbers
   - Investment values: System parameter describing the investments values in Euro for different parts of the DH system [Integer].
   - Participation level offered: System parameter describing at which Arnstein level the

households can participate [Integer between 1 and 8].
- Ownership level offered: System paramter describing how much households will be owner of the DH system [0 = none, 0.5= some, 1.0=full ownership].
- Choice level offered: System parameter describing how much households will be able to choose their preferred heat supplier [0.6 = not possible, 0.8 = somewhat possible, 1 = fully possible].
- Energy label: Household characteristic describing the energy label of the household [A=1, B=2, C=3, D=4, E=5, F=6].
- Spendable income: Household characteristic describing the annual spendable income in Euro [integer].
- Willingness to Pay: Household characteristic describing how willing a houshold is to pay for a new heating system [Real number between 0 and 1].
- Willingness to Choose: Household characteristic describing how important a household finds it to be able to choose their preferred heat supplier [Real number between 0 and 1].
- Willingness to Participate: Household characteristic describing which place on the Arnstein ladder of participation the household prefers to participate [Integers between 1 and 8, 1 being the lowest level and 8 the highest level on the ladder].
- Willingness to Own: Household characteristic describing how important a household finds it to own their heating system [Real number between 0 and 1].
- Value fulfillment individual: Household characteristic describing how the individual heating option fulfills each of their 5 values [5 numbers, each a real number between 0 and 1].
- Value fulfillment system: Household characteristic describing how the DH system option fulfills each of their 5 values [5 numbers, each a real number between 0 and 1].

3. Booleans (represents true or false values in logic)
    - Part of System: Household characteristic describing if the household is part of the DH system (1) or not (0).
    - Installations: Household characteristic describing if the household has solar PV panels on the roof (1) or not (0).
    - Garstkamp: Household characteristic describing if the household is part of the Garstkamp appartment complex (1) or not (0).
4. Strings (string of characters or text)
    - DH system offered: System parameter describing which DH system is considered. ["collective" or "semi-collective"]
    - Value conceptualization: System parameter describing which conceptualization of a value is to be considered during the simulation ["C1 Individual investment", "C2 comparability of cost", ...]

5.4 Step 4: Model formalisation

Now that is established what and who is in the model, a closer look needs to be taken at who does what and when (Van Dam et al., 2012, p.88). This will be done by virtue of a model narrative and pseudo-code of the model. A model narrative is an informal story, describing what the agents in the model do, when they do it and with whom they interact. Pseudo-code on the other hand is one step closer to a formal model, and describes algorithms to be executed by a computer in human-understandable language. This code provides the final step for formalizing a real-world socio-technical system in specific computer code (Van Dam et al., 2012, p.89)

Model narrative

In this model, agents (households) decide if they want to remain with their current form of heat supply (individual gas boiler), or switch to a shared heating system, either collective district heating or semi-collective through shared heatpumps. At initialization of the model, the households are build according to the geography of Geerdinkhof and individual characteristics (income, energylabel, etc.) are randomly attributed to each household. Also the system parameters (type of system, investment cost, etc.) are specified together with the conceptualizations of values considered. Every time-step in the model (a so-called "tick"), all households can decide whether they want to join the district heating system or remain with individual heating. Households determine each tick how much their values are fulfilled in the case of an individual heating system and in the case of the DH system offered. The value fulfillments are a function of the household characteristics, the system parameters and the conceptualization chosen. Households sum the fulfillments for each heating option, and choose for the heating option that overall fulfills their values best. When a household is done with making their choice, the next household makes their choice.

Joining the DH system influences it. If more people join in, the system will become cheaper as the infrastructure cost is shared among more households. The same applies for the efficiency of the system, as larger systems can be more energy efficient. In turn, households also look at the actions of their neighbors and weigh this in their value fulfillment calculations.

After each tick, a value conflict is denoted for a household when a value is negatively influenced by the decision. Households that encounter a certain conflict have their characteristics saved to an embedded list (e.g. [[income1 income2] [energylabel1 energylabel2] [...]]) for data analysis purposes. The goal is not to predict the choices agents will make, rather it is to investigate what value trade-offs or conflicts the agents will encounter. Switching heat supply implies the alternative better satisfies their values, but this may come at a cost for other values. The model is run until equilibrium is reached, i.e., when there are no more households switching between the two heating alternatives and no new value conflicts can emerge.

Pseudo-code

The pseudo-code can be found in Appendix B. The code is structured in two parts: setup and go. Within the setup algorithm, the model is initiated, relevant data is loaded and the households are built with their relevant characteristics. The second part describes the simulation part of the model. Within this part of the pseudo-code, household evaluate how the system fulfills their values, make the decision for their preferred heating system and value conflicts are denoted and prepared for data analysis.

5.5 Step 5: Model implementation

Now that the model is fully formulated, it is ready to be implemented in software. Van Dam et al. (2012) describe several modelling environments suitable for ABM, and choice was made to implement the model in Netlogo 6.1.1. Reasons for choosing Netlogo over other environments was prior experience with Netlogo, its easy programming syntax and an active support community. A screenshot of the implemented model can be seen in Figure 5.1.

Next to choosing the modelling environment, within this step (Van Dam et al., 2012, p.95) also describe several modelling practices such as version control, documentation and for larger projects

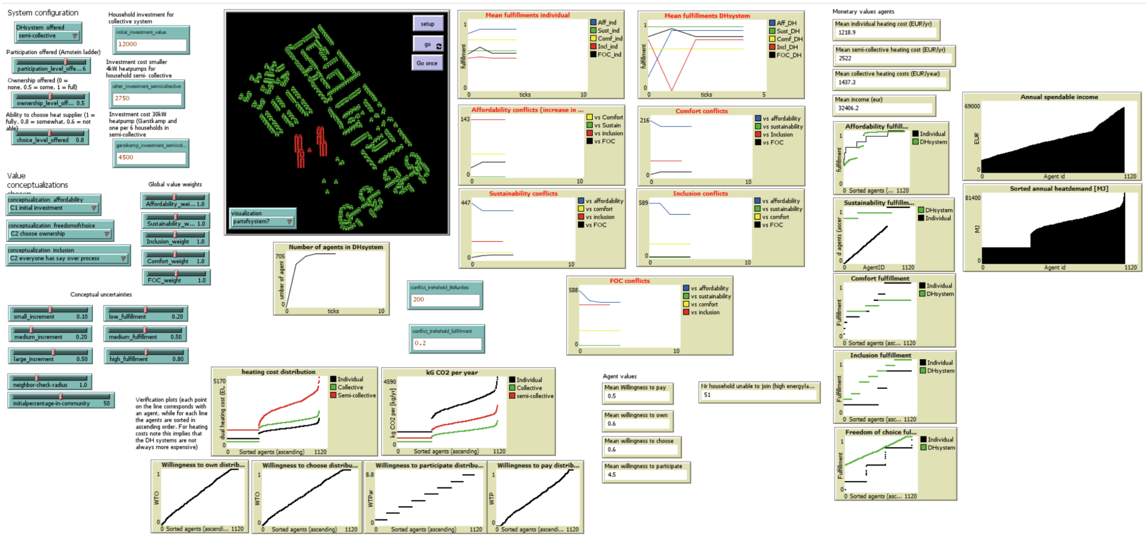


Figure 5.1: Graphical User Interface of the implemented model. On the left are the inputs (system parameters and conceptual uncertainties), in the middle the households and on the right the various plots used for verification and analysis purposes.

also bug tracking, divisions of tasks and standardized naming conventions for variables. The code was documented during the implementation phase, and when parts of the model were finished a new version of the model was started. This helped in the process of verification process described below.

5.6 Step 6: Model verification

Van Dam et al. (2012) state *"When we have a working model in computer code we must ask ourselves an important question: did we correctly translate the conceptual model into the model code? Computers will do exactly what we tell them to do, and not what we want them to do, which are often not the same. Therefore, we must take some time to make sure that model implementation corresponds with the model design before we can continue analysing and using the model."* (p.98). The question we now must ask is have we built the model right, and is this model fit to serve the original purpose: that of providing answers to our problem. Galán et al. (2009) state that *[verification]... "is the process of ensuring that the model performs in the manner intended by its designers and implementers."* (p.9).

Verification of agent-based models is no easy feat, as it requires making the distinction between programming artifacts and errors (Van Dam et al., 2012, p.99). An error is best understood as a mismatch between what the modeller think the model is, and what it actually is (Galán et al., 2009). An artefact on the other hand can be understood as the significant emergent behavior embedded within the computer model (Galán et al., 2009), and has more to do with the assumptions that have been made than discovering new emergent behavior. Van Dam et al. (2012) state 4 main parts to verifying agent-based models:

- Recording and tracking agent behavior
- Single-agent testing
- Interaction testing

- Multi-agent testing

Recording and tracking agent behavior
Recording and tracking of agent behavior is a means of model verification in which we follow the behavior of an agent and see if the behavior is as expected (Van Dam et al., 2012, p.100). This means following a single agent through the course of a simulation, and see what happens with the internal states and outputs of the system. In this stage of the verification, errors were found in which minus signs had to be plus signs and even an accidental inclusion of an unrelated variable.

Single-agent testing
Within single-agent testing Van Dam et al. (2012) propose two fundamental tests: theoretical prediction / sanity checks and breaking the agent. Through theoretical prediction, the modeller predicts a single-agent behavior using the theoretical model. If there is any deviation between what the theoretical model predicts and what the implemented agent does, there is an implementation error present (Van Dam et al., 2012, p.101).

Breaking the agent on the other hand entails taking a closer look at agent behavior under extreme input conditions. Galán et al. (2009) propose a similar approach, in which parameter values take extreme values and other model settings are varied drastically to see when the agent 'breaks'. Through varying the amount of households to much higher and lower amounts, setting system parameters to the most extreme values and varying agent characteristics such as energylabel, income and amount of solar PV panels a few errors were found. Most of the times, these were caused by improperly defined boundaries for certain agent properties like value fulfillments.

Interaction testing
Interaction testing is at the basis the same as single-agent testing with theoretical prediction test and breaking the agents, but focused on interactions between agents. Here we check if the desired interaction works as intended, and check for the presence of other unintended interactions (Van Dam et al., 2012, p.103). Interactions between the agents only take place when agents are checking what heating system their neighbours choose, and when calculating the feasibility and cost of the semi-collective heating system. These interactions were implemented as intended.

Multi-agent testing
Multi-agent testing is mainly done to verify that the order of agent interaction does not significantly alter the outcomes of the simulation. As Netlogo is unable to let all agents do their thing simultaneously, agents undertake their actions in a sequential order. This order is randomly generated every time the agents are asked to do something[3], and ensures there are no first-mover artefacts.

Multi-agent testing was done through the virtue of variability testing. Variability testing entails running the model many times, and see if the random change in agent order has significant outcome. In Figure 5.2 the variability analysis performed for a collective system can be seen in the form of a boxplot. Choice was made to perform this variability analysis on the mean fulfillments, as this is the deciding measure for which value conflicts emerge. One can easily see from the figure that for many value fulfillments the variation and standard deviation is negligible. The largest variability is found in the mean fulfillments of inclusion and freedom of choice. This is explained as these

[3]The Netlogo Programming Guide has a more elaborate description of this order `https://ccl.northwestern.edu/netlogo/docs/programming.html#agentsets`

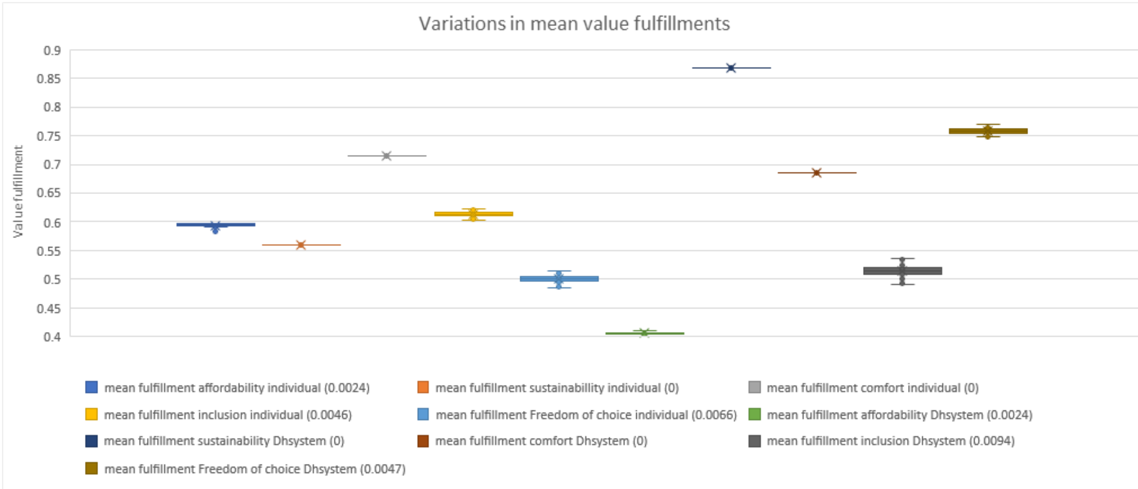


Figure 5.2: Variability analysis of mean value fulfillments for 100 simulations of the same collective system. In brackets in the legend is the standard deviation.

fulfillments are largely determined by what the neighbours of the household decide, and it can matter if the household next to you already switched heating system or not.

The same variability analysis has been performed for a semi-collective system, and only smaller standard deviations were found for the mean fulfillments.

Unit consistency

In addition to the four means of verification described by (Van Dam et al., 2012), (Galán et al., 2009) also propose executing a unit consistency check. This check is done to make sure that all variables have consistent units, before and after mathematical manipulation in the simulation. Here an error was detected in calculating the heating cost, as one unit was in MJ and the other in GJ.

Conceptual uncertainties

In addition to the verification methods above, the effect of conceptual uncertainties was also investigated. This group of parameters is the quantitative conversion of assumed qualitative relations. These parameters include the range in which households check what heating systems their neighbors have, the initial percentage of households in the heating system and a group of parameters that is used for model uniformity (See Appendix C.1). These model uniformity parameters were used to make sure that an assumed small or large influence on a certain variable always is the same step size. For example, a small negative influence on a fulfillment means that there is always a subtraction of the *small increment*-variable.

