THE ACCEPTABILITY OF DECENTRALIZED ENERGY SYSTEMS

Identifying Value Conflicts Through Simulations Of Decentralized Energy Systems For City Districts

A.R. Boijmans
4306422
a.r.boijmans@student.tudelft.nl

Master Thesis (EPA2942)
Engineering and Policy Analysis
Faculty of Technology, Policy and Management
Delft University of Technology

Ministry of Economic Affairs and Climate Policy

The Hague, The Netherlands
July 15, 2019

The Acceptability of Decentralized Energy Systems

Master thesis submitted to Delft University of Technology

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in

Engineering and Policy Analysis

Faculty of Technology, Policy and Management

by

A.R. Boijmans

Student number: 4306422

To be defended in public on July 15, 2019

Graduation committee

Chairperson	: Prof.dr.ir. I.R. van de Poel, Ethics/Philosophy of Technology section
First Supervisor	: Dr.ir. E.J.L. Chappin, Energy & Industry section
Second Supervisor	: Dr.ir. J.H. Kwakkel, Policy Analysis section
External Supervisor	: Ir. T.E. de Wildt, Energy & Industry section
External Supervisor	: Drs. E.J. ten Elshof, The Ministry of Economic Affairs & Climate Policy

Preface

This report is a master thesis and written as final part of the master degree 'Engineering and Policy Analysis' of the Faculty Technology, Policy and Management at Delft University of Technology. Since the research has both societal and academic implications, this thesis is written for two target audiences: policymakers and academic researchers. The first two chapters introduce the problem and explain the research approach. These chapters are quite important for both audiences in order to understand the remaining report. The same goes for Chapter 8, where the conclusions of this research are presented. For the other chapters is explained if reading the chapter is useful for the specific audience.

For policymakers:

- Chapter 3: In this chapter the case ('De Vruchtenbuurt') is analyzed and is explained what different components are important when considering the social side of the change to a decentralized energy system on city district level.
- Chapter 7: In this chapter the translation of the analysis to real world implications for 'De Vruchtenbuurt' and other city districts are given. The lessons that are given in this chapter can be used by policymakers to come a step further in the change to decentralized energy systems in the Netherlands. Furthermore, this chapter shows the added value of using a modelling approach.
- Chapter 9: In this chapter is reflected on the work and the contribution of the work is discussed. For policymakers the reflection on the research process and the parts that discuss the societal contribution are interesting. Also, the recommendations given to policymakers for further research are useful to read.

For academic researchers:

- Chapter 3: In this chapter the case ('De Vruchtenbuurt') is analyzed by filling in the different building blocks of the Capability Approach. The case analysis in this chapter is the step prior to the (further) conceptualization and specification of the social side of the change to a decentralized energy system on city district level.

- Chapter 4: In this chapter the model conceptualization, formalization and specification of the building blocks analyzed in the previous chapter are presented, in order to implement it in an Agent-Based Model. The way the values are conceptualized can be used as inspiration for making values operational.

- Chapter 5: In this chapter the application of the 'evaludation' method by Augusiak et al. (2014) is presented. By verifying and validating the model using this method allowed the author to test the strengths and weaknesses of the model. Also, the method allowed to test to what extent the model is fit for the aimed purpose.

- Chapter 6: In this chapter the analysis of different experiments, conducted with the use of the Exploratory Modelling and Analysis workbench, are presented. Open exploration, sensitivity analysis and scenario discovery are the analysis used to draw conclusions from the experiments.

- Chapter 7: In this chapter the translation of the analysis to real world implications for 'De Vruchtenbuurt' and other city districts are given. For academic researchers this chapter is interesting since it shows what lessons can be drawn from the model and what the usage of the model is, given the limitations of the research.

- Chapter 9: In this chapter is reflected on the work and the contribution of the work is discussed. For academic researchers the reflection on the concepts, frameworks, methodologies, model and the research process are interesting and also the parts that discuss the scientific contribution. Also, the recommendations given to academic researchers for further research are useful to read.

Acknowledgements

Writing this thesis was the last part of my studies at Delft University of Technology. Mostly, I enjoyed doing research on an topic that is multidisciplinary and allowed me to put all my skills I learned so far into practise. It was a pleasure to discuss with so many enthusiastic people, that are also trying to find solutions for the complex energy transition. As probably every master student will say, sometimes writing the master thesis was tough. However, I learned a lot from this process and I am happy with the product I created in a bit more than five months.

Even though the master thesis is an individual project, there were many people that helped me going through the process and I want to thank them for that.

First of all, I want to thank my graduation committee. The collaboration with all the members was pleasant and together we brought this thesis to a good end. I want to thank Tristan for all the meetings, brainstorms and discussions. It was nice to contribute to your PHD research and to know that my work could be used in a bigger picture. I also want to thank you for always answering my questions and helping me through the tougher moments. Also, I am very happy that we could use your computer for running the experiments. Then I want to thank Emile for being critical at all times, by helping me to see the value of my work and by structuring my report. Also, I want to thank Jan for giving me feedback on the analysis I did and making the EMA workbench work on my laptop, when it crashed for some reason. Then I want to thank Ibo for giving me critical advice on the ethical parts of my thesis work, it made me realize that every word in this discipline can mean something else for someone else.

Of course I also want to thank Erik, who had faith in me the first moment I entered the ministry. You brought me into contact with many interesting people and gave me the opportunity to explore the world of the national government. Also, I want to thank all my colleagues at the ministry that were always willing to discuss or coach me through the moments they have gone through some years ago. I also want to thank all the interviewees within and out of the ministry.

Absolutely, I want to thank my family. I am so happy that I can unconditionally share my moments of doubt or stress with you. You know always how to get me going again. Also, I want to thank my friends and my roommates that always were willing to distract me when I was working hard, but also supported me when I needed their advice. Lastly, I want to thank Idrisse for coaching me through the whole process and listening to all my complaints and worries. You made me always smile again after a tough day!

Executive Summary

To achieve the goals of carbon dioxide reduction stated in the international Paris Agreement and the Dutch Climate Agreement, it is necessary to increase the share of renewable energy sources. The shift from highly-centralized energy systems to decentralized energy systems can contribute in the change to renewable energy sources. The change to decentralized energy systems may also have negative effects that can lead to public resistance, non-acceptance and protests of the end-users. The Dutch government and in particular the Ministry of Economic Affairs and Climate Policy have to deal with trade-offs between different system criteria. The national government has the obligation to take actions in order to meet the climate goals, but is also responsible for creating a socially responsible energy system that supports the welfare of the Dutch society. The national government is puzzling what policy decisions to take, since it is subjective to argue which system criteria are more important than other system criteria, no consensus can be found on the best solutions and the decisions have an unpredictable impact.

The national government is lacking sufficient knowledge about the kind of trade-offs it is dealing with and about the consequences of dealing with these trade-offs. It seems that no real global examples and scientific literature are able to provide this knowledge to the national government. Some studies discuss the social side of decentralized energy systems, but the integration with the the technical and economic side is missing. Other studies discuss the trade-offs between criteria, but limit the discussion to privacy and data security issues. Other studies examine the influence on the end-user, but do not analyze the trade-offs that result from the way the end-users are affected. Lastly, the ethics field discusses criteria trade-offs of energy systems as value conflicts and also examines the integration with the technical and economic side. However, these studies do not focus on decentralized energy systems specifically and do not examine under what conditions value conflicts appear in order to achieve guidelines that can be used by policymakers.

The aim of this research is to analyze a comprehensive set of values and to identify under what conditions value conflicts can be identified when changing to a decentralized energy system given the characteristics of the households in a city district. Furthermore, strategies that can reduce the occurrence of these

value conflicts are also examined. The following research question is addressed in this research:

"How can household value conflicts be identified and reduced when designing decentralized energy systems?"

In this research a modelling approach is used, as it allows to experiment with multiple uncertainties, i.e. conceptual uncertainties, but also different scenarios (conditions of the city district and policies). One specific case is analyzed in order to limit the level of abstractness and to use real input data. Besides, this gives the opportunity to validate the results. 'De Vruchtenbuurt' in The Hague, the Netherlands is used as case, since this district contains a bottom-up community that is initiating to change to a decentralized energy system focusing on the heat transition. Furthermore, this research is examining the acceptability (and not the acceptance) of a decentralized energy system. This implies that in this research it is identified if the households can fulfill their values without being in conflict with other households or with other values they have. This does not imply that the adoption of a decentralized energy system is also preferred and really executed by the households if no conflicts are identified. However, acceptability and acceptance are expected to be related to each other. The Capability Approach is used as normative framework and the values are used to evaluate the acceptability of the capabilities. The capabilities can be defined as the feasible options a household has to join or change from a community. The conditions of a household and of the characteristics of the house it is living in (conversion factors) can constrain its options and therefore hamper the options to fulfill its set of values.

Conducting interviews and consulting existing literature resulted in a set of governance models, technical designs, conversion factors and values that is used in this research (see Figure 1).

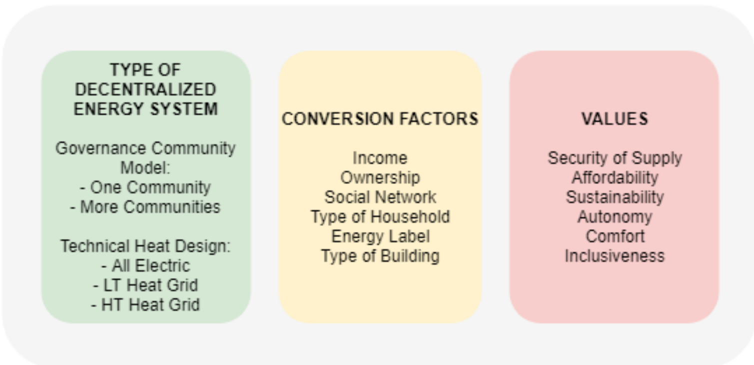


Figure 1: Identified Components Used in this Research.

Some of the conflicts are inherent and already revealed by conducting the interviews, which can be found in the conceptualization. Mainly, inherent conflicts can be identified between the more traditional values, i.e. security of supply, affordability and sustainability and the more progressive value, i.e. autonomy. This conflict is related to the requirement of collective solutions for the fulfillment of traditional values, which opposes the fulfillment of the value autonomy.

However, conflicts that result specifically from the conditions of the case 'De Vruchtenbuurt' are identified by modelling. Agent-Based Modelling in combination with Exploratory Modelling and Analysis are the methods used to simulate the city district 'De Vruchtenbuurt' and to evaluate the values and the possible conflicts under different conditions between different conversion factor groups.

Mostly conflicts between the more traditional values and the more progressive values, i.e. autonomy, comfort and inclusiveness are identified in 'De Vruchtenbuurt'. Also, cases can be observed in which autonomy is in conflict with comfort and inclusiveness and cases in which comfort is in conflict with inclusiveness. In 'De Vruchtenbuurt' most conflicts arise *between* and *within* income groups and *between* and *within* energy label groups, due to the diversity of income levels of the households and the diversity of energy labels of their houses. For example, in some cases a low income level group of households cannot fulfill the value inclusiveness for an all electric design (too expensive), while a high income level group of households can fulfill the value sustainability by applying the all electric design (most sustainable design). Another example, in some cases a group of households with an energy efficient house cannot fulfill both the values security of supply and comfort when the all electric design is chosen. One reason can be the properties of the design, since it supports the fulfillment of security of supply and opposes the fulfillment of comfort (which is embedded in the conceptualization and is not context dependent). Another reason can be the other characteristics of the households (income or ownership) that differ within the discussed household group. As can be seen in the examples, the choice for the technical design together with the combinations of conversion factors are determining the conflicts the most.

In interviews with policymakers, local initiators and technical experts the results have been validated. Further it is discussed to what extent these conflicts also could result in non-acceptance and what strategies could contribute to deal with value conflicts when designing decentralized energy systems. The following lessons are identified:

- Policies (financial instruments and supporting innovations) that create more feasible solutions for the heterogeneous households are effective to limit the context dependent value conflicts.

- It is not realistic to eliminate all value conflicts, since some of the values are inherently in conflict with each other. For these conflicts thresholds can be formulated that should be met for every value.
- Given that value conflicts exist, focusing on the process of the change to a decentralized energy system is seen as important factor for support and participation.

The aim of this research is to find out what strategies can reduce and deal with value conflicts that can be identified when designing a decentralized energy system considering the properties of a city district ('De Vruchtenbuurt'). The previous points give an idea what the focus of policymakers should be on, when dealing with the identified value conflicts. Similar ideas can also be applied more generally and could work for other city districts too. However, it should be always kept in mind that the limitations of the research, context dependency and uncertainties of the development of technologies and stakeholders can influence these results.

The approach used in this research to examine the acceptability of decentralized energy systems can be used as an example to integrate the social, technical and economic side of designing decentralized energy systems in a systematic manner. It is important to realize that values and technology evolve both over time. It is therefore recommended to repeat the identification of values and technologies over time, to make sure that emerging values and technologies are not neglected.

For further research it is recommended to validate the results for other city districts and to identify if the set of governance models, technical designs, conversion factors and values has to be extended and how these components evolve over time. Also, it is interesting to focus more on the principles of justice (especially the distributive and procedural justice) in further research. Furthermore, it is interesting to invest research time in the influence of Dutch politics and the choice behaviour of the households (especially concerning autonomy) to find out if the acceptability of the decentralized energy system can also be converted into acceptance and real adoption of the new energy system.

Contents

Preface i

Acknowledgements iii

Executive Summary v

Abbreviations xiv

1 Introduction 1

1.1 Tackling Climate Change with Decentralized Energy Systems . . . 1
1.2 Trade-Offs for the Dutch Government . . . 3
1.3 Societal and Academic Knowledge Gap . . . 4
1.4 Main Research Question . . . 6
1.5 Structure of the Report . . . 7

2 Research Approach 8

2.1 Problem Statement . . . 8
2.2 Research Objective and Approach . . . 9
2.3 Sub Research Questions . . . 10
2.4 Scope of the Research . . . 11
2.4.1 Types of Decentralized Energy Systems . . . 12
2.4.2 Specific Case: 'De Vruchtenbuurt' . . . 13
2.4.3 Conceptual Scoping Challenges . . . 14
2.5 Research Concepts and Frameworks . . . 16
2.5.1 Acceptability and Acceptance . . . 16
2.5.2 Criteria Dilemmas Evaluated As Value Conflicts . . . 17
2.5.3 Values in Energy Systems . . . 18
2.5.4 Capability Approach . . . 21
2.5.5 Values Used in the Capability Approach . . . 23
2.6 Research Methods and Data Collection . . . 24
2.6.1 Literature and Interviews . . . 25
2.6.2 Agent-Based Modelling . . . 29
2.6.3 'Evaludation' Method . . . 30

2.6.4 Exploratory Modelling and Analysis 31
2.7 Research Flow Diagram 31

3 Case Analysis **33**
3.1 Case Identification 34
3.2 Goods and Services 37
3.2.1 Governance Models 37
3.2.2 Technical Designs 39
3.2.3 Policies and Innovations 40
3.3 Values and Capabilities 41
3.3.1 Interviews and Selection of Values 41
3.3.2 Explanation of Values 43
3.4 Conversion Factors 47
3.4.1 Personal and Social Conversion Factors 47
3.4.2 Environmental Conversion Factors 49
3.5 Conclusions 51

4 Model Description **54**
4.1 Model Objective and Key Performance Indicators 54
4.2 Concept Formalization 55
4.2.1 Overview of the Concept Formalization 55
4.2.2 Global Variables 56
4.2.3 Agents 57
4.3 Model Formalization 58
4.3.1 Narrative 58
4.3.2 Pseudo-Code 63
4.4 Model Specification 63
4.4.1 City District Specifications 63
4.4.2 Options for Changing from Community 65
4.4.3 Evaluation of the Values 65
4.4.4 Values in Conflict 72
4.5 Conclusions 73

5 Verification and Validation **74**
5.1 Process of Verification and Validation 74
5.2 Stochastic Uncertainty 75
5.3 Step 1: Data Evaluation 77
5.3.1 Statistical Data 77
5.3.2 Literature and Local Research 78
5.3.3 Interviews 78
5.4 Step 2: Conceptual Model Evaluation 79
5.4.1 Building Blocks 79
5.4.2 Evaluation of Values 80

5.4.3 Feasibility of Capabilities 83
5.5 Step 3: Implementation Verification 83
5.6 Step 4: Model Output Verification 84
5.7 Step 5: Model Analysis 87
5.8 Step 6: Model Output Corroboration 89
5.9 Conclusions 89

6 Experimentation **91**
6.1 Uncertainties and Policies 92
6.1.1 Group 1: Conceptual Uncertainties 92
6.1.2 Group 2: Policies and Innovations 92
6.2 Outcomes of Interest 95
6.3 Experiment Design 96
6.3.1 Number of Runs 96
6.3.2 Run Length 97
6.3.3 Sampling Method 97
6.4 Data Analysis and Conclusions 97
6.4.1 Conditions Resulting in Value Conflicts 98
6.4.2 Conclusions 112

7 Lessons and Implications **115**
7.1 Limitations of the Research 115
7.1.1 Meaning of the Results 116
7.1.2 Data and Detail Level 117
7.1.3 Translation of the Conceptual Model 118
7.1.4 Development of City Districts 119
7.2 Real World Implications for 'De Vruchtenbuurt' 120
7.2.1 Lessons for 'De Vruchtenbuurt' 121
7.2.2 Support of Decentralized Energy Systems in 'De Vruchtenbuurt' 123
7.3 Lessons for Other City Districts 124
7.3.1 Feasibility of Designs 125
7.3.2 Inherent Conflicts and Thresholds 125
7.3.3 City Districts in a Bigger Picture 126
7.3.4 Process and Distribution 126
7.3.5 Distrust in the Government 127
7.3.6 Good Practices and Local Experiences 127
7.4 Use of the Model for Policymakers 128

8 Conclusions **129**
8.1 Short Summary of the Research 129
8.2 Answer to the Sub Research Questions 130
8.3 Answer to the Main Research Question 133

9 Reflection, Contribution and Recommendations 134
9.1 Reflection on the Concepts and Frameworks 134
9.1.1 From Capabilities to Functionings 135
9.1.2 Is Acceptability Also Fairness? 135
9.1.3 Direct and Indirect Prioritization of Values 137
9.1.4 Contribution of this Research 137
9.1.5 Recommendations For Policymakers 138
9.1.6 Recommendations For Academic Researchers 139
9.2 Reflection on the Methods 139
9.2.1 Interviews 140
9.2.2 Agent-Based Modelling and Exploratory Modelling and Analysis 140
9.2.3 Contribution of this Research 140
9.2.4 Recommendations For Policymakers 141
9.2.5 Recommendations For Academic Researchers 141
9.3 Reflection on the Scoping and Modelling Choices 142
9.3.1 Conceptual Simplifications 142
9.3.2 Scoping Simplifications 143
9.3.3 Contribution of this Research 143
9.3.4 Recommendations For Policymakers 144
9.3.5 Recommendations For Academic Researchers 145
9.4 Reflection on the Research Process 145
9.4.1 Bringing Multiple Disciplines Together 146
9.4.2 Contribution of this Research 146
9.4.3 Recommendations For Policymakers 147
9.4.4 Recommendations For Academic Researchers 147

References 148

A Interview Questions 155
A.1 Round 1: Orientation 155
A.2 Round 2: Validation 156
A.3 Round 3: Implications 157

B Stakeholder Identification 158
B.1 Households 161
B.2 Other Stakeholders 162
B.2.1 National Government 162
B.2.2 Region and Municipality 163
B.2.3 System Operator 163

C Governance Models and Technical Designs **165**
C.1 Governance Models 165
C.1.1 Commercial 165
C.1.2 Public 166
C.2 Technical Designs 166
C.2.1 Decentralized Energy Generation 166
C.2.2 Flexibility 167

D Model Formalization and Specification **168**
D.1 Assumptions and Simplifications 168
D.1.1 Conversion Factors 168
D.1.2 Policies and Innovations 170
D.2 Pseudo-code 171
D.2.1 Set-up Phase 171
D.2.2 Main Procedure 174
D.2.3 Sub Procedures 176

E Use of Model **179**
E.1 Explanation of the Interface 179
E.2 Steps for Using the Model 181
E.3 Parameters 181
E.4 Monitors and Graphs 182

F Verification and Validation **183**
F.1 Stochastic Uncertainty 183
F.2 Conceptual Model Evaluation 189
F.3 Implementation Verification 195
F.3.1 Tracking of Agent Behaviour 195
F.3.2 Single-agent Verification 199
F.3.3 Minimal Model Interaction Verification 201
F.3.4 Multi-agent Verification 201
F.4 Model Output Verification 202
F.5 Model Analysis 204

G Experiments and Data Analysis **205**
G.1 Traditional Values and Autonomy in Conflict 205
G.2 Traditional Values and Comfort in Conflict 211
G.3 Traditional Values and Inclusiveness in Conflict 219
G.4 Autonomy, Comfort and Inclusiveness in Conflict 226

H Model Files **238**

Abbreviations

ABM	Agent-Based Model(ling)
CA	Capability Approach
DES	Decentralized Energy System(s)
EMA	Exploratory Modelling and Analysis
EV	Electric Vehicle
HT	High Temperature
LT	Low Temperature
PV	Photovoltaics

List of Figures

1 Identified Components Used in this Research. vi

1.1 Change from Centralized to Decentralized Energy System (NeoSmart, n.d.). 2

2.1 Main Components of the New Energy System (TNO, 2015). . . . 13
2.2 Scope of this Research. 15
2.3 Capability Approach Applied to this Research. 22
2.4 Research Methods. 24
2.5 Interview Rounds. 26
2.6 The Structure of Agent-Based Models (Van Dam et al, 2013). . . 29
2.7 Research Flow Diagram. 32

3.1 Core of Capability Approach in this Research. 33
3.2 'De Vruchtenbuurt', Neighbourhood (dark red) and City District (light red). This Research Focuses on the City District. 34
3.3 'De Vruchtenbuurt' (Gemeente Den Haag, 2015). 36
3.4 Governance Community Models in this Research. 39
3.5 Technical Heat Designs in this Research (RLI, 2018). 40
3.6 Overview of the Selected Governance Model, Technical Design, Conversion Factors and Values. 53

4.1 Overview of the Concept Formalization. 56
4.2 Income as Constraint. 60
4.3 Ownership as Constraint. 61
4.4 Energy Label as Constraint. 62
4.5 Evaluation of the Values. 66

5.1 Covariance between Security of Supply (Sec) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis). 76
5.2 Covariance between Security of Supply (Sec) and Comfort (Com) (y-axis) for 50 Replications (x-axis). 76
5.3 Covariance between Security of Supply (Sec) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis). 76

5.4 Covariance between Security of Supply (Sec) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 81
5.5 Covariance between Security of Supply (Sec) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 82
5.6 Covariance between Security of Supply (Sec) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 82
5.7 Boxplot of the Covariances (y-axis) between Security of Supply (Sec) - Affordability (Aff) - Sustainability (Sus) (x-axis). 86
5.8 Feature Scoring: Uncertainties. When the result is more yellow in the feature scoring, the outcome of interest is more sensitive for this parameter. 88
5.9 Feature Scoring: Uncertainties and Policies. When the result is more yellow in the feature scoring, the outcome of interest is more sensitive for this parameter. 88

6.1 XLRM Framework Applied to this Research. 91
6.2 Shift in Values. 99
6.3 Box Plot: Conflicts between Security of Supply and Autonomy (y-axis) between and within Income Groups (x-axis). 100
6.4 Explanation of Interpretation of the Boxplots. 101
6.5 Ranking of Determining Factors for Conflicts between Security of Supply and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict. . . . 102
6.6 Sensitivity to Technical Design (x-axis: 1 = all electric, 2 = LT heat grid and 3 = HT heat grid) for Relation between Security of Supply and Autonomy (y-axis: negative = conflict and positive = no conflict). 103
6.7 Box Plot: Conflicts between Security of Supply and Autonomy (y-axis) between and within Energy Label Groups (x-axis). 103
6.8 Box Plot: Conflicts between Security of Supply and Comfort (y-axis) between and within Income Groups (x-axis). 104
6.9 Ranking of Determining Factors for Conflicts between Security of Supply and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 105
6.10 Box Plot: Conflicts between Affordability and Comfort (y-axis) between and within Income Groups (x-axis). 106
6.11 Box Plot: Conflicts between Security of Supply and Inclusiveness (y-axis) between and within Income Groups (x-axis). 107

6.12 Ranking of Determining Factors for Conflicts between Security of Supply and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict. . . . 107
6.13 Sensitivity to Technical Design (x-axis: 1 = all electric, 2 = LT heat grid and 3 = HT heat grid) for Relation between Affordability and Inclusiveness (y-axis: negative = conflict and positive = no conflict). 108
6.14 Box Plot: Conflicts between Autonomy and Comfort (y-axis) between and within Energy Label Groups (x-axis). 109
6.15 Dimensional Stacking of the Conflicts between Autonomy and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 110
6.17 Ranking of Determining Factors for Conflict between Autonomy and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 110
6.16 Sensitivity to Technical Design (x-axis: 1 = all electric, 2 = LT heat grid and 3 = HT heat grid) for Relation between Autonomy and Comfort (y-axis: negative = conflict and positive = no conflict).111
6.18 Box Plot: Conflicts between Autonomy and Autonomy (y-axis) between and within Income Groups (x-axis). 112

B.1 Diffusion of Innovations (Rogers, 2003). 162

D.1 The Influence of the Policies and Innovations. 171

E.1 Interface of the Agent-Based Model. 180

F.1 Covariance between Security of Supply (Sec) and Affordability (Aff) (y-axis) for 50 Replications (x-axis). 183
F.2 Covariance between Security of Supply (Sec) and Sustainability (Sus) (y-axis) for 50 Replications (x-axis). 184
F.3 Covariance between Security of Supply (Sec) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis). 184
F.4 Covariance between Security of Supply (Sec) and Comfort (Com) (y-axis) for 50 Replications (x-axis). 184
F.5 Covariance between Security of Supply (Sec) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis). 185
F.6 Covariance between Affordability (Aff) and Sustainability (Sus) for (y-axis) 50 Replications (x-axis). 185
F.7 Covariance between Affordability (Aff) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis). 185
F.8 Covariance between Affordability (Aff) and Comfort (Com) (y-axis) for 50 Replications (x-axis). 186

F.9 Covariance between Affordability (Aff) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis). 186
F.10 Covariance between Sustainability (Sus) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis). 186
F.11 Covariance between Sustainability (Sus) and Comfort (Com) (y-axis) for 50 Replications (x-axis). 187
F.12 Covariance between Sustainability (Sus) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis). 187
F.13 Covariance between Autonomy (Aut) and Comfort (Com) (y-axis) for 50 Replications (x-axis). 187
F.14 Covariance between Autonomy (Aut) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis). 188
F.15 Covariance between Comfort (Com) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis). 188
F.16 Covariance between Security of Supply (Sec) and Affordability (Aff) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 190
F.17 Covariance between Security of Supply (Sec) and Sustainability (Sus) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 190
F.18 Covariance between Security of Supply (Sec) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 191
F.19 Covariance between Security of Supply (Sec) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 191
F.20 Covariance between Security of Supply (Sec) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 191
F.21 Covariance between Affordability (Aff) and Sustainability (Sus) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 192
F.22 Covariance between Affordability (Aff) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 192
F.23 Covariance between Affordability (Aff) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 192
F.24 Covariance between Affordability (Aff) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 193

F.25 Covariance between Sustainability (Sus) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 193
F.26 Covariance between Sustainability (Sus) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 193
F.27 Covariance between Sustainability (Sus) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 194
F.28 Covariance between Autonomy (Aut) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors). 194
F.29 Covariance between Autonomy (Aut) and Inclusiveness (Inc) for 50 Replications (x-axis) with Different Sets of Weights (colors). . 194
F.30 Covariance between Comfort (Com) and Inclusiveness (Inc) for 50 Replications (x-axis) with Different Sets of Weights (colors). . . . 195
F.31 Number of Households with Community Number 1 196
F.32 Number of Households with Community Number 1 and Community Number 2 196
F.33 Energy Label of Households 197
F.34 Income Level of Households 197
F.35 Distribution of Conversion Factor Income 198
F.36 Distribution of Conversion Factor Social Network (Default) 198
F.37 Distribution of Conversion Factor Social Network (Radius = 3) . . 198
F.38 Distribution of Conversion Factor Social Network (Radius = 1) . . 199
F.39 Feasibility and Level of Values of a Household 200
F.40 Feasibility: Base Case 202
F.41 Feasibility: Houses 10% More Efficient 202
F.42 Feasibility: Everyone is Owner 203
F.43 Feature Scoring: Policies. When the result is more yellow in the feature scoring, the outcome of interest is more sensitive for this parameter. 204

G.1 Box Plot: Conflicts between Security of Supply and Autonomy (y-axis) between and within Income Groups (x-axis). 205
G.2 Box Plot: Conflicts between Security of Supply and Autonomy (y-axis) between and within Energy Label Groups (x-axis). 206
G.3 Ranking of Determining Factors for Conflicts between Security of Supply and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict. . . . 206
G.4 Dimensional Stacking of the Conflicts between Security of Supply and Autonomy. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 207

G.5 Box Plot: Conflicts between Affordability and Autonomy (y-axis) between and within Income Groups (x-axis). 207
G.6 Box Plot: Conflicts between Affordability and Autonomy (y-axis) between and within Energy Label Groups (x-axis). 208
G.7 Ranking of Determining Factors for Conflicts between Affordability and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 208
G.8 Dimensional Stacking of the Conflicts between Affordability and Autonomy. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 209
G.9 Box Plot: Conflicts between Sustainability and Autonomy (y-axis) between and within Income Groups (x-axis). 209
G.10 Box Plot: Conflicts between Sustainability and Autonomy (y-axis) between and within Energy Label Groups (x-axis). 210
G.11 Ranking of Determining Factors for Conflicts between Sustainability and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 210
G.12 Dimensional Stacking of the Conflicts between Sustainability and Autonomy. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 211
G.13 Box Plot: Conflicts between Security of Supply and Comfort (y-axis) between and within Income Groups (x-axis). 212
G.14 Box Plot: Conflicts between Security of Supply and Comfort (y-axis) between and within Social Network Groups (x-axis). 212
G.15 Box Plot: Conflicts between Security of Supply and Comfort (y-axis) between and within Energy Label Groups (x-axis). 213
G.16 Ranking of Determining Factors for Conflicts between Security of Supply and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 213
G.17 Dimensional Stacking of the Conflicts between Security of Supply and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 214
G.18 Box Plot: Conflicts between Affordability and Comfort (y-axis) between and within Income Groups (x-axis). 214
G.19 Box Plot: Conflicts between Affordability and Comfort (y-axis) between and within Energy Label Groups (x-axis). 215
G.20 Ranking of Determining Factors for Conflicts between Affordability and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 215