A sensitivity analysis was performed for each individual conceptual uncertainty, for each combination of conceptualizations and systems offered. During each test, a single conceptual uncertainty was varied significantly and then a close look was taken at any difference in value conflicts observed. After all tests, it can be concluded that the model is not sensitive to any particular conceptual uncertainty. Changing the parameters this way did not lead to disappearance or emergence of conflicts, and the chosen values for these parameters were used for the experimentation and validation.

5.7 Step 7: Experimentation

Now that the model has been formalized, implemented and verified it is time to use it for experiments. Three experiments have been designed: a social collective system, a less social collective system and finally a semi-collective system. Each experiment is described using its system parameters below. Choice was made for only three experiments due to time constraints. Of course, with this model it is possible to experiment with a large variety of system parameters, but these experiments are believed to cover the range of likely heating alternatives. Choice is made for two variants of the collective DH system, and one possible implementation of the semi-collective system.

The two collective experiments are different in how 'social' they are: high levels of participation, ownership and freedom of choice or less so in the case of the less-social system. These are chosen as they represent the two implementation methods of DH systems that are historically present. Older systems are usually implemented in a more top-down approach with little real consideration of local conditions and households were given little choice other than being connected to the offered network or not. On the other hand, there are examples of community initiated DH systems that are more bottom-up, and are based on choosing for the best option for that locality and deciding together.

There is only one semi-collective experiment, as this is believed to be the only viable implementation of a semi-collective system. Sharing heatpumps on a small scale with up to 6 neighbours requires larger levels of participation, as the chance is small there will be an organization willing to organize all these small heating communities. The same goes for ownership, as a centralized organisation owning the heating system of these communities is assumed unlikely. As such, the households are assumed to share ownership of the systems between them and carry the full cost. Additionally, this system has a high value for freedom of choice as the heat is generated through the use of electricity. Households are therefore their own heat supplier, and are always able to choose their electricity provider of choice.

- **Social collective**
  - The social collective experiment is characterized by *higher* values of ownership, participation and freedom of choice for heat supplier. This experiment is chosen to represent a more bottom-up approach where citizens are more in charge of their future heating system.
  - Participation levels offered: 4 and 6.
  - Ownership levels offered: 0.5 and 1.
  - Choice levels offered: 0.8 and 1.
  - Conceptualizations chosen: all.
  - Investment values: 12000 (collective connection).
- **Less social collective**
  - The less social collective experiment is characterized by *lower* values of ownership, participation and freedom of choice for heat supplier. This experiment is chosen to represent a more top-down approach, where citizens more or less presented with an alternative heating system they can choose to accept or not.
  - Participation levels offered: 2 and 4.
  - Ownership levels offered: 0 and 0.5.
  - Choice levels offered: 0.6 and 0.8.
  - Conceptualizations chosen: all.
  - Investment values: 12000 (collective connection).

- **Semi-collective**
  - The semi-collective experiment is the only experiment with the semi-collective system. The characteristics of this system configuration implies households are their own heat suppliers through heatpumps, close participation between neighbors and likely full ownership over the heatpumps. Configuration with lower levels of participation, ownership and choice of heat supplier are therefore unlikely, and only one experiment with the semi-collective system is undertaken with below parameters.
  - Participation levels offered: 6 and 8.
  - Ownership levels offered: 1.
  - Choice levels offered: 1.
  - Conceptualizations chosen: all.
  - Investment values: 4500 for large heatpump, 2750 for any additional smaller heatpump.

Experimental setup

Other than the type of experiments and what system parameters you want to research, it is also important to clarify a few things about the experimental setup.

Experiments were performed using the BehaviorSpace tool built into Netlogo 6.1.1. This tool can be used for "parameter sweeping", in which the space of parameters and associated model outcomes can be explored. Within the BehaviorSpace environment, you specify the range of parameters you want to test, the amount of ticks the model has to run for and the reporters you want to have saved for data analysis.

As said before each simulation will be run until equilibrium of identified value conflicts takes place[4]. Each combination of system parameters is run three times in order to account for the stochastic nature of the model. More runs do provide better results, but as limited time was available and little difference between runs with the same settings was found, 3 is believed to be an appropriate number of runs.

Next to the number of runs, it is important to address randomness (Galán et al., 2009). Improperly considering randomness can sometimes lead to unwanted situations (consider for example first-mover artifacts), and one needs to especially consider pseudo-random algorithm cycling and exact run replication[5] (Van Dam et al., 2012, p.111). Several household properties are distributed using Netlogo's *random-float* command, which generates a floating point number (i.e. with decimals) in the range specified. Netlogo makes use of the Mersenne Twister algorithm to generate these (pseudo-)random numbers. It is a pseudo-random number generator, because it generates seemingly random numbers that are actually generated by an algorithm, and given enough time a pattern can be recognized[6]. For the number of simulations and times the *random-float* command was used this is unlikely to be a problem: the Mersenne Twister algorithm only repeats itself every 4.3×10^{106001} numbers generated (Van Dam et al., 2012, p.111).

Additionally, the model was run on a single machine. Galán et al. (2009) describe that running the simulation on different machines using different programming languages or different pseudo-random number generators could help find errors in artefacts. Again, due to limited time the model was only tested on a single machine, and it might be worthwhile to check the experiment results on different

[4] In practice this was around 2 or 3 ticks, but for safety measure the stop condition was put at 5 ticks.

[5] An exact run replication allows the researcher to repeat the experiment with exactly the same random values using a *random seed*.

[6] See Uri Wilensky's notes on the Problab sample model: `https://ccl.northwestern.edu/netlogo/models/RandomBasic`

Individual fulfillment	Difference	Collective fulfillment
Comfort = 0.6	<	Comfort = 0.8
Affordability = 0.8	>	Affordability = 0.5

Figure 5.3: Hypothetical example of a conflict: in a transition from individual to the collective system, a gain in Comfort fulfillment can be realized, although Affordability decreases. This conflict is denoted as *Comfort vs Affordability* with decrease of 0.3. As fulfillments range from 0 to 1, a decrease in value fulfillment of 0.3 is moderate but significant.

machines.

Data output
After each model run, relevant metrics are saved for later data analysis. This include the system parameters used for this simulation run, the conceptual uncertainties used and finally the 'results': the amount of households that were part of the system in the end, the mean fulfillments of households for all values and finally for every possible value conflict two metrics. The first metric describes the average size of all households experiencing this conflict (i.e. with how much one value fulfillment decreases when another value increases). The second metric was used to save household characteristics of households experiencing this conflict (energy label, income, percentage PV ownership, percentage house ownership).

5.8 Step 8: Data analysis

Now that the data has been generated, it is time to process and analyse this data in such a way that meaningful conclusions can be drawn. Van Dam et al. (2012) wrote the following about data analysis: "*We are embarking on an adventure in "experimental data land", where no one has gone before, where there are no maps and where we do not know what manner of weird and wonderful creatures we will meet. Data analysis requires a truly open mind and an exploratory spirit.*" (p.116). Van Dam et al. (2012) describe four phases in data analysis: Data exploration, pattern visualization and identification, pattern interpretation and explanation and finally experiment iteration.

In the rest of this section, value conflicts will be discussed as *Value 1 vs Value 2* conflicts with a number indicating the decrease. For clarity reasons, Figure 5.3 shows a hypothetical example of what is meant with denoting a conflict like this. Furthermore, the terms "DH system", "heating alternative" or "heating option" are used to describe both the collective and semi-collective system.

Data exploration
During data exploration we ask the question "what do we have here?", and identify relevant emergent patterns for answering the research questions (Van Dam et al., 2012, p.117). In order to do so we need to transform the raw data into something we can see patterns in.

The BehaviorSpace tool generated a .csv format file, and using the Excel 'text to column' function the file was prepared for data analysis. Each row in the Excel now corresponds to a single run done by the BehaviorSpace, and the columns were used to store data regarding the system parameters and metrics for the value conflicts. Using MATLAB R2021a, the metrics containing the household characteristics for each value conflict was used to identify the 'length' of this particular

run	particip	choice_	owners	conceptualization_affordability	conceptualization_freedomofchoice	conceptualization inclusic	affordability_vs_sustainability	affordability_vs_comfort	affordability_vs_inclusion	affordability_vs_FOC	sustainability_vs_affordability	sustainability_vs_comfort
109	6	0.8	0.5	C2 compar	C1 choose	C1 everyor	0	349	349	342	677	103
110	6	0.8	0.5	C2 compar	C1 choose	C1 everyor	0	349	349	340	677	103
111	6	0.8	0.5	C2 compar	C1 choose	C1 everyor	0	349	349	342	677	103
112	6	0.8	0.5	C2 compar	C1 choose	C2 everyor	0	382	0	398	677	103
113	6	0.8	0.5	C2 compar	C1 choose	C2 everyor	0	355	0	349	677	103
114	6	0.8	0.5	C2 compar	C1 choose	C2 everyor	0	363	0	352	677	103
115	6	0.8	0.5	C2 compar	C2 choose	C1 everyor	0	349	349	0	677	103
116	6	0.8	0.5	C2 compar	C2 choose	C1 everyor	0	349	349	0	677	103
117	6	0.8	0.5	C2 compar	C2 choose	C1 everyor	0	349	349	0	677	103
118	6	0.8	0.5	C2 compar	C2 choose	C2 everyor	0	452	0	0	677	103
119	6	0.8	0.5	C2 compar	C2 choose	C2 everyor	0	452	0	0	677	103
120	6	0.8	0.5	C2 compar	C2 choose	C2 everyor	0	452	0	0	677	103

Figure 5.4: Part of the lengths table of the social collective experiment. Each row corresponds to a single run, and shows some model parameters, the conceptualizations chosen for this run and finally the lengths per conflict: the number of household experiencing this conflict. Colors in the table are based on the gradient in that column: lowest values for the length in that column are green and the higher the more red the cell gets.

conflict. The length of a matrix simply describes the number of elements present in the matrix, in this case this means the number of households experiencing this certain conflict. These numbers were then put together in a separate Excel file, and using a gradient color function the conflict lengths were given a color: red for high values and green for low values. A screenshot of this table can be seen in Figure 5.4.

The data was explored using a sub-set of research questions. We are interested in what value conflicts are embedded within the different system, what the effect is of different conceptualizations, what the effects are of individual system parameters and finally what conflicts have the most impact on households. In other words:

1. What value conflicts can be observed?
2. What are the effects of different conceptualizations?
3. What are the effects of ownership, participation and choice levels offered?
4. What value conflicts have the most impact?

Pattern visualization and identification

The tables for each experiment as shown Figure 5.4 give a general feeling of how many households experience each conflict, and what the effects are of conceptualizations and different system parameters. However, to recognize patterns between the different experiments and identify which conflicts have the most impact a different overview is required. A new overview table was constructed by merging the different tables containing the value lengths with the original raw data file, and a closer look was taken at when which value conflicts are present. Some value conflicts are only present when certain conditions are met: certain (combinations of) value conceptualizations or certain parameter settings are used.

In Figure 5.5 this new overview table is presented. The three different experiments are displayed side-by-side, and for each possible value conflict the average number of households experiencing this conflict and the average fulfillment decrease are shown. To further visualize the outcomes the *number of households*-columns and *fulfillment decrease*-columns were filled in with a gradient color. The longer the colored bar is, the closer it is to the maximum value over the three columns.

Conflict	Collective (social)			Collective (less social)			Semi-Collective		
	Number of households	Fulfillment decrease	Condition	Number of households	Fulfillment decrease	Condition	Number of households	Fulfillment decrease	Condition
affordability_vs_sustainability	0	0.00		0	0.00		0	0.00	
affordability_vs_comfort	338	0.21	C2 affordability	334	0.16	C2 affordability	305	0.25	C1 affordability
affordability_vs_inclusion	285	0.21	C2 affordability	392	0.24	C2 affordability	592	0.26	C1 affordability and C1 Inclusion
affordability_vs_FOC	267	0.15	C2 affordability	237	0.18	C2 affordability	179	0.18	
sustainability_vs_affordability	676	0.54	always	676	0.54	always	677	0.31	C2 affordability
sustainability_vs_comfort	226	0.21	always	103	0.24	always	349	0.25	always
sustainability_vs_inclusion	620	0.21	C2 inclusion or low participation level	614	0.24	always	671	0.61	C1 Inclusion
sustainability_vs_FOC	463	0.16	C1 inclusion and low choice level	521	0.19	C1 FOC	201	0.18	
comfort_vs_affordability	328	0.54	always	451	0.54	always	0	0.00	
comfort_vs_sustainability	0	0.00		0	0.00		0	0.00	
comfort_vs_inclusion	301	0.21	C1 inclusion	409	0.24	always	0	0.00	
comfort_vs_FOC	262	0.17	C1 FOC	351	0.19	C1 FOC	0	0.00	
inclusion_vs_affordability	425	0.57	C2 Inclusion	107	0.57	C2 Inclusion	680	0.46	C2 Inclusion
inclusion_vs_sustainability	0	0.00		0	0.00		0	0.00	
inclusion_vs_comfort	287	0.22	C2 Inclusion	55	0.17	C2 Inclusion and some level of ownership	655	0.32	C2 Inclusion
inclusion_vs_FOC	428	0.16	C2 Inclusion	86	0.18	C2 Inclusion	198	0.17	
FOC_vs_affordability	682	0.57	C2 FOC	753	0.57	C2 FOC	586	0.46	always
FOC_vs_sustainability	0	0.00		0	0.00		0	0.00	
FOC_vs_comfort	542	0.23	C2 FOC	416	0.17	C2 FOC	600	0.33	always
FOC_vs_inclusion	787	0.21	C2 FOC	830	0.24	C2 FOC	786	0.77	C1 Inclusion

Figure 5.5: Overview table of the value conflicts in the three experiments. For each experiment and value conflict, the average number of households experiencing this conflict, the average decrease in value fulfillment and the condition required for value conflict is presented.

Note that this table shows averages: these were calculated by taking the average length of a conflict over all simulation runs. Runs in which this particular value conflict was not present were excluded from the average. This implies two consequences. Firstly, this means that this table shows only how households are affected *if they are affected*. This if-clause is represented in the *condition*-column. In practice this means that certain conceptualizations are needed to make a value conflict emerge. Secondly, as these are averages, some specific situations where conflicts are very large (or small) can be lost in this metric. This only happened in very specific system parameters however, and it is believed that averages tell more about the embedded value conflicts over all system parameters tested in an experiment than specific cases. The condition 'always' means that the conflict was present in every simulation of this particular experiment.

5.8.1 Pattern interpretation, pattern explanation and experiment iteration

When looking at Figure 5.5 several patterns can be identified. Notable groups of conflicts and individual conflicts are discussed below.

Group 1: Conflicts with sustainability

One of the first things to notice from the table, is that conflicts with sustainability are not present in any of the simulations. These are the conflicts *Affordability vs Sustainability*, *Comfort vs Sustainability*, *Inclusion vs Sustainability* and *FOC vs Sustainability*. Apparently, none of the households sacrificed fulfillment in the Sustainability value for the increase of other values. This is explained through the use of Figure 5.6.

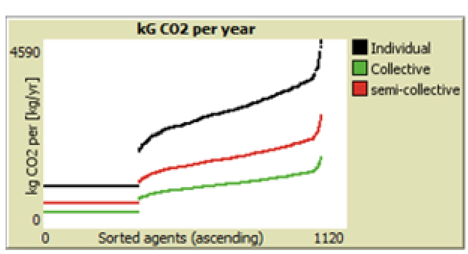


Figure 5.6: Yearly CO2 emissions for all households, sorted by households.

In the figure, the yearly CO2 emissions per household for different heating options are displayed. Note that the households have been sorted in ascending order of CO2, and that x-coordinates represent a single household. One can easily see that both the collective and semi-collective systems emit less CO2 than the individual systems. As the fulfillment of the sustainability value is dependent on the amount of CO2 emitted per year, no household will experience a value conflict in which sustainability decreases.

Group 2: Conflicts with Affordability for collective systems

Another noticeable pattern can be observed for both collective experiments, and to some extent in the semi-collective system. In Figure 5.5 the conflicts with affordability are experienced by a significant number of households and experience a relatively large decrease in value fulfillment. The value conflicts of *Sustainability vs Affordability, Comfort vs Affordability, Inclusion vs Affordability* and *FOC vs Affordability* can be explained through the use of Figure 5.7.

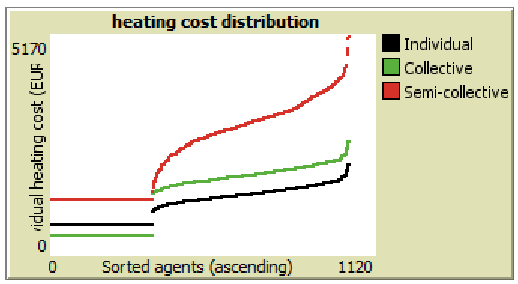


Figure 5.7: Yearly heating cost for all households, sorted by households.

In this figure, the heating cost per household for different heating options is displayed. Again, a place on the x-axis corresponds to a single household. For most households, the two DH system varieties are more expensive than their individual heating solution. This doesn't hold for the households in the flat region of the graph, here we see that the individual cost is higher than the collective costs. This flat region are the households in the Garstkamp apartment complex, and for them a collective system would be cheaper than individual heating. As the fulfillment of the affordability value[7] is dependent on the comparison of cost between systems, a more expensive system would imply a lower fulfillment of the Affordability value.

An interesting feature for this group of conflicts is the conditions required to show these conflicts. For *Inclusion vs Affordability*, C2 (inclusion as participating on the desired level) is required. Apparently, households will only trade-off an increased inclusion fulfillment against decreased affordability fulfillment when looking at how they can participate rather than if they can make the same choice as their neighbors (C1 Inclusion). This can mean that an increase in inclusion fulfillment is not possible when considering the first conceptualization, or that affordability fulfillment is only compromised on when households are able to participate at their desired level.

For *FOC vs Affordability* something similar can be observed. C2 FOC (can the household choose for ownership?) is required for this value conflict. Households only compromise affordability for FOC if ownership is at stake, and not when considering the freedom to choose heat supplier (C1 FOC). This could imply that households are willing to pay more for a new heating system, if some type of ownership is offered over this system.

[7] Note that C1 Affordability looks only at initial investment as ratio of spendable income, and that C2 Affordability is a comparison of cost of use.

Group 3: Conflicts Sustainability and FOC vs Inclusion

Another group of conflicts that is noticeable is with *Sustainability vs Inclusion* and *FOC vs Inclusion* in all experiments. Although the conflicts have a relative small decrease in value fulfillment, there are many households experiencing these conflicts.

For *Sustainability vs Inclusion*, the second conceptualization of Inclusion or low participation levels are found as a condition. Apparently, household experience this conflict only when there is participation considered or low participation offered. This can be explained through the definition of a conflict used in the model: a conflict is only denoted if there is a decrease of the second value (in this case Inclusion). This decrease is only observed with low levels of participation and the participation conceptualization, or always in a less social system. For the semi-collective system however the condition is the first conceptualization of inclusion (C1 is everybody able to make the same choice?). This conflict is grounded in the fact that not all clusters of households are viable for a semi-collective system: some are too poorly insulated or simply cannot afford the initial investment. This can also be seen in the relatively large number of households experiencing the *Affordability vs Inclusion* conflict.

For *FOC vs Inclusion*, the second conceptualization of FOC is found as a condition. This conceptualization considers the possibility of ownership, which leads to believe that households are willing to give up on the inclusion fulfillment if there is ownership offered to the households. This is similar to the *FOC vs Affordability* conflict described in group 2.

Group 4: Conflicts with comfort for semi-collective

The final group of conflicts discussed here concerns the value conflicts with comfort. In the semi-collective experiment, many households experienced conflicts in which Comfort fulfillment decreased with respect to Affordability, Sustainability, Inclusion and FOC. Inversely, there were no households experiencing conflicts where an increase in comfort took place with respect to any other value. The model implies that in a transition towards a semi-collective households seem to have little to gain in terms of comfort. This loss of of comfort can be interpreted as lower thermal comfort, lower ease of use or other types of nuisances.

For the collective experiments, there are also two individual conflicts with comfort. The first being the *Sustainability vs Comfort* conflict. This was the only value conflict that was present in *all* simulations across all experiments. Although the conflict is not experienced by an exceptionally large number of households or has a large decrease, it is always present. Embedded within each simulation is thus a trade-off between higher sustainability and lower comfort. The second conflict is that of *FOC vs Comfort*. Although partly discussed already above for the semi-collective experiment, this conflict can also be observed in the collective systems. This is only when the second conceptualization of FOC (ownership) is used.

5.8.2 Recognition of conflict groups

Figure 5.5 gives a good overview of all conflicts, but gives little insight into which households experience which conflicts. This is an essential part of recognition justice, which is concerned with identifying who is affected by injustices. For each group of value conflicts identified, 4 characteristics of households have been saved to see which households are affected. These are the average decrease in value fulfillment, the average percentage of home-ownership, the household energy labels and household incomes.

The energy labels and household incomes were visualized in histograms for each group of

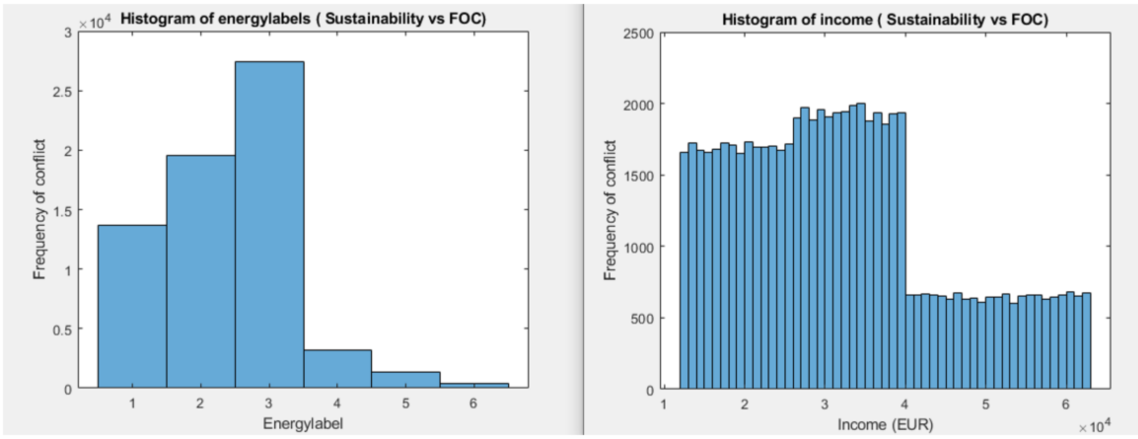


Figure 5.8: Example of created histograms for the Sustainability vs FOC conflict of the less social experiment. The Y axis denotes the frequencies of the x axis values (note that energy label 1 corresponds to label A, 2 to B and so on).

conflicts. One example of such histograms can be seen in Figure 5.8. Compare the distribution to the overall energy label distribution in Figure C.1 and spendable income in Figure C.2 in Appendix C.1. These comparisons were done for each group of conflicts to see which households experience the conflict in question. Below, groups 2, 3 and 4 are discussed.

Group 2: Conflicts with Affordability for collective systems

For the conflicts with lowered Affordability, three things can be said about the affected households in general. Firstly, there is no observable difference between the distribution of incomes. This was unexpected, as these conflicts were expected to be concentrated among low income households. This is discussed in more detail in Section 6.3. Secondly, home-owners were over represented. In all simulations the percentage home-owners was higher than the 44% average in the neighborhood, where some conflicts even had a 100% home-ownership average (Inclusion vs Affordability). Thirdly, there was also a higher share of households with energy label A compared to the neighborhood distribution.

So in general it is mostly home-owners with well-insulated households (independent of income) that are affected by this group of conflicts. A reason for these affordability-related conflicts could be that these households have already invested in insulating their houses and, as home-owners, are also responsible for the initial investment sum. These households are maybe already satisfied with their heating system and are not eager to invest (again) in a heating system.

Group 3: Conflicts Sustainability and FOC vs Inclusion

For the conflicts with sustainability and FOC + Inclusion, again spendable income was little different from the neighborhood distribution. The same applied for energy labels, which were very comparable to the neighborhood distribution. Notable about these conflicts however is that there is again an over representation of home-owners, with some conflicts having a 100% home-ownership rate (Sustainability vs Inclusion). Together with the conditions necessary for these conflicts, two explanations are suggested.

Firstly, home-owners might feel conflicted as they have less FOC in terms of heat supplier compared to their individual heating. For tenants this is maybe less the case, because they might care less about what choice they have (if their landlord even allows choice). Sustainability can be improved, but at the cost of home-owners' ability to choose heat supplier. Secondly, these home-owners experience this group of conflicts either if there is a high participation possibility or when there are neighbours in the area that cannot join due to either too low income or low energy label.

So for this group of conflicts, it is generally home-owners that either have neighbors that are unable to join due to poor insulation/low income or home-owners that get less participation offered than desired. Additionally, the ability to have a choice in heat supplier could lower the effect of this group of conflicts.

Group 4: Conflicts with comfort

In contrast to the conflict groups discussed above, this group of conflicts is experienced more by tenants than by home-owners. Moreover, the households that experience conflicts with lowered comfort fulfillment are generally well-insulated and have lower solar PV ownership rates than the neighborhood average.

These households are believed to experience the *Sustainability vs Comfort* and *FOC vs comfort* conflicts for two reasons. Firstly, the group of households that always experiences the first conflict have either too low energy labels and are thus unable to join, or are well-insulated. These well-insulated households experience this conflict if there is some sort of ownership offered by the system. The second reason is ownership. If there is ownership offered over the new system, the tenants will also be responsible for maintenance cost, effectively lowering the comfort fulfillment. So although FOC can be fulfilled better trough the use of ownership, especially tenants experience decreased comfort.

5.9 Step 9: Validation

Where verification addresses the question "did we built the thing right?", validation addresses the question "did we built the *right thing*?" (Van Dam et al., 2012, p.127). Does the model answer the original research questions, and are the outcomes convincing? Validation is traditionally concerned with if the model is an accurate representation of the real world, and comparing the model data with real world data (Van Dam et al., 2012, p.127). However, as this comparison cannot be made due to the fact 'what-if'[8] scenarios are tested and real world data is unavailable, other means of validation have to be used. Van Dam et al. (2012) propose three other types of validation: Face validation through expert consultation, literature validation and model replication. Model replication means the model is implemented again with a different decomposition or modelling technique. This is however very labour intensive and is outside the scope of this validation exercise. Choice is made to make use of expert validation to see how convincing and relatable the outcomes are and to use literature validation to see if these conflicts can be identified in scientific literature and what solutions are proposed.

5.9.1 Validation through expert consultation

Van Dam et al. (2012) make two notes on validation through the use of experts. Firstly, experts may have a proper understanding of what has happened in the past, but may be unable to systematically

[8] In a 'what-if' scenario you can consider what happens when you for example make the system 20% more expensive. This type of experimentation cannot be done in the real world as there are consequences, which is of course not the case in a computer model.

investigate possible future states. As experts rely on their own experience or internal models of system behavior, subjective, biased or otherwise flawed views on the outcomes can be possible (Van Dam et al., 2012, p.128-129). Secondly, models validated by experts are said to have *face validity* (Van Dam et al., 2012, p.129). They write the following on face validity: "*Finally, a model validated in this way by consulting experts is often said to have face validity, which means the model "appears reasonable" and it "looks like" it will do what it is supposed to do. Experts can be wrong too, but expert validation remains an appropriate way to address the validation of agent-based models.*" (Van Dam et al., 2012, p.129). To overcome possible bias in validation, two expert validation sessions have been organized, in which the outcomes were systematically discussed.

Session 1: Consultation with interviewee 5
Interviewee 5 (see Section 4.2) was invited to discuss the outcomes of the model. The interviewee was updated on the progress after the interview. The model was shown, the selected values and conceptualizations were explained and the definition of what a value conflict is was clarified. After that, the outcomes were discussed in the same order as described in Section 5.8. The expert found the model outcomes an addition to the discussion on social acceptance of DH systems and did not find any inexplicable results. Some remarks from the consultation session are discussed below.