G.21 Dimensional Stacking of the Conflicts between Affordability and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 216
G.22 Sensitivity to Radius Social Network (x-axis) for Relation between Affordability and Comfort (y-axis: negative = conflict and positive = no conflict). 217
G.23 Box Plot: Conflicts between Sustainability and Comfort (y-axis) between and within Income Groups (x-axis). 217
G.24 Box Plot: Conflicts between Sustainability and Comfort (y-axis) between and within Energy Label Groups (x-axis). 218
G.25 Ranking of Determining Factors for Conflicts between Sustainability and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 218
G.26 Dimensional Stacking of the Conflicts between Sustainability and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 219
G.27 Box Plot: Conflicts between Security of Supply and Inclusiveness (y-axis) between and within Income Groups (x-axis). 220
G.28 Box Plot: Conflicts between Security of Supply and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis). 220
G.29 Ranking of Determining Factors for Conflicts between Security of Supply and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict. . . . 221
G.30 Dimensional Stacking of the Conflicts between Security of Supply and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 221
G.31 Box Plot: Conflicts between Affordability and Inclusiveness (y-axis) between and within Income Groups (x-axis). 222
G.32 Box Plot: Conflicts between Affordability and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis). 222
G.33 Ranking of Determining Factors for Conflicts between Affordability and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 223
G.34 Dimensional Stacking of the Conflicts between Affordability and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 223
G.35 Box Plot: Conflicts between Sustainability and Inclusiveness (y-axis) between and within Income Groups (x-axis). 224

G.36 Box Plot: Conflicts between Sustainability and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis). 224
G.37 Ranking of Determining Factors for Conflicts between Sustainability and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 225
G.38 Dimensional Stacking of the Conflicts between Sustainability and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 226
G.39 Box Plot: Conflicts between Autonomy and Autonomy (y-axis) between Income Groups (x-axis). 227
G.40 Ranking of Determining Factors for Conflicts between Autonomy and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 227
G.41 Dimensional Stacking of the Conflicts between Autonomy and Autonomy. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 228
G.42 Box Plot: Conflicts between Autonomy and Comfort (y-axis) between and within Income Groups (x-axis). 228
G.43 Box Plot: Conflicts between Autonomy and Comfort (y-axis) between and within Energy Label Groups (x-axis). 229
G.44 Ranking of Determining Factors for Conflicts between Autonomy and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 229
G.45 Dimensional Stacking of the Conflicts between Autonomy and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 230
G.46 Box Plot: Conflicts between Autonomy and Inclusiveness (y-axis) between and within Income Groups (x-axis). 230
G.47 Box Plot: Conflicts between Autonomy and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis). 231
G.48 Ranking of Determining Factors for Conflicts between Autonomy and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 231
G.49 Dimensional Stacking of the Conflicts between Autonomy and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 232
G.50 Box Plot: Conflicts between Comfort and Comfort (y-axis) between Income Groups (x-axis). 232

G.51 Box Plot: Conflicts between Comfort and Comfort (y-axis) between Social Network Groups (x-axis). 233
G.52 Box Plot: Conflicts between Comfort and Comfort (y-axis) between Energy Label Groups (x-axis). 233
G.53 Ranking of Determining Factors for Conflicts between Comfort and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 234
G.54 Dimensional Stacking of the Conflicts between Comfort and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 234
G.55 Box Plot: Conflicts between Comfort and Inclusiveness (y-axis) between and within Income Groups (x-axis). 235
G.56 Box Plot: Conflicts between Comfort and Inclusiveness (y-axis) between and within Social Network Groups (x-axis). 235
G.57 Box Plot: Conflicts between Comfort and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis). 236
G.58 Ranking of Determining Factors for Conflicts between Comfort and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict. 236
G.59 Dimensional Stacking of the Conflicts between Comfort and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis. 237

List of Tables

2.1 Values Identified by Kunneke et al. (2015). 19
2.2 Values Identified by Demski et al. (2015). 19
2.3 Values Identified by Ligtvoet et al. (2015). 20
2.4 Values Identified by Milchram et al. (2018a). 20
2.5 Values Identified by Milchram et al. (2018b). 21
2.6 Interviews Conducted in Round 1 and Round 2. 27
2.7 Interviews Conducted in Round 3. 28

3.1 Remarkable Characteristics of City District 'De Vruchtenbuurt' (Gemeente Den Haag, 2015) 35
3.2 Selected Set of Values. 42

4.1 City District Specifications. 64
4.2 Evaluation of Value Security of Supply. 67
4.3 Evaluation of Value Affordability. 68
4.4 Evaluation of Value Environmental Sustainability. 69
4.5 Evaluation of Value Autonomy. 70
4.6 Evaluation of Value Comfort. 71
4.7 Evaluation of Value Inclusiveness. 71

6.1 Conceptual Uncertainties. 93
6.2 Policies and Innovations. 94
6.3 Categorization of Conversion Factors Groups. 95

9.1 The Evaluative and Normative Contributions of Energy Justice (Jenkins et al., 2016). 135

B.1 Actor Scan (Part 1). 159
B.2 Actor Scan (Part 2). 160

Chapter 1

Introduction

Firstly, the situation concerning the use of decentralized energy systems to tackle climate change is introduced (1.1). In section 1.2 the difficult position of the Dutch national government (problem-owner) in this situation is discussed. In section 1.3 the academic and societal knowledge gap is addressed, with the aim to show the relevance of this research. Following from this knowledge gap, the main research question is defined (1.4). Lastly, the structure of the report is given (1.5).

1.1 Tackling Climate Change with Decentralized Energy Systems

To tackle climate change, it is necessary to reduce carbon dioxide emissions fast. The combustion of fossil fuels is one of the main causes that concentration of carbon dioxide in the atmosphere is increasing (Wuebbles & Jain, 2001). The Paris Agreement has been established to limit the use of fossil fuels in order to ensure that the temperature rise will not exceed the limit of two degrees Celsius. In the Netherlands, and also in other European Union countries, national agreements are established with a national approach to commit to the climate goals specified in the Paris Agreement. In the concept version of the Dutch Climate Agreement ('Klimaatakkoord'), it is specified that the Netherlands want to eliminate all the carbon dioxide emissions in 2050 (Klimaatakkoord, 2018). The development of renewable energy is necessary to meet the stated goals (United Nations, 2015; Klimaatakkoord, 2018).

The shift from highly-centralized energy systems into decentralized energy systems (Figure 1.1) can be the solution to meet the above mentioned climate goals (European Parliament, 2010). Decentralized energy generation is mainly using small-scale renewable energy sources and is therefore eliminating the use of large traditional coal-fired or gas-fired power plants.

A decentralized energy system can be defined as follows:

"A decentralized energy system is characterized by locating energy production facilities closer to the site of energy consumption. A decentralized energy system allows for more optimal use of renewable energy as well as combined heat and power, reduces fossil fuel use and increases eco-efficiency." (United Nations, n.d.)

Decentralized energy systems can contribute in reducing carbon dioxide emissions, since these systems are: (1) relying to a larger extent on small-scale generation of renewable energy sources available on a local basis (like solar PV and wind energy), (2) therefore limiting the use of fossil fuels and (3) helping to use energy in a more efficient way by energy storage methods and active demand-side management (European Parliament, 2010; Von Wirth et al., 2018).

Furthermore, decentralized energy systems allow end-users (households, companies and the utility sector) to participate actively (European Parliament, 2010). The change to decentralized energy systems supports consumer empowerment (PwC, 2016) which implies that the end-user does not have the role of a consumer anymore. The end-user becomes a central player in the new energy system and can even influence the new energy system (Energy Systems Expert 2).

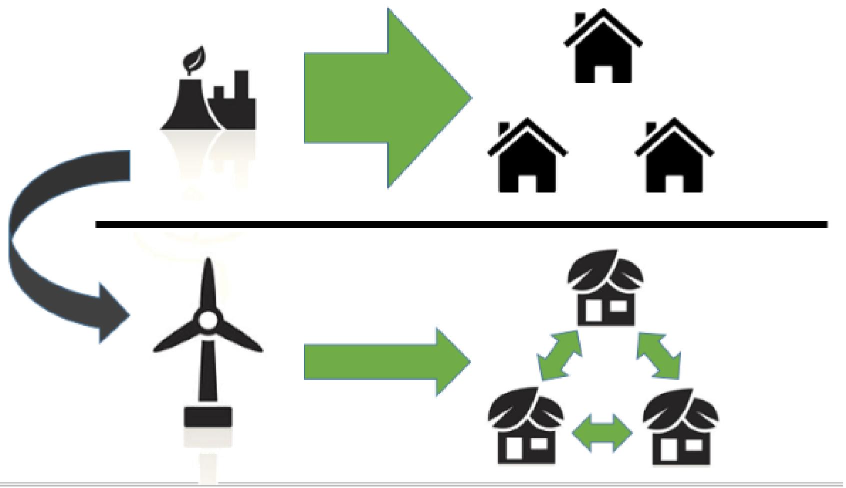


Figure 1.1: Change from Centralized to Decentralized Energy System (NeoSmart, n.d.).

1.2 Trade-Offs for the Dutch Government

The change to a decentralized energy system has, besides the positive effects, also possible negative effects that can lead to public resistance, non-acceptance, and protests of the end-users. Because of this, the implementation of these systems and hence the realization of the climate goals are not secured. The negative effects of decentralized energy systems can be (European Parliament, 2010): (1) the decline in security of supply, due to the intermittent generation from renewable energy sources, (2) the need for upgrades in the grid and/or creation of flexibility and (3) the increase in costs, which can result in inaccessibility for some end-users. This last point happened in Germany, where the 'Energiewende' (transition to renewable energy) led to higher income inequality and so called 'Energy poverty' (Der Spiegel, 2014). The fulfillment of the relevant system criteria can be different when is changed to a new energy system (System Operator 1).

The Dutch government and in particular the Ministry of Economic Affairs and Climate Policy have to deal with trade-offs between different system criteria. The Ministry has the obligation to take actions in order to meet the climate goals set in the Paris Agreement and the national Climate Agreement (United Nations, 2015; Klimaatakkoord, 2018), but is also responsible for creating a socially responsible energy system that supports the welfare of the Dutch society. It is very likely that not all system criteria are in line with each other, as already is shown in the positive and negative effects of decentralized energy systems. To clarify trade-offs between system criteria, a few examples are given below.

Example 1: when environmental groups argue that more renewable energy should be developed by the government (criterion 'sustainability'), but no inhabitant of the country wants to have a windmill close to their house due to the negative sides effects, like noise disturbance and shadow flickering (criterion 'health'). This phenomenon is called 'Not In My Back Yard (NIMBY)' (Valentine, 2015). For both values it can be argued that they are important and are in dilemma in this case. **Example 2:** the 'yellow vests movement (mouvement des gilets jaunes)' in France, where the French government is planning to increase the fuel taxes to improve the position of France in the world economy and discourage the use of fossil fuels (criteria 'economic development' and 'sustainability'). The citizens protest against this tax increase, because they argue that the working class should not pay for a problem that is caused by multinational companies (criterion 'justice') (Atkin, 2018; Le Figaro, 2018). When the French government decides to continue to execute their plan, it means that the criterion 'justice' is not fulfilled (which also depends on the interpretation of the criterion 'justice'). In this case the criterion 'justice' is not in line with the criteria 'sustainability' and 'economic development' (for France as a whole). **Example 3:** the natural gas winning in the Dutch province Groningen. Even though natural gas winning was economically beneficial for the Netherlands (criteria 'economic development'), it caused safety risks (like earthquakes) for the citizens of Groningen (criterion 'safety') (NU.nl, 2017). The national government decided to stop the natural gas winning to meet the criterion 'safety'. However, this means that other sources have to be used to heat the Dutch houses and buildings, which is likely to influence the criterion 'economic development' negatively. This is a criteria trade-off, because it means that the criterion 'economic development' cannot be achieved in this case. All the examples are possible criteria dilemmas and trade-offs that can also arise with the change to a decentralized energy system.

The national government does not know what policy decisions to take, since (1) it is subjective to argue which system criteria are more important than other system criteria, (2) no consensus can be found on the best solutions and (3) the decisions have an unpredictable impact. The last point is caused by the development of technologies, the integration in a certain context and the behaviour of end-users (PBL, 2019). The risk that the realization of chosen policies do not result in socially responsible implications and do not support the well-being of the Dutch society is big.

1.3 Societal and Academic Knowledge Gap

To support the national government, knowledge about the possible trade-offs and the consequences of dealing with these trade-offs is desired. The change to a new energy system, where the end-users play a central role, can lead to new, relevant and not yet identified system criteria and trade-offs (between these system criteria). No decentralized energy systems projects are executed on a larger scale than pilot projects, where lessons can be learned from. However, Denmark could be used as best practice, since decentralized energy systems are implemented on a large scale in this country (HIER, 2017). Even though the lessons from Denmark can be useful to take knowledge of, it is expected that the context differs too much from the Netherlands to give the national government enough tools to deal with trade-offs.

The scientific literature is also limited in providing an answer to the knowledge gap of the national government. In the next paragraphs, there has been elaborated on the academic knowledge gap.

While scientific literature on decentralized energy systems mainly focuses on the social side, it lacks to examine the integration of the social side with the technical and economic side. Therefore knowledge about the influence on specific criteria (trade-offs) is missing. Adil & Ko (2016) state that *"the decentralizing transitions of urban energy systems, particularly solar PV and thermal technologies, require a comprehensive assessment of their socio-technical co-evolution how technologies and social responses evolve together and how their co-evolution affects urban* *planning and energy policies" (p. 1025).* In this study the necessity of integration is noticed, but the influence on specific criteria is not examined. Von Writh et al. (2018) conducted a systematic literature review on the barriers and drivers for social acceptance of decentralized energy systems. This study highlights that knowledge on the support of decentralized energy systems and real world examples are scattered but growing. Lastly, a study examines the contribution of local community energy initiatives to a decentralized energy system (Van der Schoor & Scholtens, 2015). This study focuses mainly on the social aspects and the governance of decentralized energy systems, but misses the integration with the technical and economic side.

In other studies, trade-offs between criteria are discussed, but these studies are not comprehensive (e.g. Bohli et al., 2010; Liu et al., 2012). Often these studies are limited to the discussion of privacy and data security issues, since decentralized energy technologies go along with the use of smart technologies. Bohli et al. (2010) mention that a tension exists between data sharing to empower smart energy mechanisms and consumer privacy. Also, because smart energy systems allow bi-directional communication and electricity flow and it enables the end-users to monitor, predict, and manage energy usage (Liu et al., 2012). The above mentioned studies do identify some criteria and issues, but do not look further than the privacy and data security level.

In a few articles the role of end-users in decentralized energy systems is mentioned, but no further analysis is done on the trade-offs that result from the new role that end-users undertake. Goulden et al. (2014) presented work where the role of end-users in such systems is central and also discussed the context in which such roles might emerge. This paper suggests that energy system designs should look further than technology, but does not look into the trade-offs that can result from energy system designs where the end-users play a central role. Furthermore, Zhang & Nuttall (2007) used quantitative modelling to get more insights in the adoption of the new technology and found that the behaviour of end-users is affected by intelligence, values, experience and general perspectives. However, this study does not examine trade-offs that results from the way the end-users are affected.

The ethics field discusses trade-offs between energy system criteria as value conflicts and also examines the integration with the technical and economic side. However, these studies do not focus on decentralized energy systems specifically and do not examine under what conditions value conflicts arise in order to achieve lessons that can be used by policymakers. Van de Poel (2009) discusses that values and value conflicts are embedded in the engineering system process. In more studies values are identified that are important for energy systems (Demski et al., 2015; Ligtvoet et al., 2015; Kunneke et al., 2015; Jenkins et al., 2016; Micharm et al., 2018ab; Hillerbrand, 2018). Furthermore, the social acceptance of renewable energy innovation is examined. Acceptance is divided by Wursthagen et al. (2007) in socio-political, community and market acceptance and includes values like justice and trust too. The values identified in these studies might be applicable to decentralized energy systems as well.

1.4 Main Research Question

Knowledge about the set of relevant system criteria of decentralized energy systems and the possible trade-offs that can emerge between these system criteria is missing. Some studies address system criteria of energy systems, which can be used as start of the identification of the relevant set of values for decentralized energy systems. Furthermore, the influence on society is examined, but real world examples are missing to determine implications that can be used in practice by the national government. Also, some studies examine the social acceptance of energy systems (also specifically of decentralized energy systems), but do not comprehensively address the underlying system criteria. The information of these studies can be useful, but a deeper understanding of system criteria trade-offs that emerge under certain conditions is desired to support the national government.

Therefore, a more comprehensive quantitative analysis on the change to decentralized energy systems, where the role of the end-user is central, can be relevant to deal with this difficult problem. It results in a better representation of a set of system criteria (more elaborated than privacy and data security) that are important for the evaluation of a decentralized energy system. By performing this analysis (quantitatively) it is possible to identify trade-offs between system criteria that arise under different combinations of conditions. Combinations of conditions (design of the decentralized energy system and the characteristics of the end-users) that result in trade-offs can lead to important lessons for the national government. Furthermore, giving advice on which strategies can influence the occurrence of these system criteria trade-offs is also addressed. Later in the research, system criteria dilemmas and trade-offs are examined as value conflicts and value trade-offs, since in the literature often values and value conflicts are used to examine the criteria of an energy system. Therefore value conflicts are included in the research question instead of system criteria dilemmas. Furthermore, households in a city district are the end-users that is focused on in this research and are included in the main research question as well. The reasons for this focus are explained further in the next chapter. The following research question, that addresses the problem and the knowledge gap, has been defined:

"How can household value conflicts be identified and reduced when designing decentralized energy systems?"

1.5 Structure of the Report

Firstly, the research approach is presented (Chapter 2) by elaborating on the objective, scope and challenges of the research. Also, the sub questions that follow from the main research question are defined and the concepts, frameworks and methodologies are explained. The approach of the research is shown in a research flow diagram. Following the decomposition of the system is explained further by describing a specific case (Chapter 3). In this chapter is elaborated on the different type of decentralized energy systems. Furthermore, the important values (criteria) and the conversion factors (characteristics) that influence the values are identified. After that, the model used for analyzing the value conflicts (criteria trade-offs) under certain conditions is described (Chapter 4). Subsequently, the verification and validation of the model is performed (Chapter 5). Following, the experimentation and results are shown (Chapter 6). The experiments focus on the occurrence of values conflicts under different conditions. In the last phase of the research the lessons and implications, by reflecting on the limitations of the research and the use of the results and the model for real world implications, are presented (Chapter 7). Then the research questions are answered in the conclusion chapter (Chapter 8). Lastly, a critical reflection is given by elaborating on the chosen frameworks and methods, the developed model, the process and the societal and scientific contribution of the research. Also, recommendations for future research are given (Chapter 9).

Chapter 2

Research Approach

The aim of this chapter is to explain the approach of this research. In section 2.1 the problem statement is given, which provides an overview of the missing elements that will be addressed in this research. After that, the research objective and approach are discussed to make clear what the deliverable of this research is and how this is going to be reached (2.2). Following, the sub research questions are given (2.3) that follow from the main research question. Furthermore, the scope of the research is presented (2.4), to give an overview of the boundaries of this research. After that, the concepts and frameworks that support the conceptualization of this problem are discussed (2.5). Followed by the explanation of the matching methods and required data collection (2.6). Finally, the planning of the research is given supported by a research flow diagram (2.7).

2.1 Problem Statement

More attention should be given to the social side of decentralized energy systems, the central role and characteristics of the end-users, and the uncertain development of technologies and end-user behaviour. This research aims to find the following missing elements:

- Identification and conceptualization of system criteria that are important for the change to decentralized energy systems and their relation with the characteristics of the end-users

- Identification of dilemmas and trade-offs between system criteria that emerge under certain conditions (characteristics of end-users, other uncertainties and policies)

- Identification of strategies that effect dilemmas and trade-offs between system criteria and support the transition to decentralized energy systems in city districts

The problem statement that is based on the above mentioned missing elements and the knowledge gap identified earlier is:

A lack of knowledge exists on strategies that take system criteria dilemmas into account in order to design an acceptable decentralized energy system for a city district with different households.

2.2 Research Objective and Approach

The aim is to identify the system criteria dilemmas that arise when is changed to a decentralized energy systems in a city district with different households. The identification of these system criteria dilemmas depends on many (uncertain) factors, like the characteristics of the end-users, their interaction and the influence of the new system on the criteria.

The problem described in the previous chapter contains multiple uncertain factors.

Firstly, the way this problem is formulated and defined is influenced by the researcher, which can be called 'observer dependency' (Van Dam et al., 2003). This also comes back in giving a definition to the different criteria, because the criteria are formulated as values which are latent concepts. Latent concepts are affected by polysemy and synonymy (De Wildt et al., 2018).

Furthermore, the co-evolution between criteria and technologies cause uncertainties in this research. The focus is put on criteria that are seen as important by the problem-owner, researcher and media at that time. However, the focus can change over time and is therefore also uncertain. Moreover, the development of technology is uncertain and might require adaptive policies. For example, it was not expected that the costs of solar and wind energy would decrease so fast (Ecofys, 2018). The same goes for the possible innovations of heat pumps, smart charging and smart meter systems. It is therefore hard to predict what issues emerge or disappear when smart technologies and other uncertain factors develop further.

To summarize, this problem contains multiple heterogeneous stakeholders and uncertainties. First of all, due to the many variations of the context and conditions and second, in the way the problem is defined and scoped. These characteristics are typical for a complex problem and make it unable to find a single formulation of the problem, as Mikulecky (2001) argues:

"Complexity is the property of a real world system that is manifest in the inability of any one formalism being adequate to capture all its properties. It requires that we find distinctly different ways of interacting with systems. Distinctly different

in the sense that when we make successful models, the formal systems needed to describe each distinct aspect are NOT derivable from each other" (p. 344).

The research objective can be reached by using the **modelling approach**. This approach makes it possible to address the complexity of the problem, since it allows to experiment with multiple (uncertain) factors and dimensions which is not achievable when using other approaches. Even though the modelling approach allows to include many factors and dimensions, it is still necessary to discuss the scope of this problem.

2.3 Sub Research Questions

Considering the objective and approach of this research, the main research question can be divided into sub research questions. One remark has to be made: further in research the dilemmas between system criteria are examined as value conflicts. The sub questions are presented below.

1. What household values are important in decentralized energy systems and what household characteristics and design choices for the energy system influence these values?

The purpose of this question is to identify a representative set of values (criteria), by looking at values that are already identified and by investigating if other values are mentioned by experts and stakeholders. Furthermore, the characteristics of households and design choices that are influencing the values are investigated. (Qualitatively).

2. How can the design choices for the energy system, household values and characteristics of 'De Vruchtenbuurt' in The Hague be specified in a simulation model?

The purpose of this question is to conceptualize the identified values and also the relation with the factors that influence the values, so they can be used in a simulation model. This means that also the type of decentralized energy system and the household characteristics have to be conceptualized. To answer this question a specific case is analyzed ('De Vruchtenbuurt' in The Hague). More information about the case is provided in the next section. (Qualitatively into quantitatively).

3. Under what conditions (uncertainties and policies) do household value conflicts occur?

The purpose of this question is to identified if certain values are in conflict with each other. Furthermore, it is identified under which conditions (household characteristics, other uncertainties and policies) the conflicts emerge. (Quantitatively).

4. What are the effects of strategies on household value conflicts?

The purpose of this question is to give advice to the national government and other stakeholders that are supporting the change to decentralized energy systems. This is done by discussing how the value conflicts resulting from the analysis (see previous question) can be reduced or handled. Also the influence of value conflicts on the actual adoption is discussed, to see what should be done to let the households actually change to a decentralized energy system. (Qualitatively and quantitatively).

2.4 Scope of the Research

Since the problem is complex and difficult to access, it is important to make clear which components of this problem are taken into account and which are not.

To start with, the scope is bounded to the built environment sector and to the representation of one city district where a type of decentralized energy system (technical design and governance model) can be implemented on a larger scale than a pilot project. The Netherlands is divided (from large to small) in provinces, regions, municipalities, residence places, districts and neighbourhoods. The Netherlands consists of 13.200 districts with an average of 1.200 inhabitants per district (CBS, 2019). An increase in initiatives by inhabitants of neighbourhoods and districts for the change to decentralized and sustainable energy systems is expected (PBL, 2014).

Multiple stakeholders are involved when concerning the change to a decentralized energy system in a city district. In Appendix B the identification of the stakeholder field regarding the change to decentralized energy systems in city districts is given. End-users (like households), the national government, decentralized governments and the system operator are critical actors. Further explanation about these critical actors is given in Appendix B.

The households are the only critical actor considered in this research, since the consideration of the social side of households is desired, interesting and undiscovered. Companies and the utility sector are end-users in the built environment with another consuming profile than households (TKI Urban Energy, 2018). Companies and the utility sector use more energy and can also adopt decentralized energy systems (Energy Systems Expert 1). Even though households consume 28% of the total energy consumption only (EBN, 2019), the heterogeneity of households is much bigger than of the other end-users. More non-acceptance and resistance is expected on this level (Policymaker 1).

Due to the central role of the households in this research, it is questionable if the term 'end-user' is right. The term implicates that the household is at the end of the chain, while that is not the case in many designs of decentralized energy systems (Energy Systems Expert 2). Therefore, from now on the term end-users is avoided, since it gives the wrong implication.

More scoping choices are made to make this complex problem accessible. Below, the main choices are explained upon which is elaborated in the remainder of the report when required.

2.4.1 Types of Decentralized Energy Systems

Decentralized energy systems come in many variations and it depends on the context which type of decentralized energy system is chosen. To get a better grip on the possible types of decentralized energy systems, it was decided to divide the type of decentralized energy system into a governance and technology layer. This division has been made, as the focus is often mainly on the new technologies, whereas governance of the decentralized energy system is also necessary to create a business case (TKI Urban Energy, 2018).

Governance Models

Governance is necessary to steer technical designs in order to make the energy transition possible in the assigned city district. Three different governance models are distinguished: commercial, public and community (TKI Urban Energy, 2018). As stated by TKI Urban Energy (2018), a combination of the three governance models is probably going to be used in the future. However, in this research, only one type of governance will be considered at the same time. This decision was made because most pilot projects also only use one type of governance and this is also expected to happen when a city district changes to a decentralized energy system. On the other hand, it might be possible that a community based initiative is taken over by the municipality (public), to make the city district change to a decentralized energy system (Decentralized Government 1). In this research the focus is on the model that is used at the start of the initiative, since this model determines the directions of the change to a decentralized energy system.

Technical Designs

The change to renewable resources and the use of more electrical products (like electric vehicles and heat pumps) eliminate the use of conventional sources of energy (like gas and oil). Because of these changes, the electricity grid is accessed more and peaks in supply and demand are harder to match. As can be seen in Figure 2.1, 'flexibility' is one of the solutions of the energy transition. However, to create enough flexibility, scaling up is necessary (TNO, 2015). The three main pillars are (1) the increase in sustainable and decentralized electricity generation, (2) the need to deal with the balance of demand and supply and (3) the increase in electricity use and peak demand. The technical designs follow from these three pillars.

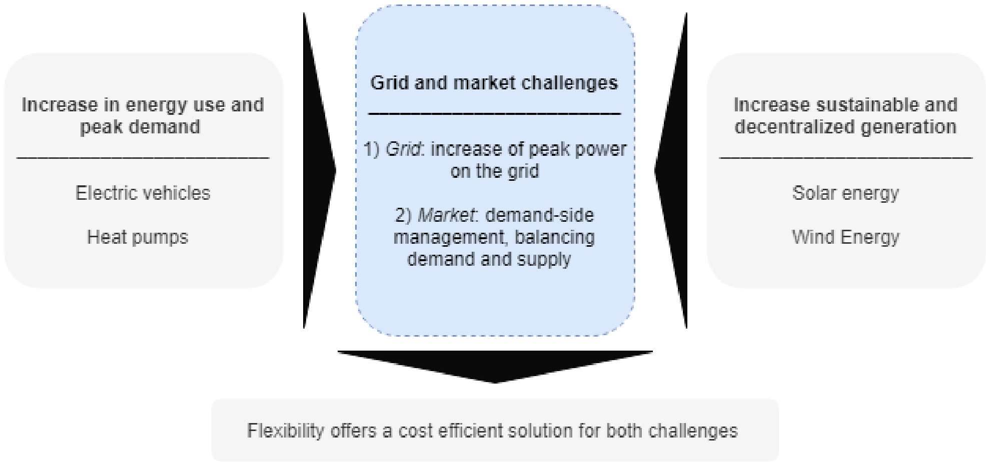


Figure 2.1: Main Components of the New Energy System (TNO, 2015).

The main developments in these energy transitions from a technical point of view are decentralized energy generation (solar PV and wind energy), flexibility (electric vehicles and storage) and the heat transition (heat pumps and heat grids). These three developments have been used most in pilot projects and are expected to have the biggest potential for upscaling in the future (Policymaker 1, Energy Systems Expert 2). A combination of different technical designs is expected to be developed within one city district (TKI Urban Energy, 2018). In this research only one technical design is applied at the same time.

On a larger scale not all three developments are implemented immediately, since expertise and experience are still missing. The size of pilot projects is often limited to 250 households and the few projects with a scale of 1.000 households face problems with shortage of equipment. The challenge is to bring the technologies to 'Technology Readiness Level 9': an actual system proven in operational environment (Energy Systems Expert 2).

2.4.2 Specific Case: 'De Vruchtenbuurt'

Even though the goal of this research is to give a generic advice on the combinations of types of decentralized energy systems and types of city districts, the research is easier accessible when analyzing a specific case. Selecting a case that shows many aspects and for which a lot of data are available, gives the option to use the analysis afterwards for other cases. When a specific case is used the level of abstractness is lower. The results are more specific and can be translated to more generic advice for other cases (by comparing other cases with this case) further on in the research.

For this research, the city district De Vruchtenbuurt is selected. In 2015, in this city district an initiative from inhabitants started called 'Warm in de Wijk' and now in 2018 an official community Duurzame Vruchtenbuurt U.A. has been established (Warm in de Wijk, 2017). More than 658 households are associated with this community and more than 240 households are member (Warm in de Wijk, 2017; Vruchtenbuurt Wijkberaad, n.d.; Local Initiator 1). This city district is interesting as a case, since many bottom-up initiatives concerning the energy transition already have been applied. Besides the 33 new residences from the pilot project 'De Groene Mient' (RVO, 2018), most of the residences in 'De Vruchtenbuurt' are built before 1945 (Wonen in Den Haag, 2015) and the district is classified as 'very strong urban' (CBS, 2017). These characteristics can have technical and economic implications and therefore criteria dilemmas and trade-offs are expected (even though the affinity of the district with sustainability is rising). Measures to save energy are taken, but the heat demand and therefore usage stays high (Local Initiator 1).

2.4.3 Conceptual Scoping Challenges

Besides the more problem specific scoping choices, also conceptual scoping choices have to be made. Firstly, different approaches (like normative or descriptive) and sources to identify the set of criteria exist. Moreover, different criteria might be valued important over time. Furthermore, it depends per situation which criteria will be considered important, which means that it depends on the researcher and the used data which criteria become apparent. Analyzing the results from different perspectives (by conducting interviews) gives a better idea of the level of uncertainty that the perception of the researcher has. Also, due to the potential technical development of energy systems it is uncertain if the evaluation of criteria will develop in the future. Besides that, it is chosen to conceptualize and quantify the criteria dilemmas, which creates the challenge of quantifying the criteria realistically. Therefore it is always important to validate the model and to find out to what extent the model is useful for policy advice. Finally, since the dilemmas and trade-offs can be ethical, it is morally seen difficult to find a good strategy and solution. Therefore the advice following from the insights of this research should aim to eliminate the criteria trade-offs or suggest a way to deal with these kind of trade-offs.

To keep this research feasible in the given amount of time, certain choices are made that do not prevent reaching the goal of the research. In Figure 2.2 an overview of the most important choices is presented. Two main conceptual choices are explained more extensively below.

WITHIN SCOPE	*OUT OF SCOPE*
Criteria: - Normative - Same set for all households - Same level of importance - Static	Criteria: - Descriptive - Different per household - Level of importance - Dynamic
Factors that influence the criteria: - Static	Factors that influence the criteria: - Dynamic
Conceptualization: - Influenced by characteristics of households - Static - Choices household by improving its well-being, given their conditions (adopting or rejecting)	Conceptualization: - Perception of the household (interpretation of the criteria dilemmas and trade-offs) - Dynamic - Choices household by personal preferences, perceptions and beliefs

Figure 2.2: Scope of this Research.

Normative Perspective

The set of criteria that are considered as important for the change to a decentralized energy system is selected normatively. A selection is made of the criteria that are mentioned over time in literature and interviews. The criteria that are perceived as most important by the interviewees and the researcher are chosen. Not all criteria can be taken into account (unmanageable) and the choice of the included criteria is based on the interpretation of literature and interviews. The analysis itself can be descriptive, but giving advice on what to do with the results is normative again.

Static

To reach the goal of this research, it is not of great importance that the research is dynamic. However, this does not mean that 'time', development and innovation do not play a big role in the change to decentralized energy systems. However, identifying criteria dilemmas under certain conditions can also be done by considering static conditions. This also does not mean that it is not interesting to conduct this research under dynamic conditions, but due to the complexity of the problem situation it is important to look for scoping possibilities without harming the goal of the research.

2.5 Research Concepts and Frameworks

Concepts and frameworks that support the conceptualization of the criteria and the impact of the type of decentralized energy system and household characteristics on these criteria are discussed in this section. Firstly, the importance of distinguishing (ethical) acceptability and (social) acceptance is elaborated on. Secondly, the use of values and value conflicts to examine criteria and criteria dilemmas is discussed. Thirdly, a definition of a value is given and a review of the values mentioned in scientific literature on energy systems is presented. Fourthly, the Capability Approach is presented that supports the quantification of values, based on the influences of the type of decentralized energy system (governance and technology) and households characteristics (like income and energy label). Lastly, the link between values and capabilities in this research is explained.

2.5.1 Acceptability and Acceptance

The national government aims to create a socially responsible energy system that supports the well-being of the Dutch society. This indicates that the aim is to create acceptable decentralized energy systems. This is examined by finding out if households with different characteristics are able to meet the set of criteria perceived as important for an energy system. Whether households also make use of the options, determines the acceptance of decentralized energy systems. Acceptance is also important for the change to decentralized energy systems. However, the acceptance of decentralized energy systems is not the core of this research.

It is important to understand the difference between the concepts 'ethical acceptability' and 'social acceptance'. Where ethical or moral acceptability is an ethical judgment and can be classified as normative, social acceptance is an empirical fact and a descriptive notion (Van de Poel, 2016). The focus in this research is normative and on the acceptability of decentralized energy systems and the value conflicts that emerge from these systems. However, this can still mean that the elimination of value conflicts and therefore a higher level of acceptability can lead to social acceptance. Van de Poel (2016) explains the coherentist view of acceptability and acceptance and argues that in debates about the acceptability and acceptance of a technology both concepts should be taken into account. When a new technology is introduced, the focus often lies on the acceptance of the technology, which could mean that ethical aspects are overlooked (Taebi, 2017). According to Taebi (2017), the two concepts are complementary and therefore both studies are important. It is chosen to focus on the ethical acceptability as a starting point and to take into account what this could mean for the social acceptance of decentralized energy systems in a further stage of the research. It should be noted that this research cannot judge if a decentralized energy system is acceptable, since this also requires to find out if the procedure and implementation are acceptable. Therefore, when acceptability is mentioned this refers to contribution to a higher level of acceptability. Also, it is questionable if the values used in this research are all 'ethical or moral' values, since 'sustainability' or 'affordability' are not per definition ethical or moral. Therefore, when the term 'ethical acceptability' is used, this refers to the normative notion and not to the 'ethical or moral' judgment.

2.5.2 Criteria Dilemmas Evaluated As Value Conflicts

In the ethics field, values are used to examine energy systems. Criteria (or requirements) are formulated that a new engineering design should meet. Van de Poel (2009) argues that some design criteria *"are formulated in terms of goals or values that can never be fully met (p. 987)"*. It is more likely that these values are in conflict with each other under certain conditions, since values like 'safety' and 'economic development' can never be fully met and it is possible that these values are not in line with each other (in certain cases). In the remainder of the report is spoken about values and value conflicts instead of criteria and criteria dilemmas. In this section the consideration of values and value conflicts is discussed.

Van de Poel (2009) argues that in many cases value conflicts are the driver of innovation and design and are therefore also of importance in this problem situation. He identifies different types of values (like instrumental, economic, moral, cultural and aesthetic values) that can conflict under specific circumstances. Subsequently, he discusses which approaches to value conflict in engineering design suit certain types of values. Optimizing approaches often cannot be used due to formal and substantive problems, but it is questionable if alternative approaches, for example non-optimizing, are doing better. An approach to deal with value conflicts in engineering design is not easily chosen. This mainly has to do with the incommensurability of values.

Munda (2004) identifies two types of value incommensurability. The variation in interpretation and perception of importance by different persons or actor groups can be called 'social incommensurability'. The other type is 'technical incommensurability', which refers to the lack of one single measurement scale for different values (Munda, 2004). A household that is potentially changing to a decentralized energy system has values, e.g. 'sustainability' and 'economic development'. The value 'sustainability' will be improved when it adopts the new technologies, but the household faces the problem that the new technology is more expensive than the current energy technologies (decreases the fulfillment of the value 'affordability'). In this case it is hard to measure which of the values of this household are more important and, as argued before, it also differs per household what values are perceived as important and how values like 'sustainability' and 'affordability' are interpreted.

Some philosophers argue that value incommensurability does not exist, since they argue that a value is superior to the other values (Van de Poel, 2009). In this research it is decided to perceive all values as equal and to not rank the values on importance or select a certain value as superior.

In order to keep the research understandable, one set of values per household with one interpretation per value is chosen. The individual perception and interpretation of the households is not taken into account in this research, since this is not part of the acceptability of the new energy system. However, value incommensurability is not denied in this research. Therefore it is necessary to reflect on the use of one set and one interpretation of the values at the end of the research.

2.5.3 Values in Energy Systems

Firstly, a definition of the term 'value' is given, following by the literature and interviews consulted that led to a set of values used for further research.

Definition of Value

When identifying values that are embedded in decentralized energy systems, it is useful to use one definition of the term 'value'. According to Rokeach (1973), a value is *"an enduring belief that a specific mode of conduct or end-state of existence is personally or socially preferable to an opposite or converse mode of conduct or end-state of existence" (p. 5).* This definition states that values can be different per actor and can have a different preferable direction per actor. Even though a value is an enduring belief according to this definition, it is possible that values change over time (System Operator Expert 1).

In this research a normative perspective is used and therefore one set of values with a preferable direction is assumed to be best the for the well-being (focusing on energy only) of the Dutch society. Also, the normative set of values is not changing over time, since the most important values over time are taken into account. However, it is possible that different values emerge in the future, which might change of extend the normative set of values.

Values in Scientific Literature

Many values have been described and in literature similar values are often given a different name, taken together or separated. (De Wildt et al., 2018). An overview of different articles and public debates on values embedded in engineering and energy systems is given.

Kunneke et al. (2015) attempted to align offshore energy systems with moral and social values more generally (Table 2.1), besides the technical and economic values. Even though this research is not about offshore energy systems, similar values for decentralized energy systems can be identified considering moral and social values.

Table 2.1: Values Identified by Kunneke et al. (2015).

Security of Supply	Procedural Justice
Sustainability and Environmental Protection	Appropriate Property and Ownership Configurations
(Near) Reversibility of Physical Assets	Privacy
Distributional Justice	Safety

Demski et al. (2015) identified public values for energy system change into different social value clusters (Table 2.2). In this work the importance of considering the system as a whole is discussed and therefore some varying values from the other referred works were identified.

Table 2.2: Values Identified by Demski et al. (2015).

Avoiding Waste	Social Justice
Efficiency	Fairness, Honesty, Transparency
Capturing Opportunities	Autonomy, Freedom
Environmental Protection	Choice, Control
Nature, Naturalness	Long-term Trajectories
Availability, Affordability	Interconnected
Reliability	Improvement, Quality
Safety	

Ligtvoet et al. (2015) argues that making a full, comprehensive overview of all components that are relevant for a system is not easy and that using an abstractive approach is helpful. The development of smart meters in the Netherlands is used to describe their arguments and in Table 2.3 the values are represented that they found in 'value sensitive design' literature.

Table 2.3: Values Identified by Ligtvoet et al. (2015).

Accountability	Informed Consent
Autonomy	Legitimacy
Calmness	Ownership
Cooperation	Participation
Correctness	Privacy
Courtesy	Reliability
Democracy	Safety, Health
Economic Development	Tractability
Efficiency	Trust
Environmental Sustainability	Universal Usability
Freedom from Bias	Welfare
Identity	

Milchram et al. (2018a) identified social and moral values that are used in public debates concerning smart grids systems in the Netherlands and The United Kingdom. Only the values that are used in the Netherlands are presented in (Table 2.4).

Table 2.4: Values Identified by Milchram et al. (2018a).

Economic Development	Accountability
Environmental Sustainability	Distributive Justice
Security of Supply	Procedural Justice
Transparency, Accuracy	Privacy
Comfort	Security of Data
Control, Autonomy	Reliability
Democracy	Trust
Cooperation	Health, Safety

Milchram et al. (2018b) conducted a literature review to identify the values that are important for the acceptance of smart grid technologies (Table 2.5). Even though this research focuses on the acceptability of decentralized energy systems, the values for acceptance presented by Milcrham et al. (2018b) are expected to be similar for acceptability studies.

Table 2.5: Values Identified by Milchram et al. (2018b).

Environmental Sustainability	Distributive, Procedural Justice
Security of Supply	Control, Autonomy
Transparency, Accuracy	Inclusiveness
Privacy	Quality of Life
Security of Data	Reliability
(Mis)Trust	Affordability of Energy
Health	

2.5.4 Capability Approach

This work adopts a normative perspective in the form of the Capability Approach.

New systems are in general deployed to increase the utility of at least a share of the stakeholders (Van de Poel (2009). The Capability Approach is a framework that links human well-being and the environment (Hillerbrand, 2018) and helps to get a grip on the impact that new decentralized energy systems have on the chances and options of different households.

The Capability Approach was first introduced by Sen (1993). It focuses on (1) that the freedom to achieve well-being is of primary moral importance and (2) that this freedom is to be understood in terms of peoples chances and options, which are called capabilities (Robeyns, 2016).

The Capability Approach does not consider energy systems as right or wrong, since this judgment is sensitive to context (Hillerbrand, 2018). When considering the version of the Capability Approach of Nussbaum (2011), the individual properties and social embeddedness of actors and their environmental conditions are taken into account (also called conversion factors). This makes it possible to measure the capabilities emerging from the deployment of decentralized energy systems. It allows to identify if the emerging capabilities lead to value conflicts considering a certain context.

Some other frameworks that consider values are not in line with the Capability Approach, like utilitarianism and resourcism (Sen, 2009). Utilitarianism states that an overlaying value (utility) should be maximized and thus does not consider the distribution of this value amongst the affected ones. The Capability Approach takes into account the distribution of social welfare of the affected (positive and negative) and does not assume that one value is superior to another value (Robeyns, 2016). Besides this, the Capability Approach is also in opposition with resourcism. Sen (2009) argues that for a fairness based theory of justice the focus should not be on resources. He states: when two people interpret a good life similarly and have access to the same resources, it does not mean that both have the same conditions to make use of these resources in the same way (Sen, 2009). However, if the Capability Approach is a full fairness based theory of justice is discussed in Chapter 9.

The way the Capability Approach can be applied in this research is presented in Figure 2.3. The continuous arrows are the aspects that are included in the core of the research (qualitatively and quantitatively) and the dotted arrows are the aspects that are included qualitatively in a further stage of the research, to make the translation from (ethical) acceptability to social acceptance. By letting a household consider if it can increase its overall level of values by changing to another chance or option, it is possible to evaluate if the value levels of this household are in conflict with the value levels of another household. In this research is not quantitatively taken into account how: personal preferences, social influences, personal history and psychology, influence the choice of a household. Qualitatively this part is taken into account to see what these value trade-offs mean for the social acceptance, which says more about the actual adoption of the options or chances. Furthermore, other policies and innovations than the governance model and the technical design that influence the values and conversion factors, are taken into account in the experiments. How these policies and innovations relate to the personal preferences, social influences, personal history and psychology of the households is not taken into account.

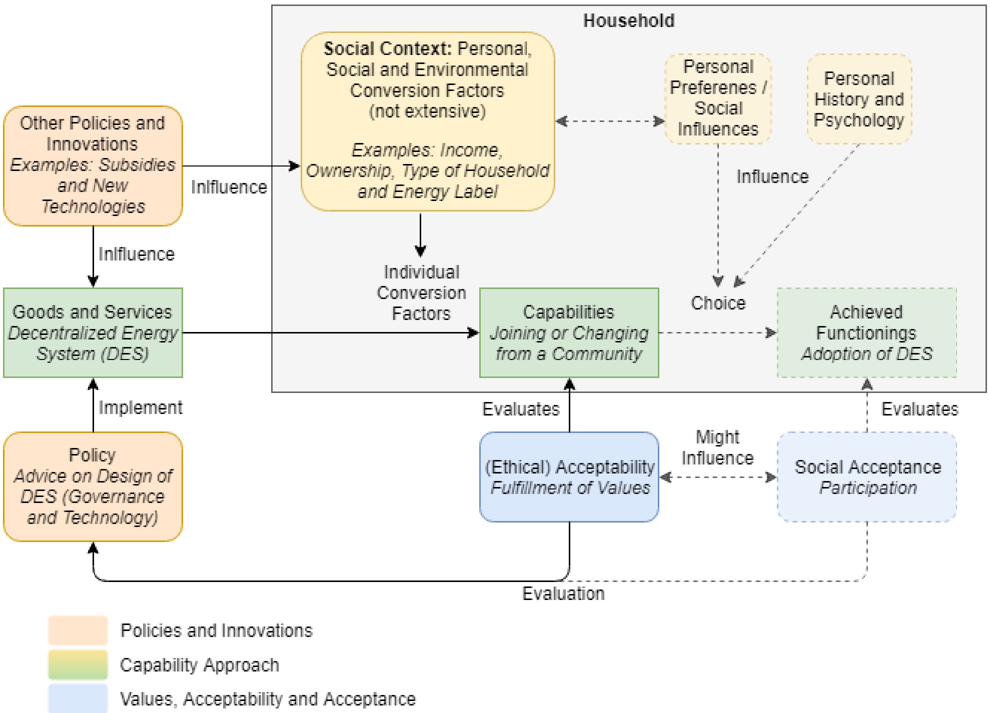


Figure 2.3: Capability Approach Applied to this Research.

2.5.5 Values Used in the Capability Approach

The Capability Approach defines the set of capabilities as the opportunity set of achievable functionings ('freedom to achieve'). In this research the 'freedom to achieve' and capabilities are interpreted in line with Nussbaum's (2011) version of the Capability Approach. She prefers to define the Capability Approach as the 'human development approach', which can evaluate every individual's well-being. Even though Nussbaum (2011) focuses on the individual in the households, in this research the focus is on the level of an entire household.

Nussbaum (2011) specified core capabilities that should be supported by all democracies and Hillerbrand (2018) linked them to energy systems and used the core capabilities to define 'energy capabilities'. The way Nussbaum (2011) and Hillerbrand (2018) define capabilities is not used literally, but the way they use the Capability Approach to evaluate the well-being (of households) is used as inspiration.

The normative perspective in this research implies that the well-being of households (concerning energy only) can be measured by a set of values which is used to evaluate the acceptability of the capabilities. The capabilities in this research are the options or chances to change to a decentralized energy system (by joining or changing from community). When assuming that every household should have the option or chance to fulfill their values (to some extent), the option of changing from or to a community is only acceptable when the households have a feasible option or chance to increase its level of values.

2.6 Research Methods and Data Collection

To answer the research questions using the proposed concepts and frameworks, different methods and tools are needed. Besides reflecting on the existing literature, the following methods are used: (1) Interviews, (2) Agent-Based Modelling and (3) Exploratory Modelling and Analysis (Figure 2.4). These methods are explained briefly below (2.6.1 - 2.6.4). Moreover, which method is applicable to which sub question is discussed. Finally, the tools and the data collection are described.

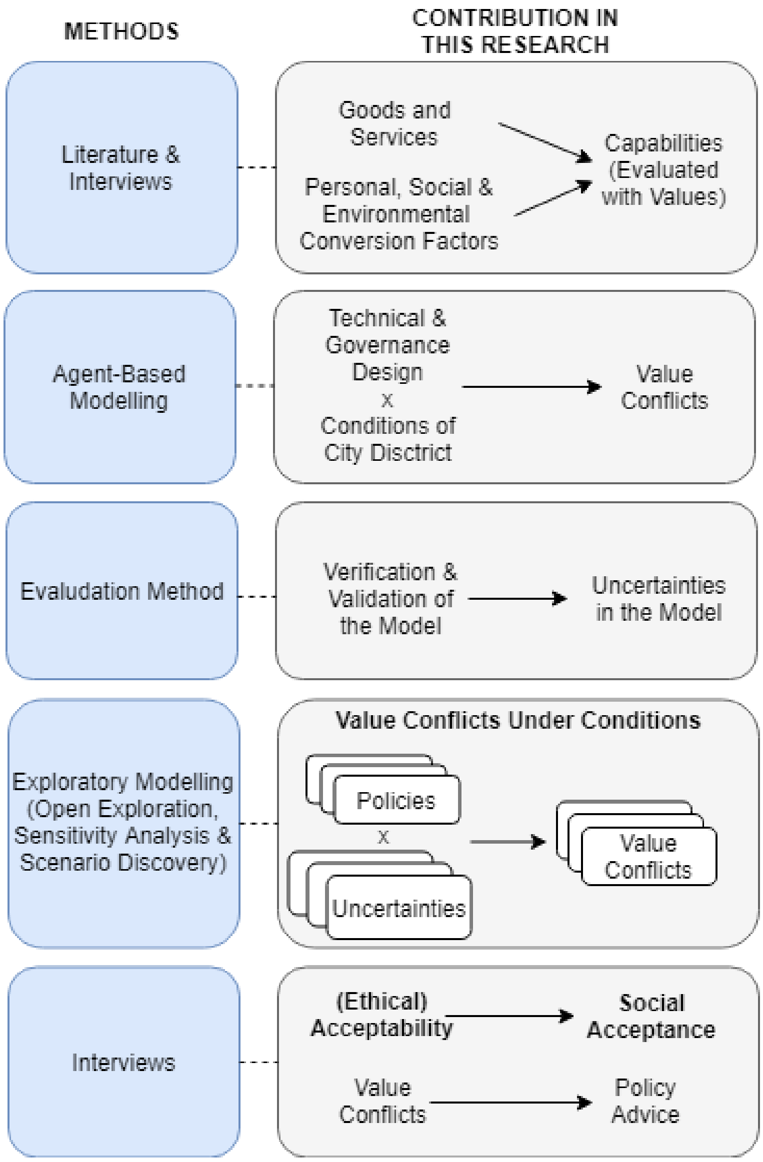


Figure 2.4: Research Methods.

2.6.1 Literature and Interviews

Scientific literature already gives some insight in the values that are embedded in the change to new engineering systems. However, for this research a more complete understanding of the household values that are important when concerning decentralized energy systems, is desired. Also, it is necessary to get more insight in the relation between the types of decentralized energy systems, the conversion factors and the values.

Besides the insights that are retrieved from scientific literature and reports, interviews are conducted to identify a set of important values. The interviews are conducted with: (1) experts who have experience with the energy transition and the change to decentralized energy systems (pilot projects), (2) different stakeholders and (3) inhabitants of 'De Vruchtenbuurt'.

When exploring the impact on the household values, also the technical designs, the governance models and household characteristics have to be identified. Most of the data to define the technical designs, the governance models and the characteristics of the households in 'De Vruchtenbuurt' can be retrieved from CBS, Klimaatmonitor, CE Delft, the Municipality of The Hague, ECN & RIGO and local documents. Besides that, some information about the properties of 'De Vruchtenbuurt' is retrieved from interviews.

However, finding out how the household characteristics, governance models and technical designs are related to the fulfillment of the values is more complicated. Publications from TKI Urban Energy, ECN, TNO, CE Delft, PBL and other research institutes on new energy systems only provide the basic understanding of these relations. Also, scientific literature on decentralized energy systems does not examine these relations thoroughly. Therefore, it was necessary to conduct interviews with experts, stakeholders and locals to get a better understanding of the above mentioned relations.

The data and information about the values and their relations with the technical designs, the governance models and the characteristics of the households are used to answer the first sub question. Through retrieving knowledge from different levels in society and consulting current available resources, the chance of getting a better understanding of the impact on values is higher. Still the risk that not all aspects are included remains (context dependency and uncertainties). The limitations of this risk is taken into account when the implications of the results are considered.

For the interviews the snowballing sampling technique was used. Most interviewees gave contacts of other experts and stakeholders who were consulted for following interviews. At some point in most interviews the same values and context were given, which was used to make a selection of values, conversion factors and designs. In interviews afterwards a check was made with experts and stakeholders if the most important values, conversion factors and designs are taken into account or that important aspects are missing. The same goes for the relations between these components.

Lastly, after conducting quantitative analysis on the value conflicts between households and within households under different conditions, interviews were conducted to find out if these value conflicts are also possible or expected in the real world. It is also questioned if those value conflicts will lead to non-acceptance and public resistance and what strategies or policies could possibly help to reduce the value conflicts and if that would also lead to more social acceptance of the new energy system. Another question is whether the findings for the specific case 'De Vruchtenbuurt' can also be applied to other city districts. These last interviews help to answer the fourth sub research question.

The questions that were used for the interviews can be found in Appendix A and in Figure 2.5 the different rounds of interviews are presented. In Table 2.6 and Table 2.7 the interviewees (and events) for the different rounds are presented. **When statements provided in the report are extracted from an interview or event, the interviewee or event is placed between brackets behind the statement.**

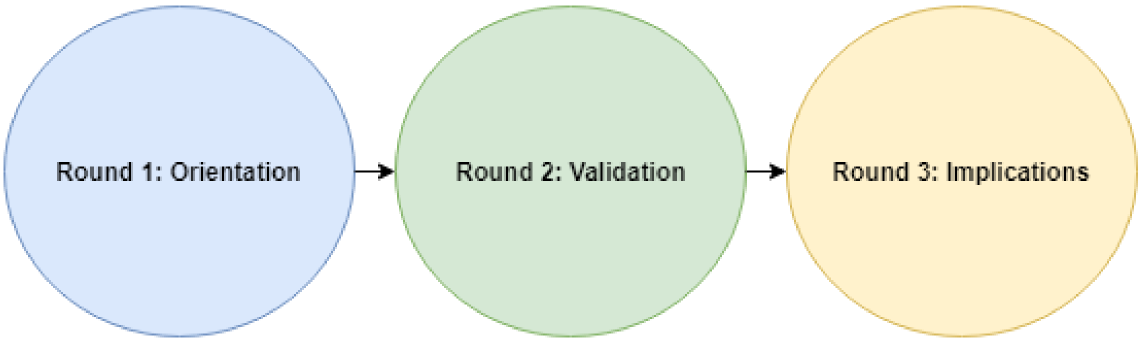


Figure 2.5: Interview Rounds.

Table 2.6: Interviews Conducted in Round 1 and Round 2.

Interviewee or Event	**Role**	**Relevance**
Policymaker 1	Senior policy advisor at Ministry of Economic Affairs and Climate Policy	Expertise on the integration of new energy systems (social, governance and technical)
Policymaker 2	Senior policy advisor Electricity at Ministry of Economic Affairs and Climate Policy	Expertise on flexibility of electricity markets
Policymaker 3	Directorate at Ministry of Economic Affairs and Climate Policy	Head of Section Energy Markets and Innovation
Energy Systems Expert 1	Research Manager Energy Transition Studies at ECN part of TNO	Expertise on smart grids, smart energy systems and all electric districts
Energy Systems Expert 2	Advisor energy research and development at Netherlands Enterprise Agency (RVO)	Expertise on pilot projects with smart grids and decentralized energy systems in the built environment
System Operator Expert 1	Manager 'Strategy' at Netbeheer Nederland	Expertise on the social side of the energy transition
System Operator Expert 2	Region coordinator for the energy transition at Stedin	Expertise on the proportions between different stakeholders and future perspectives
Local Initiator 1	Active initiator in district 'De Vruchtenbuurt'	Expertise on the proceedings on local level (for the selected case)
Local Initiator 2	Active board member of the community in district 'De Vruchtenbuurt'	Expertise on the proceedings on local level (for the selected case)
Local Initiator 3 (Event)	Meeting with the active members of the community in district 'De Vruchtenbuurt'	Insights in the different kind of members and problems the community is facing
Decentralized Government 1	Senior policy advisor energy transition at the Municipality of The Hague	Expertise on the proceedings on municipality level (for the selected case)
Decentralized Government 2 (Event)	Gathering from different stakeholders from the Province Zuid-Holland on local energy initiatives	Insights on the proceedings on provincial level (for the selected case)
Technical Experts 1 (Event)	URSES+: Uncertainty Reduction in Smart Energy Systems (NWO)	Insights of finished researches (5 years) on the technical and social level on the uncertainties in smart energy systems
Technical Experts 2 (Event)	WattsLocal (Stedin)	Insights of different stakeholders (governments, technical companies, research institutes, energy suppliers, system operators, consultancies and communities) on local energy communities

Table 2.7: Interviews Conducted in Round 3.

Interviewee	Role	Relevance
Policymaker 1 (same as first rounds)	Senior policy advisor at Ministry of Economic Affairs and Climate Policy	Expertise on the integration of new energy systems (social, governance and technical)
Policymaker 4	Senior policy advisor at Ministry of Economic Affairs and Climate Policy	Expertise on the acceptance and participation of new energy systems
Policymaker 5	Policy advisor at Ministry of Economic Affairs and Climate Policy	Expertise on the heat transition in city districts
Policymaker 6	Policy Officer (Trainee) at Ministry of Economic Affairs and Climate Policy	Expertise on the social side of the energy transition in regions
Local Initiator 2 (same as first rounds)	Active board member of the community in district 'De Vruchtenbuurt'	Expertise on the proceedings on local level (for the selected case)
Energy Systems Expert 3	PhD researcher at Delft University of Technology	Researcher in the field of values and acceptability of smart grid systems

2.6.2 Agent-Based Modelling

A method is needed that can examine a type of decentralized energy system including different households that make decisions by evaluating their values (considering their characteristics). In this research households are heterogeneous agents and are interacting with each other ('active agents').

The properties (mentioned above) suit the Agent-Based Modelling method (Railsback & Grimm, 2012). Agent-Based Modelling can be used for modelling systems which include interacting and self-deciding agents (Macal & North, 2010). This method is selected to take different agents (in this research households) into account and can give outcomes on the system performance (in this research in the form of value conflicts) (Figure 2.6).

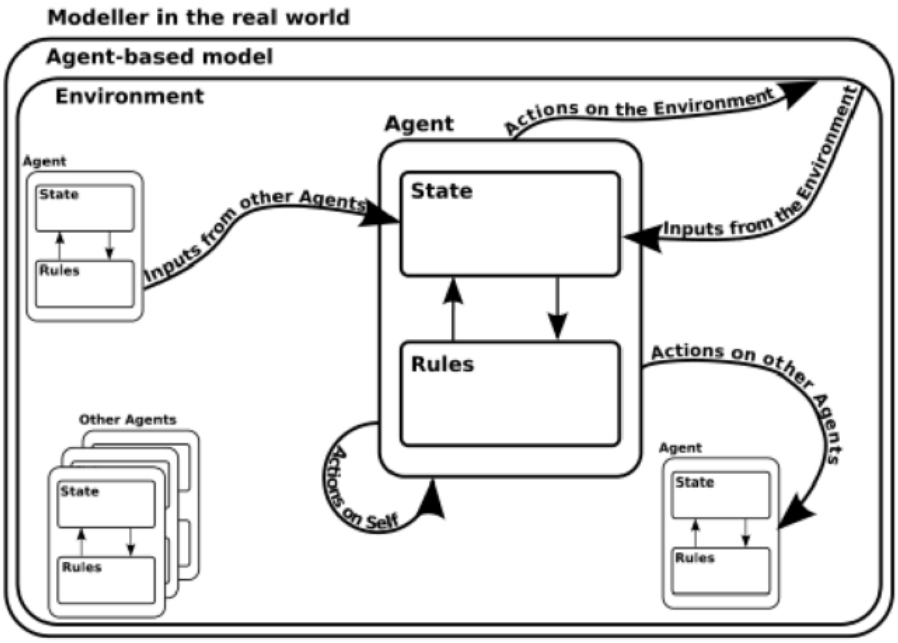


Figure 2.6: The Structure of Agent-Based Models (Van Dam et al, 2013).

More approaches can be used to simulate the change to decentralized energy systems. Vangheluwe & de Lara (2002) identified three main types of simulation models, one of which is Agent-Based Modelling. The other two are system dynamics and discrete-event simulation, probably these models could also be used as method to simulate the social side of decentralized energy systems. However, the main two properties why Agent-Based-Modelling is the favorable method, are the heterogeneity of the households and the interaction of the households (Rahmandad & Sterman, 2008). Because the value conflicts are expected to be especially influenced by the diversity of the households.

Agent-Based Modelling is used to answer the second sub question (and the model is used for further analysis to answer the third sub question). The values, conversion factors and their relation provide the information that is needed to develop the Agent-Based Model. It is necessary to conceptualize and operationalize the information retrieved from the first sub question into quantitative variables in order to build the model.

2.6.3 'Evaludation' Method

Verification and validation of the model are of great importance to test if the model actually does what it is intended to do and if the model is fit for its purpose.

A lot of confusion by modellers about the validation step in the modelling process has been identified (Oreskes et al., 1994; David, 2009; Augusiak et al., 2014). The validation step concerns the credibility of the model, but no clear definition is given over the last years. It is therefore hard to identify the credibility of the model. The users of the implications of the model (often policymakers) are not always the ones that are used to modelling. This can cause a wrong implication of the model, which can lead to failed policy making.