For the Group 2 conflicts involving lowered Affordability, the expert found little surprise in the amount of conflicts. The €12.000 initial investment for the collective system is a large sum of money for most households, and the expert stated from experience that most households tend to ask first what it is going to cost them, rather than what else changes (comfort, sustainability, reliability, etc.). Cost are for most households the first consideration, and paying more than what they pay now is a significant hurdle to overcome. Additionally, credit risk was mentioned by the expert as a reason for high costs in DH systems. Credit risk in this case is the risk for the heat supplier of losing income due to the fact households are unable to pay their heating bills. For the heat supplier, this risk is higher with individual households than with an owners association for example, as the owners association carries the credit risk. This makes it unattractive for a heat supplier to connect individual households, and this could have been reflected in the price offered. Economies of scale also play a role in this consideration, as the expert stated that if less than 70% of households are connected to a DH system it becomes unprofitable for a potential heat supplier to supply the heat.

For the group 3 conflicts involving lowered Inclusion, the expert found a connection between the *Sustainability vs Inclusion, Sustainability vs FOC, Inclusion vs FOC* and *FOC vs Inclusion* conflicts. The expert described that, especially for home-owners, households are not unwilling to invest in 'green alternatives'[9], but would like to remain in power over that decision. An example for this is the *Menukaart woningisolatie*[10] (Menu Household isolation), a document created by residents for residents in Geerdinkhof, explaining what the different options are for insulating their households. Interestingly, the last page of the document has an overview of different companies and how to contact them. These companies have been approached by the residents for a price indication, before they were included in the overview. According to the expert, this demonstrates a willingness to act collectively, but the importance of deciding individually. These group 3 conflicts were not unexpected, as switching to a collective heating system will have benefits in terms of sustainability but also possibly infringe on the individual decision-making capabilities of households. Households

[9] Green alternatives here is used to mean the variety of technologies and possible actions households can make use of to reduce impact on the natural environment.

[10] This menu can be found on `https://geerdinkhof.nl/geerdinkhof/energietransitie/menukaart-woningisolatie/`

might lose control over their individual decision, and especially homeowners will want to stay in control over the heating of their household.

Session 2: Consultation with Energie lab Zuidoost
The same day, a second consultation was held with experts from the Energie lab Zuidoost. In this online meeting, several experts including a political scientist, a lecturer on urban challenges, innovation broker and two energy commissioners in the region Zuid-Oost were present. Later during the meeting, interviewee 1 (see Section 4.2) also joined. Although some struggled with fully understanding the model and resulting value conflicts, generally the results were not unexpected. Generally, they provided similar narratives as the expert in the first consultation session. Below are some remarks made during the meeting in addition to what is discussed above.

The first remark is on the group 3 conflicts with lowered Inclusion. One of the experts could place the group 3 conflicts with lowered inclusion in perspective with an example elsewhere in Amsterdam. The expert understood the hesitance households had to give up control over their heating system, as this happened in North-Amsterdam. There, the party that was to realize a DH system invited locals to discuss options about a new heating system. They were invited to agree on the best option for that location, but it soon turned out the decision was already made for a particular DH system and the participation of the locals can be considered as a form of tokenism (see section 3.1.3). In the end, households seemed only to be invited to agree on a DH system and not really find the best solution.

The second remark was on the perception of comfort. After a discussion on the assumptions used to determine the comfort fulfillment, comfort was found to be mostly dependent on how it is perceived. Different people appreciate different heat levels, and when taking into account factors as ease of use, nuisance and how quickly a desired heat level can be achieved the fulfillment of comfort becomes complex to determine. The fulfillment as determined in the model does not take all factors into account that could affect how comfortable somebody feels. As interviewee 1 remarked, the cooling capacity of the semi-collective system is not taken into account. This could significantly increase thermal comfort in the summer period, and could change the fact that group 4 conflicts (conflicts with Comfort in Semi-Collective systems) are currently not present.

Thirdly, a remark on ownership. During the meeting, several experts found the second conceptualization of Freedom of choice (the ability to have ownership) a little underdeveloped. This conceptualization was a condition for conflicts for *FOC vs Inclusion* and *FOC vs Affordability*, and these conflicts were quite large compared to other conflicts. One of the experts assumed a large difference in FOC fulfillment when considering what the household would own. A household could for example only own (part of) the house connection, or go as far as co-owning the infrastructure or perhaps even the heat source. Another expert agreed, and also discussed the risk that comes with ownership such as maintenance costs.

Generally speaking, the meeting concluded that the model outcomes 'seem reasonable' but that the fulfillment of comfort and the influence of ownership could have been further developed.

5.9.2 Validation through literature

For additional validation, the scientific literature is considered to see if similar decreases in value fulfillment can be observed as presented in Section 5.8. Literature was sought after that either reported the same value conflict or examples of how these value conflicts could look like in practice in district heating systems.

A note on this literature validation is that the literature discussed below is not specifically about Geerdinkhof. This would make the validation in light of recognition justice more relevant, however this literature is not always available. Instead, the below literature validation is used to demonstrate that the identified value conflicts are in the realm of possibilities when considering sustainable (district) heating systems, thus validating the findings.

Group 1: Conflicts with sustainability

The model found no conflicts with decreased sustainability, and when looking into literature regarding the sustainability, energy efficiency or CO2 emissions of (semi-)collective systems similar findings are found.

Sayegh et al. (2017) report a large potential for these kinds of systems to meet sustainability-related goals. In their study of DH systems and their use of fossil fuels, renewable energy sources, energy efficiency and impact on environment and human health was investigated, and a large number of opportunities are described. Lake et al. (2017) add to this that DH systems are in general more efficient than individual heating systems and more environmentally beneficial. Both Sayegh et al. (2017) as Lake et al. (2017) mention flexibility and the use of modern technologies as conditions to realize these benefits though.

As for the semi-collective systems, Abokersh et al. (2020) found the integration of heat pumps in DH systems a sustainable and competitive solution. Molyneaux et al. (2010) found similar results in their research on (de)centralized heat pumps. They state that "*Heat pumps, particularly when integrated with co-generation into district heating systems, are to play a major role in decreasing greenhouse gas emissions in the future.*" (Molyneaux et al., 2010). The sustainability of heat pumps is for a large part dependent on the electricity use, and in a Life-cycle Assessment by Greening & Azapagic (2012) the environmental benefits of heat pumps are surprisingly low if there is low renewable energy penetration in the energy mix, as up to 84% of emissions are dependent on the type of electricity used (Greening & Azapagic, 2012). Nevertheless, heat pumps could realize significant carbon reductions. For example, Zhang et al. (2019) found that for a large city as Beijing up to 21% reduction of CO2 can be possible if 25% of heat is supplied through the use of heat pumps.

Group 2: Conflicts with Affordability for collective systems

As for the group 2 conflicts involving a lower fulfillment of the Affordability value, little explicit findings can be found in the scientific literature. Van Aalderen et al. (2021) mentions Affordability as the main condition for acceptance in their research into DH systems, and Bouw (2017) reports a high dependence on price for social acceptance. In their study on willingness to pay for DH systems, Krikser et al. (2020) found that this is highly dependent on the costs of installation and operation (both conceptualizations of Affordability in the model).

Although not explicitly present in scientific literature, concerns over lower Affordability of DH systems is abundant in Dutch news articles. Consider for example the articles by De Telegraaf (Schoot, 2021), NOS (Ekker, 2019), Leeuwarder Courant (Leeuwarder Courant, 2019) or Tubantia (Smink, 2021). This leads to believe that decreases in Affordability fulfillment are common, and these articles can serve as validation that affordability conflicts are within the realm of possibilities.

Group 3: Conflicts Sustainability and FOC vs Inclusion

When looking for inclusion related conflicts with sustainability and FOC, little explicit mentions of this conflict can be found. In her study about inclusion in the governance of Dutch energy infrastructures, Hendriks (2008) found that current procedures and structures failed to include many affected by the infrastructures (either through insufficient representation or participation). Although efforts exist to increase the awareness of inclusion in energy infrastructure, Valkenburg & Cotella (2016) found that inclusion of actors was underdeveloped in literature and proposed a framework for analysis.

On the other hand, conflicts with inclusion, or *inclusiveness*, were found by De Wildt et al. (2020) in a similar analysis for a neighborhood in The Hague (cf. de Wildt et al. (2021)).

Group 4: Conflicts with comfort

Firstly, for the semi-collective system, the (thermal) comfort of heat pumps is often discussed together with demand side response or thermal energy storage (cf. Schibuola et al. (2015), Sweetnam et al. (2019), Arteconi et al. (2013)). Thermal comfort of households is said to be an object of study (Karytsas & Theodoropoulou, 2014), but as a value conflict it is little studied. When taking into account the adjustments that have to be made to households to fit a semi-collective system (heavier electricity connection, placement of heatpump, associated infrastructure) and the sound nuisance the heat pumps can bring, decreased Comfort fulfillment is at least plausible. A more elaborate reflection of the conflicts with Comfort can be found in Section 6.3

For the collective systems, validation in literature is sought after for *Sustainability vs Comfort* and *FOC vs comfort*. The higher fulfillment in Sustainability has been discussed before, but the associated decrease in Comfort is again not explicitly found in literature. Cao et al. (2014) found higher thermal comfort for individual heating systems as compared to DH systems, mainly due to the fact residents were better able to control the amount of heating. Consider also the findings of Luo et al. (2016), who found that residents that are used to high thermal comfort might have high expectations for comfort and find it difficult to adapt to different situations regarding comfort. When households switch from an individual heating system with high associated comfort, lower comfort is maybe quickly perceived by households which leads to lower fulfillment.

For *FOC vs Comfort* in collective systems the scientific literature was considered where consumer ownership (a condition for this conflict) was related to comfort. The study by Djørup et al. (2021) provides a critical discussion on consumer ownership of district heating systems. Consumer ownership is said to improve prices for consumers and efficiency of the system, although no mention of loss of comfort is described. As other literature on this conflict was very difficult to find, the author concludes that this conflict cannot be fully validated through literature.

5.9.3 Validation through comparison to De Wildt (2020)

As this research can be considered as an extension of the work by De Wildt (2020) to a different neighborhood, it might be interesting to see how our findings compare to that of De Wildt (2020). Although De Wildt (2020) used similar values to this research, the conceptualizations are somewhat different (cf. (De Wildt, 2020, p.106)). Note also that use was made of experiments with a high and low temperature DH system and an all-electric solution, and that these findings do not correspond directly to the systems tested in this research. This comparison is however done to see if the identified value conflicts are surprising or could be considered validated in some sense.

The group 1 conflicts in this research is not directly reflected in a group of conflicts identified by De Wildt (2020). However, *Environmental sustainability* is the increased fulfilled value in 6 out of 8 identified groups. Therefore it is reasonable to say that the value conflicts with increased fulfillment for sustainability are not surprising.

The group 2 conflicts in this research is seen back in the group 2, 3, 5 and 7 conflicts (De Wildt, 2020, p.115). These groups have increased values for *Environmental sustainability, Autonomy* and *Comfort* at the cost of lowered affordability. Conflicts where affordability is less fulfilled than other values are therefore seen back in both studies.

The group 3 conflicts in this research are seen back in the groups of conflicts where *Inclusiveness* is less fulfilled (Groups 4 and 8 in De Wildt (2020)). In his work, these inclusivity-related issues follow from households being unable to pay the initial investments. This is maybe not directly related to the participation, ownership and inclusion-related issues described before, but it does show a risk of households not being able to make use of a new heating alternative.

Finally, the group 4 conflicts in this research (lowered comfort) are related to the groups 1 and 6 in the work of De Wildt (2020). In his work, the conflicts with comfort are mostly present in households that make use of individual heatpumps. Compared to high temperature DH systems, these heatpumps are limited in the heat they can provide and as such fulfill the comfort value less well. When comparing this to the comfort-related value conflicts identified by this research, other reasons are relevant. We conclude therefore that comfort is at risk of being less fulfilled, however the findings are not fully comparable as the underlying reasons for the emergence of these conflicts are not the same.

5.10 Step 10: Model use

In the final step of the method, the model is put to use. Among others, it describes how to present findings, raising new questions and how to engage stakeholders with the findings. In our case, we will do an impact assessment: which validated conflicts as discussed above have the largest impact?

5.10.1 Impact assessment

From previous steps there is an overview of groups of value conflicts. This collection of value conflicts tells little however on which value conflict could be considered more impactful than another. Consequently, until now this analysis doesn't tell the municipality of Amsterdam which value conflicts should be resolved first. As is often the case, there is a limited amount of resources available to deal with social acceptance issues. As such, the municipality can benefit from a proposed prioritization of value conflicts. It is proposed that value conflicts should be prioritized in three situations: if there is a large number of households experiencing the conflict, if the associated value decrease is significant or if there are implications for a specific group of households.

Firstly, a value conflict should be prioritized if there is a large number of households affected. This may be rather obvious: the more households experiencing the same conflict, the more impact it has overall.

Secondly, a value conflict should be prioritized if the associated value decrease is significant. This condition is chosen to address the value conflicts that are not experienced by a large number of households, but do pose considerable effects on the households' human values. If, for instance, there is a single household experiencing such a low comfort fulfillment that it is problematically cold in the residence, it could be argued that this has as much impact as some households having only a slightly lower than desired temperature. Value conflicts that have severe decreases in value fulfillment should therefore also be considered with priority. Whether or not a value decrease is significant is determined in comparison to the other value decreases. In practice this meant that fulfillment decreases from 0.4 and up were significant, as most other conflicts were in the 0.15 to 0.35 range.

Thirdly, value conflicts should be prioritized based on severity. With severity two things are meant: severity of implications and severity in terms of recognition. Severity of implications is concerned with the practical implications following a value conflict. Per the example above, a practical implication could be being cold in the household or maybe also significantly increased heating bills or if less CO_2 is saved than initially planned. Severity in terms of recognition is concerned with recognizing severity when a value conflict is confined to a certain demographic. A value conflict should be considered more impactful if it is only experienced by a certain type of household (insulation), income group or other.

Using these situations, three groups of conflicts are prioritized in the recommendations to the municipality in the next chapter. These are the conflicts with Affordability, comfort related conflicts and finally conflicts that are due to various levels of participation or ownership.