According to Augusiak et al. (2014) the validation step should be a mix of validation and evaluation. Therefore they came up with a new term 'evaludation', which is defined as: *"the entire process of assessing model quality and establishing model credibility throughout all stages of model development, analysis, and application" (p. 125)*. This term is also used to propose a process of validation that is not too limited (as the traditional validation step of comparing model output with new empirical data). The proposed validation process contains six steps (specified in Chapter 5 when the steps are applied) and helps to validate and evaluate the full modelling process (which includes the verification of the model). It also contributes in identifying the uncertainties that come along with the model, which are necessary to use in further analysis and when making implications of the model.

2.6.4 Exploratory Modelling and Analysis

To find out what the uncertainties of the conceptualization and the combinations of conversion factors with governance models and technical designs mean for the value conflicts, a method is required that allows to experiment with these different conditions.

Exploratory Modelling and Analysis (EMA) helps to figure out complex and uncertain systems (Kwakkel & Pruyt, 2013). This method allows to experiment with (combinations of) input parameters in order to find how the outcomes of interest are influenced by that. This method supports the determination of conditions (uncertainties and policies) under which value conflicts arise.

Exploratory Modelling and Analysis is used to answer the third sub question and a part of the last sub question. The outcomes of the experiments, retrieved from the Agent-Based Model, are used for further data analysis. An evaluation of the conceptual uncertainties and the sensitivity of outcomes of interest to the input parameters (policies and innovations) is conducted. The value conflicts under certain conditions are translated into qualitative lessons for the national government with the help of interviews, which will answer the fourth sub question.

2.7 Research Flow Diagram

A research flow diagram is constructed (Figure 2.7), in order to give a clear representation and structure of the full research. Every coloured block forms a chapter and the arrows indicate how certain parts of the research influence other parts. Chapter 2 forms the backbone of the research (as can be seen from the large number of arrows leaving block 'Chapter 2'). Chapter 8 provides answers on the questions formed in the research approach. Chapter 9 gives a reflection on the used elements in the research and the research process. Also, the contribution of this research and the recommendations for future research are discussed in this chapter.

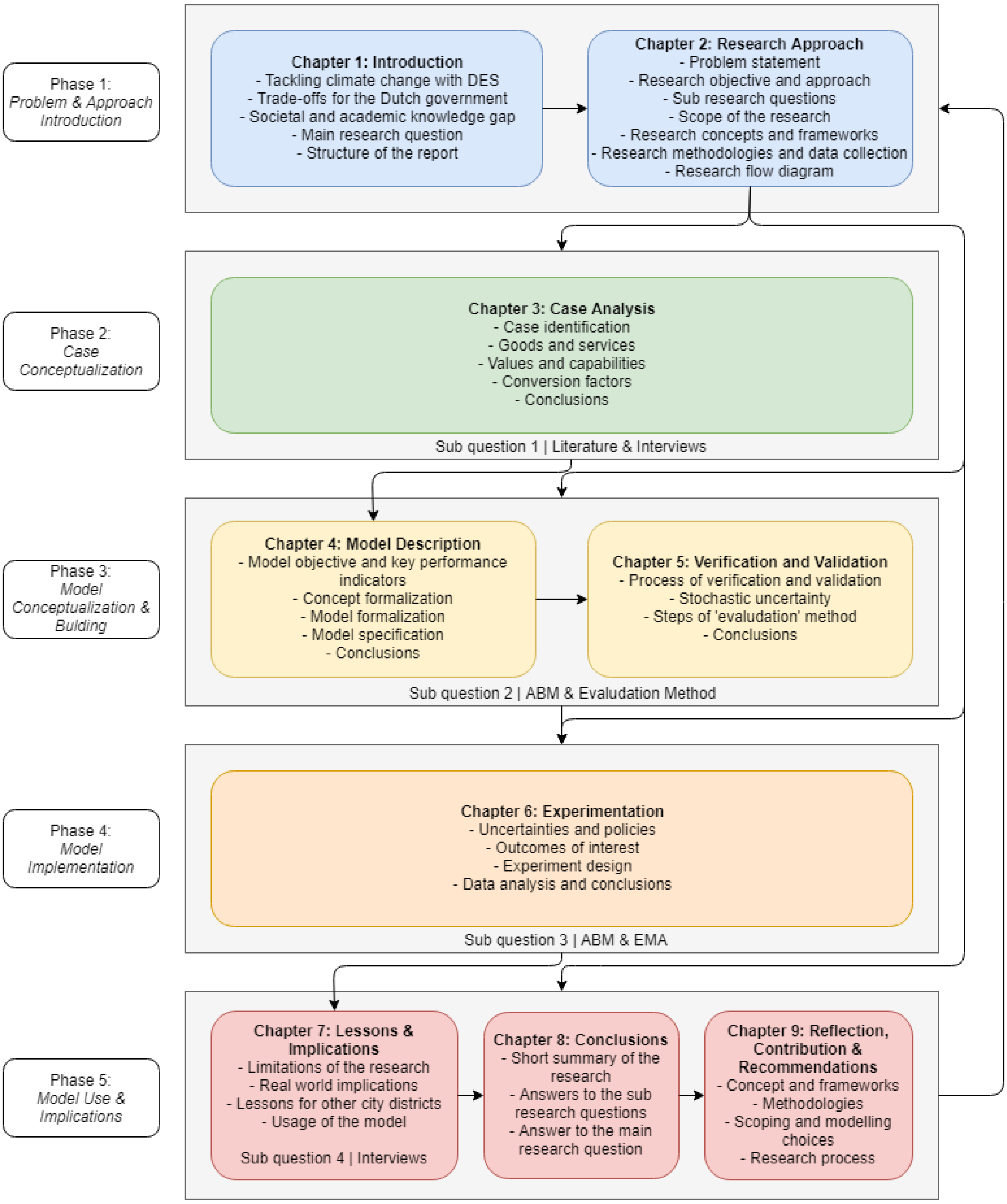


Figure 2.7: Research Flow Diagram.

Chapter 3

Case Analysis

The goal of this chapter is to answer the first sub research question:

"What household values are important in decentralized energy system and what household characteristics and design choices for the energy system influence these values?"

As explained in chapter 2, the Capability Approach (CA) is used as framework in this research. The components of this framework that form the core of this research are presented in Figure 3.1:

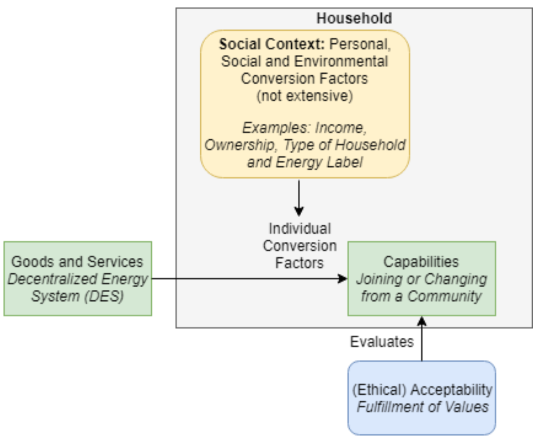


Figure 3.1: Core of Capability Approach in this Research.

Before elaborating on the goods and services (3.2), values and capabilities (3.3) and the conversion factors (3.4), it is important to get a better understanding of the specifications of 'De Vruchtenbuurt' (3.1). The aim of the case identification is to understand the specific context of the city district that is going to be analyzed. Finally, in section 3.6, the conclusions of this chapter and the answer to the first sub research question is provided.

3.1 Case Identification

This research focuses on a specific case: 'De Vruchtenbuurt' in The Hague, the Netherlands, which is a district and also a neighbourhood (Figure 3.2) (CBS, 2017). From now on when 'De Vruchtenbuurt' is mentioned, the city district is meant. A board exists that creates plans and supports initiatives for 'De Vruchtenbuurt' considering the district (Wijkberaad Vruchtenbuurt, n.d.).

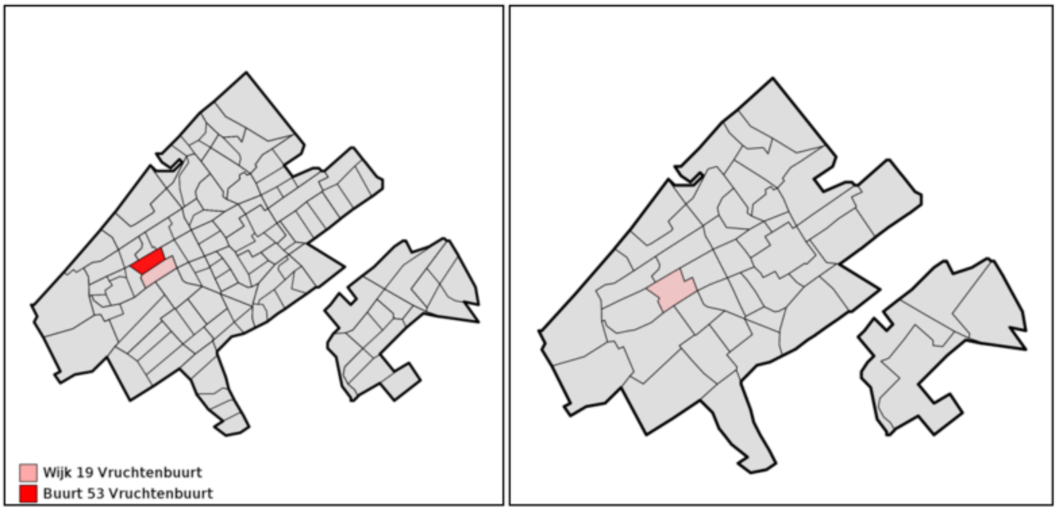


Figure 3.2: 'De Vruchtenbuurt', Neighbourhood (dark red) and City District (light red). This Research Focuses on the City District.

'De Vruchtenbuurt' has 9,705 inhabitants (4,590 men and 5,115 women) and its density is 9,370 inhabitants (and 5,064 addresses) per square kilometre. The district contains 4,470 households with an on average size of the household of 2.1 persons. The size of the district is 104 hectares. The district is classified as very strong urban (CBS, 2017).

The district has some remarkable characteristics that are specified in Table 3.1. In Figure 3.3 can be seen how De Vruchtenbuurt is mapped.

Table 3.1: Remarkable Characteristics of City District 'De Vruchtenbuurt' (Gemeente Den Haag, 2015)

Domain	**Remarkable Characteristics**
Youth and Education	More than 27% of the inhabitants of the district is younger than 25 years old, which is 2.5% less than the average in The Hague. Relatively few inhabitants between the age of 20 and 25 and relatively a lot of children between the age of 0 and 10 live in the district. The youngsters with the age between 15 and 25 are doing well on the labour market, the percentage of not working youngsters that are looking for a job is 2.7%, which is low compared to the average of The Hague, which is 5.3%. In general, the young children grow up in a healthy way. However, the inhabitants would like to see more initiatives for the growing group of youngsters with the age of 12 or older in order to involve them more in the district.
Living	The district exists for 82% out of apartments that are mostly inhabited by owners, which are united in small Vereniging van Eigenaren (VvEs). The percentage of social rental housing is quite low: 5%. The percentage of inhabitants that are Dutch is 76.6%, which is higher than the average in The Hague (61.5%). The older houses are maintenance sensitive. A part of the houses is not very energy efficient and have a less healthy indoor climate. In the field of sustainability a lot of goals are reached.
Business	Quite some small diverse shops can be found in the Appel- en Vlierboomstraat, but since the economic crises the amount of shops decreased and some of the shops are rebuild to residents. After the crises more shops are opened in the Vlierboomstraat.
Quality of Life and Safety	In this district parking problems exist. Solving this problem and keeping the district green (at the same time) results in difficult situations. Besides the traffic, the inhabitants feel safe in this district.
Jobs and Income	The unemployment rate is low in this district and the average income is higher than the average is city part Segbroek. Almost no poverty occurs in this district.
Health Care	Compared to the average of The Hague, a little more citizens with the age of 65 or older live in this district. It is expected this is going to increase in the next years.
Social Cohesion	The residents are motivated for social subjects and are pleased with the social contacts they have in the district. The district has an active organization of inhabitants and also has active street representatives.

Figure 3.3: 'De Vruchtenbuurt' (Gemeente Den Haag, 2015).

Besides the pilot project 'De Groene Mient', more initiatives created in this district concerning the energy transition are taken. The 'sustainability' work group, stimulated by the district board, created the last years multiple initiatives in the field of sustainability. Examples are the collective buying of solar panels and, together with '070-Energiek', the organization of different energy parties, followed by initiatives of inhabitants to save energy in their own house (Warm in de Wijk, 2017).

In 2015, with support from the municipality The Hague, a new initiative has started: 'De Vruchtenbuurt' wants to get rid of natural gas and wishes to change to alternative ways for heating and cooking. How many inhabitants are motivated to connect the district to a sustainable heat grid was investigated. A high temperature heat grid is interesting in 'De Vruchtenbuurt', since the houses in this district are quite old and hence not optimally insulated. Besides some measures to save energy, the demand for heat stays relative high. The work group 'Warm in de Wijk' has started to sustain the heat demand. Together with professional parties, like Dunea, Stedin, the municipality and the province, the district is trying to realize the collective heat grid in 'De Vruchtenbuurt'. The goal of this project is to develop a sustainable local heat grid to which 'De Vruchtenbuurt' and neighbouring areas can be connected to (Warm in de Wijk, 2017).

The work group realized the following so far (Warm in de Wijk, 2017; Local Initiator 1):

- 658 households are interested in the community and receive information and updates about the project.
- 240 households are part of the community and have voting rights in the general meetings.
- 69 households changed the temperature of their boiler to 70 degrees (only one household did not continue the trial, since it was too cold in house).
- Energy coaches are in training.
- Covenant with estate agents has been established.

3.2 Goods and Services

The goods and services in the Capability Approach are defined as the 'means to achieve', which are the different types of decentralized energy systems in 'De Vruchtenbuurt'. The types of decentralized energy systems are a combination of a governance model and a technical design, which is elaborated on in this section. The identification of the characteristics of the governance models (3.3.1) and technical designs (3.3.2) are important for this research, since they influence the values and capabilities (section 3.4). Also, it is specified which governance model and technical design are expected to be used in 'De Vruchtenbuurt', so it will be clear which type of decentralized energy system is the base case and which ones are alternatives. Furthermore, suggestions for other policies and innovations, that can influence the values and conversion factors, are made (3.3.3).

3.2.1 Governance Models

Three different governance models that are used in the change to decentralized energy systems are identified: commercial, public and community (TKI Urban Energy, 2018). As stated by TKI Urban Energy (2018), probably a combination of the three governance models will be used in the future. The three governance models are discussed briefly below.

- Commercial governance is a model where households buy the product(s) to adopt a decentralized energy design themselves because it is profitable for them.

- Public governance is a model where a public organization (like the municipality) takes the initiative to bring different parties together to make the change to decentralized energy systems happen.

- Community governance is a model where the households themselves take the initiative to change to a decentralized energy system.

In 'De Vruchtenbuurt' the community governance model is applied and is described in more detail below. The other two governance models are explained in more detail in Appendix C.

The households in 'De Vruchtenbuurt' identify options for their city district and include other parties, e.g. the distribution system operator and the municipality. The active households promote the ideas in their city district to create more support and let other households join the project. In pilot projects it became clear that households prefer to get information from neighbours rather than from, for example, system operators (TKI Urban Energy, 2018). This could be a benefit from the community model. Furthermore, the level of autonomy is higher in this governance model compared to the other governance models. However, volunteers are needed to make the project successful. Other parties, like the municipality, can decide to help and support the community in the city district to make sure the ideas of the community can be executed.

It is important to keep in mind that bottom-up initiatives require a lot of volunteers and not in every district people are available with the right knowledge and the needed amount of time (TNO, 2018). It is therefore expected that not in every city district the community model will work. It should be noted that even though a lot of volunteers are available in a city district, often the set-up of a community costs more time than expected (Local Initiator 1).

'De Vruchtenbuurt' created a community 'Warm in de Wijk' in their district, in which different work groups are active in the heat transition. Besides the community 'Warm in de Wijk', a community that is related to the pilot project 'De Groene Mient' exists. Even though good connections exist between 'De Groene Mient' and 'Warm in de Wijk', the communities are separated. Since the houses in 'De Groene Mient' are newly built houses, these are not taken into account in this research and are also not expected to grow in number. The other houses in 'De Vruchtenbuurt' are mostly houses built before the 1945 (CBS, 2016; Wonen in Den Haag, 2015) and the change to a decentralized energy system is especially a challenge for this kind of houses.

For the older houses in 'De Vruchtenbuurt' only one community is established (for now). However, scenarios are possible for which more smaller communities exist next to each other within one city district (as can be seen in Figure 3.4). It is interesting to take the option of more communities into account in the core of this research to draw extra lessons of analyzing different community model options.

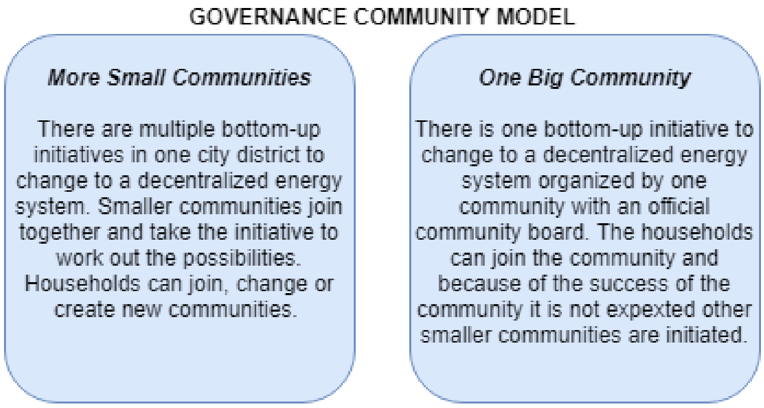


Figure 3.4: Governance Community Models in this Research.

3.2.2 Technical Designs

The technical side of the decentralized energy system is seen as highly important. The main developments of the technical designs are decentralized energy generation, flexibility and the heat transition. In 'De Vruchtenbuurt' the community focuses on the heat transition and therefore this development is discussed in this section. The other two developments are discussed in Appendix C.

The Netherlands are still highly dependent on the natural gas in Groningen and 98% of the Dutch households is connected to natural gas (OnsAardgas, n.d.). However, the safety for the citizens in Groningen is not secured and also the fossil fuel is harmful for the environment (even though it is less harmful than coal and oil) (HIER, 2018). The aim is therefore to heat the households and buildings with sustainable heat (Klimaatakkoord, 2018). This means that a heat transition has to take place, which requires many changes in and around buildings.

In Figure 3.5 the technical designs concerning the heat transition are given. The option for renewable gas is not taken into account, since this option is not considered in the municipality of The Hague so far. However, in a meeting with the members of the community of 'De Vruchtenbuurt' it turned out that the members are open for any technical option that meets their criteria. Also, it became clear that besides more obvious criteria (affordability and sustainability), also autonomy and participation are seen as important (Local Initiator 3). In this research is assumed that one technical heat design is used in the city district, while it is possible that mixed technical designs can be used as well. For 'De Vruchtenbuurt' a research by IF Technology (2018) is executed and it is expected that a 'high temperature heat grid' is the best option, since the houses are for 92% of the houses built before 1945 (CBS, 2016; Wonen in Den Haag, 2015) and are therefore not insulated well. Even though 'high temperature heat grid' source might not be feasible, a 'low temperature heat grid' source is planned to be used in combinations with a collective heat pump that can increase the temperature.

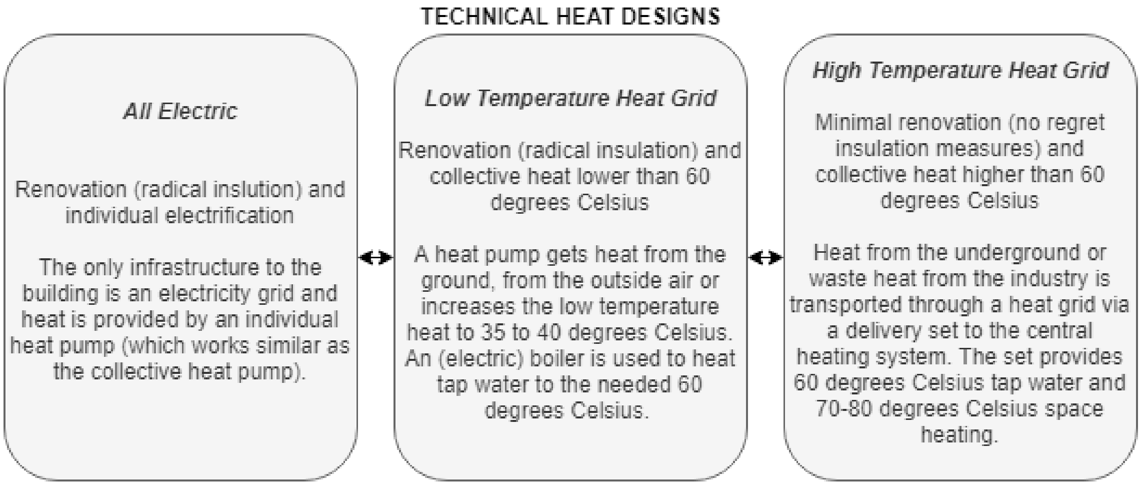


Figure 3.5: Technical Heat Designs in this Research (RLI, 2018).

3.2.3 Policies and Innovations

In this research some other policies (than the governance model and technical design) and innovations are identified that can influence the values and conversion factors. It should be noted that these factors are taken into account in a simplistic way and are mainly used for the discussion of the results. Furthermore, this list is not exclusive.

Subsidies

Targets from the Paris Agreement (international), the Climate Agreement (national) and the Urgenda case (national) give the incentive and attention to sustainability and therefore more financial means are invested in the energy transition. For example, more subsidies are available which means that the households have to spend less of their income on the change to a decentralized energy system.

Cheaper renovations
If current technologies like solar PV, heat pumps, electric vehicles, insulation materials and storage batteries are purchased in larger orders, it is possible to create these products more efficiently. This means that the products become cheaper, which hence influences especially the affordability positively.

Technologies more sustainable
New invented or optimized technologies can make it possible that the storage of electricity is easier and requires less space or that technologies become more sustainable (for example, more energy efficient). If the sustainability of technologies increases, the environmental sustainability is influenced positively.

Influence of companies and the utility sector
When other buildings, like utility buildings, restaurants and shops with another energy profile can be found in a city district (Energy System Expert 1), it is possible that those buildings can help creating flexibility. If it is cheaper for companies and the utility sector to produce at other times and it is possible in their business, they can stabilize the supply and demand to some extent. This can influence the security of supply in a city district positively.

3.3 Values and Capabilities

Interviews with experts from different fields are used to make a selection of values that are perceived important to examine a decentralized energy system. Subsequently, the selected set is validated and where necessary adjusted. In this section the selected values are presented and explained.

3.3.1 Interviews and Selection of Values

After the literature review on values specified for the energy domain, quite an extensive set of values was collected. However, for this research not all values were included, because this would lead to an unmanageable research. Therefore, during the first orientation interviews was tried to find a clearer overview of the values that play a role in the change to a decentralized energy system for households specifically. Values found in literature were presented and discussed. Also was focused on the identification of new values that did not appear in literature yet. For the orientation phase two conferences about energy systems and energy communities, three policymakers within the Ministry of Economic Affairs and Climate Policy and two experts on energy systems working at RVO and TNO were consulted.

The final list of values validated by the interviews is presented in Table 3.2. The preferred direction is maximizing the value. Below the table, an explanation on the selection of the values is given.

Table 3.2: Selected Set of Values.

Value	**Explanation**
Security of Supply	The extent a household is secured of enough electricity and heat at all times when changing to a decentralized energy system
Affordability	The extent a household pays a reasonable amount of its spendable income for the investments that have to be made to change to a decentralized energy system as well as for the energy bill
Environmental Sustainability	The extent a household is using renewable energy and is changing to a decentralized energy system efficiently
Autonomy	The extent a household has the freedom to choose when and to which type of decentralized energy system it is changing
Comfort	The extent a household understands the benefits of the decentralized energy system and is not hindered when changes are made in and around the house
Inclusiveness	The extent a household is able to participate in the change to a decentralized energy system and sacrificing the same as the other households to participate in that change

In most conversations it became clear that the values that refer to the ICT and data level are complex and are in some way a layer on top of the governance model and technical design suiting a certain city district. Therefore it has been decided not to focus on this level in this research, also since this has already been discussed considerably in existing literature.

Furthermore, the focus of this research is not on the social process and the actual adaptation of the households, but on creating a acceptable decentralized energy system in the built environment. Values like transparency', procedural justice and 'recognition justice' are therefore not taken into account in this research. However, the interviews revealed that the process towards realization and the way is dealt with this phase can cause conflicts and should not be neglected.

Moreover, 'distributive justice' is not considered as separate value in this research, since this research is not able to identify the exact distribution of the burdens and benefits. The characteristics of households are taken into account in categories and it is therefore not possible to determine how the benefits and burdens are distributed over the households.

However, the previous point does not imply that justice is not taken into account at all in this research, since justice is taken into account with the consideration if all households have the option to join the change to a decentralized energy system (see the value 'inclusiveness' in Table 3.2). Energy is perceived as a basic necessity of life and according to Rawls' (1971) principles of justice everyone needs to be able to retrieve these. However, only one principle of justice is taken into account in this research.

Furthermore, the interviews made clear that the values considered important for an energy system change a lot over time. The change of values over time is not included in this research. The set of selected values is normative and includes the values that are perceived most important over time. However, it is possible that in the future new values are perceived as important.

After the orientation interviews a set of values was selected and these values were presented in the second round of interviews. In these interviews the explanation of these values was discussed and it was questioned if values were missing or if some values were unnecessary, given the defined focus.

Important to notice is that choices in the research (for example: the focus) influence the set of values. For example, the value 'health' is not taken into account, since the difference between the chosen technical designs do not differ a lot in health risks. When an 'all electric' option would be compared with a 'natural gas' option it would be recommended to include 'health' as an important value. For the identified values, trade-offs for inclusion are made by reasoning like this.

3.3.2 Explanation of Values

The selected set of values is used to evaluate the acceptability of the capabilities. A capability is (more) acceptable when this capability fulfills the values (to a large extent). The values are explained below, by explaining how different governance models, technical designs and conversion factors are influencing the fulfillment of the values.

Some messages were revealed quite often in the interviews and are presented in italics at the end of the explanation of a value.

Security of Supply

The security of supply of the conventional energy sources is higher than from the renewable energy sources. Changing means therefore that the fulfillment of the value 'security of supply' is less secured. Large investments have to be made to deliver the same 'security of supply' as with the current energy system and it is questionable if it is worth it to do that (System Operator 1). When looking into the security of supply of the new heat technologies: the security of supply of the 'all electric' option is higher than from the heat grids (RVO, 2012). Furthermore, it depends on the amount of connections and possibilities to share energy, how the energy is divided and secured in the city district. When more households are connected to the same grid, the system can play more with the distribution of the energy than in a case of only one household is part of the system. However, here is not taken into account if the system operator should extend the grid or if should be worked with storage of electricity, when more electricity is used by a city district which has large impacts on the electricity grid (System Operator 2). For the new heat options however, it is expected that more electricity is used anyway (PBL, 2018) and therefore the electricity grid has to be changed anyway. The security of supply of the new options are therefore compared with each other. Expecting that the system operator adjusts the grid, the bigger the community the higher the level of security of supply.

'The security of supply becomes more uncertain when using renewable energy sources.'

Affordability

The affordability of energy is seen as an important value and is mentioned in almost all of the interviews. The example of 'energy poverty' in Germany illustrates that the worries about the affordability of the change to renewable energy are grounded. Furthermore, in research by RLI (2018) is shown that the costs per household are higher compared to the current option. The heat technology 'all electric' is the most expensive, mainly due to the high costs for the renovation of the house. Followed by the heat technology 'LT heat grid', since still renovations in the house are necessary. The most cheap option is the 'HT heat grid', since only 'no-regret' renovations have to take place (RLI, 2018). However, since less renovation is necessary for the 'HT heat grid', it also means that the energy use stays high, which in the long run means that the costs are higher, especially if more persons are living in the household (more energy use). Only the implications of the short term investment costs are taken into account and therefore the higher energy bills in the long run are not evaluated (the 'HT heat grid' option is still seen as the least expensive option).

Furthermore, when the change to a new energy system is done with many participants, it is possible to divide the costs over more households. Also, when products (like insulation materials and heat pumps) are bought together in a large order, economies of scale can be reached.

'When no one wants to invest, the products never get cheaper'

Environmental Sustainability

The main reason of the Paris Agreement and the Climate Agreement is that carbon dioxide reduction has to be established. By changing from natural gas to another source for heating and cooking, an improvement for environmental sustainability is reached. However, the new technical designs that are optional do not all have the same level of sustainability. The 'all electric' option often makes use of an 'air' heat pump that has an efficiency higher than 100%, since it uses mostly energy from the air. The heat grids use other sources, like geothermal, biomass and residual heat. The sustainability of a heat grid depends on three factors: (1) emissions during generation (including carbon dioxide), (2) energy loss and use during transport and (3) how future-proof the heat source is (CE Delft, n.d.).

Furthermore, the renovation requirements per technical option differ. For the 'all electric' option radical insulation of the building is necessary (RLI, 2018), which implies that the house becomes more energy efficient and uses less energy. For the 'LT heat grid' option also renovations are required, but less radical as for the 'all electric' option (RLI, 2018). However, for the 'HT heat grid' no renovations are necessary (of course can be chosen to take 'no regret' insulation measures) (RLI, 2018). It means that with the 'HT heat grid' the buildings do not have to become more energy efficient, which implies that more energy will be used. This can be seen as less sustainable.

Lastly, when the change to a new energy system is done with many participants, it is expected that the goods and services can be produced and used more efficiently, which makes the change itself also more 'sustainable'.

'We need to get rid of natural gas, that is the focus'

Autonomy

Many interviews and discussions revealed that the 'freedom of choice' of the households is important and should not be overseen with the change to a new energy system. It is questionable how much autonomy households have in the current energy system, since the only choice households have (that use natural gas for heating) is the supplier. However, since changes have to be made while not one option is clearly better than all the other options and the role of the government has been changed (by being transparent about their own lack of knowledge), it seems that the value 'autonomy' gets more attention. When looking at the change to decentralized energy systems, it depends on the ownership of the household if it is allowed to make changes in its building. Furthermore, it depends on the type of building the household is living in. When the household is living in an 'one family building', it does not have to discuss with the other households in their building what changes are made to the house (which is the case in a 'multiple family building'). Besides that, it also depends if the household is joining a community and is more dependent on the other households. Lastly, an individual technical design (like all electric) can be applied any time, while a collective technical design (like heat grids) has to happen in a greater group preferably at the same time.

'You should not take the choices away from the consumers'

Comfort

A change in the energy system can influence the comfort of the households. Debates on the comfort of the new technologies exist. Some argue that the transparency of the electricity usage with the new smart technologies increase the comfort and others argue that the comfort decreases, since users find it difficult to understand the benefit of the new technologies. Automation can cause convenience (Milchram et al., 2018), which means that new products like smart meters can cause comfort. However, it depends on the understanding of the user if the desired comfort level is reached. It is expected that households with a larger social network have more interaction with other households and are able to share knowledge about the use of new technologies.

Furthermore, the level of comfort is influenced by the chosen technical heat design. For the 'all electric' design radical insulation of the building is necessary (RLI, 2018), which implies that the change to this design requires time and causes nuisance for the households. For the 'LT heat grid' design also renovations are required, but less radical as for the 'all electric' design (RLI, 2018). Therefore it is expected that the changes to the 'LT heat' design cost less time and cause less nuisance as with the 'all electric' design. Lastly, for the 'HT heat grid' no renovations are necessary (RLI, 2018) and therefore the change to this heat design is the most comfortable (compared to the other considered options).

'People do not understand how it works, they do not know what the advantages are when using the new technologies'

Inclusiveness

In many interviews the accessibility of households to join the energy transition is discussed. It is questioned if all households are able to deal with the costs of a new more expensive energy system and if all households own a house that is compatible with the technical designs. It is questionable if all households have a feasible option to access the basic necessity of life 'energy' when is changed to a decentralized energy system.

Furthermore, it is questioned if the households that 'chose' the same option also have to make the same sacrifices to fulfill the option. For example, when a household with a low income level joins a community for which all other households have a high income level, the household with a low income level has to invest a higher percentage of its spendable income to join.

Quite some different opinions on the accessibility and the distribution of the burdens and benefits of the energy transition can be identified. In this research the value 'inclusiveness' is defined as (1) the ability of a household to access the basic necessity of life 'energy' and (2) the amount of sacrifices that a household has to make to access the basic necessity of life (compared to other households).

'When is changed to a new energy system, is everyone still able to join?'

3.4 Conversion Factors

Conversion factors are the individual aspects that influence the capabilities of people (in this case households). The conversion factors can be seen as the constraints for households to reach their options (in this case joining or changing from community). In the Capability Approach, conversion factors can be distinguished in personal and social conversion factors (3.5.1) and environmental conversion factors (3.5.2).

3.4.1 Personal and Social Conversion Factors

Many personal and social conversion factors that can influence the values and capabilities can be identified. However, by conducting interviews and consulting the research of ECN & RIGO (2013), some important personal and social conversion factors stood out (which are described below).

The factors like 'gender', 'age' and 'origin' are not taken into account. 'Gender' is not taken into account, since not individuals are analyzed in this research, but households. No information is found that specifies the mix of gender in a household and what influence this would have on the energy system. The same counts for the factor 'age'. The people that join the community in 'De Vruchtenbuurt' are from very different ages (Local Initiator 1). One of the reasons why older people join is that they want to change to a sustainable system because they want to leave the world behind in good conditions for their children and grandchildren (Local Initiator 1). Furthermore, retired citizens have more time to help in the community and when they do not understand the new technologies, like 'smart meters', they have more time to figure out how the technology works and what the benefits are. The 'origin' of the persons that are part of the households is also not taken into account, since in no interview or document is mentioned that this could influence the evaluation of values.

Income

It is questionable if all households have the option to join the energy transition, since investments have to be made and it is questionable how long it takes to earn back these investments. In a research on the fairness of the energy transition by CE Delft (2017) is stated that the costs of the Dutch climate policy as fraction of the spendable income of households for different income groups is 1.5% for the top 10% incomes, 2.0% for the middle incomes and 5.1% for the lowest 10% incomes (current situation for Dutch households). If the costs become even higher, when is changed to the new energy system, the energy transition has an even bigger impact on the lower income groups. To what extent the households that select the same option (to join a community or form a community on their own) have a similar income level says something about the value 'inclusiveness'. When a household is one of the few households with a high income in a community, it has to spend less of its spendable income than the other households with a lower level of income and this can be seen as unfair.

The income level of a household can be a constraint for the household in achieving its options. Some technical designs require more renovations than other designs and renovations are rather expensive. For example, the 'all electric' and 'LT heat grid' designs require radical insulation, while the 'HT heat grid' design requires only no regret insulation measures (RLI, 2018). Also is expected that a larger group of households that join together to invest, divide the costs of the investments, and also economies of scale can be reached when the households order a large amount of products (like insulation materials).

Ownership

This conversion factor is related to the possibility of a household to make changes to the house it is living in. When the household lives in a house that is bought by the household, it has the option to change from energy system. However, when the household rents the house it is not obliged to make changes in the house. The rental houses can be owned by a housing corporations or by other renters. These corporations or renters can invest in new energy systems, but are not included in the 'social cohesion' of the district as the households. It is expected that housing corporations and other renters are less involved in the initiatives of the district and it is therefore less likely that changes are made in rental houses.

Social Network

When a household has a social network in its city district, it gets more information about the possibilities of changing to a decentralized energy system. Moreover, it affects their understanding of the new technologies which influences the comfort of using the new technologies. The social network of a household is also important according to the lessons learned from pilot projects by TKI Urban Energy (2018).

Literature indicates that social cohesion arises between households that live close to each other and between households that have similar conditions. One of the mentioned conditions is income. In the United States it was found that different income groups in mixed city districts do not form a social network and that only between moderate income heterogeneity interaction is seen (Van Kempen & Bolt, 2009). In this research the social network of a household is determined by the amount of households that have the same income level in the surroundings of the household.

3.4.2 Environmental Conversion Factors

Many environmental conversion factors that can influence the values and capabilities can be identified. However, a selection is made of the factors that are mentioned by the interviews as most influencing. Also, some of the factors contain information of other factors (for example, the construction year is embedded in the energy label).

Type of Household

Different kinds of households with different specifications can be identified. Different types of households are 'one person households', 'households without children' and 'households with children'. The type of household could be specified in more detail, but it is expected that this distinction is sufficient. The type of household says something about the amount of persons being part of the household. Different documents state that the amount of persons living in a house influence the amount of electricity (and gas), that is used to keep the house warm, to cook, etc. ECN & RIGO (2013) found that the number of persons in a household determines 20% of the electricity use. Furthermore, in studies is reported that the electricity use of a house is determined for 24% by the age of the inhabitants of the house. However, in this research the age is of the persons belonging to a household (as explained in the previous section) is not taken into account. The type of household implies how much energy is used by the household and therefore how high the energy bill is.

Energy Label

The energy label of a building indicates how energy efficient a building is. When the energy label is the highest, 'A', then the house is energy efficient and sustainable. It means that houses like these have more options to uses alternative heat sources, like electric heat pumps. When the energy label is the lowest, 'G', then the house is not energy efficient and not sustainable, which means that an electric heat pump cannot heat the house and geothermal heat or an alternative gas has to be used as heat source. The energy label is related to the possibilities and the costs to insulate the house, and this influences the capabilities. When a house is not energy efficient, the options for the household are lower and therefore this conversion factor is important to include in this research. The construction year is embedded in the energy label, but the energy label takes also into account that some of the older houses are insulated well. The energy label says more about the energy efficiency of the building and is therefore of more importance in this research.

Type of Building

The type of buildings the households live in can be specified in multiple categories. In this research, the type of building is specified in two categories: 'one family building' or 'multiple family building'. The type of building could also be specified on the surface, the architecture, etc. However, more detailed information is needed to use the implications of these factors on the options and it is therefore decided to not specify the type of buildings further than the two categories mentioned above.

The reason for the division of the 'one family building' and the 'multiple family building' is because it effects the value 'autonomy'. When a household lives in a one family building it does not have to discuss and come to a concluding decision with other households, which needs to happen when a household is living in a multiple family building. Since 83% of the households in 'De Vruchtenbuurt' is part of a 'Vereniging van Eigenaren (VvE)', this conversion factor is important to take into account.

3.5 Conclusions

The goal of this chapter is to answer the first sub research question:

"What household values are important in decentralized energy system and what household characteristics and design choices for the energy system influence these values?"

To answer this sub research question the type of decentralized energy system that is planned for 'De Vruchtenbuurt' is defined. The type of decentralized energy system is considered as the goods and services in the Capability Approach and are in this research divided in a governance model and a technical design (section 3.2). In 'De Vruchtenbuurt' a bottom-up community is taking the initiative to change to a sustainable city district. **In this research the community model is taken into account.**

The community in 'De Vruchtenbuurt' focuses (first) on the 'heat transition' in and executed research (with help of third parties) on the best technical 'heat' design for their city district. The following options are considered:

- All Electric
- Low Temperature Heat Grid
- **High Temperature Heat Grid**

'De Vruchtenbuurt' considers a **'collective high temperature heat grid'** with a 'low temperature heat source' in combination with a 'collective heat pump' as the most feasible technical 'heat' design for their city district (see section 3.2). This technical design is therefore also considered as the **base case**. In this research the other mentioned technologies are taken into account as alternatives.

Besides the governance model and technical design other policies and innovations can influence the decentralized energy system. **In the core of this research these policies and innovations are taken into account in a simplistic way.** However, these aspects are taken into account in more depth when is determined how the identified value conflicts can be eliminated or limited.

In this research only the values of the households are taken into account and **the values are used to evaluate the acceptability of the capabilities**. The capabilities in the Capability Approach are the options and chances the households have given their conversion factors. The options and chances are the possibilities the households have to join or change from a community given their characteristics. The following set of values is selected after consulting literature and executing interviews with experts on decentralized energy systems, other stakeholders and local initiators:

- Security of Supply
- Affordability
- Environmental Sustainability
- Autonomy
- Comfort
- Inclusiveness

In the literature and interviews is also focused on the conversion factors that are influencing the values and capabilities (section 3.4). A distinction between the conversion factors that are personal and social, which belong to a household, and the environmental conversion factors, that belong to the house where the household is living in, can be made. The personal and social conversion factors that are selected for further research are:

- Income
- Ownership
- Social Network

The environmental conversion factors that are taken into account for further research are:

- Type of Household
- Energy Label
- Type of Building

Important to note is that some of the conversion factors are correlated with each other, which is taken into account as an uncertainty in further research. Furthermore, the set of values, conversion factors and type of decentralized energy system are not exclusive. The selected aspects are mentioned repetitively in scientific literature and interviews and are therefore considered as relevant (which is a normative judgment by the researcher).

An overview of the selected governance model, technical design, (in blue the personal and social and in green the environmental) conversion factors and the values to evaluate the capabilities is given Figure 3.6. The other policies and innovations are not shown in this figure, since these are not of great importance in the core of the research.

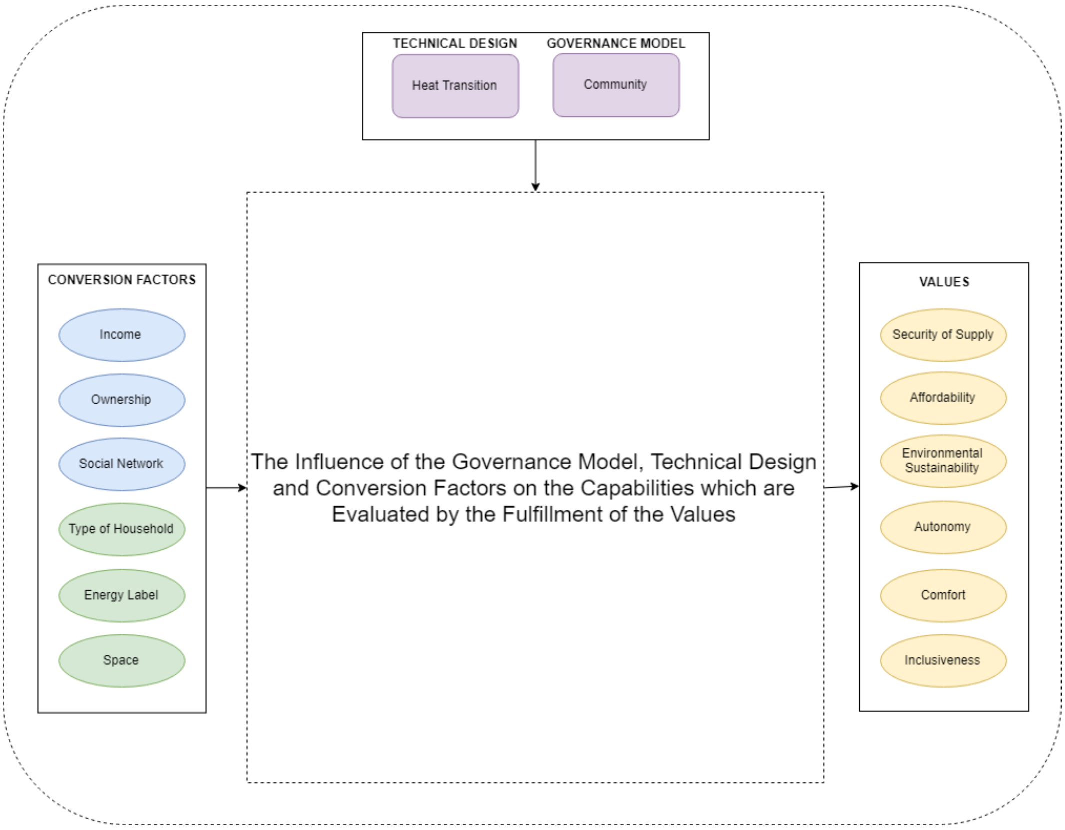


Figure 3.6: Overview of the Selected Governance Model, Technical Design, Conversion Factors and Values.

Chapter 4

Model Description

The goal of this chapter is to answer the first sub research question:

"How can the design choices for the energy system, household values and characteristics of 'De Vruchtenbuurt' in The Hague be specified in a simulation model?"

The values, conversion factors and type of decentralized energy system are defined and can be used as input for the Agent-Based Model, which is formalized and specialized in this chapter. Firstly, the objective of the model and the way this is evaluated is explained (4.1). After that, the concept formalization (4.2) and the model formalization (4.3) are shown. In these two sections the case is translated from a concept to a model. In the last section, the model specification is presented (4.4). Here is elaborated on the data used as input for the model and the calculations made in the model. The way the model can be used is explained in Appendix E and the way the model itself can be found is explained in Appendix H.

4.1 Model Objective and Key Performance Indicators

An Agent-Based Model is built for this research, since it is complex to find out under what conditions the fulfillment of the values of the households are conflicting when is changed to a decentralized energy system in 'De Vruchtenbuurt'. The application of the Capability Approach for this specific case gave insight in the following components: values (which are used to evaluate the acceptability of the set of capabilities), the type of decentralized energy systems (governance and technical) and the conversion factors of households and the houses they live in (which are used to evaluate the feasibility of the set of capabilities). However, it is difficult to find out what combinations of elements lead to value conflicts, since it is complex and time consuming to observe that qualitatively.

Modelling can help to deal with this complexity. First of all, because experimentation can be done with the uncertain conceptualization of the evaluation of the capabilities and the way the conversion factors and the technical design form a constraint for the fulfillment of the capabilities. Secondly, because it is uncertain how the household characteristics are divided (due to privacy reasons) and different combinations of characteristics can lead to different results. Lastly, by clustering the households on certain characteristics (like income and energy label), it is possible to identify value conflicts between and within clusters of conversion factor groups.

Considering the previous points, the model objective is: **"Identifying for what combinations of conversion factors, governance 'community' models, technical 'heat' designs and other policies value conflicts arise (given the uncertainty of the conceptualization)"**.

The following key performance indicators are used to achieve the model objective:

- The level of values per household (clustered in conversion factor groups)
- The covariances between the level of values (representing the value conflicts)

4.2 Concept Formalization

The boundaries of the system and the components taken into account in the system are specified and the key performance indicators are described above. These aspects are all input for the concept formalization, which is discussed in this section. The concept formalization can be called the ontology and presents the translation of the concepts into a language that can be put into a model (Van Dam et al., 2013). Firstly, a visualization of the formalization is shown (4.2.1), to give a clear overview. Subsequently, the global variables (4.2.2) and the agents (4.2.3) are listed with their coherent attributes. Only the essential variables and attributes are mentioned. Thus, derived variables or attributes, when they are solely used to help generate other, more important variables, are not mentioned.

4.2.1 Overview of the Concept Formalization

In Figure 4.1 a schematic overview of the formalization is given, where the different agents households and city district , the most important agents attributes conversion factors and values , and the globals type of decentralized energy system, other policies and innovations are visually represented. In this overview only the most important variables are presented, since the aim is to show how the different agents, agent attributes and globals on the main lines relate to each other. Because of this reason the KPIs are not presented in this overview. These indications only have a monitoring role and no real interactions with the other components (it does not mean that these indicators are not of great importance). Furthermore, it should be noted that the city district can be seen as a agent, but since in the model only one city district is presented, it is easier to model the city district variables as global variables. When more city districts are presented in one model, the city districts could be modelled as agents.

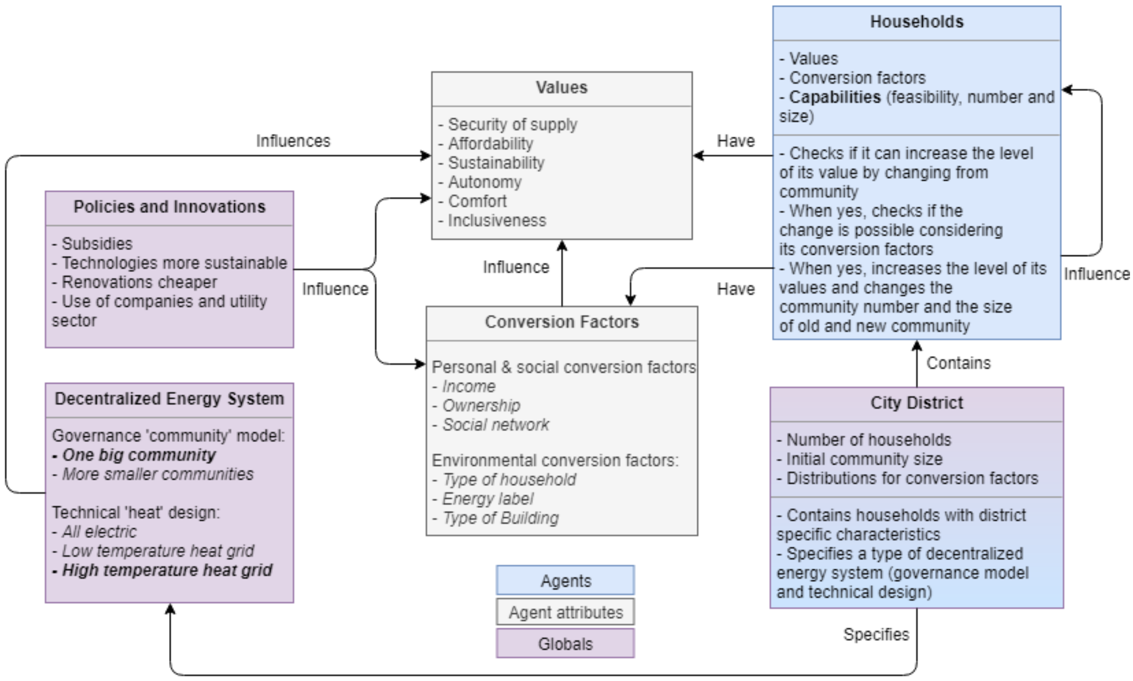


Figure 4.1: Overview of the Concept Formalization.

4.2.2 Global Variables

In this section the objects and the global variables are discussed. These variables are the same for the entire model and are specified in the set-up phase of the model.

- Technical 'heat' design (object):
  - All electric (renovation and individual electrification)
  - LT heat grid (renovation and collective heat, lower than 60 degrees Celsius)
  - HT heat grid (minimal renovation and collective heat, higher than 70 degrees Celsius)

- Governance 'community' model (object):
  - **Initially one community (size can be set) and the other households start alone**
  - Initially two communities (size can be set) and the other households start 'alone'
- Policies and innovations:
  - Subsidies
  - Technologies more sustainable
  - Cheaper renovations
  - Use of companies and utility sector
- Key Performance Indicators (KPIs):
  - The level of values per household (clustered in conversion factor groups)
  - The covariances between the level of values (representing the value conflicts)
- City district has:
  - Number of households
  - Initial size of community
  - Governance model (see objects)
  - Technical design (see objects)

4.2.3 Agents

This section discusses the agents attributes. As assumed before, all agents have the same set of values and conversion factors. However, the conditions of the conversion factors differ per agent and the values are therefore evaluated differently.

Households have:

- Values
  - Security of supply
  - Affordability
  - Environmental sustainability
  - Autonomy
  - Comfort
  - Inclusiveness

- Conversion factors
  - Income
  - Ownership
  - Social network
  - Type of household
  - Energy label
  - Type of building

- Capability
  - Community number
  - Community size
  - Feasibility

The acceptability of the capabilities is evaluated by the fulfillment of the set of values. The household selects one capability (which results in the highest overall level of values) and is conceptualized with a community number and a community size. Furthermore, it is determined if the capability is feasible, since this influences the fulfillment of the values, too.

4.3 Model Formalization

The previous section clarified 'who' and 'what' is incorporated in the model. This section clarifies what actions are taken 'when'. It is important to clarify the sequence of actions to use it as a model narrative for a comprehensive translation into NetLogo. This software is used to develop the Agent-Based Model, which is easy to use due to the easy programming syntax. In section 4.3.1 the model narrative is presented where the actions of the agents are shown, also the relation with the global variables are clarified here. To translate the narrative in a more precise algorithmic representation a pseudo-code can be used, which is explained further in section 4.3.2.

4.3.1 Narrative

In the model narrative the story line of the model is explained. It explains the steps where the households (may) go through during each time step of the model, which is the main procedure. However, also the set-up procedure, which happens before the main procedure to initialize the model, is explained shortly.

Set-up Procedure

When the model is set-up, some procedures are executed to set-up the global variables, i.e. the households with their specific conditions, the initial assignment of the community or communities and the KPIs (so when the model is run the KPIs can be evaluated). The set-up procedure of the initial assignment depends on the chosen governance model. In the base case only one community is formed with the size of 240 households (the current members of the community in 'De Vruchtenbuurt'). However, in the model is determined whether the option is feasible for the households that are assigned to the community, given their conditions. When the option for a household is not feasible, another household is assigned to the community. Also for the newly assigned household is tested whether the option of joining the community is feasible. If less households than the initial size of the community have the right conditions to join the community, the size of the community is set to the amount of households for who the option is feasible. In reality, the community in 'De Vruchtenbuurt' might have members in their community that are not able to join in the end. On this limitation should be reflected when analyzing the results.

Main Procedure

The main procedure can be divided in three main actions of the households and are explained below.

Selection of Capability
In this step, in a random order, the households are testing if options are available that increase the level of their values. Firstly, the household evaluates its current level of values with the current size of the community it is in. For the households that keep their current community is checked whether this option is still feasible for this household. It might be possible that the size of the community changed and that the option is not feasible for the household anymore, which influences the evaluation of the values. Then the household tests (when it is not already alone in a community) what the level of values would be if it changes to a community on its own. After that, it checks what the level of values would be when it changes to the community with the highest amount of members. Then the options are compared and is chosen for the option which gives the household the highest overall level of values.

Feasibility of Capability
In this step the feasibility of the selection of the households is tested by considering their conversion factors. This step is only executed when the selection of a household is different from the current community it is in. The conversion factors income, ownership and energy label can form a constraint for the household to change to the option that gives it the highest level of values. When a household is limited by one of the following conversion factors, the option is not feasible and therefore cannot change to the new option. It is also possible that a household cannot find any feasible solution given its conditions. This means that no values can be fulfilled. The way the conversion factors can form a constraint is specified in more detail below.

To explain Figure 4.2: if a household has a high income level, it has a feasible option (if the other conversion factors do not form a constraint). If a household has a middle income level and the technical design 'all electric' is chosen as technical heat solution for the city district, this household does not have a feasible option to join a community that is planning to implement the 'all electric' option (too expensive). If a household has a middle income level and the technical design 'LT heat grid' or 'HT heat grid' is chosen as technical heat solution for the city district, this household does have a feasible option to join a community that is planning to implement the 'LT heat grid' or 'HT heat grid' option, when the community has a medium size (otherwise it is too expensive). If a household has a low income level and the technical design 'all electric' or 'LT heat grid' is chosen as technical heat solution for the city district, this household does not have a feasible option to join a community that is planning to implement the 'all electric' or 'LT heat grid' option (too expensive). If a household has a low income level and the technical design is 'HT heat grid' is chosen as technical heat solution for the city district, this household does have a feasible option to join a community that is planning to implement the 'HT heat grid' option, when the community has a large size (otherwise it is too expensive).

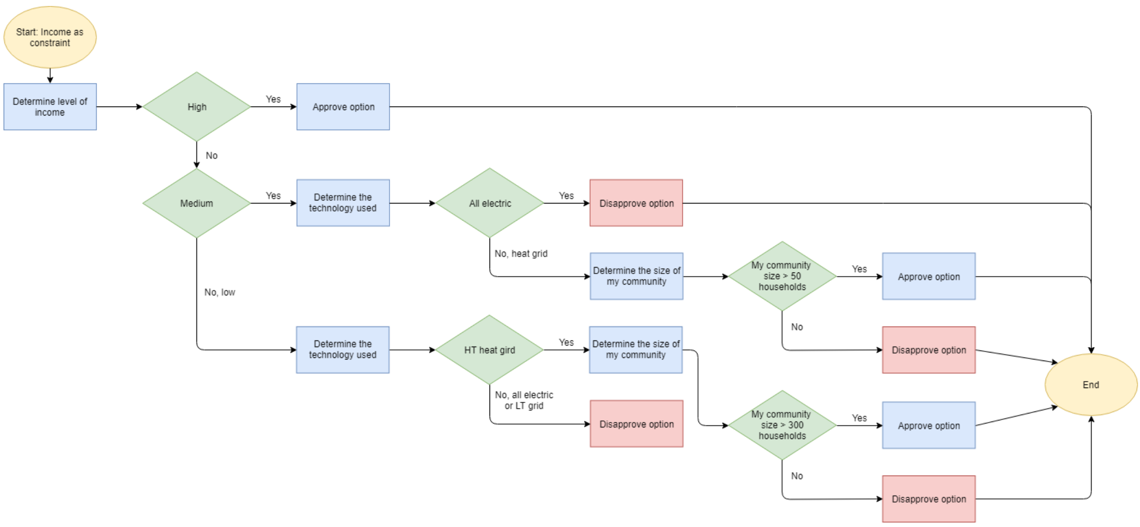


Figure 4.2: Income as Constraint.

To explain Figure 4.3: if a household is renting the house where it is living in, the household it not the one who is obliged to change from energy system. The party that rents the residence to the household is the one who can make changes.

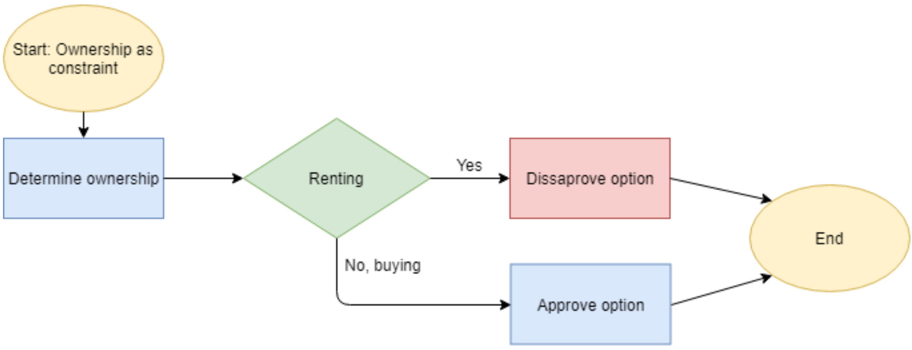


Figure 4.3: Ownership as Constraint.

To explain Figure 4.4: if the technical design 'HT heat grid' is chosen as technical heat solution for the city district, it means that all houses are compatible with this option (CE Delft, n.d.). It depends on the other conversion factors (income and ownership) whether the household has a feasible option. If the technical design 'all electric' is chosen as technical heat solution for the city district, it means that a household living in a house that has energy label C, D, E, F or G does not have a feasible option (CE Delft, n.d.) to join a community that is planning to implement the 'all electric' option. If the technical design 'LT heat grid' is chosen as technical heat solution for the city district, it means that a household living in a house that has energy label E, F or G does not have a feasible option (CE Delft, n.d.) to join a community that is planning to implement the 'LT heat grid' option.

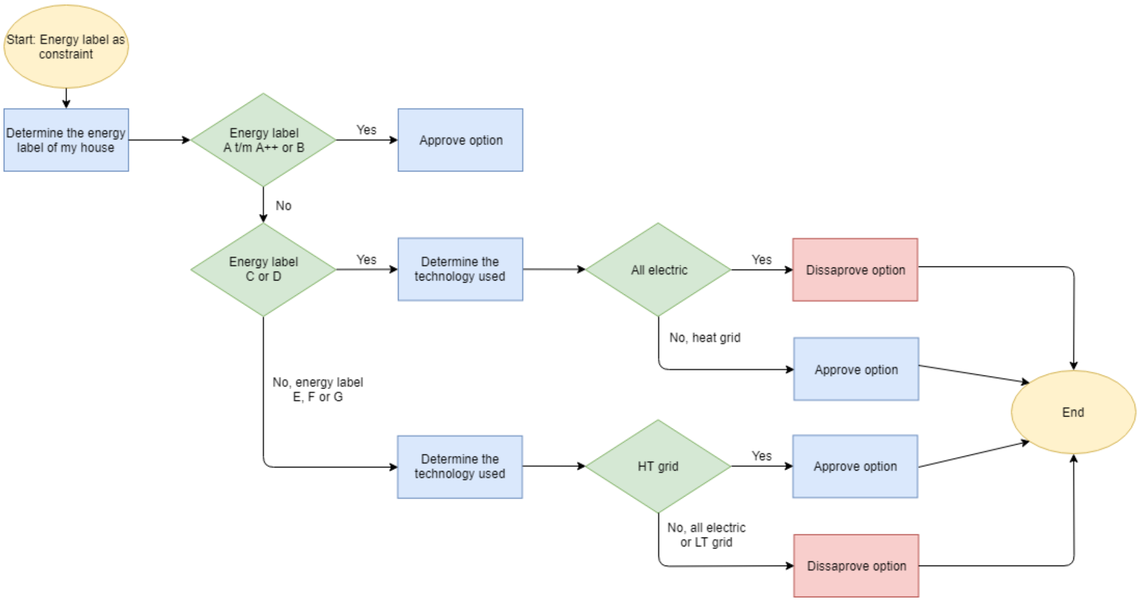


Figure 4.4: Energy Label as Constraint.

Change to Selected Capability

In this step the households change to the selected option (when this option is feasible according to the previous step, otherwise the households stay in the same community). The community number and the community size are changed. Also, the levels of the values are changed to the evaluation of the values with the new option (which is overall higher than the current option). Furthermore, the KPIs are updated, which means that the levels of the values per household is updated and also the average level per value per cluster of conversion factor groups is updated. Also, the covariance between these different conversion factor groups is updated.