6. Synthesis

In this final chapter, the research outcomes are synthesised. Three recommendations are done to the municipality of Amsterdam in support of social acceptance of heating alternatives in Geerdinkhof. Finally, the research questions are answered in the conclusion after which a discussion follows on limitations and future work.

6.1 Recommendations for the municipality of Amsterdam

The author acknowledges that the heat transition in Amsterdam Zuid-Oost is a complex problem, with many technologies, actors, policies or means that have to be mobilized to realize this Herculean task. Nevertheless, 3 recommendations for the municipality of Amsterdam can be isolated from this thesis. The first recommendation is made with regards to the neighborhood specifics, and the other two might be obvious but relevant still for support of social acceptance.

Respond to neighborhood specifics

This thesis reported several findings that point at the neighborhoods specifics. One of the interviewees described the residents in Geerdinkhof as willing to act collectively, but the decision should be left to the individual. People in Geerdinkhof in general have the time and means available to act on the heat transition. This could create opportunities for the municipality if a proper response is given to the neighborhood characteristics. A DH system after 2030 offers little perspective for those that want to act now, and it might be worth to investigate together with the residents what can be done on a collective level before that time.

The group 3 value conflicts (Section 5.8.1) showed that households could experience conflicts due to low levels of participation, ownership or inclusion otherwise. From Section 5.8.2 we have seen that mostly home-owners in well-insulated houses experience these conflicts. These conflicts find their basis in households either having neighbors that are unable to join or the system having lower ownership and participation levels than desired by the household.

In some cases, households have neighbors that are unable to join in on the heating alternative as the house was below a certain threshold of insulation or simply could not afford the initial investment. A way to resolve these inclusion-related value conflicts is to focus on establishing a minimal insulation level for all Geerdinkhof households and subsidize those that are unable to finance the initial investment.

In other cases, these home-owners experience value conflicts in the model due to low participation and ownership levels offered. These value conflicts could be resolved by more closely including the households or take a new look at how ownership over the heating alternative can be organized. Consider for example Thermo Bello[1], a community-owned DH system in Culemborg (NL) that operates at lower cost than DH systems in Amsterdam while simultaneously providing local job and investment opportunities. Shared community ownership could perhaps be a tool to make households feel more part of the heat transition, while distributing benefits to participating households. This, together with proper process design regarding participation, can help alleviate tokenism-related issues that were identified by the model. Opportunities lie with proper choice of process design, where the step on the Arnstein ladder of participation should reflect the capabilities of the households and where ownership be shared in support of social acceptance (cf. Ivask et al., 2021). This is in line with the intentions of the municipality of Amsterdam, which aims to organize open access to decision-making processes for citizens (Municipality of Amsterdam, 2020a), in support of empowering citizens and safeguarding trust and transparency.

Two recommendations are therefore made with regards to the neighborhood specifics: make sure every household is suitable for a DH connection trough insulation and initial investment subsidies and reconsider shared ownership and participation for this neighborhood.

Improve affordability of heating alternatives

The second recommendation concerns the affordability of heating alternatives. Although it may be unsurprising that the cost of heating alternatives can pose social acceptance issues, it is still important to discuss. In the modelling exercise, both systems considered are more expensive for the largest part of households. The only exception here are the Garstkamp apartments in a collective system, but moreover especially the semi-collective system is more expensive than individual heating. This may in part be due to the data and assumptions used, but nevertheless shows a risk of higher prices for households. The heating bill or initial investment is possibly the most directly visible impact for households. One of the interviewees stated from experience that households will often ask first what it is going to cost them, rather than what the benefits of a new heating system can be. Framing is also very important here, as an initial investment could be justified by lower monthly heating cost. The challenge is in convincing households that a new heating alternative is not necessarily more expensive, but that the cost structure is different from traditional heating. Low perceived affordability can therefore be a significant hurdle to overcome in support of social acceptance.

Two possible options are identified. Firstly, the municipality could wait until 2030 to start rolling out a heating alternative for this neighborhood as per the transition vision[2]. By then, the system cost has probably decreased due to learning effects and efficiency gains in technology. Secondly, if reduction of system cost is unrealistic or the wait until 2030 is too long, subsidies can be considered more extensively. Subsidies currently have conditions which excludes tenants for example, and there is no specific subsidy for the Geerdinkhof neighborhood[3]. Additionally, these subsidies vary over time while households are benefited by stable policy environments (Ivask et al. (2021), Fernández et

[1] https://www.thermobello.nl/

[2] https://www.amsterdam.nl/wonen-leefomgeving/duurzaam-amsterdam/aardgasvrij/

[3] From Subsidy Area specific gas free Amsterdam https://www.amsterdam.nl/veelgevraagd/?productid=%7B2A76669F-942B-4324-9BF8-E2DFDD9BC1FD%7D

al., 2016, p.13).

The recommendation therefore is to improve the affordability in the long-term through awaiting the learning curve and the use of subsidies. These subsidies should have less conditions than the subsidies currently available and should remain stable in the years to come. The municipality state in their Routemap Amsterdam Climate Neutral 2050 that energy justice is very important in the coming energy transition, especially for lower income households (Municipality of Amsterdam, 2020a). The desire is to not increase housing costs, but little concrete steps for the implementation of heating alternatives are found. The municipality can work on specifying on how they are hoping to overcome affordability-related issues in a sustainable manner.

Improve comfort of heating alternatives

Simultaneous to the conflicts with Affordability, there were households compromising comfort for other values. On top of that, no increases in comfort fulfillment were observed in the model for the semi-collective system. Again, this may be due to the data and assumptions used, but it does imply that the heat transition in Geerdinkhof should pay attention to what it can deliver in terms of comfort, at an equal price.

One of the most effective ways is probably better insulation of households (Poortinga et al., 2018). Although the households in Geerdinkhof are generally well insulated, it is estimated there are roughly 50.5% of households with energy label C or lower[4]. Insulation helps save energy the day it is implemented, and allows households to improve their thermal comfort. Currently, the willingness to isolate is present for households in Geerinkhof[5], but other than individual motivation there is little true incentive to insulate. Subsidies for better insulation are either discontinued or converted to loans[6]. Additionally, ensuring a baseline insulation for Geerdinkhof households can also improve on inclusion-related social acceptance issues (See Section 5.8.2), as it will make all households suitable for a new heating alternative.

Insulation is not the only answer to comfort-related value conflicts. Some of the conflicts were experienced by a relatively high share of well-insulated households. This lower comfort fulfillment is not due to poor insulation, but rather being responsible for maintenance cost in cases of co-ownership. For these households, comfort could be realized in the long-term through investments in heatpumps. Heat pumps are a viable way to produce one's own heat independent of heat suppliers or other parties. In summertime, these heatpumps can also provide cooling, further improving the thermal comfort throughout the year. A possible way to nudge households towards the use of heatpumps is to encouraging solar PV installations. Although this does not directly increase residential comfort, renewable electricity can make the installation of a heat pump more attractive to meet their heat demand at a lower cost and increased sustainability.

The recommendation for comfort-related value conflicts is therefore to establish a baseline insulation level for all households in Geerdinkhof and to make the installation of heatpumps more attractive.

Final words on recommendations

In short, from the interviews and modelling exercise three recommendations can be formulated.

[4]The observed energy labels in the Nationale EnergieAtlas have been used to make this estimate, see Appendix C.1

[5]Consider the menu for household insulation, created by Geerdinhof residents https://geerdinkhof.nl/geerdinkhof/energietransitie/menukaart-woningisolatie/

[6]See the Energy Loan by the municipality https://www.amsterdam.nl/veelgevraagd/?productid=%7BD94DCF5C-3E4F-4DDE-83C7-2DBFEB7088DF%7D

First and foremost is to respond to the neighborhood characteristics. Geerdinkhof residents are different from other neighborhoods, and require different considerations regarding participation and ownership. The other two recommendations can be considered obvious but can be summarized as a recommendation to improve the status quo of heating alternatives. Households should be convinced that a heating alternative can offer a larger comfort, at a comparable or lower price with beneficial effects for the natural environment.

6.2 Conclusion

This thesis was aimed at exploring reasons for lower social acceptance of household heating alternatives in Geerdinkhof, Amsterdam. The main research question was "*How can social acceptance of residential heating alternatives in Amsterdam Geerdinkhof be anticipated using a value conflict and agent-based modelling approach?*". The research made use of a combination of qualitative and quantitative elements to explore reasons for social acceptance issues. The social acceptance of a collective and semi-collective district heating system were explored using the concept of value conflicts (Van de Poel, 2009) in a Storyline-and-Simulation (Alcamo, 2008) research approach. In this approach, qualitative expert interviews were used to identify what values are relevant for household acceptance of heating alternatives. These values were subsequently used in an Agent-Based Model to explore what value conflicts households in Geerdinkhof could experience. The impact of these conflicts were assessed and several recommendations to the municipality of Amsterdam have been made. The research was divided in the below research sub-questions in order answer the main research question.

Sub-question 1: What are the relevant values and what are their conceptualizations for heating alternatives in Geerdinkhof (Amsterdam Zuid-Oost)?
Using a literature study on social acceptance, district heating and renewable energy systems 10 values were found to be of importance for social acceptance in Geerdinkhof: *Affordability, (thermal) comfort, Flexibility, Freedom of Choice, Inclusion, Locality, Participation, Sustainability, Transparency* and *Trust*. Based on literature and the interviews, some values were considered as constituents of parenting values and five values were selected for use in the Agent-Based Model. These values were *Affordability, comfort, freedom of choice, inclusion* and *sustainability*.

As values are latent topics, different ways to interpret values were also taken into account in the modelling exercise. These were so-called conceptualizations, and for three values different conceptualizations have been tested. For Affordability, the first conceptualization considered the affordability of the initial investment and the second considered the comparability of cost of use. For Inclusion, the first conceptualization considered if everybody can make the same decision and the second conceptualization considered if a household can participate in the process on the desired level. For Freedom of Choice there were also two conceptualizations: the first considered the ability to choose a preferred heat supplier and the second considered the ability to choose for a level of ownership.

Sub-question 2: How can the Agent-Based Modelling approach from (De Wildt, 2020) be translated to the case of Amsterdam to identify value conflicts in anticipation of social acceptance?
De Wildt (2020) used an Agent-Based Model to anticipate social acceptance issues for a district heating system in a neighborhood in The Hague. The method by Van Dam et al. (2012) was used

to construct a new model in Netlogo 6.1.1 for Geerdinkhof specifically. Household data and demographics were used to simulate the Geerdinkhof neighborhood as accurately as possible. Choice was made to deviate from the approach of De Wildt (2020) through different operationalizations of when a value conflict occurs, how value fulfillments are determined and how households make the choice between heating systems. These were either based on data, the performed interviews or assumptions. The model is available upon request[7].

Additionally, two types of heating alternatives were formalized in the model: a collective district heating system and a semi-collective heating system in which groups of 6 households share a heatpump installation. These heating alternatives were evaluated for their embedded value conflicts using three experiments.

Sub-question 3: What value conflicts can be observed in the neighborhood of Geerdinkhof and what is their relative impact?

Value conflicts have been sought after for three experiments: a semi-collective system and two collective systems with higher or lower values for 'social' parameters (ownership, participation, freedom of choice). An overview of the identified value conflicts, the number of households experiencing this conflict and the average value decrease can be found in Figure 5.5.

In these experiments the effect of different conceptualizations was also tested. Conceptualizing a value in a different way lead to the emergence of new value conflicts, indicating the importance of considering different value interpretations in human value-related research.

The identified value conflicts were assessed on their relative impact on households. Conflicts are said to have a large impact if conflicts were experienced by a large number of households, had severe practical implications (i.e. households left in the cold), showed a large fulfillment decrease or concentrated around a specific demographic.

In the end, three groupings of conflicts have been found to impact households significantly. The first group of conflicts was with the Affordability value: many households experienced a large decrease in Affordability fulfillment when switching to a heating alternative. This is explained through the fact that the heating alternatives were more expensive for most households. Interestingly, these conflicts were experienced by all types of households, and not confined to lower-income households only. See for further discussion Section 6.3..

The second group of conflicts was with the Inclusion and Freedom of Choice values. These values experienced lower fulfillments when switching heating alternatives, especially in cases where less ownership, participation or heat supplier choice was offered. These conflicts were noticeably more present in well-insulated households that are privately owned.

Finally, the last identified conflicts concerned low Comfort fulfillment. Comfort was often times compromised on compared to other values and this group of conflicts was mainly observed in well-insulated households occupied by tenants. Additionally, the absence of conflicts where Comfort increases in the semi-collective systems were surprising. This could be due to the fact that the cooling capacity of heatpumps was not implemented in the model, see for further discussion Section 6.3.

Sub-question 4: How can social acceptance be supported by the use of the identified value conflicts?

For each groups of conflicts identified under sub-question 3, a recommendation to the municipality

[7] https://github.com/JLvanliefland/Value-conflicts-in-Geerdinkhof

of Amsterdam has been made. The groups are prioritized over the other identified value conflicts on basis of the impact assessment done in section 5.10.1.

For the conflicts with Freedom of Choice and Inclusion (group 3, Section 5.8), close attention needs to be paid to the specific characteristics of Geerdinkhof. People in Geerdinkhof are in general well-educated and have time and means available to participate in the heat transition. This gives extra opportunities to support social acceptance of a new system through choosing appropriate participation levels, reconsidering how to use consumer ownership of the system and ensuring equal chances for everybody. A baseline insulation level and subsidies ensure all households are able to join, and proper process design could help resolve some social acceptance issues.

For the affordability related conflicts (group 2, Section 5.8), social acceptance can be supported by lowering the initial investment and cost of use of the heating alternative. The heating cost is often one of the first considerations for a new heating alternative, and is considered one of the most direct impacts for a household in this heat transition. Affordability can be supported through stable subsidies, but new ways of governing district heating systems and their ownership can be promising in lowering the overall cost.

Finally, regarding the Comfort related conflicts (group 4, Section 5.8), improving households insulation can be a quick-fix in terms of comfort and making households suitable for future heating systems. Insulation of the less well-insulated households is a way to improve the residential comfort, but for households that are already well-insulated other measures are needed. The installation of solar PV panels could for example be encouraged, such that well-insulated households produce their own electricity with which they could power their individual heat pump installations. The comfort is then not directly from the solar power, but rather from remaining in charge over your own heating system while having cooling capacities during warmer periods.