4.3.2 Pseudo-Code

After creating a narrative it is possible to translate this behaviour in a more precise algorithmic representation. This can be done using pseudo-code, this forms a bridge between the informal model narrative and the actual code used in Netlogo. In the pseudo-code mathematical and logical descriptions of the behaviour of the agents to combine the model narrative and the formalized concepts (Van Dam et al., 2013). The pseudo-code is too extensive for the main text and is therefore presented in Appendix D.

4.4 Model Specification

In this section the model specification is presented. Firstly, the data that specify the city district is given (4.4.1). Followed by the equation that is used to evaluate an option by the overall level of values (4.4.2) and the evaluation and the scoring of the values (4.4.3). Lastly, the determination and calculation whether the values are in conflict or not is explained (4.4.4). It is expected that the specification of these parts determine and influence the model behaviour the most. The specification of the policies and innovations is given in Appendix D.

4.4.1 City District Specifications

In this research the specifications of 'De Vruchtenbuurt' are of great importance, since these specify the different households (determined by the conversion factors) that are present in the city district. In this section the data used to specify the city district 'De Vruchtenbuurt' are presented in Table 4.1.

As can be seen below, the conversion factors are divided in groups. The main reason for this division is that the data is found in this format. Furthermore, this division can be used for the clustering of households for further analysis.

The correlation between the conversion factors is not specified. However, the division of the conversion factors over the households is taken into account as an uncertainty, which is explained in more detail in section 5.2.

In Appendix D the assumptions and simplifications are explained in more detail.

Table 4.1: City District Specifications.

Characteristic	**Groups**	**Data**	**Source**
Number of households	n.a.	2,235 households	Due to the time it takes to run the model, it is decided to run the model for half of the 4,470 households that are actually present in 'De Vruchtenbuurt' (CBS, 2017).
Initial size of community	n.a.	240 households	In 'De Vruchtenbuurt' the community exists now of 240 households that are interested in changing to a decentralized heating system in their city district (Warm in de Wijk, 2017; Vruchtenbuurt Wijkberaad, n.d.; Local Initiator 1).
Income	3 levels	26.7% = low income 45.1% = middle income 28.2% = high income	(CBS, 2018)
Ownership	2 options	77% = owner of their house 23% = renting their house	(CBS, 2017)
Social network	3 levels	No/small = less than 10 households Medium = in between 10 and 20 households High = more than 20 households	No data available on the social network in De Vruchtenbuurt, therefore the social network is related to the amount of other households around the household (initial radius = 2) with the same income level
Type of household	3 options	37% = one person household 27% = pair without children household 36% = pair with children household	(CBS, 2017)
Energy label	7 categories	0.3% = energy label A t/m A++ 6.1% = energy label B 14.3% = energy label C 26.9% = energy label D 18.2% = energy label E 19.3% = energy label F 15.0% = energy label G	(Klimaatmonitor, 2018)
Type of building	2 options	17% = one family building 83% = multiple family building	(CBS, 2017)

4.4.2 Options for Changing from Community

When a household checks if another community can increase the level of its values, the household evaluates the different options by evaluating the overall level of values for the different options. The equation for the overall value level is given below (where y = overall value level for the option that is tested).

In the reference settings the weight of the values are all the same (= 1). However, in Chapter 5 is tested what it means for the model behaviour when different weights are given to the values. The perspective that all values have the same importance is used and therefore the values get the same weight. However, other perspectives can give other weights to the values.

Furthermore, it is important to notice that it is possible that evaluating the different options like this, prioritizes values indirectly. For example, when one value retrieves a lower level for the option that is tested than the current level, but the other values retrieve all higher levels for the option that is tested than the current levels, the overall value level might be higher for the new option. However, when is chosen to only change from option when it is pareto-efficient (when all the levels of the values are affected positively or stay the same), the model does not show much behaviour, since some values are inherently in conflict. It is therefore chosen to work with the overall value level as evaluation of the different options.

$$y = \frac{\sum_{i=1}^{N} level_i weight_i}{\sum_{i=1}^{N} weight_i}$$

4.4.3 Evaluation of the Values

It is important to note that the evaluation of the value is done by comparing the options and giving the best option the highest score and the worse option the lowest, given the interpretation of the value (ordinal scale). When an option scores + 1 and another option scores + 0.5 for one of the values, it does not mean that the first option is twice as good as the other option. The aim of this research is to determine whether values are conflicting under certain conditions and therefore it is not of great importance to know exactly how much a certain option is better than another option for the fulfillment of the values. In 4.5 an overview is given of the factors that influence the values. The specification per value is given in the next sections. More detailed information about the reasons behind the specification can be found in section 3.4.3.

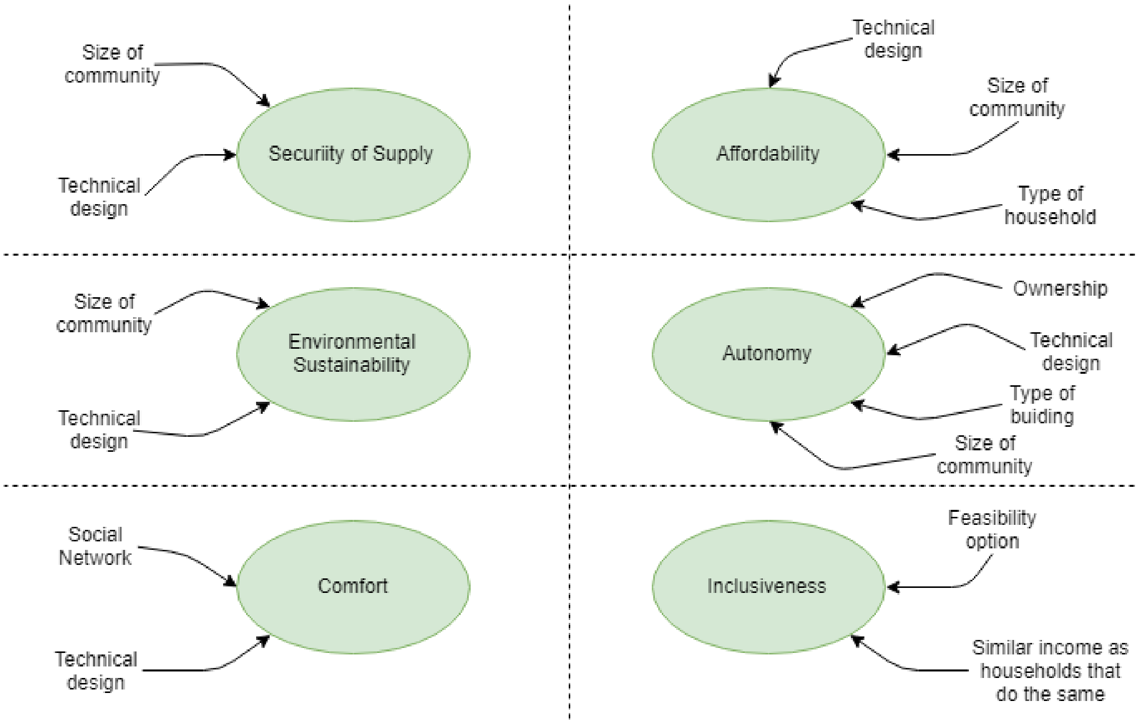


Figure 4.5: Evaluation of the Values.

Furthermore, the community size to evaluate the values security of supply, affordability, sustainability, and autonomy and the range of income to evaluate the value inclusiveness are modelled as thresholds. The thresholds are uncertain and therefore assumptions are made, which are explained and tested in Chapters 5 and 6.

Evaluation of the Value: Security of Supply

In Table 4.2 the evaluation of the value security of supply is presented. Security of supply is influenced by the chosen technology and community size. The security of supply of the 'all electric' design is higher than the security of supply of the heat grid designs. Furthermore, the community size influences the level of the value security of supply. When more households are connected to the same system, the system can play more with the distribution of the energy than in a case where only one household is part of a system.

Table 4.2: Evaluation of Value Security of Supply.

Technology	**Community Size**	**Value Score**
All electric	Larger than 300 households	+ 1
	Larger than 50 households	+ 0.5
	Smaller or equal to 50 households	0
Heat grid	Larger than 300 households	0
	Larger than 50 households	- 0.5
	Smaller or equal to 50 households	- 1

Evaluation of the Value: Affordability

In Table 4.3 the evaluation of the value affordability is presented. Affordability is influenced by the chosen technology, the community size and the type of household. The 'all electric' design is the most expensive, then the 'LT heat grid' design and then the 'HT heat grid' design. An increase in the community size is beneficial for decreasing the costs which increases the fulfillment of the value affordability. When the household size (which is embedded in the type of household) is larger, it has a negative influence on the affordability.

Table 4.3: Evaluation of Value Affordability.

Technology	**Community Size**	**Type of Household**	**Value Score**
All electric	Larger than 300 households	One person household	+ 1/3
		Pair without children	0
		Pair with children	-1/3
	Larger than 50 households	One person household	0
		Pair without children	- 1/3
		Pair with children	- 2/3
	Smaller or equal to 50 households	One person household	- 1/3
		Pair without children	- 2/3
		Pair with children	- 1
LT heat grid	Larger than 300 households	One person household	+ 2/3
		Pair without children	+ 1/3
		Pair with children	0
	Larger than 50 households	One person household	+ 1/3
		Pair without children	0
		Pair with children	- 1/3
	Smaller or equal to 50 households	One person household	0
		Pair without children	- 1/3
		Pair with children	- 2/3
HT heat grid	Larger than 300 households	One person household	+ 1
		Pair without children	+ 2/3
		Pair with children	+ 1/3
	Larger than 50 households	One person household	+ 2/3
		Pair without children	+ 1/3
		Pair with children	0
	Smaller or equal to 50 households	One person household	+ 1/3
		Pair without children	0
		Pair with children	- 1/3

Evaluation of the Value: Environmental Sustainability

In Table 4.4 the evaluation of the value environmental sustainability is presented. Environmental Sustainability is influenced by the chosen technology and the community size. The 'all electric' design is most sustainable, then the 'LT heat grid' design and then the 'HT heat grid' design. An increase in the community size is beneficial for increasing the fulfillment of the value sustainability, because the goods and services can be produced and used more efficiently.

Table 4.4: Evaluation of Value Environmental Sustainability.

Technology	**Community Size**	**Value Score**
All electric	Larger than 300 households	+ 1
	Larger than 50 households	+ 0.5
	Smaller or equal to 50 households	0
LT heat grid	Larger than 300 households	+ 0.5
	Larger than 50 households	0
	Smaller or equal to 50 households	- 0.5
HT heat grid	Larger than 300 households	0
	Larger than 50 households	- 0.5
	Smaller or equal to 50 households	- 1

Evaluation of the Value: Autonomy

In Table 4.5 the evaluation of the value autonomy is presented. Autonomy is influenced by he ownership, the type of building, the community size and the chosen technology. A household has more autonomy when it is owner of its house and when it does not have to discuss with other households in its building what changes are made to the building. Also, when the household is in a large community, it is more dependent on the decisions of other households than when it is on its own in a community. Furthermore, the 'all electric' design can be applied at any time, while for the heat grid designs this has to happen with a group of households at the same time.

Table 4.5: Evaluation of Value Autonomy.

Ownership	**Type of Building**	**Community Size**	**Technology**	**Value Score**
Buying	One family building	Larger than 300 households	All electric	+ 2/3
			Heat grid	0
		Larger than 50 households	All electric	+ 2/3
			Heat grid	+ 1/3
		Smaller or equal to 50 households	All electric	+ 1
			Heat grid	+ 2/3
	Multiple family building	Larger than 300 households	All electric	0
			Heat grid	- 1/3
		Larger than 50 households	All electric	+ 1/3
			Heat grid	- 1/3
		Smaller or equal to 50 households	All electric	+ 2/3
			Heat grid	0
Renting	n.a.	n.a.	n.a.	- 1

Evaluation of the Value: Comfort

In Table 4.6 the evaluation of the value comfort is presented. Comfort in influenced by the chosen technology and the social network. The change to an 'all electric' design is less comfortable than changing to a 'LT heat grid' design. The change to a 'HT heat grid' design is most easy and therefore most comfortable. Furthermore, it is expected that a larger social network leads to a better understanding of new technologies. When the understanding of new technologies is better, the households see the advantages of the technologies and can use the technologies more comfortable.

Table 4.6: Evaluation of Value Comfort.

Technology	**Social Network**	**Value Score**
All electric	High	0
	Medium	- 0.5
	Low	- 1
LT heat grid	High	+ 0.5
	Medium	0
	Low	- 0.5
HT heat grid	High	+ 1
	Medium	+ 0.5
	Low	0

Evaluation of the Value: Inclusiveness

In Figure 4.7 the evaluation of the value inclusiveness is presented. Inclusiveness is influenced by the feasibility of the option (the option to join) and the determination if the households that do the same have a similar income. By 'doing the same' is meant the households that have the same community size, which can result in being compared to the households in a larger community (if the household is in that community) or being compared to the households that are also alone in a community. When a household has the same income level as the average income level (with a deviation that is taken into account as uncertainty) of the households with the same community size, the level of the value inclusiveness is increased (if the household has a feasible option, otherwise the household has no option the be included at all).

Table 4.7: Evaluation of Value Inclusiveness.

Feasibility	**Income Within Range**	**Value Score**
True	True	+ 1
	False	0
False	n.a.	- 1

4.4.4 Values in Conflict

To identify if the values are in conflict, the covariance between the different values is calculated (see equation of the covariance below). The covariance allows to identify the joint variability of the values. The covariance is affected by the scale of the values and therefore it can be argued why the correlation is not used to identify the relation between values (the correlation is corrected for the differentiation of the scales). Since only the direction of the covariance (positive or negative) is used in this research and the values all have the same scale (with a minimum of -1 and a maximum of +1), it is not necessary to use the correlation. However, it is therefore not possible to say something about the strength of the conflicts. It is not possible to compare or rank the conflicts on strength.

$$cov_{x,y} = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})}{N-1}$$

In the built Agent-Based Model the mean of the values from the different households are used to identify the conflicts. However, it is more interesting to find out what the value conflicts are between different households. Therefore, in the Agent-Based Model also conversion factor groups and their fulfillment of the values are specified. When using the Exploratory Modelling and Analysis method, the conflicts between these different conversion factor groups can be identified (by looking at the mean and variance of the conversion factor groups for the relation between two values).

4.5 Conclusions

The goal of this chapter is to answer the second sub research question:

"How can the design choices for the energy system, household values and characteristics of 'De Vruchtenbuurt' in The Hague be specified in a simulation model?"

In this chapter the Capability Approach applied to 'De Vruchtenbuurt' is translated to a simulation model. The components that were identified in Chapter 3 are operationalized, with the aim to meet the purpose of the model: **"Identifying for what combinations of conversion factors, governance 'community' models, technical 'heat' designs and other policies value conflicts arise (given the uncertainty of the conceptualization)"**.

The main conclusions from this chapter are that **the model is not specified in more detail than necessary**. This means that the values are evaluated with an **ordinal scale**, which implies that it is not specified how much better or worse a certain option is or fulfilling a specific value. It only implies that the option is better or worse than another option for fulfilling a specific value. Moreover, this means that **the value conflicts cannot be ranked looking at the level of covariance**. So, it only indicates which values are conflicting under different conditions, which meets the model objective. A limitation of the model is the way the households **choose for a different community** (which can also be 'alone'), since it is **determined by the comparison of the overall value level**. It can be doubted if this way of determining which choice leads to the highest value level is influencing the model behaviour. The same goes for the perspective, that no values are superior to other values, is used in this research, which implies that **the same weight is applied to the values**. Another limitation of the model is the way the conversion factors are used as constraints. **The combination of conversion factors are assigned randomly in the model**, which can lead to less realistic results.

In the following chapter the model is verified and validated and is tested if the model is useful and able to reach to model objective.

Chapter 5

Verification and Validation

The goal of this chapter is to test if the model that is built in Chapter 4 is correct and is actually able to simulate the value conflicts that arise when a decentralized energy system is applied in 'De Vruchtenbuurt'. In other words, in this chapter is tested if the model objective (stated in Chapter 4: **"Identifying for what combinations of conversion factors, governance 'community' models, technical 'heat' designs and other policies value conflicts arise (given the uncertainty of the conceptualization)"** can be reached with the developed model.

The process of verification and validation is explained in section 5.1. In section 5.2 the stochastic uncertainties that are embedded in the model are discussed. In the following sections (5.3 - 5.8) the six steps based on the 'evaludation' method (as introduced in section 2.6.3) are examined in order to verify and validate the model. Finally, in section 5.9 the conclusions of this chapter are given and the most important uncertainties that are identified in the 'evaludation' steps are summarized.

5.1 Process of Verification and Validation

The process of verification and validation is conducted by using the 'evaludation' method from Ausgusiak et al. (2014) (see section 2.6.2). However, before the steps of this approach are consulted, the stochastic uncertainties that are embedded in Agent-Based Modelling are discussed. Stochastic uncertainties are only one type of possible uncertainties. Other types of uncertainties are: parameter uncertainties, heterogeneity and structural uncertainties (Briggs et al., 2012). In the six steps of the 'evaludation' method the other types of uncertainties are identified. Using these different steps (including the identification of stochastic uncertainties) gives a good reflection on the model. It helps to reconsider every step and element that is added to the model. Furthermore, it forces the researcher to reconsider all the choices and assumptions that have been made to develop the model and to think about the limitations that come along with these choices and assumptions.

To conduct the different verification and validation steps results from interviews, the Agent-Based Model (Netlogo) and EMA workbench (Python) are used. The set-up of the experiments conducted by using the EMA workbench are explained in Chapter 6 and Figure 6.4 explains how to interpret the results.

5.2 Stochastic Uncertainty

In this section the stochastic uncertainties that are embedded in the Agent-Based Model are discussed, which means the aspects that are determined randomly within the model. The stochastic uncertainties of this model are listed:

- The assignment of the conversion factors
- The location of the households (influences the determination of social network)
- The random order that households make choices (influences especially which households are assigned to the initial community)

To test the influence of the stochastic uncertainty an experiment with 50 replications (and the same parameter settings) is conducted in Netlogo. The overall conflicts (so not per conversion factor group) between value security of supply and the values autonomy, comfort and inclusiveness are given below (Figure 5.1, 5.2 and 5.3). In the results can be seen that in some replications conflicts are identified, but in other replications no conflicts are found. The results of the relations between the other values can be found in Appendix F.

Only the covariance at the last time step is used for the interpretation of the results (and shown in the figures), since the model behaviour is stabilizing at this time step and no actions are taken by the households anymore. For the aim of this research, the relations between the values are only interesting when the model behaviour is stabilized.

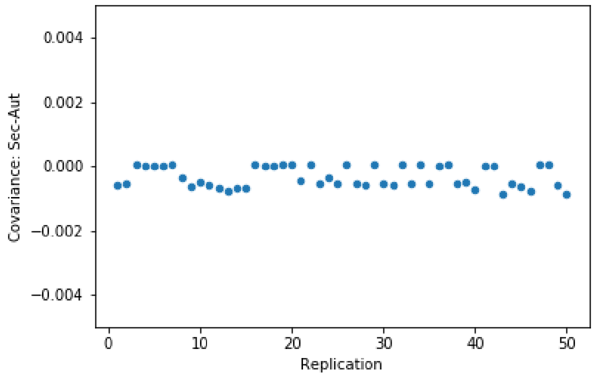


Figure 5.1: Covariance between Security of Supply (Sec) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis).

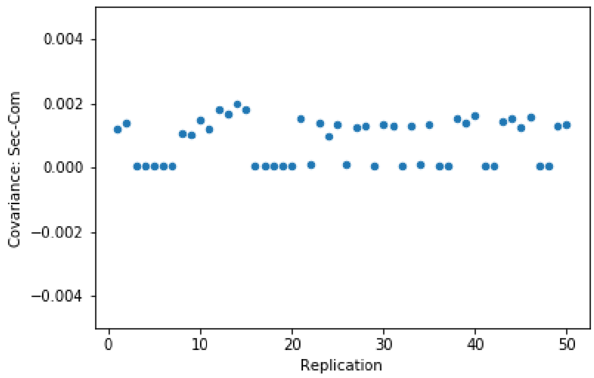


Figure 5.2: Covariance between Security of Supply (Sec) and Comfort (Com) (y-axis) for 50 Replications (x-axis).

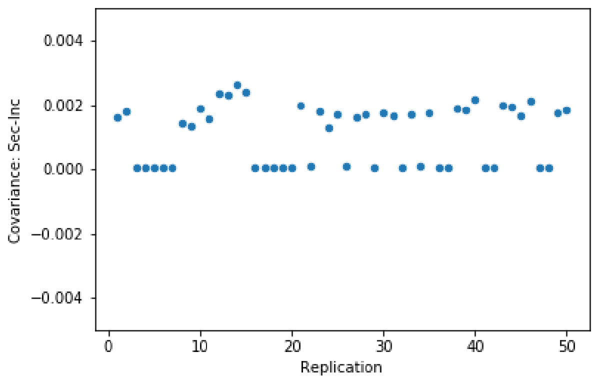


Figure 5.3: Covariance between Security of Supply (Sec) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis).

It is expected that the way the conversion factors are divided over the households is the main stochastic uncertainty and causes the differences in the results. It is therefore possible that in some replications more favorable or less favorable combinations of conversion factors are assigned to the households than in reality can be found. It is therefore important to include model replications in the experiments conducted with this model, in order to determine the robustness of the results. To be sure, also interviews are conducted to validate if the identified value conflicts are also expected to emerge in the real world.

5.3 Step 1: Data Evaluation

Augusiak et al. (2014) define the first step as *"the assessment of the quality of numerical and qualitative data used to parameterise the model, both directly and inversely via calibration, and of the observed patterns that were used to design overall model structure, whereby not only the measurement protocols need to be evaluated but conclusions drawn from the data should be challenged as well"*. This means that the data used for the specification of the model should be questioned on its reliability. The data used for this model can be split up in three categories and is evaluated underneath: (1) statistical data (5.2.1), (2) literature and local research (5.2.2) and (3) interviews (5.2.3).

5.3.1 Statistical Data

Statistical data is mainly used for the specifications of 'De Vruchtenbuurt' and other city districts, to compare the statistical data of 'De Vruchtenbuurt' and put this specific city district in context. Due to privacy reasons it is not possible to find the link and correlation between different conversion factors. In the work of ECN & RIGO (2013) is mentioned that the income level of a household is correlated with the energy label of the house its living in. Probably, more conversion factors are correlated. However, the correlations are not taken into account in the model. The random assignment of the conversion factors is taken into account as a conceptual uncertainty. Furthermore, assumptions and simplifications were necessary to make, when the desired data was not present. For example, the distribution of energy labels in 'De Vruchtenbuurt' is not based on all the buildings in the city district. However, this distribution is used to assign the energy label to all the buildings. The full list of assumptions and simplifications can be found in Appendix D.

The assumptions and simplifications that are made can influence the results. This means that exact advice cannot be given by using this model. For example, it is not possible to conclude with certainty how many households have a feasible option, but an indication can be given. Since the model is not developed to give this exact advice, it is expected that the assumptions and simplifications do not prevent achieving the model objective.

5.3.2 Literature and Local Research

Different scientific papers and local research documents could be used as input for this research. Some relations between certain technical designs and values or the way conversion factors can limit the options of a household. However, the scientific papers are often not focused, specifically, on the change to decentralized energy systems in city districts and the local research documents do not always, specifically, focus on the city district 'De Vruchtenbuurt'. The exact impact of governance models, technical designs and conversion factors on the values and on the feasibility of an option is hard to define. Thus, only is identified whether a model, design or conversion factor combination is fulfilling a certain value more than another combination.

To achieve the goal of this research it is not necessary to specify the impacts exactly and therefore it is unnecessary to be more detailed and make more assumptions. It should be noted that because of the ordinal scale used to rank the combinations of governance models, technical designs and conversion factors does not allow to imply how much better or how much worse a combination is, which is also not the aim of the model. The combinations are just compared to determine which combination is fulfilling a certain value more than another combination.

5.3.3 Interviews

On this specific topic no research is executed already. It is therefore not sure if the information retrieved from other sources also applies to this specific research and the specific city district 'De Vruchtenbuurt'. Therefore, interviews are executed to get a grip on the missing links and information.

Three rounds of interviews were conducted. The first 'orientation' round was used to find important components to fill in the building blocks (see next section) that are used to build the model. When information was mentioned multiple times in different interviews, it is assumed to be important. After conducting multiple interviews no new information was revealed and a selection was made of components that are taken into account. The second 'validation' round was used to check with other interviewees if the selection missed any important components and the selection was adjusted when necessary.

The snowball sampling technique was used, since contacts of other experts and stakeholders were given by earlier interviewees. It should be noted that the use of this technique can lead to a less representative group of interviewees. However, since the interviewees have different backgrounds and roles in the energy transition, it is expected that the information retrieved from interviews is quite extensive and reliable.

5.4 Step 2: Conceptual Model Evaluation

Augusiak et al. (2014) define the second step as *"the assessment of the simplifying assumptions underlying a models design and forming its building blocks, including an assessment of whether the structure, essential theories, concepts, assumptions, and causal relationships are reasonable to form a logically consistent model"*. The conceptual framework that is the backbone of this research is the Capability Approach. In Figure 3.1 can be seen which components of the Capability Approach are used to build up the model. However, the relations between these building blocks (5.4.1), the way the values are evaluated (5.4.2) and the feasibility of the chosen option (5.4.3) are uncertain. These previous points are discussed in more detail underneath. The assumptions and simplifications are listed in Appendix D.

5.4.1 Building Blocks

A part of the Capability Approach is used to classify different data and information needed to retrieve the goal of the research, also the links between these blocks were necessary to identify.

Goods and Services
The goods and services are one of the building blocks and represent in this research the type of decentralized energy system, split up in a governance model and a technical design. It should be noted that in this research only one governance model and technical design can be chosen or used at the same time. However, in reality it is possible that mixed models and designs are used within one city district. Therefore not much time is spend on the technical design a household would use when it would form a community on its own. It is not realistic that a household that forms a community on its own is going to create its own heat grid (since that is not feasible). It is however expected that this household decides on a individual technical design or joins the heat grid later and does not get the benefits of buying insulation materials in a large order. This model does not identify the exact technical designs that can be used in a city district, since other models can do this better (like the Vesta MAIS model of PBL (2018)). The model does evaluate the values of a household that decides to form a community on its own.

Conversion Factors
The conversion factors are another building block and represent in this research the households characteristics present in 'De Vruchtenbuurt'. Some of the conversion factors are used as constraints to check whether an option is feasible. Since a selection of conversion factors is made, it is possible that not all the possible constraints are identified. For example, law and regulation can also form a constraint for achieving options (Technical Experts 2). However, in this research is focused on the conversion factors of the households and the houses they are living in. Therefore the overall constraints (like law and regulation) are not taken into account.

Values and Capabilities
The values and capabilities are the last building block. The selected values are used to evaluate the acceptability of the capabilities. Since a selection is made for the values and a interpretation is assigned, it is possible that not all values that have to do with a new energy system are covered. However, the selected set is expected to form a quite extended set of the most important values.

5.4.2 Evaluation of Values

The evaluation of the values is done by scoring the different combinations of conversion factors and the chosen governance model and the chosen technical design. The minimum score is - 1 and the maximum score is + 1. The scores are evaluated every time step again, so a value can never retrieve a lower score than - 1 and never a higher score than + 1. However, the variables that effect the values differ per value (as can be seen in Figure 4.5. More possible scores for the value affordability than for the value security of supply are used. For example, for the value affordability the following scores are possible: - 1, - 2/3, - 1/3, 0, + 1/3, + 2/3 and + 1 and for the value security of supply: - 1, - 0.5, 0, + 0.5 and + 1. This could mean that in some cases a better or worse score can be reached, even though the other factors are evaluated the same for both values (because another factor influences one of the values). Besides this, when a household has no feasible option, it means that the values all get the lowest score (- 1). It is not possible for a household to fulfill any of the values when it has no feasible options.

The way the different options (current community, other (larger) community or alone in a community) are evaluated can be doubted. The values all have the same weight and indirect prioritization of values is embedded in the comparison of the different options. Some of the values achieve a high score for the same kind of conditions and are therefore indirectly prioritized. For example, security of supply, affordability and security of supply score all higher with a large community size, so when an option has the condition of a large community size this option is favoured, while this option effects the value autonomy negatively. This limitation is unavoidable and will also reveal in the real world. Only when the weight of certain values is set higher than the weight of other criteria, the prioritization of values can be influenced manually.

An experiment with four different sets of weights for the values is executed (200 runs in Netlogo), to find out how much influence the chosen perspective that no values are superior to another value has on the results and the embedded indirect prioritization of values. The other parameters are not changed in this experiment. Four different sets are defined in the model and tested. The overall conflicts (so not per conversion factor group) between value security of supply and values autonomy, comfort and inclusiveness are given underneath (Figures 5.4, 5.5 and 5.6). The results of the other values can be found in Appendix F.

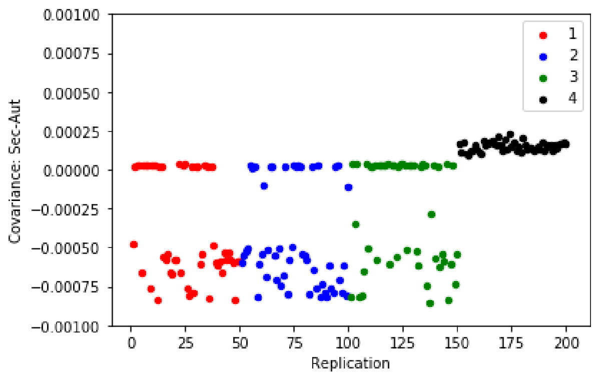


Figure 5.4: Covariance between Security of Supply (Sec) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

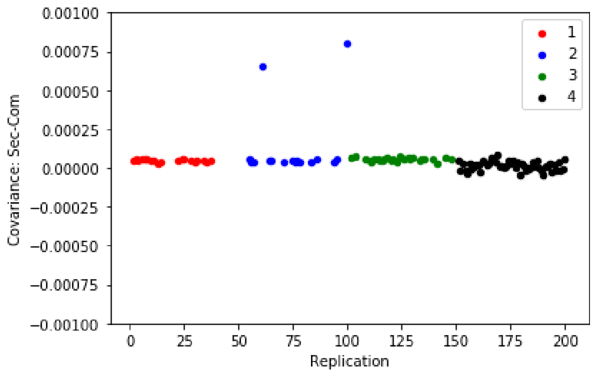


Figure 5.5: Covariance between Security of Supply (Sec) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

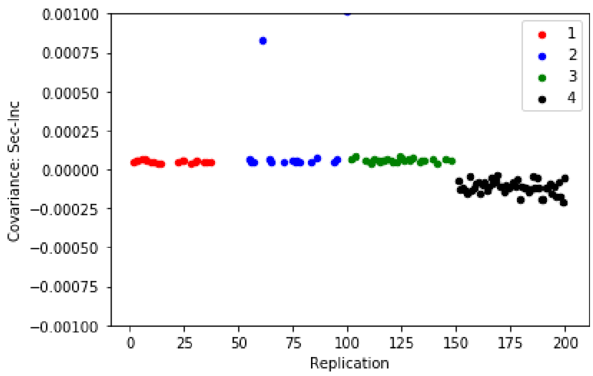


Figure 5.6: Covariance between Security of Supply (Sec) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

The results for the first three sets of weights are similar as the results where the stochastic uncertainty is tested. However, the results are rather different for the fourth set of weights. In this set of weights security of supply, affordability and sustainability (traditional values) get the weight of 1.5 and autonomy, comfort and inclusiveness get the weight of 0.5. Since in this results only the overall conflicts can be seen (and not the conflicts between conversion factors), no further conclusions can be drawn. However, it is important to note that weighting the traditional values higher than autonomy, comfort and inclusiveness effects the results.