Final remarks

This thesis showed how social acceptance of a heating alternative in Geerdinkhof can be considered using a value conflict and agent-based modelling approach. Other than making recommendations to the municipality of Amsterdam, this research made three contributions. First and foremost, it is an extension of the work of De Wildt (2020) to a different neighborhood. Using more extensive empirical methods, the approach proved viable in exploring social acceptance issues in sustainable heating systems. Interesting still is to see if and how this approach could be translated to other energy infrastructures. Secondly, the research contributed to the impact of value conceptualizations. Through conceptualizing 3 values in different ways, it is concluded that some conceptualizations of values are conditions for the emergence of a value conflict. This is important for policy-makers, as through considering values in a variety of ways, better resolving of social acceptance issues is possible. Finally, this research contributed in suggesting a way to prioritize value conflicts over others in resolving. This is also important for policy-makers, as it is often not possible to overcome all value conflicts due to limited resources and tough choices have to be made.

6.3 Discussion

In this section, the presented research is reflected upon. As is the case with any research, simplifications and assumptions along the way have been made in order to execute the research in the allotted time. Below two general points are discussed, and after that the identified limitations and recommendations for future work are described. Finally, a reflection is given and we consider what we would have done differently if the research were repeated.

The first point of discussion is that of reproducability and conversion. Both qualitative and quantitative research methods have their own challenges, and when combining the two as done in the Storyline-and-Simulation approach (Alcamo, 2008), you have twice the challenges then when opting for one of the two. Qualitative research can be challenging to reproduce, as it is in this case highly dependent on the expert interviewed (Alcamo, 2008). Different experts can have different mental models of the system, and produce different values and relations. Quantitative modelling of socio-technical systems on the other hand can be challenged on its data, assumptions and formalization. There is no singular correct answer, as cause-effect relations between for example income, willingness to pay and yearly savings are not fully known.

Additionally to facing issues of reproducability and challenges inherent to one of the two methods, there is a the challenge of conversion (Alcamo, 2008). Qualitative findings are converted into the quantitative model, after which these findings are qualitatively interpreted for a conclusion. Information could have been lost in these conversions, and the question arises if the findings remain meaningful after each conversion. This became evident during the validation phase of the findings: what exactly does a value decrease of "0.3" tell us? Values cannot always be compared (Martinez-Alier et al., 1998), and tells us little about how a household is practically impacted by a new heating alternative. The combination of a qualitative and quantitative methods deserved a more *ex ante* consideration of how to remain meaningful in conversion, rather than an *ad hoc* decision on how to interpret each conversion.

The second point of discussion is on the use of agent-based models in socio-technical systems. Although considerable efforts have been put in verification and validation, the model remains an abstract simplification of a complex real-world system. Complexity implies non-linearity (e.g. of perception and response), self-organization (e.g. of households in a community collective), networks (e.g. of relations and interactions) or adaptability (e.g. to lower value fulfillments). These are things that take place in the real-world, and have not necessarily been incorporated into the model. The study is therefore an exploration, an educated guess, in what value conflicts residents in Geerdinkhof could experience.

Finally, on a more detailed level is the surprising fact that value conflicts are seemingly independent of income in the model. From the work of De Wildt (2020) it was expected for lower-income households to experience more affordability-related conflicts, but this was not the case. This is in part due to the rudimentary assumption that a households' available savings is a percentage of the yearly income, and fully available for heating investments. Additionally, relations between household size and income have not been closely considered, and closer consideration of how income, savings and willingness to invest are distributed among households could overcome this surprising finding.

6.3.1 Limitations

Next to the difficulties described above, the research was also limited in what it could produce. Five limitations of the research have been identified and are discussed below, in ascending order of level of detail.

Firstly is the formalization of comfort fulfillment regarding the semi-collective experiment. The rudimentary assumption has been made that residential comfort is mostly determined by the energy label, rather than being able to have a comfortable level of heat in the household over the year. This, in addition with the fact that the cooling capacity of heatpumps was not taken into account, gives a skewed image of how comfortable a semi-collective system could be. This is evident from the fact no value conflicts with increased comfort fulfillment were present for this experiment.

Secondly, households are not rational decision makers (Section 5.3), but are modelled to be just that. Emotions, perceptions and the way information is presented can influence the decision-making. These are not taken into account in the model, but have the potential to bring new findings when taken into account.

Thirdly, only five out of ten identified relevant values are used for the modeling exercise. This was partly overcome by the use of different conceptualizations, but the point remains that there are values not taken into account. For a full exploration of all possible value conflicts, more values need to be taken into account. Especially the Locality value can make an interesting addition here, as it involves the modelling of a local economy / job opportunities, insider vs outsider dynamics and associated flow of capital.

Additionally, the value change scenarios were underdeveloped. These scenarios could have supported the analysis on which prioritizations of values are possible in the future. However, during the interviews and later stages in the analysis it quickly became evident that these scenarios should be a separate study all together.

Finally, although this research was hoping to do justice to recognition justice, it did not explicitly consider Geerdinkhof residents. No interviews were held with the households there, and the argument can be made that the offered policy recommendations have little to do with Geerdinkhof specifically. A lot is written in this thesis *about* Geerdinkhof, but not *with* Geerdinkhof. Assumptions about perceptions, relations between variables and local conditions could very well be falsified if an actual household is contacted, despite the best efforts in verification and validation.

6.3.2 Future work

The recommendations for future work are three-fold. Firstly, applying an agent-based approach with value conflicts to a different neighborhood can yield additional insights. The effects of neighborhood geography, characteristics and type of systems evaluated can lead to different value conflicts and give the municipality of Amsterdam insights for their neighborhood-by-neighborhood approach.

Secondly, future works on anticipating social acceptance using a modeling approach are encouraged to rethink the use of perceptions, emotions and decision-making. Rather than making use of the simplified rational decision-making theory, households could make use of 'satisficing' to see what choices they make when only considered if they are 'good enough' (Simon, 1956). This is also a response to the weak comparability of values, as through satisficing agents can consider a heating alternative for each value individually. In this sense, it might also be worthwhile to reconsider the value fulfillment relations formalized in this model. They are currently often based on assumptions, and use of more expert interviews or household surveys can more accurately describe cause-effect relations. Especially the inclusion of households in these types of analyses are a step in the direction of recognition justice in the heat transition.

Thirdly and finally, value change and specifically value change scenarios deserve more attention. The premise of this research was to see which value conflicts can be anticipated over the lifetime of a DH system. Properly analysing which value conflicts are to become more likely or severe can help the municipality in prioritizing which value conflicts to resolve first. This requires additional attention to constructing value change scenarios, taking into account the different modes of value change (Van de Poel, 2018). Taking this direction can also give additional considerations for prioritizing certain value conflicts to the approach used in this research.

6.3.3 Reflection on own work

When looking back at the previous six months, the modelling exercise and the delivered report, a few things can be reflected upon. Along the way, choices have been made and now that the work is completed, it is time to see what choices could have been made differently.

The first point of reflection is on my personal work style. In hindsight, I noticed a lot of choices were made rather *ad hoc*, instead of considering different possible approaches and how one piece of output would serve as input elsewhere. Other than time lost figuring out how to make the transition from the qualitative part to the quantitative part and back, proper consideration of this work flow had given a better synthesis of different parts. This was especially evident at the start of the data analysis, where a 'now what'-moment ensued and after all the modelling work was done it was unclear to me why I had all this data and what I was trying to find. If I had properly considered why I was gathering which data and to serve what goal, less time would have been lost and more thought-out analysis could have been done. Related to time lost due to *ad hoc* decisions, my work style could have more closely followed my initial research planning. They say diamonds are made under pressure, but when it comes to modelling especially I think diamonds are made under consistent work and numerous iterations. Starting too late on the modelling exercise caused me to be unable to explore different modelling routes, and sticking to assumptions that later could have been improved upon.

When reflecting on what I would have done differently in terms of the research, a few things come to mind. Following the structure of the research, the choice of interviews should have included some representation of actual Geerdinkhof residents. In hindsight it is quite incomprehensible that they are not taken into account, despite the 'recognition justice'. In light of this, the value of person-to-person interaction was underestimated and I believe much more relevant input could have been gathered from the interviews if they were in person. Although understandable due to the pandemic, a point of reflection nonetheless.

With respect to the modelling, I should have been more conscious about what effects a choice regarding implementation, formalisation or later validation can have on your analysis. I'm a bit of a intuitive modeller, and as such did not always think of the trickle-down effects some modelling choices have. This can maybe seen back in parts of my code, where I strongly believe it could have been coded a lot more efficient instead of repeating blocks of similar code.

It is also now I realize the true importance of scoping. After almost every discussion during our weekly meetings, my first reaction often was to 'also include that'. Including these points was often to provide a deeper analysis of the problem at hand, but this comes at the cost of not giving some topics the attention they deserve. This was for example the case for the value change scenarios and impact analysis. At some point, concrete choices of what and what not to include adds more to the research quality than simply adding in more. I know this comes for an intrinsic interest in the research I was performing, but next time I should not be afraid to say no and argue why not to include rather than to try and see where it fits.

A final point of reflection is on the findings. Every researcher probably hopes to find groundbreaking results, forever changing the way social acceptance in this case is considered. The reality can be different, as is the case with the aforementioned research findings. One could very well argue that the recommendations to the municipality are rather obvious: a tailored approach for this neighborhood is required and the households need additional value in reduced costs and increased comfort is of course not surprising. These unsurprising findings are explained in two ways. Either it is what it is, and there is no way around the findings. One cannot take decisions in support of social acceptance without reducing cost, increasing comfort and making sure your decisions fit the local conditions.

That is also why many studies find similar results, including this one. Either that, or groundbreaking results have not been found because the research steers to closely to traditional thinking. Although the value conflict perspective is relatively new, in general most of the assumptions and data used are quite traditional or conservative. The use of more extreme or innovative assumptions and conditions could have produced findings that are still relevant but come from another point of view than the *status quo*. It should of course not be a goal on its own to produce surprising findings, but more creativity in earlier steps of the research could have given more innovative insights.

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A. Topic guide

Topic guide interviews

Inleiding
Mijn onderzoek is gericht op de sociale acceptatie van warmtenetten in Amsterdam Zuid-Oost. Gemeentes zien soms een risico voor weerstand van huishoudens bij het implementeren van nieuwe warmtenetten. Deze sociale acceptatie problemen komen vaak voort uit het verkeerd rijmen van de technische keuzes van het warmtenet met wat de huishoudens belangrijk vinden.

Tijdens dit onderzoek ga ik achterhalen wat huishoudens belangrijk vinden om een warmtenet in Amsterdam te accepteren aan de hand van ethische waarden. Waarden worden hier geïnterpreteerd als *blijvende overtuigingen die groepen mensen belangrijk vinden.* Het lastige aan waarden is dat er verschillende definities en interpretaties mogelijk zijn, en dat waarden kunnen veranderen met de tijd. Zo was duurzaamheid bijvoorbeeld in de vorige eeuw een stuk minder belangrijk dan nu. Wanneer niet alle waarden nageleefd kunnen worden, ontstaat er een zogenoemd waardeconflict. Waardeconflicten kunnen de sociale acceptatie van het warmtenet verlagen, en de uitdaging voor de gemeente is om huidige en toekomstige waardeconflicten in kaart te brengen. Om waardeconflicten te kunnen identificeren, ben ik benieuwd van welke waarden jij verwacht dat ze een rol spelen, en welke scenario's voor de toekomst je zou kunnen identificeren op basis van je achtergrond en expertise. Deze waarden ga ik samen met de scenario's modelleren om te kijken welke keuzes de gemeente Amsterdam kan maken om sociale acceptatie van warmtenetten te ondersteunen.

Tijdens dit interview gaan we in twee delen te werk: in het eerste deel kijken we van welke waarden je verwacht dat ze relevant zijn voor de acceptatie van warmtenetten, en hoe je deze waarden interpreteert. In het tweede deel wil ik naar de toekomst kijken. De prioritering van waarden kan veranderen over de tijd, en daarom wil ik kijken naar hoe waarden zich in de toekomst kunnen gaan verhouden, en of we verschillende scenario's kunnen opstellen.

Objectives

1. Identificeren relevante waarden voor sociale acceptatie Amsterdam
2. Bepalen conceptualisatie/interpretatie van deze waarden.
3. Scenario's voor waardeverandering opstellen.

Interview method

Semi-structured in twee delen. In het eerste deel is het met name doel om een overzicht te krijgen wat de interviewee relevant acht voor sociale acceptatie, en hoe deze waarden geïnterpreteerd of geconceptualiseerd worden. Het tweede deel heeft als doel om verschillende kwalitatieve narratives op te stellen, om te kijken hoe de interviewee denk dat deze waarden zich over de tijd tot elkaar kunnen gaan verhouden.

Toestemming+Confidentiality

Voordat we beginnen moet ik je vragen toestemming te geven voor het opnemen van het interview en het verwerken ervan. Ik zal de input anonimiseren, en in het uiteindelijke verslag alleen verwijzen naar interviewee X met een generalisatie van de functie. (vragen consent form te ondertekenen)

Deel 1

Warming up identificeren en karakteriseren waarden
Waarde = iets wat mensen belangrijk vinden
Voorbeeld: De gemeente gaat een nieuw park aanleggen, welke waarden zijn van belang?

- medezeggenschap: burgers moeten kunnen meebepalen welke faciliteiten er in het park komen
- Inclusiviteit: iedereen is welkom in het park
- Veiligheid: bezoekers en omwoners moeten zich veilig voelen
- Gezondheid: het park moet de gezondheid van bewoners verbeteren
- Prestige: het park moet het aanzien van de gemeente verhogen

Interpretatie/karakterisatie waarden

Gezondheid:

Kan zijn fysieke gezondheid (dus het realiseren van sportvelden)

Kan zijn mentale gezondheid (een groene oase voor ontvluchten drukke stad)

Kan zijn als gevolg van luchtkwaliteit (luchtzuiverende bomen en andere planten)

(zie je een mogelijk waardeconflict? Veiligheid kan in het geding komen als ongure types ook welkom zijn). Wat nou als veiligheid belangrijker wordt in de toekomst? Hier gaan we in het tweede deel naar kijken.

Identificatie relevante waarden
Nu gaan we naar een warmtenet in een woonwijk in Amsterdam Zuid-Oost. De gemeente is voor verschillende wijken technische alternatieven aan het overwegen, en overweegt verschillende processen, warmtebronnen en vormen van beleid.

Wat verwacht je dat bewoners belangrijk vinden voor zo'n warmtenet?

- Probes
  - Wat vinden mensen **technisch** gezien belangrijk?
  - Wat vinden mensen **procesmatig** belangrijk?
  - Wat vinden mensen **sociaal** gezien belangrijk?
  - Voorbeelden van problemen met:
    - Keuze van warmte aanbieder
    - Prijs
    - Duurzaamheid
    - ..
  - … (achtergrond?) …

Waarden karakteriseren (POST IT TOOL: Ideaflip.com)

Geïdentificeerde belangrijke zaken scharen onder een noemer: de waardes. Vanuit de literatuur zijn de volgende waarden gevonden:

- Betaalbaarheid
- Duurzaamheid
- Transparantie (proces)
- Keuzevrijheid (van aanbieder)

- Vertrouwen
- Rechtvaardigheid/eerlijkheid

Per waarde:

Welke overwegingen horen bij deze waarde?

- Probes
  - Hoe zou je deze waarde op verschillende manieren kunnen **interpreteren**?
  - Wat is van belang om deze waarde te **realiseren**?
  - Zijn sommige waarden **belangrijker voor bepaalde typen huishoudens?**
  - **Is de realisatie van bepaalde waarden anders voor bepaalde types?**

Deel 2

In dit gedeelte gaan we kijken welke toekomst-scenario's je voor deze waarden kunt identificeren. Deze scenario's ga ik gebruiken om te kijken wat de impact is als de prioritering van waarden verandert. Het doel is om verschillende rangordes van waarden op te stellen met bijbehorende context. De vraag is welke prioriteringen jij mogelijk acht, en onder welke omstandigheden deze kunnen ontstaan.

Verschillende prioriteringen van waarden in het park: (herhaling: medezeggenschap, inclusiviteit, veiligheid, gezondheid, prestige)

- Eerste prioritering: mensen vinden het in de toekomst belangrijker dat er sociale besluitvorming is, voor en door de mensen. Prioriteit (van hoog naar laag): Medezeggenschap, inclusiviteit, gezondheid, veiligheid, prestige
- Tweede prioritering: mensen vinden belangrijk dat er een goed park komt, maakt niet uit hoe, zodat er meer jonge gezinnen naar de gemeente komen. Prioriteit: Prestige, Gezondheid, Veiligheid, inclusiviteit, medezeggenschap.

"Zou je de eerder geïdentificeerde waardes kunnen prioriteren op verschillende manieren, en er een kwalitatief verhaal bij geven?"

Probes (wanneer brainstorm vastloopt)

- Welke prioriteringen op basis van jouw expertise / ervaring kun je verzinnen?
- …. op basis van wat misschien grote impact kan hebben? (economische crisis,…)
- …. op basis van wat je misschien heel onrealistisch lijkt?
- ... op basis van politieke ontwikkelingen (rechts, links …)

Ending

Dan is hier het interview hiermee afgelopen. Ik wil je bedanken voor je tijd en input, als je wil kan ik je verder toelichten wat ik met deze input ga doen. Als je het leuk vindt, kan ik je over enkele maanden ook het uiteindelijke resultaat van het onderzoek toesturen.

Dankjewel!

B. Pseudo code

Appendix: Pseudo-code

To set-up

- Build households: assign X,Y-coordinates, energylabel and installations according to input file to households.
- Determine spendable income according to CBS statistics.
    - 36% of households has income of 12.000 – 26.000 EUR (randomly assigned)
    - 23% of households has income of more than 40.000 EUR (randomly assigned)
    - 41% of households has income of 26.000 – 40.000 EUR (randomly assigned)
- Determine heat demand
    - Select gas use conversion factor from list according to energy label
    - heat demand = surface area * gas use conversion factor * 0.8 (unit: MJ per year)
- Determine heating cost
    - Individual heating cost: (heat demand / energy in m3 gas) * gas price + yearly cost of maintenance gas boiler (unit: EUR/yr)
    - Collective heating cost: (heat demand * price per unit energy DH system) + set DH costs + investment amount / lifetime investment (unit: EUR/yr)
    - Semi-collective heating cost:
        - Sum heat-demand of six nearest neighbors with high enough energylabel
        - Calculate heatpump power required to meet demand, determine number of heatpumps required
        - Cost = summed power of heatpumps * hours per year fully used * electricity price + investment cost / lifetime (unit: EUR/yr)
- Determine associated CO2 emissions
    - Individual: annual gas use * kg CO2/m3 (unit: kg CO2 per year)
    - Collective: heat demand * kg CO2/unit energy (unit: kg CO2 per year)
    - Semi-Collective: CO2 emissions associated with electricity use
- Determine willingness:
    - Willingness to pay = random number between 0 and 1 (2 decimals)
        - Presence of PV installations add a medium increment to this number
        - When the household is home-owner a small increment is subtracted
        - If > 1 then 1, if < 0 then 0
    - Willingness to choose = random number between 0 and 1 (2 decimals)
        - Ownership adds a small increment
        - Highest income group also adds a small increment
        - If > 1 then 1, if < 0 then 0
    - Willingness to own = random number between 0 and 1 (2 decimals)
        - Ownership adds a small increment
        - Highest income group also adds a small increment
    - Willingness to participate = random integer between 1 and 8.
- Build globals: build empty lists and variables to be later filled with household characteristics or other metrics.
- Determine value weights: give each agent a weight for their values according to system inputs

To go

- Percentage households in community
    - Count households that would choose for DH system
- Fulfillment affordability
    - Learning curve: subtract up to 30% from the (semi-)collective heating cost dependent on the percentage of turtles in the DH system
    - If conceptualization = C1 initial investment
        - Set fulfillment individual 1 – 0.1* energy label
        - Determine investment ratio: investment value / spendable income, if more than an expected year's worth of saving the ratio is lower, the less percentage of income the higher the ratio
        - Set fulfillment DH system: (1 – investment value / spendable income) * investment ratio
    - If conceptualization = C2 comparability of cost

        - Individual fulfillment is low if it is more expensive than the DH alternative
        - Individual fulfillment is high if it is less expensive than the DH alternative
        - (semi-)collective fulfillment high fulfillment if less expensive than individual, low fulfillment if more expensive than individual
- Fulfillment Freedom of choice
    - If Conceptualization = C1 choose heat supplier
        - Individual fulfillment: 1 – (1 – willingness to choose)
        - Collective fulfillment: willingness to choose * choice level offered
        - Semi-collective fulfillment: 1, if installations = false minus a medium increment
    - If conceptualization = C2 choose ownership
        - Individual fulfillment:
            - If ownership = true
                - And willingness to own > 0.5 high fulfillment
                - And willingness to own <0.2 low fulfillment
                - And willingness to own <0.5 and >0.2 medium fulfillment
            - If ownership = false
                - And willingness to own > 0.5 low fulfillment
                - And willingness to own <0.2 medium fulfillment
                - And willingness to own <0.5 and >0.2 high fulfillment
        - (Semi-)collective fulfillment
            - If willingness to own < ownership level offered
                - Medium fulfillment + (ownership level offered – willingness to own
            - If willingness to own > ownership level offered
                - Medium fulfillment – absolute ((ownership level offered – willingness to own))
- Fulfillment comfort
    - Individual fulfillment: 1 – 0.1 * energylabel, minus medium increment if home-owner, plus medium increment if highest energylabel
    - Collective fulfillment: 1 – 0.1* energylabel
    - Semi-collective fulfillment: collective fulfillment minus small increment, minus increments dependent on level of ownership
    - (semi-collective) fulfillments: 0 if the energylabel is higher than 3
- Fulfillment Inclusion
    - If conceptualization = C1 everyone can make the same decision
        - Make lists of 6 nearest neighbors and neighbors in a certain radius
        - Set individual fulfillment: 1 – percentage of neighbors in radius that are part of the system
        - Set collective fulfillment: 0 if energylabel > 3 and initial investment >8% of spendable income. If one of the two conditions is true, fulfillment is low. Otherwise it is the percentage of households in radius that are part of the system
        - Set semi-collective fulfillment: high fulfillment if all 6 nearest neighbors have sufficient savings and high enough energylabel, otherwise it is 1 – 1/6 * households with too little savings – 1/6* households with too low energylabels.
    - If conceptualization = C2 Everyone has say over the process
        - Individual fulfillment = medium, if household has >4 participation willingness it is high, if willingness is higher than 4 and participation offered is higher than 4 low fulfillment
        - (semi-)collective fulfillment: 1 if willingness to participate equal to participation offered, otherwise it is medium fulfillment + (the difference between the two * 0.1) if more participation offered than wanted, otherwise minus the difference.
- Fulfillment Sustainability
    - Individual fulfillment: order households from low to high individual CO_2 emission, household rank in this order determines individual satisfaction (highest CO_2 gives lowest fulfillment, lowest CO_2 the highest)

    - (Semi-)Collective fulfillment: Low fulfillment if more CO2 than individual, else high fulfillment
- Evaluate fulfillments
    - If garstkamp = false
        - Per household: Total individual fulfillment = sum (individual fulfillment value 1 * weight value 1 + …. Individual fulfilment value 5 * weight value 5)
        - Per household: Total DH system fulfillment = sum (DH system fulfillment value 1 * weight value 1 + …. DH system fulfilment value 5 * weight value 5)
    - If garstkamp = true
        - Same as for garstkamp = false, except that all fulfillments for the households in the Garstkamp are summed together to make 1 fulfillment block.
- Choose and conflicts
    - Switch to preferred heating system
        - Households in Garstkamp: see which of the two options (individual / DHsystem) had the highest total value fulfillment and switch to that heating option
        - Households outside Garstkamp: switch to the option with the highest total value fulfillment
    - Determine differences
        - For each value, determine what the difference is between the individual value fulfillments and the DH system fulfillment, set these values in a list
    - Note conflicts
        - For each value difference in the list, check if the value is lower (indicating that this value has decreased in fulfillment when switching to DH system), and note the household "who" (ID) in a list for this specific conflict
        - Remove duplicate ID's in lists
        - Create separate lists for each conflict, and fill these with the sizes of the conflict (i.e. difference in value fulfillment) of all turtles with this conflict.
- Track conflicts
    - Translates the list of agent ID's into an embedded list (lists within list) of agent characteristics for this specific conflict: energy label, spendable income, PV ownership and home ownership
- Stop
    - Stop simulation after no more new conflicts emerge OR
    - Stop after predetermined amount of ticks

C. Data and assumptions

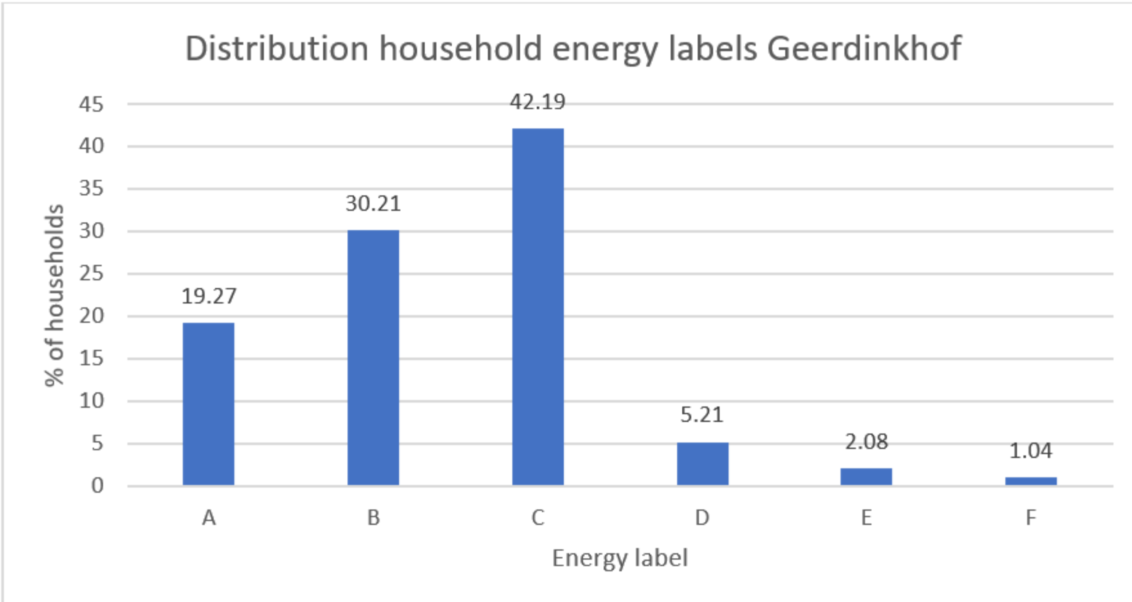


Figure C.1: Visualization of the distribution of energy labels in Geerdinkhof

C.1 Data

1. Number of households
    - Data: list of addresses (679 households, 349 apartments (energylabel A and tenants only), and surface areas)
    - Used for: create right number of households with surface area and where possible energy label
    - Source: `data.amsterdam.nl`
2. Income of households
    - Data: 34-38% of households has ‘low income’
    - Data: 20-25% of households has ‘high income’
    - Rest has ‘medium income’
    - Used for: Dividing households in income groups
    - Source: `https://cbsinuwbuurt.nl/`
3. Income groups
    - Data: ’low income’ is 0 - 40.000 EUR
    - Data: ’high income’ is > 40.000 EUR
    - Data: Average income is 30.800 EUR
    - Used for: households given income according to income group
    - Source: `https://www.cbs.nl/nl-nl/visualisaties/inkomensverdeling`
    - Source: `https://www.cbs.nl/nl-nl/cijfers/detail/83739NED`
4. Solar PV panels
    - Data: 199/679 Geerdinkhof roofs have solar panels
    - Data: Appartments have solar panels
    - Used for: giving households solar panels
    - Source: satellite pictures from `maps.google.com`

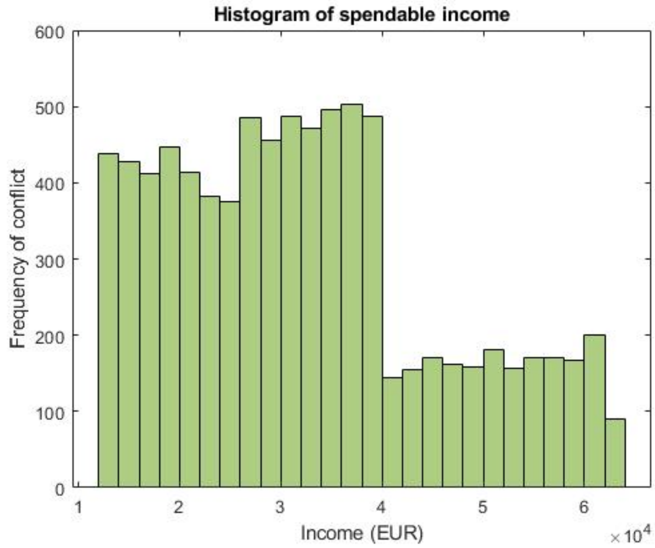


Figure C.2: Histogram of spendable incomes. This histogram was created through initializing the model 8 times and record the generated incomes. This is to account for the stochastic nature of how incomes are determined. From the histogram, one could identify the 3 income groups: low, medium and high.