Since in this research no further time has been spent on the weight of the values, no further real world conclusions can be given. However, it should be noted that prioritization of values can happen without being aware of it.

Lastly, it is important to discuss if the model behaviour would be different when using the correlation to calculate the relation between the values (to identify possible conflicts) instead of the covariance. It is expected that the use of the covariance is sufficient, since similar scales are used for the values. However, some of the values are influenced by more variables than other values. It is questionable if this influences the validity of using the covariance for calculating the relation between the values. However, only the direction of the relation between the values is used for the interpretation of the results and not the strength of the relation. It is therefore still expected that the covariance is sufficient. This does not mean that the correlation also could have been used, but it should be noted that the question remains whether the strength of the relation between values would lead to realistic implications (when using the correlation for calculating the relation).

5.4.3 Feasibility of Capabilities

The conversion factors income, ownership and energy label can form a constraint to the feasibility of an option. However, it is not known how the conversion factors are linked or correlated and therefore the conversion factors are randomly assigned to the households. It is important to note that the identified value conflicts can be different than in reality. Firstly, the robustness of the results can be determined by running the model for different replications. Furthermore, interviews are conducted to test whether the identified value conflicts can emerge in the real world.

5.5 Step 3: Implementation Verification

Augusiak et al. (2014) define the third step as *"the assessment of (1) whether the computerised implementation the model is correct and free of programming errors and (2) whether the implemented model performs as indicated by the model description. The aim is to ensure that the modelling formalism is accurate"*. When considering Agent-Based Modelling, it is according to Van Dam et al. (2013) important that the verification of the model is done on individual and overall level. The individual characteristics do not explain the overall behaviour totally. The interactions between agents (households) explain part of the emerging overall behaviour. Van Dam et al. (2013) identifies four ways for verification that are in line with the implementation verification defined by Augusiak et al. (2014).

- Recording and tracking of agent behaviour, which allows if the operationalization is done right by monitoring the output variables.

- Single-agent verification, which allows to identify if the agent behaves the way the modeller intended it.

- Minimal model interaction verification, which allows to test whether the interactions between a limited amount of agents in the model is correct or not.
- Multi-agent verification, which allows to test whether the model behaviour on an overall level is in line with the expected behaviour.

In Appendix F the application of the above mentioned steps can be found. After this step no implementation errors are expected anymore. However, if the model also leads to understandable behavioural patterns is discussed in the next step.

5.6 Step 4: Model Output Verification

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

The idea of this step is to check whether the behaviour of the model matches the observed or expected behaviour in the 'real world' or not. Instead of only testing whether the concepts are translated well into a model, it is also tested if the model leads to understandable model behaviour that can be clarified. The third 'implications' round of interviews is used to define some observations and those are compared to the model behaviour. It should be noted that the model is a simplified representation of the reality, so scoping and modelling choices had to be made to keep the problem accessible.

The results where is referred to in the following paragraphs can be found in Chapter 6 and Appendix G.

Observation 1: The sense of autonomy increased the last years. To fulfill this value, the more traditional values (sustainability, affordability and security of supply) will suffer.
When looking at the results of the experiments where the uncertainties and the policies are varied, it becomes clear that especially autonomy is in conflict with the other values. This makes sense, since the more traditional values score higher when households join together. However, the value autonomy scores higher when the household can decide without the dependence on other households. Therefore, under most conditions, conflicts between autonomy and the more traditional values arise.

Observation 2: When a household is not joining a large community to maintain more freedom of choice, inclusiveness can be in conflict with autonomy.

When looking at the results of the experiments where the uncertainties and the policies are varied, it becomes clear that autonomy is in some cases in conflict with inclusiveness. When a household has the ability to form a community by its own or join the bigger community, it might choose to not join the community and decide on its own when it wants to change to an individual heat technology (all electric). It should be noted that the households that do not have any feasible solution also are not joining a larger community. The value inclusiveness is defined by comparing the income level of the household by the mean of income level of the households that do the same as the household, which leads to a variety in the households that do not have a feasible option and the households that do have a feasible option of being alone in a community exists. Therefore the level of inclusiveness is low for the household that is alone in a community to maintain autonomy and therefore in conflict with its value autonomy.

Observation 3: Sustainability can be in conflict with affordability and security of supply, since from a technical perspective the more sustainable solutions are in many cases more expensive and can be less reliable.

The model shows less conflicts between the more traditional values (sustainability, affordability and security of supply) than between the more traditional values and autonomy, comfort and inclusiveness. However, in some cases conflicts are identified between the more traditional values (see Figure 5.7). Some of the technical designs are less sustainable, but are cheaper and the same goes for the value security of supply. Since not all the aspects that influence the security of supply and sustainability are taken into account in this research (the same goes for the other values), the evaluation of the value sustainability and the value security of supply are that different. This is because the sources that are used for the LT heat grid and HT heat grid are not considered. When the heat companies decide to use non-sustainable sources, this influences the sustainability of the heat grid options, but the heat sources are not taken into account in this research. Since in this research is focused on the possible conflicts between the more traditional values (sustainability, affordability and security of supply) and the more progressive values, this limitation is not of great importance.

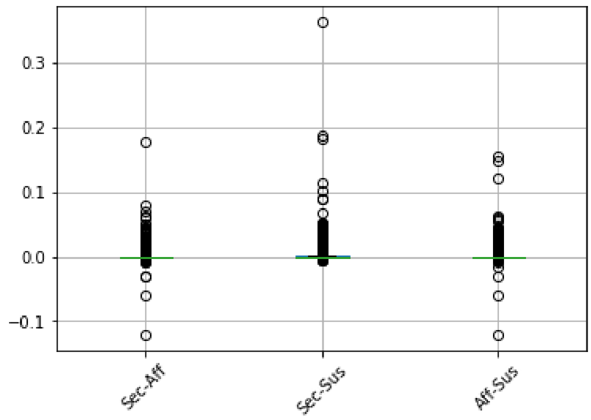


Figure 5.7: Boxplot of the Covariances (y-axis) between Security of Supply (Sec) - Affordability (Aff) - Sustainability (Sus) (x-axis).

Observation 4: The composition of a city district influences the value conflicts. For example, the ownership and the construction year (embedded in the energy label) distribution influence the value conflicts in a city district.
Since some of the conversion factors (income, ownership and energy label) form constraints for achieving certain options, the distribution of these factors influence the results. As a test, the conversion factors are differentiated. The results differ and the amount of households having a feasible option is also varying (see Appendix F). The composition of another city district can be totally different. When making generalizations of the results, where the specific distributions of city district 'De Vruchtenbuurt' are used, this is important to keep in mind.

Observation 5: The comfort of the new technologies are not secured (as with gas) and it is hard to find a technical option that supports as well the comfort, as the more traditional values (sustainability, affordability and security of supply).
Some of the new technologies require large renovations in the buildings (to secure that the building is heated enough with the chosen source of heat). The most comfortable technical design considered in this research is also the least expensive one (in the short run) and therefore not many conflicts can be found between the values comfort and affordability. However, in the results becomes clear that comfort of a certain conversion factor group can still be in conflict with sustainability of another conversion factor group. Since the least comfortable technical option is the most sustainable option and scores the highest on security of supply, the value comfort is often in conflict with the values sustainability and security of supply.

5.7 Step 5: Model Analysis

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

Feature scoring is used as sensitivity analysis and helps to find out which input parameters influence the outcomes of interest most. In this section the uncertainties that can vary in reality are used, since the precise parameter settings are not clear. In Figure 5.8 the results of the sensitivity analysis for the runs where only the conceptual uncertainties are varied and in Figure 5.9 the runs where also the policies are varied (see Chapter 6 for the explanation of the experiments) are shown. In Appendix F the results of the sensitivity analysis for the runs where only the policies are varied are displayed.

Most of the results of the sensitivity analysis can be explained by the conceptualization. For example, the chosen heat technology has a big influence on the feasibility of the options a household has. Whether a household can find a feasible option influences the value inclusiveness. The conflicts between inclusiveness and other values are therefore highly sensitive to the chosen technical heat design.

Furthermore, the model is strongly sensitive to the size a community needs to have to achieve large scale benefits (when no policies are applied), since this uncertainty is modelled as a threshold. The way the community size and other conceptual uncertainties are modelled lead to strong turning points. It is also possible to use functions to conceptualize the uncertainties, but this would make the conceptualization more complex. When varying the policies, the model behaviour is mainly sensitive to the technical heat design and not to the conceptual uncertainties. It is therefore expected that the conceptualization of the uncertainties has a lower priority than the conceptualization of the technical heat designs.

It is not the aim of this research to give a conclusion on the exact conditions of the uncertainties. It is expected that the model objective can still be reached given the sensitivity of the model to certain parameters and modelling choices. It is the aim of the model to find out which parameters lead to value conflicts in order to know which parameters influence the outcomes of interest most. Further research on the exact conditions of these important parameters have to be conducted.

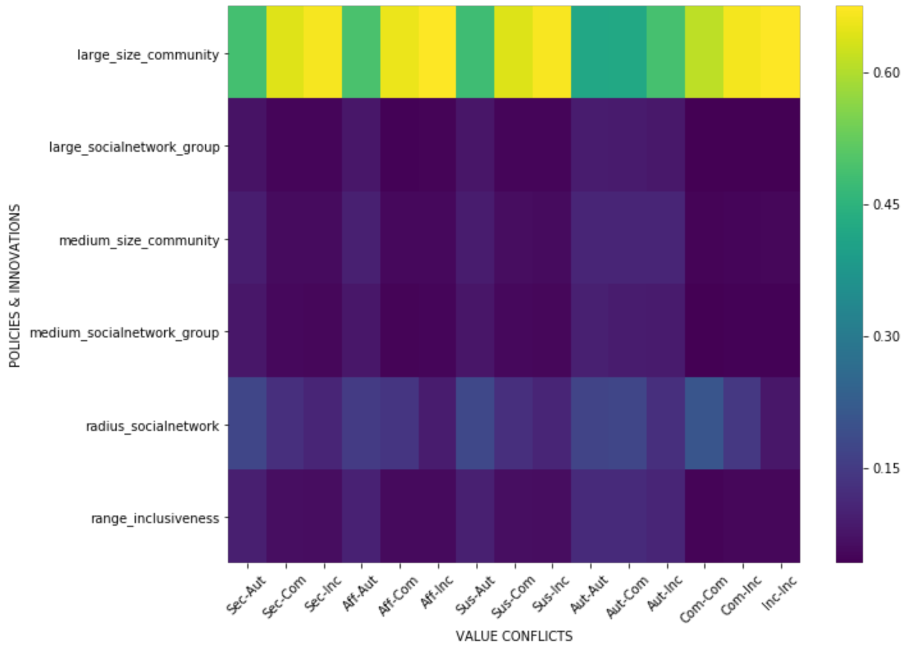


Figure 5.8: Feature Scoring: Uncertainties. When the result is more yellow in the feature scoring, the outcome of interest is more sensitive for this parameter.

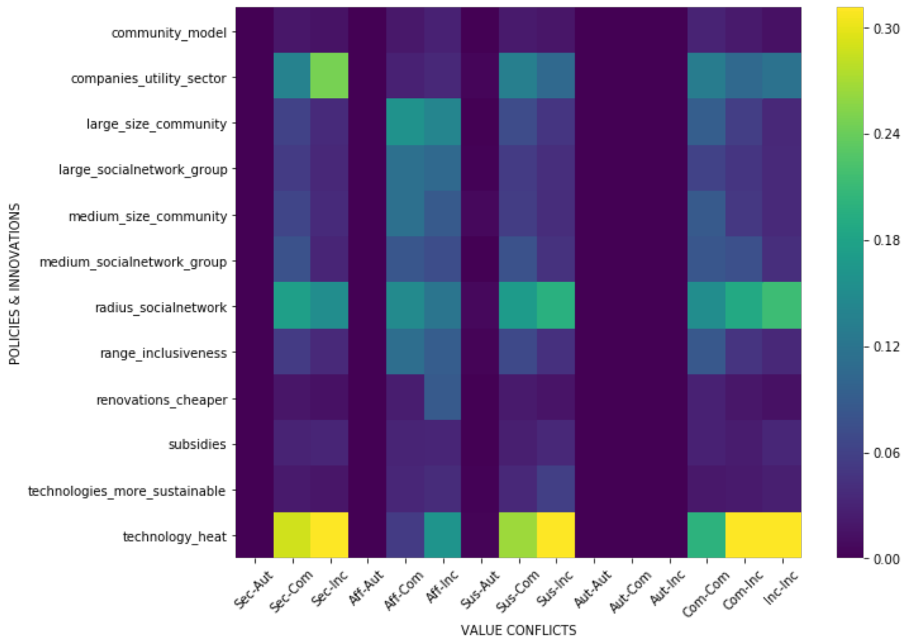


Figure 5.9: Feature Scoring: Uncertainties and Policies. When the result is more yellow in the feature scoring, the outcome of interest is more sensitive for this parameter.

5.8 Step 6: Model Output Corroboration

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

Since the decentralized energy system is not applied in 'De Vruchtenbuurt' yet and no other models and studies on the same specific topic exist, it is difficult to test whether the outcomes of the model could be reproduced again. However, four policymakers from the Ministry of Economic Affairs and Climate Policy, one researcher from Delft University of Technology and one local initiator from 'De Vruchtenbuurt' are interviewed and questioned if the identified value conflicts can also be expected in reality. Also, is questioned what these findings mean and to what extent it is expected that these outcomes can be generalized. Furthermore, it is questioned under what conditions these outcomes are expected to emerge. The results of these interviews are discussed in Chapters 7 and 9.

5.9 Conclusions

In this section the conclusions that can be drawn from the use of the 'evaludation' method, which is used to verify and validate the model, are given. The conclusions are focused on explaining to what extent the model is able to reach the model objective: **"Identifying for what combinations of conversion factors, governance 'community' models, technical 'heat' designs and other policies value conflicts arise (given the uncertainty of the conceptualization)"**.

The model is sensitive to the random assignment of the characteristics to the households (stochastic uncertainty). Therefore it is important to use model replications when experiments are conducted. The use of these replications can lead to findings that are useful for policy advice.

Most of the statistical input parameters could be retrieved easily and are expected to be true. However, the relations between the technical designs, governance models, conversion factors, values and capabilities are not certain. It is only possible to evaluate which option is better than another option, considering a certain value (given the chosen interpretation of the value). The main reasoning line for taking decisions on the level of detail in this research is: when no precise data or information could be retrieved, also no precise conceptualization is made. The exact quantification of the results should therefore not be used. The aim of the model is to find out under which conditions the results are positive or negative, which is achievable with this model.

The conceptual framework (the Capability Approach) used for this model can be doubted, since only a part of the framework is used and other frameworks would evaluate the acceptability of decentralized energy systems differently. For example, in this framework the well-being of every household is determined and all values have the same weight, while the utilitarianism framework would aim for maximizing one value to reach overall well-being. The model aims to give better insight in the trade-offs the national government is dealing with and to find out under what conditions these trade-offs arise. It is not the aim to predict the truth with the model. Even though only one specific framework is used, it is expected that this attempt is contributing to the societal and academic knowledge gap.

A different set of weights for the values influences the results, especially when the values security of supply, affordability and sustainability retrieve a low weight and the values autonomy, comfort and inclusiveness retrieve a high weight. It is possible that the inclusion of the importance of values results in prioritization of certain values. The embeddedness of indirect and direct prioritization is not taken into account.

The model is extensively verified, which gives confidence in the correctness of the implementation. All errors found in the implementation verification step are solved.

The output of the model can be explained and is mostly in line with the expectations that follow from the interviews, literature and local research. Due to privacy reasons it is not clear which characteristics belong exactly to which household. It is therefore possible that combinations of conversion factors occur in the model that do not occur in reality. However, interviews are used to validate the identified value conflicts, which should prevent that unrealistic conclusions are drawn from the model results.

The model behaviour is most sensitive to the size that a community needs to have to achieve large scale benefits when the policies are not varied. The community size and other conceptual uncertainties are modelled as thresholds, which leads to strong turning points. However, when the policies are varied, the model behaviour is mainly sensitive to the technical heat design and not to the conceptual uncertainties. This implies that the conceptualization of the uncertainties has a lower priority than the conceptualization of the technical heat designs. Nevertheless, the thresholds are taken into account as uncertainties for further analysis, since the used values for the thresholds are uncertain as well.

The credibility of the model is tested by interviews and is discussed in Chapter 7 and reflected on in Chapter 9.

Chapter 6

Experimentation

The goal of this chapter is to answer the third sub research question:

"Under what conditions (uncertainties and policies) do household value conflicts occur?"

To get a clear overview of the experiments that are executed, the XLRM framework, introduced by Lempert et al. (2003), is used. This framework structures the relevant information of a model (Kwakkel, 2017c). It enables to structure the desired input and output of the research and specifies the uncertainties (input), policies (input) and outcomes of interest (output). In Figure 6.1 the XLRM framework applied to this research is shown.

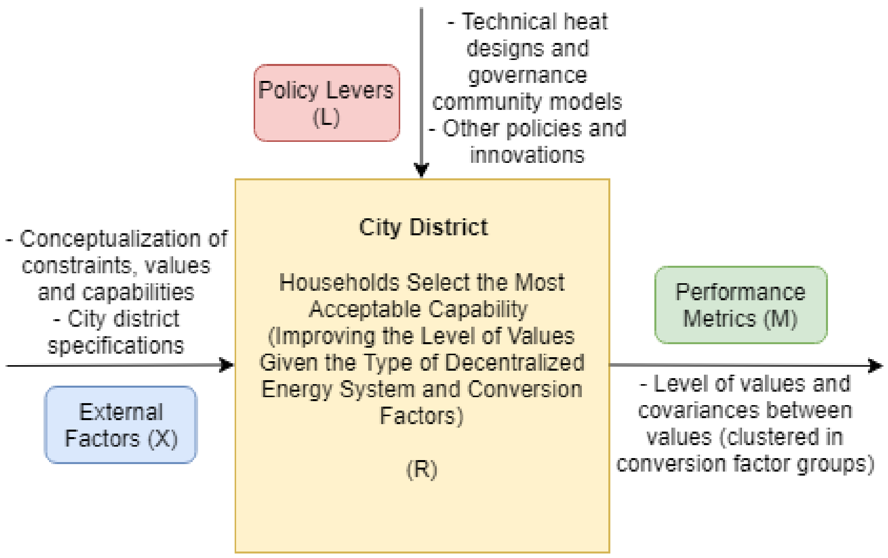


Figure 6.1: XLRM Framework Applied to this Research.

6.1 Uncertainties and Policies

In this section the conditions (uncertainties and policies) taken into account in the experimentation are discussed. The input of the experimentation can be specified in two groups. One of the groups contains the uncertainties that have to do with the conceptualization (6.1.1). The other group contains the policies and innovations that are interesting for policy advice (6.1.2). The file with the code that specifies the experiments does not allow (yet) to specify the policies separately from the uncertainties. Therefore it is chosen to specify the policies in the code also as uncertainties (when the intention of the experiment was to vary the policies), which does not have any implications for the results.

Also, the parameter settings are specified. The default (reference and base case) settings and ranges for experimentation are given.

6.1.1 Group 1: Conceptual Uncertainties

The conceptual uncertainties are the uncertainties that are not of interest for policy advice, but are important to take into account, since it is an indication for the credibility of the model and therefore the credibility of the results. In Table 6.1 the conceptual uncertainties are presented.

In Table 6.1 the random assignment of the conversion factors to the households (stochastic uncertainty) is not specified. However, this is also conceptual uncertainty and is varied automatically (due to randomness) when conducting experiments.

6.1.2 Group 2: Policies and Innovations

The policies and the innovations that are interesting for giving policy advice are specified in Table 6.2. The aim of experimenting with this group is to find out for what policies and innovations less or no values conflicts arise. The policies and innovations are further specified in Appendix D.

Table 6.1: Conceptual Uncertainties.

Conceptual Uncertainty	**Range for Experimentation**	**Type of Parameter**	**Explanation**
Medium size community	25 - 75 (default: 50)	Integer	It is expected that small scale benefits can be reached when 50 or more households join together (for example: when insulation materials are all bought together)
Large size community	150 - 450 (default: 300)	Integer	It is expected that large scale benefits can be reached when 300 or more households join together
Radius social network	1 - 3 (default: 2)	Real	When testing the model (when keeping the social network group parameters the same) a radius of 2 gave a normal distribution of households with a high, medium and no/small social network
Medium social network group	5 - 15 (default: 10)	Integer	When testing the model (when keeping the other social network parameters the same) a parameter setting of 10 gave a normal distribution of households with a high, medium and no/small social network
Large social network group	20 - 30 (default: 25)	Integer	When testing the model (when keeping the other social network parameters the same) a parameter setting of 25 gave a normal distribution of households with a high, medium and no/small social network
Range inclusiveness	5 - 35 (default: 20)	Real	With a range of 20% is expected that the mean of the income levels in the group of households that do the same is giving the right range to examine if a household has a similar income level as most of the other households (in its group)

Table 6.2: Policies and Innovations.

Policy or Innovation	**Experimentation Options**	**Explanation**
Technical heat design	1 = 'All electric', 2 = 'LT heat grid' and 3 = 'HT heat grid' (default: 3)	The HT heat grid option is expected to have to most potential in 'De Vruchtenbuurt'
Governance community model	1 = 'one bigger community' and 2 = 'two smaller communities' (default: 1)	In 'De Vruchtenbuurt' one bigger community is formed (and therefore used as default setting)
Subsidies	0 = 'off' and 1 = 'on' (default: 0)	In the base case no subsidies are available
Renovations cheaper	0 = 'off' and 1 = 'on' (default: 0)	At the moment renovations are very expensive, since the insulation materials are expensive (RLI, 2018). When a market is created for renovating houses, it is expected that innovation takes place and possibly cheaper or other insulation materials are going to be used. Therefore the model is tested for cheaper or other insulation materials which influences the value affordability
Technologies more sustainable	0 = 'off' and 1 = 'on' (default: 0)	The 'all electric' option is the most sustainable option of the three technical designs. However, how sustainable the heat grids are depends on the three factors that are also mentioned in section 3.4.3: the emissions during generation (including carbon dioxide), the energy loss and use during transport and how future-proof the heat source is (CE Delft, n.d.). The sustainability is partly determined by the choices of the heat suppliers and partly by innovations that can decrease the emissions and energy loss. Therefore the model is tested for more sustainable heat grids which influences the value sustainability
Use of companies and utility sector	0 = 'off' and 1 = 'on' (default: 0)	In this research only the households are taken into account while in city districts also companies and utility buildings exist. These end-users can be used to create flexibility, since these end-users have a different profile of using energy (Energy System Expert 1). Therefore the model is tested for the use of companies and utility sector for flexibility which influences the value security of supply

6.2 Outcomes of Interest

The outcomes of interest are the conflicts between values, which are evaluated as the covariance between the values. The overall covariance between the values is less interesting than identifying the conflicts between different conversion factor groups (see Table 6.3. Since too many results are generated when identifying the value conflicts between and within the households, it is decided to create categories of the conversion factors for which the conflicts are measured. The conflicts can be identified between and within the conversion factor groups. Most of the conversion factors were already specified in two or three groups, but the conversion factor 'energy label' is specified in seven groups. For further analysis is decided to divide the conversion factor 'energy label' also in three groups, since it decreases the amount of results to analyze. Energy label A to A++ and B are joined together, since this energy label can be combined with all considered technical heat designs. Energy label C and D are combined, since for both these labels the the heat grid designs are possible, but the all electric design is not. Lastly, energy label E, F and G are joined together to one group, since for these labels only the HT heat grid design is possible (CE Delft, n.d.).

Table 6.3: Categorization of Conversion Factors Groups.

Conversion Factors	**Number of Groups**	**Division of Groups**
Income	3 groups	1 = low 2 = middle 3 = high
Ownership	2 groups	1 = renting 2 = buying
Social network	3 groups	1 = no/small 2 = medium 3 = high
Type of household	2 groups	1 = one person household 2 = pair without children 3 = pair with children
Energy label	3 groups	1 = E/F/G 2 = C/D 3 = A to A++/B
Type of building	2 groups	1 = one family building 2 = multiple family building

6.3 Experiment Design

Many experiments with varying parameters for the uncertainties and policies for multiple outcomes of interest can be conducted, but experiments are time consuming and computational power is required. Therefore choices are made for the amount of runs (6.3.1), the run length (6.3.2) and the sampling method (6.3.3).

6.3.1 Number of Runs

Different experiments are executed using Exploratory Modelling and Analysis. All the experiments are conducted with **5 model replications**. The reason why three types of experiments are executed is to find out what the influence of the conceptual uncertainties are when using the base case, what the influence of the policies are when using the reference settings and what the influence on the outcomes of interest are when varying both groups.

- 3,000 runs, uncertainties and policies are varied
- 2,000 runs, only uncertainties are varied
- 1,000 runs, only policies are varied

The number of runs is larger when the uncertainties are varied than when only the policies are varied, because more possible combinations of uncertainties that form the scenarios exist than possible combinations of policy levers that form the policies. The uncertainty variables contain real and integer parameters, while all of the policy variables are integer or binary parameters.

The minimum amount of desired runs is determined by testing if the results show a large variety in the outcome space when the amount of runs are changed. A test is executed with 1,500 runs for which the uncertainties and policies are varied and also, a test is executed with 3,000 runs without the model replications for which the uncertainties and policies are varied. The outcomes of interest did not vary a lot between the tests and the results of the first experiment presented above. Only the strength of the conflicts vary slightly. Since the strength of the conflicts is not taken into account in this research, this variation is not a limitation to reach the goal of the research. Moreover, the same conclusions would have been drawn from the results of the tests (based on a different amount of runs/replications) as has been done in this research.

The maximum amount of runs is determined by testing how much time is needed to execute ten runs and then how much runs would be possible in the amount of time. This resulted in the amount of runs presented above.

6.3.2 Run Length

The model is static and the dimension 'time' is not important for achieving the goal of the research. The run length for the experiments is important, to make sure that enough time steps are taken in order to let the households check there options and change when their conditions allow them. When testing the Agent-Based Model, by using different parameters, the model was stabilizing at 5 time steps (and the model behaviour was not changing anymore). Therefore the run length is set on 5 time steps.

6.3.3 Sampling Method

As a default setting the Latin Hypercube sampling method (which gives a better distribution over the entire space in comparison to the Monte Carlo sampling method) is used in the workbench for sampling over uncertainties and sampling over levers (Kwakkel, 2017a). On the other hand, an advantage of the Monte Carlo sampling method could have been that it generates completely independent experiments (Chrisman, 2014), which makes it possible to combine the results of multiple experiments. Since the experiments could be run in one time and it was not necessary to combine independent experiments, it is expected that the default setting is sufficient.

6.4 Data Analysis and Conclusions

Model-based support is used to identify what values conflicts arise between and within different conversion factor groups under varying conditions. Exploratory Modelling and Analysis (EMA) is helping to figure out of the complexity and uncertainty of decentralized energy systems (Kwakkel & Pruyt, 2013). The EMA workbench, developed by J.H. Kwakkel, is used to execute the EMA method. The Agent-Based Model is linked to the EMA workbench in a way that multiple experiments can be performed. Different exploratory techniques are used to analyze the experiments: open exploration, sensitivity analysis (feature scoring) and scenario discovery (PRIM, dimensional stacking, regional sensitivity analysis and extra trees feature scoring).

Open exploration is used to present the uncertainty space and the decision space to the outcome space (Kwakkel, 2017a). A point in the uncertainty space is called a scenario and a point in the decision space is a policy. The full uncertainty space is combined with the full decision space to see what points in the space of the different outcomes of interest are possible. Every combination of a scenario and a policy is called an experiment (Kwakkel, 2017b). The more experiments, the more complete the possible outcome space is.

Sensitivity analysis is used to find out what uncertainties and policies have the most influence on the outcomes of interest and is part of the vulnerability analysis. The sensitivity analysis investigates how sensitive the outcomes of interest are for the input variables (Kwakkel, 2017a). This analysis is useful to get an idea which uncertainties and policies are important for the model behaviour. When a policy is sensitive, it will influence the outcomes of interest more. Feature scoring is a simple form of a sensitivity analysis, which gives visual insight into the relative influence of uncertainties on the model outcomes (Kwakkel, 2017c).

Scenario discovery is an important type of vulnerability analysis and forms the core of robust-decision making. Scenario discovery methods aim at finding combinations of conditions for uncertain input parameters that lead to similar outcomes of interest. It will help to identify the restrictions on uncertainties that result in possible output spaces. This analysis can be performed using the Patient Rule Induction Method (Friedman & Fisher, 1999). PRIM seeks for hyper rectangular boxes of the uncertainty space where the value of a single outcome of interest is notably different from the average value over the whole field. These rectangular boxes are obtained by slicing away small amounts of data until a subspace is obtained with a balanced trade-off between coverage and number of restrictions. The input for the PRIM analyses are computational experiments which are also used for open exploration and sensitivity analysis. Through PRIM these experiments are classified as experiments of interest, or not (Kwakkel et al., 2016). Other approaches for supporting scenario discovery are dimensional stacking, regional sensitivity analysis and extra trees feature scoring, which all make use of binary classification. The last mentioned approaches result in visuals that are easier to understand (compared to PRIM).

6.4.1 Conditions Resulting in Value Conflicts

To find out under what conditions the most value conflicts occur, it is necessary to identify which value conflicts emerge *between* and *within* which conversion factor groups. Since many conflicts between the different values and the conversion factor groups can be identified, it is chosen to structure the results using expectations and observations that were revealed in the third 'implication' round of interviews.

In these interviews became clear that in the current energy system some values, i.e. security of supply, sustainability and affordability are anchored. The other values, i.e. autonomy, comfort and inclusiveness became more explicit since decentralized energy systems are introduced. It is possible that some values were already implicit present in the current energy system, but the change to a new energy system made these values more explicit. By taking the more **progressive values**, i.e. autonomy, comfort and inclusiveness into account, it means that the fulfillment of the values in the new set might change (Figure 6.2). The relation between the more **traditional values**, i.e. sustainability, affordability and security of supply is better known. Exploration of the conflicts that can be identified between and within the more progressive values and the relation between the more progressive values and the more traditional values is therefore more interesting.