5. Home ownership
    - Data: 67% is homeowner, 33% rental
    - Data: Garstkamp appartments are all rental.
    - Used for: dividing home-ownership over households
    - Source: `https://allecijfers.nl/buurt/g-buurt-oost-amsterdam/`
    - `data.amsterdam.nl`
6. Energy labels
    - Data: Energy labels present: 131xA, 205xB, 286xC, 35xD, 14xE, 7xF (Geerdinkhof), Garstkamp is all A. See Figure C.1 for visualization
    - Used for: Households given energy labels given according to same ratio
    - Source: `https://www.nationaleenergieatlas.nl/kaarten`
7. Heat demand
    - Data: Gas consumption per m2 per energylabel for dutch households
    - Data: 80% of gas use is used for residential space heating, rest is warm water
    - Data: 1 m3 of natural Dutch gas is 35.17MJ
    - Used for: used to calculate the annual heat demand per household based on energylabel and surface area.
    - Source: (Majcen, 2016, p.70)
    - Source: `https://www.milieucentraal.nl/energie-besparen/duurzaam-warm-water/bespaartips-warm-water/`
    - Source: `https://www.3nergie.nl/blog/mwh-naar-m3/`
8. Heating cost
    - Data: Individual cost of a gas boiler is 288 EUR per year (rental cost Vattenfall)
    - Data: Gas price: 0.80 EUR
    - Data: Initial investment for DH system connection is 12.000 EUR

- Used for: Cost calculations
- Source: `https://www.vattenfall.nl/producten/cv-ketel/huren/`
- Source: `https://www.unitedconsumers.com/energie/energieprijzen/gasprijs.jsp`
- Source: price indication given to Geerdinkhof neighborhood according to Interviewee 5.

C.2 Assumptions

1. General assumptions
   - Households are rational decision makers: they have all the information they need to assess how a heating alternative fulfills their values, they maximize their choice on value fulfillment and are not influenced by perceptions or emotions surrounding the choice.
   - There are no interactions with the outside world other than the parameters of the heating alternative offered.
   - Household heat demand is independent of the amount of people in the household.
   - System parameters, global variables, conceptual uncertainties and agent characteristics are static during a simulation.
   - Value conceptualizations are static during a simulation.
   - Residents are assumed not to move between houses.
   - There are no correlations between income and the characteristics of the house (energy label, surface area, PV panels, ...).
   - Only one type of system is considered as a heating alternative per simulation: a collective or semi-collective system.
   - A conflict is denoted if any increase in a value is associated with a decrease in another value.
   - Agent characteristics are only saved if the value passes either a threshold for number of households or a threshold value decrease (to save on model run time).
   - Households with an energy label lower than C are unable to join (semi-)collective systems.
2. Household Willingnesses
   - Willingness to pay: Random value between 0 and 1. Plus medium increment if solar panels are present (sustainability-oriented people have higher willingness to pay (Krikser et al., 2020)). Minus medium increment if household is home-owner (assumed less willing to invest if already paying for maintenance etc.)
   - Willingness to choose: Random value between 0 and 1. Plus medium increment if home-owner (assumed higher desire to stay in control). Plus medium increment if in high income group (assumed higher desire to stay in control)
   - Willingness to own: Random value between 0 and 1. Plus small increment if home-owner (assumed more willing to be owner of heatig system). Plus medium increment if in high income group (assumed higher desire to own)
   - Willingness to participate: Random place on the Arnstein ladder of participation (no assumed relations between characteristics).
3. Heat demand: Annual heat demand is 20% of the home surface area multiplied by the annual gas user per energy label per m2. Energy use of warm tap water is not taken into account.
4. Heating cost
   - Individual cost: annual heat demand [MJ] / energy per m3 gas (35.17 [MJ/m3]) * gas

price (80cents) + annual boiler cost (288 EUR)
    - Semi-collective cost (Garstkamp): summed heat demand of residents in Garstkamp, divided by number of 30kW heatpumps required to cover peak demand times cost of these units (4700 EUR).
    - Semi-Collective cost (non-Garstkamp): summed heat demand of 5 closest neighbors, peak power - 30kw heat pump and the remainder of power divided by 4kW units (2750 EUR).
    - Semi-collective additional assumptions: Required heatpump power[1] for Garstkamp is 60 W/m2, for households 82 W/m2. 30kW Heat pump is 4500EUR[2], 4kW heatpump is 2700EUR[3]. Heatpumps are used 2422 hours per year on full power on average[4]. Installation costs and labour are not included
    - Collective cost (Garstkamp): Residents pay 26,6EUR/GJ (no additional costs) according to interviewee 5.
    - Collective cost (non-Garstkamp): prices based on Vattenfall Amsterdam: 25,51 EUR/GJ + 306.25 EUR + 1/40 * initial investment (assumed lifetime of 40 years)
5. CO_2 emissions: For individual this is the heatdemand times the kg CO_2 per m3 gas use (56.4kg CO_2/ GJ[5]). For Collective it is 21,53kg CO_2/GJ[6]. For semi-collective the CO_2 is 30% of individual heating[7]
6. Income: Same income groups as by CBS, assumed no incomes below 12.000EUR/yr due to welfare system, assumed no incomes above 60.000 EUR per year due to size of households.
7. Value fulfillments: Households sum the fulfillments of values for both systems and choose for the highest scoring one.
8. Fulfillment Affordability
    - Households determine the initial investment as percentage of their yearly income. Households save on average 12.7% per year[8]. The closer to this percentage, the lower the fulfillment.
    - Households only compare reasonably expected yearly cost over a set lifetime. Previous investments, lifetime of installations etc. are not taken into account.
9. Fulfillment sustainability: agents only look at the CO_2 emissions associated with the heat consumed. For the individual fulfillment agents are assumed to compare themselves to people in the neighborhood, for collective fulfillments it is high or low depending on if there is a CO_2 saving or not. Semi-collective fulfillment is assumed to be positively influenced by high energy labels.
10. Fulfillment comfort:
    - Comfort assumed to mostly depend on house energy label: the better the higher.

[1] https://www.warmtepompverwarming.net/warmtepompen/vermogen-warmtepomp/

[2] https://www.flexpro-industry.com/e-commerce/nl/multi-functions-warmtepompen/217-lucht-water-multi-function-warmte-pomp-30kw.html

[3] https://www.cvtotaal.nl/techneco-elga-warmtepomp.html

[4] https://warmtepomp-weetjes.nl/uitleg/energieverbruik-warmtepomp-berekenen/

[5] https://www.rvo.nl/sites/default/files/2020/05/vaststelling-standaard-co2-ef-aardgas-jaar-nationale-monitoring-2020-en-ets-2020-def_0.pdf

[6] https://www.co2emissiefactoren.nl/lijst-emissiefactoren/

[7] https://www.milieucentraal.nl/energie-besparen/duurzaam-verwarmen-en-koelen/warmtepomp-duurzaam-elektrisch-verwarmen/

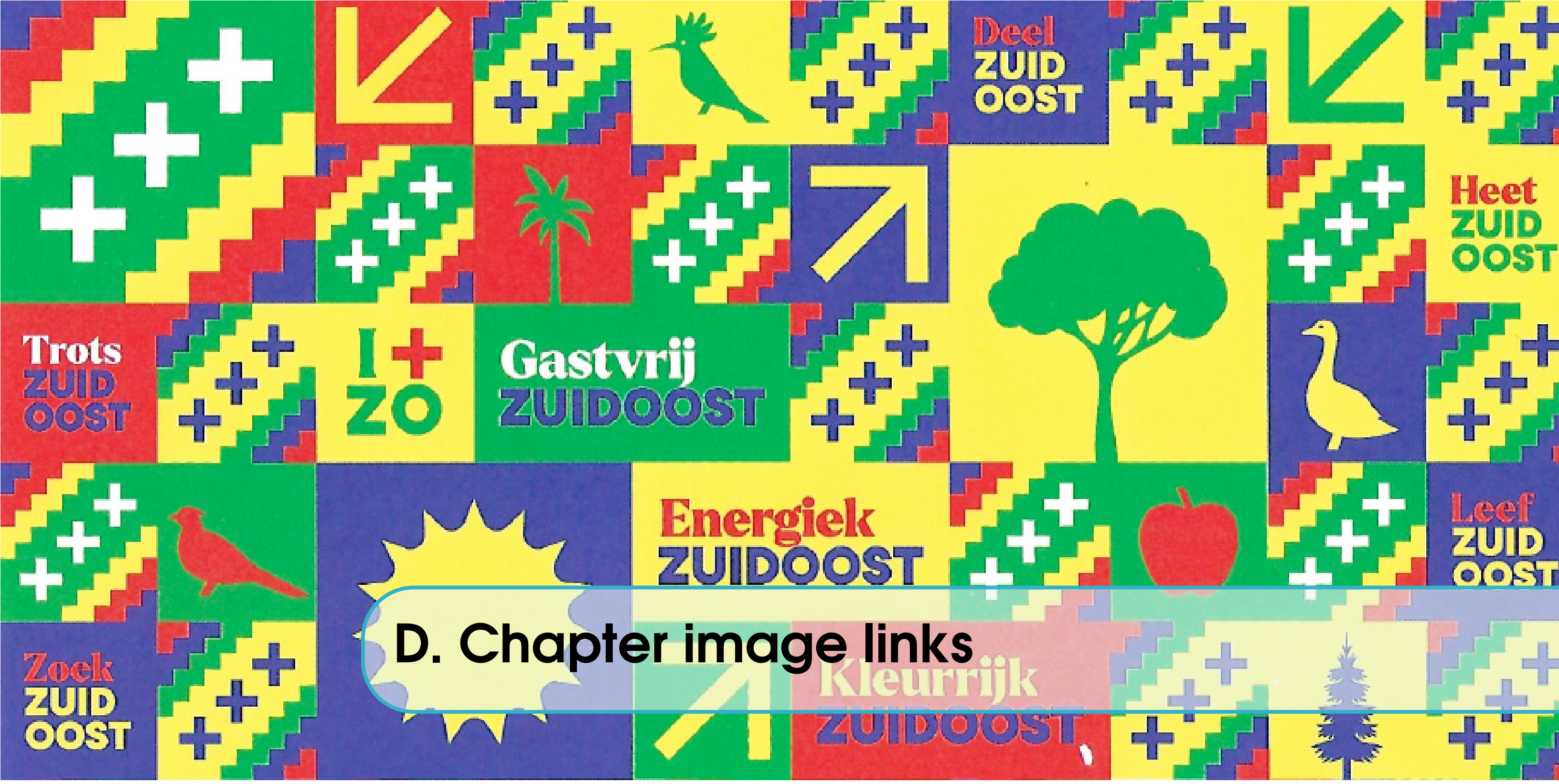
[8] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Households_-_statistics_on_disposable_income,_saving_and_investment

- Assumed increments: minus small increment for gas boiler (safety), minus medium increment if home-owner (maintenance cost), plus medium increment if energylabel A. Minus small-increment for semi-collective due to noise of heatpumps.
- Households with energylabel worse than C are unable to join and will have no comfort benefit.

11. Fulfillment Inclusion: Households are assumed to check if they are able to switch to a new system: are their energy labels sufficient and do they have enough assumed savings to pay the investment? For the participation conceptualization the fulfillment is assumed to be dependent on the difference between what is desired and what is offered.
12. Fulfillment Freedom of choice: As Inclusion, dependent on the difference between how important households find it to choose and what choice level is offered. Distinction is made between tenants and home-owners, as the first is assumed to find it less important to choose.

C.3 Model Uniformity

13. Model uniformity:
    - Value fulfillments: range from 0 (low) to 1
    - Uniform increments are used for assumed relations: small (0.1), medium (0.2) or large (0.5) increments
    - Uniform levels of fulfillment: low (0.2), medium (0.5) and high (0.8)
    - Checks have been performed value fulfillments can reach the entire range from 0 to 1.



D. Chapter image links

Here references to the chapter images can be found as well as a minor explanation of what they represent.

- Table of contents: The image is an overview of the TransitionVision Heat Amsterdam, image taken from `https://02025.nl/message/43887/transitievisie-warmte-amsterdam`
- Introduction: The image is a Transition Map, found in the TransitionVision Heat Amsterdam. Image taken from `https://overmorgen.nl/wp-content/uploads/2020/09/tvw-amsterdam.pdf`.
- Problem Definition: Image from the new identity of Amsterdam Zuidoost. Image was taken from a postcard send by the municipality, see for reference `https://zuidoostcity.nl/`
- Theory and Methodology: Image is by the municipality of Amstedam, on their webpage for the routemap Amsterdam Climate Neutral 2050. See `https://www.amsterdam.nl/bestuur-organisatie/volg-beleid/coalitieakkoord-uitvoeringsagenda/gezonde-duurzame-stad/klimaatneutraal/`
- Part 1: Qualititative interviews: Picture of the construction of a DH system, image taken from `https://amsterdam.groenlinks.nl/standpunten/amsterdam-aardgasvrij`