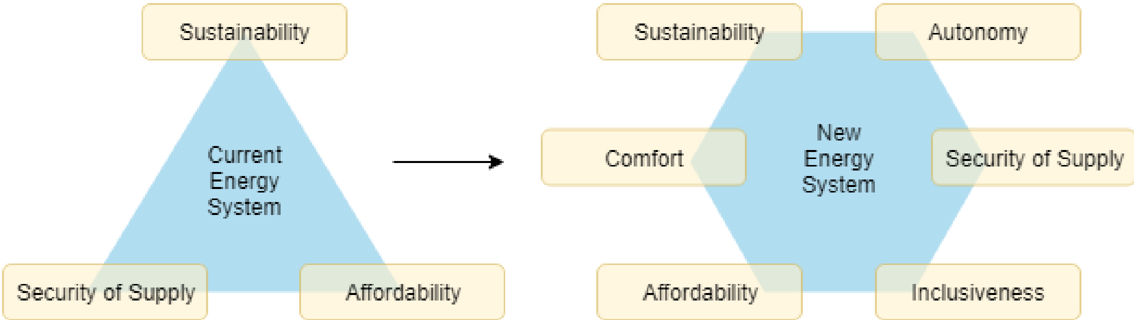


Figure 6.2: Shift in Values.

Looking at the traditional values, the fulfillment of these values all require cooperation, since for the fulfillment of these values it is favored to join together in large communities. This is however inherently in conflict with the value autonomy. It is questionable if these **inherent conflicts** also occur under different conditions (uncertainties and policies). Furthermore, it is also not clear if these conflicts between and within all conversion factor groups occurs. The same goes for the conflicts between the values that require cooperation and the values comfort and inclusiveness. Besides the previous points, it is also interesting to take a look at the relations between the values autonomy, comfort and inclusiveness itself.

In addition, analysis can be executed on the following aspects: (1) to what conceptual uncertainties are the selected value conflicts sensitive and what combinations of uncertainties result in the same value conflicts and (2) to what policies and innovations are the selected value conflicts sensitive and what combinations of policies and innovations result in the same value conflicts.

Traditional Values and Autonomy in Conflict

In Figure 6.3 can be seen that in 'De Vruchtenbuurt' the values security of supply and autonomy are in conflict mostly *within* the group of households with a high income level, to a lesser extent (in fewer cases) *between* the group of households with a middle income level and the group of households with a high income level. Also, a few cases can be seen for which a conflict *between* the lowest and highest income groups is identified. The conflict between security of supply and autonomy is quite obvious, because the way autonomy is defined leads to an inherent conflict with the values that require cooperation (like the value security of supply). However, almost no cases can be seen for which value conflicts between security of supply and autonomy *within* the group of households with a low income level occurred. It is expected that in many cases the low income level households in 'De Vruchtenbuurt' do not have a feasible option and therefore cannot fulfill any of their values (so the inherent conflicts also do not occur in these cases). The same results can be found for the values affordability and sustainability in conflict with autonomy (Appendix G). Also, the conflict that autonomy has with affordability and sustainability can be clarified, since affordability and sustainability also require cooperation for their fulfillment.

The way how the results can be interpreted and used to identify value conflicts **between** and **within** conversion factor groups is explained in more detail in Figure 6.4.

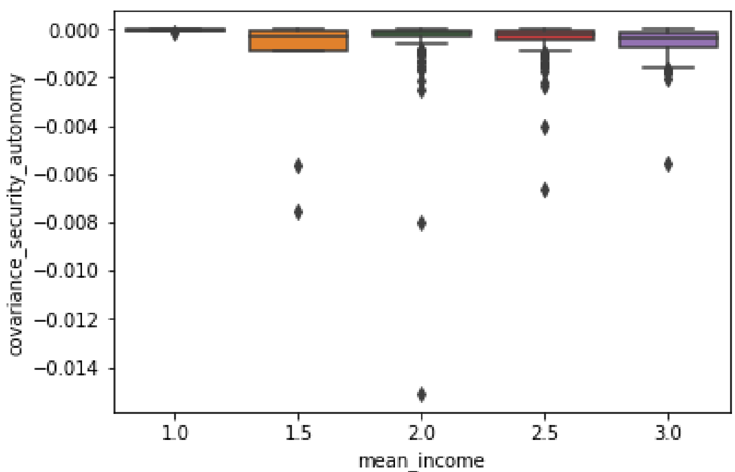
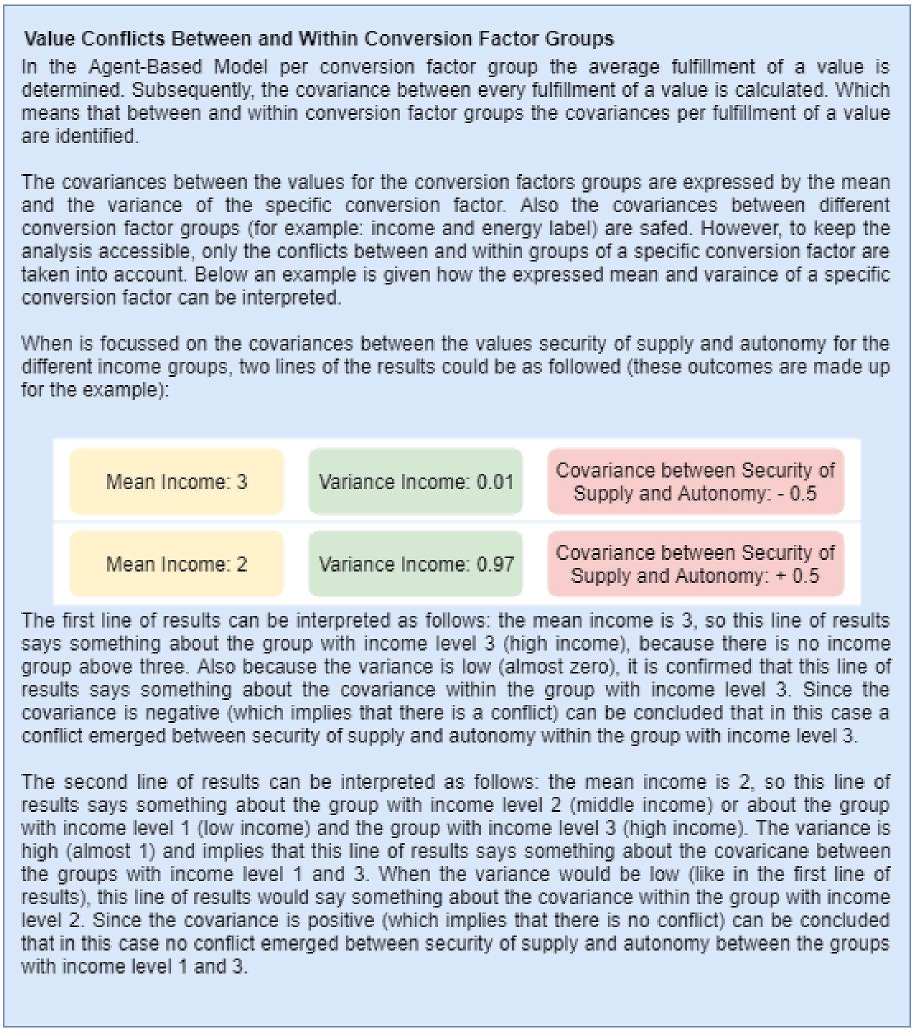


Figure 6.3: Box Plot: Conflicts between Security of Supply and Autonomy (y-axis) between and within Income Groups (x-axis).



Value Conflicts Between and Within Conversion Factor Groups

In the Agent-Based Model per conversion factor group the average fulfillment of a value is determined. Subsequently, the covariance between every fulfillment of a value is calculated. Which means that between and within conversion factor groups the covariances per fulfillment of a value are identified.

The covariances between the values for the conversion factors groups are expressed by the mean and the variance of the specific conversion factor. Also the covariances between different conversion factor groups (for example: income and energy label) are safed. However, to keep the analysis accessible, only the conflicts between and within groups of a specific conversion factor are taken into account. Below an example is given how the expressed mean and varaince of a specific conversion factor can be interpreted.

When is focussed on the covariances between the values security of supply and autonomy for the different income groups, two lines of the results could be as followed (these outcomes are made up for the example):

Mean Income: 3	Variance Income: 0.01	Covariance between Security of Supply and Autonomy: - 0.5
Mean Income: 2	Variance Income: 0.97	Covariance between Security of Supply and Autonomy: + 0.5

The first line of results can be interpreted as follows: the mean income is 3, so this line of results says something about the group with income level 3 (high income), because there is no income group above three. Also because the variance is low (almost zero), it is confirmed that this line of results says something about the covariance within the group with income level 3. Since the covariance is negative (which implies that there is a conflict) can be concluded that in this case a conflict emerged between security of supply and autonomy within the group with income level 3.

The second line of results can be interpreted as follows: the mean income is 2, so this line of results says something about the group with income level 2 (middle income) or about the group with income level 1 (low income) and the group with income level 3 (high income). The variance is high (almost 1) and implies that this line of results says something about the covaricane between the groups with income level 1 and 3. When the variance would be low (like in the first line of results), this line of results would say something about the covariance within the group with income level 2. Since the covariance is positive (which implies that there is no conflict) can be concluded that in this case no conflict emerged between security of supply and autonomy between the groups with income level 1 and 3.

Figure 6.4: Explanation of Interpretation of the Boxplots.

When taking a look at the ranking of determining factors of the cases for which a conflict between security of supply and autonomy is identified (Figure 6.5), can be seen that the choice of technical design determines these cases the most. In Figure 6.6 can be seen that in 'De Vruchtenbuurt' the 'all electric' design (option 1) does not result in conflicts. Since for many households in 'De Vruchtenbuurt' this option is not feasible, both values retrieve a negative evaluation. This clarified why no conflicts occur, since the covariance can be positive between two values when both are evaluated negatively. For the heat grid designs (option 2 and 3), cases exist for which conversion factor groups are aligned for this specific values, but also cases where they are in conflict. It is interesting to find out which conversion factor groups retrieve a positive evaluation and which conversion factor groups not (which causes the conflict).

technology_heat	0.496145
radius_socialnetwork	0.155311
companies_utility_sector	0.116766
technologies_more_sustainable	0.038696
medium_socialnetwork_group	0.032724
range_inclusiveness	0.030248
large_socialnetwork_group	0.028989
large_size_community	0.028633
medium_size_community	0.027168
subsidies	0.020820
community_model	0.012595
renovations_cheaper	0.011906

Figure 6.5: Ranking of Determining Factors for Conflicts between Security of Supply and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

The results of the conflicts between social network groups are not easy to clarify, since the social network conversion factor is only used to determine the value comfort. It is therefore not expected that the division in social network groups influence the conflict between security of supply and autonomy (also since this conflict is not sensitive to the parameters that determine the social network of a household). The households with an assigned social network also have an assigned income level which is used to assign the social network to a household. It might be possible that this relation causes conflicts between social network groups.

Figure 6.7 shows that between all energy label groups conflicts can be identified and especially *within* the highest energy label group (most energy efficient houses). It is expected that these conflicts arise between households with a high income level and an energy efficient house and households with a lower income level and an energy efficient house. It is questionable if these cases also occur in reality, since a correlation is found between income level and energy label (ECN & RIGO, 2013) and this correlation is not taken into account in this research. However, interviews are conducted to test whether the conflicts are expected to arise in reality too. In 'De Vruchtenbuurt' it is expected that some high income level households live in a less energy efficient house (Local Initiator 3).

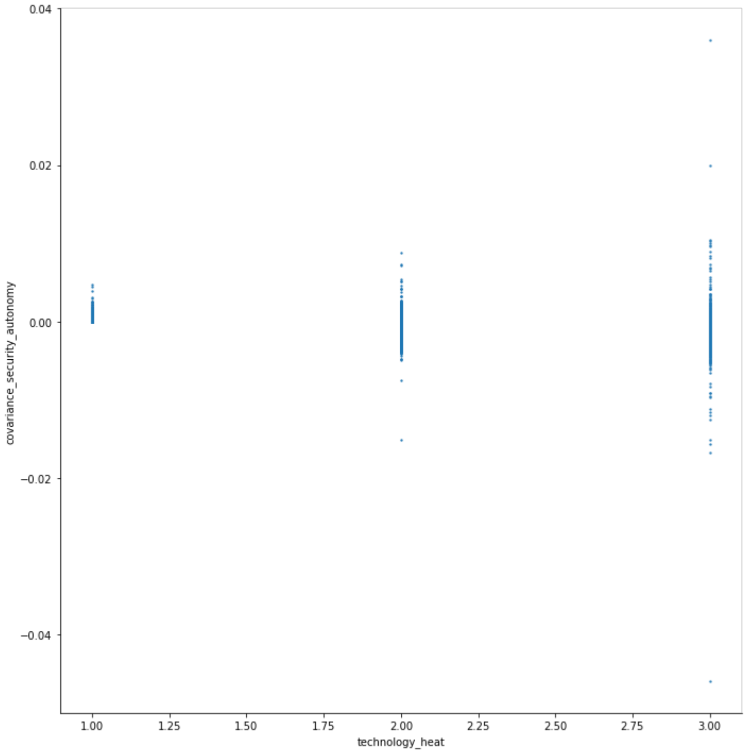


Figure 6.6: Sensitivity to Technical Design (x-axis: 1 = all electric, 2 = LT heat grid and 3 = HT heat grid) for Relation between Security of Supply and Autonomy (y-axis: negative = conflict and positive = no conflict).

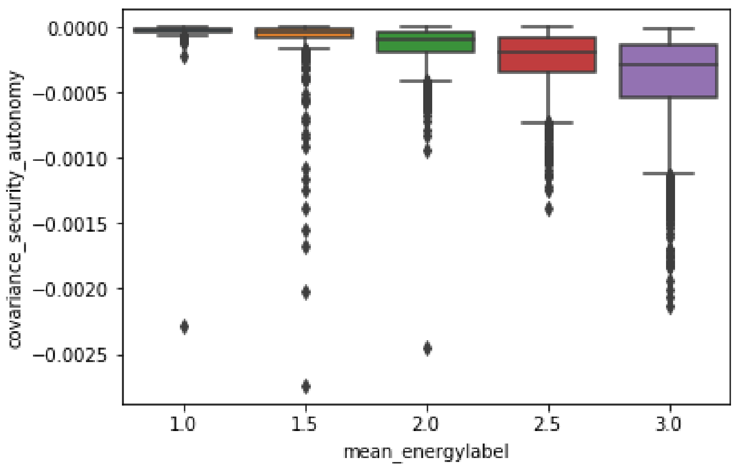


Figure 6.7: Box Plot: Conflicts between Security of Supply and Autonomy (y-axis) between and within Energy Label Groups (x-axis).

Traditional Values and Comfort in Conflict

In Figure 6.8 can be seen that the value security of supply and comfort are in conflict mostly *within* the group of households with a high income level, to a lesser extent *between* the group of households with a middle income level and the group of households with a high income level. Also, a few situations can be found for which a conflict *between* the lowest and highest income groups is identified. Comfort is not evaluated by the community size and therefore it is not expected that the conflict between security of supply and comfort can be clarified by the cooperation that is required to fulfill security of supply. The conflicts of comfort in relation to affordability and sustainability can also not be clarified by the community size (see Appendix G for these results).

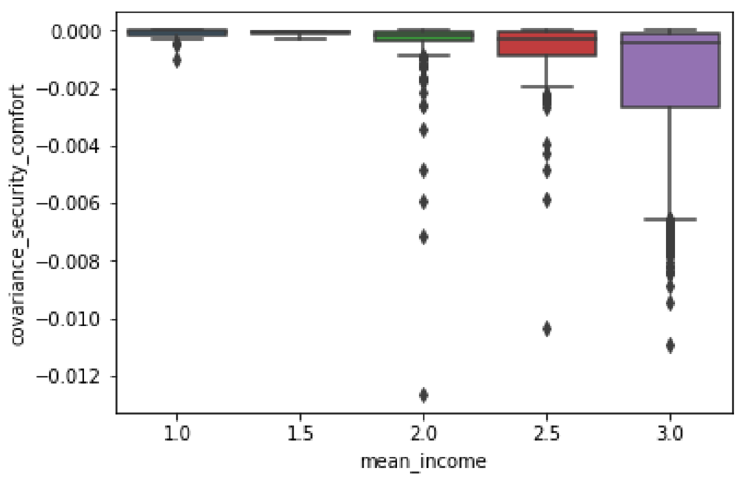


Figure 6.8: Box Plot: Conflicts between Security of Supply and Comfort (y-axis) between and within Income Groups (x-axis).

When taking a look at the ranking of determining factors of the cases where a conflict between security of supply and comfort is identified (Figure 6.9), can be seen that the choice of technical design determines mostly these cases. The reason why the technical design choice is determining these conflicts the most can be clarified when looking at the conceptualization of the values. The technical option 'all electric' is the least comfortable, but is considered the most reliable and sustainable. However, for affordability the 'all electric' design is the least favored option, but still cases can be identified for which a conflict occurs between affordability and comfort (Figure 6.10). Therefore another aspect has to influence the cases for which a conflict occurs between affordability and comfort.

technology_heat	0.500752
radius_socialnetwork	0.150343
companies_utility_sector	0.092232
medium_socialnetwork_group	0.042387
technologies_more_sustainable	0.038928
large_socialnetwork_group	0.031133
range_inclusiveness	0.030485
large_size_community	0.030186
medium_size_community	0.029703
subsidies	0.022296
renovations_cheaper	0.018704
community_model	0.012851

Figure 6.9: Ranking of Determining Factors for Conflicts between Security of Supply and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

When taking a look at the ranking of determining factors of the cases where a conflict between affordability and comfort is identified, can be seen that the technical design and the radius of the social network (a conceptual uncertainty) are influencing the conflicts the most (see Appendix G for these results). To get a better understanding of the influence of the radius of the social network on the conflict a scatter plot is used to find out for what radius the most conflict occur (see Appendix G for these results). Here can be seen that an increase in the radius of the social network increases the strength of the conflict slightly. Since no statements can be done on the strength of a conflict (only the direction), this observation is not well-grounded.

Another reason for the conflicts can be the assignment of other conversion factors. For example, the conflicts that arise *within* the high income level group can be caused by the conversion factors energy label and ownership. These conversion factors can be different *within* the high income level group and can therefore cause that some of the households do not have a feasible option, while their income level is high. As mentioned before, it is expected that in 'De Vruchtenbuurt' some high income level households live in a less energy efficient house. Since in less cases conflicts arise between affordability and comfort than between security of supply and comfort or sustainability and comfort, it is expected that the conflicts between affordability and comfort can be explained by the assignment of conversion factors.

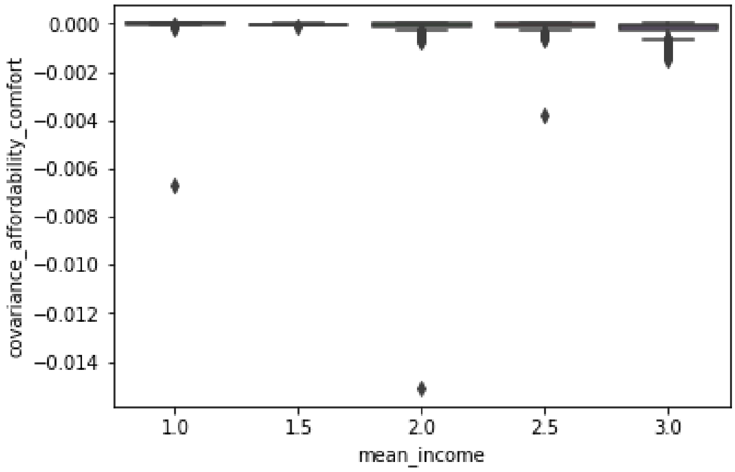


Figure 6.10: Box Plot: Conflicts between Affordability and Comfort (y-axis) between and within Income Groups (x-axis).

Traditional Values and Inclusiveness in Conflict

In Figure 6.11 can be seen that the value security of supply and inclusiveness are in conflict mostly *within* the group of households with a high income level, to a lesser extent *between* the group of households with a middle income level and the group of households with a high income level. Also, a few situations can be found for which conflicts *between* the lowest and highest income groups is identified. Since the value inclusiveness is not evaluated by the community size (the level of cooperation) and the chosen technical design, it is questionable what influences these conflicts. Since not many conflicts are found, which is also the case for the conflicts of inclusiveness in relation to affordability and sustainability (see Appendix G for these results), it is expected that these conflicts can be explained by the diversity of income levels in 'De Vruchtenbuurt' (since inclusiveness is partly determined by the income level).

When taking a look at the ranking of determining factors of the cases where a conflict between security of supply and inclusiveness is identified (Figure 6.12), can be seen that the choice of technical design determines mostly these cases. The explanation for this sensitivity is that inclusiveness is determined strongly by the feasibility of the options a household has. For example, only the households that live in a house with energy label A to A++ or B have the option to conduct all technical options. Furthermore, only the households with a high income level have the option to conduct all technical options. Therefore it is expected that especially conflicts arise when some of the households in 'De Vruchtenbuurt' have a feasible option and other households do not have a feasible option.

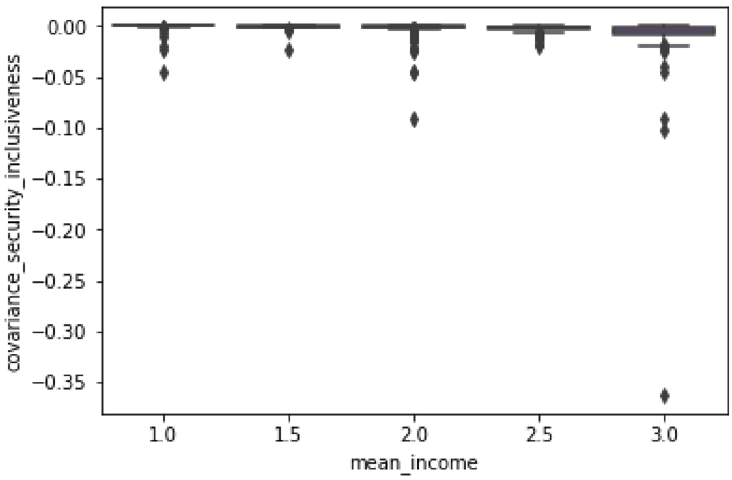


Figure 6.11: Box Plot: Conflicts between Security of Supply and Inclusiveness (y-axis) between and within Income Groups (x-axis).

technology_heat	0.784625
radius_socialnetwork	0.065810
companies_utility_sector	0.036838
medium_socialnetwork_group	0.016107
range_inclusiveness	0.015553
large_socialnetwork_group	0.015415
large_size_community	0.015093
medium_size_community	0.014405
subsidies	0.013227
technologies_more_sustainable	0.009662
renovations_cheaper	0.006816
community_model	0.006450

Figure 6.12: Ranking of Determining Factors for Conflicts between Security of Supply and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

When looking at Figure 6.13 can be seen that the conflict between affordability and inclusiveness mostly occurs when the 'all electric' design or the 'LT heat grid' design is chosen. Just a few cases can be found for which the choice for the 'HT heat grid' design causes this conflict. This can be clarified by the high amount of households that have a feasible options when the 'HT heat grid' design is chosen compared to the other designs. Also, because the 'HT heat grid' is the least expensive, the values affordability and inclusiveness are more often aligned.

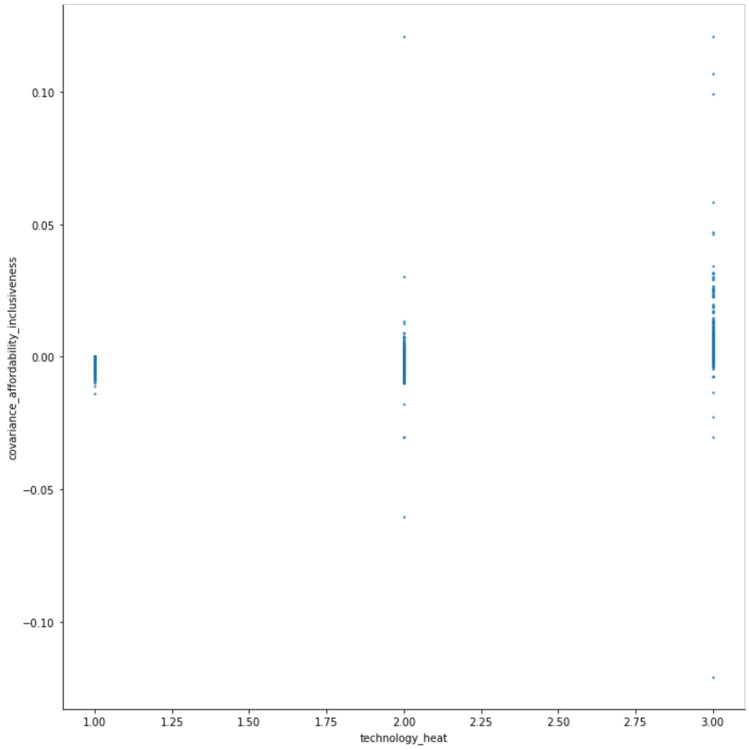


Figure 6.13: Sensitivity to Technical Design (x-axis: 1 = all electric, 2 = LT heat grid and 3 = HT heat grid) for Relation between Affordability and Inclusiveness (y-axis: negative = conflict and positive = no conflict).

Autonomy, Comfort and Inclusiveness in Conflict

Whether the more progressive values, i.e. autonomy, comfort and inclusiveness are in conflict with each other or with themselves is discussed in this section.

Between the values autonomy and comfort conflicts are expected, since the fulfillment of these values require different technical designs (conceptualization). However, other factors that influence these values (directly) are different. When looking at Figure 6.14, can be seen that mainly conflicts *within* the group of households that live in a house with energy label A to A++ and B arise. These cases can be influenced by the technical designs that are feasible for households that live in an energy efficient house. For the fulfillment of value autonomy, the 'all electric' design is most desired and this is the least desired technical design for the fulfillment of value comfort. A household in 'De Vruchtenbuurt' that has a feasible option with the 'all electric' design can fulfill the value autonomy, but therefore does not fulfill the value comfort and the other way around.

Furthermore, in Figure 6.15 can be seen that a combination of 'LT heat grid' or 'all electric' design and a low radius for social network causes conflicts between

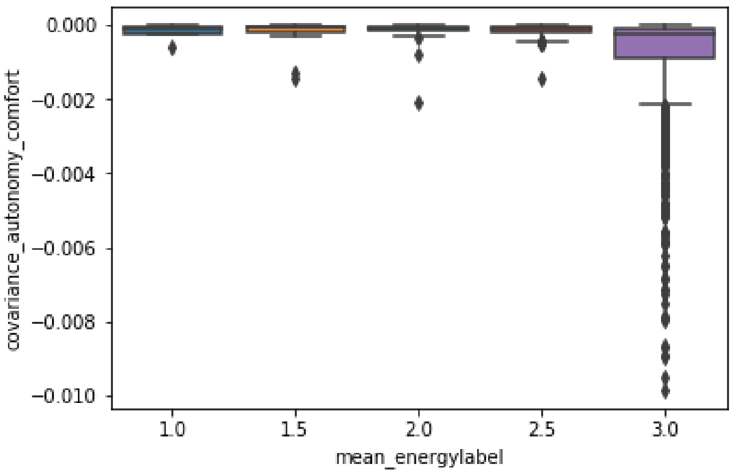


Figure 6.14: Box Plot: Conflicts between Autonomy and Comfort (y-axis) between and within Energy Label Groups (x-axis).

autonomy and comfort. The same goes for the relation between comfort and inclusiveness (see for this results Appendix G). When looking at the sensitivity of the conflict between autonomy and comfort to the technical design (see Figure 6.16), can be seen that besides conflicts for the 'all electric' and the 'LT heat grid' design also conflicts occur when the 'HT heat grid' is chosen. However, these conflicts can also be determined by the combinations of assigned conversion factors. A household in 'De Vruchtenbuurt' that is renting its house and therefore has a low level of autonomy can be in conflict with a household that is owner of its house and is able to fulfill its value comfort.

When analyzing the relation between autonomy and inclusiveness, this conflict is not sensitive the the chosen technical heat design (Figure 6.17), but to the radius of the social network. The value inclusiveness is not influenced by the technical design directly (the feasibility of the technical design for a specific household is influencing the value inclusiveness) and autonomy is also influenced by ownership, type of building and the community size (next to the technical design). This can clarify why the conflicts between autonomy and inclusiveness are not determined to a large extent by the technical design (in comparison to most other conflicts). When is determined for what radius of social network most conflicts occur, no clear answer can be given. Therefore more research on the clarification of this conflicts have to be conducted.

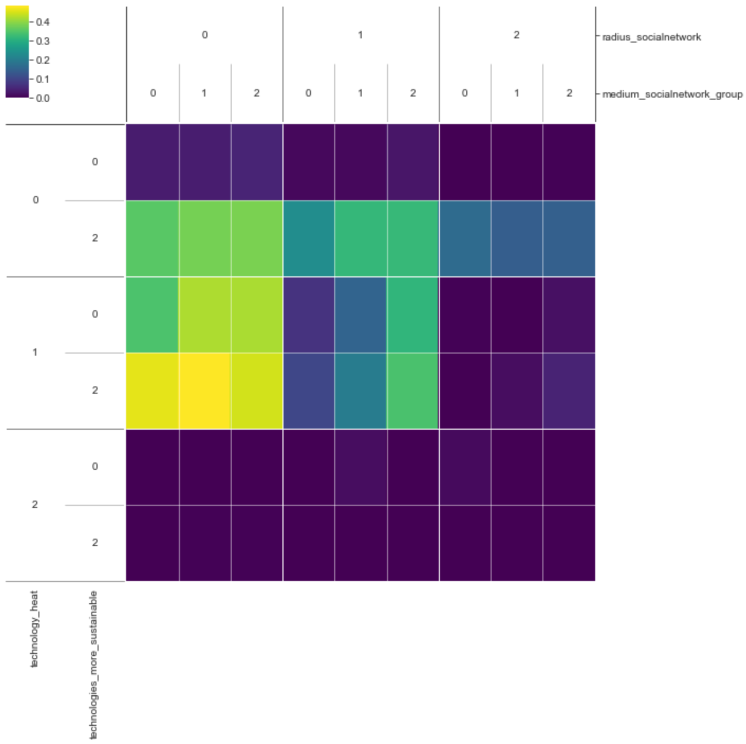


Figure 6.15: Dimensional Stacking of the Conflicts between Autonomy and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

radius_socialnetwork	0.160471
medium_size_community	0.141703
large_size_community	0.137960
large_socialnetwork_group	0.118367
range_inclusiveness	0.117903
medium_socialnetwork_group	0.117357
technology_heat	0.049797
subsidies	0.040175
renovations_cheaper	0.035884
technologies_more_sustainable	0.031865
companies_utility_sector	0.028264
community_model	0.020255

Figure 6.17: Ranking of Determining Factors for Conflict between Autonomy and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

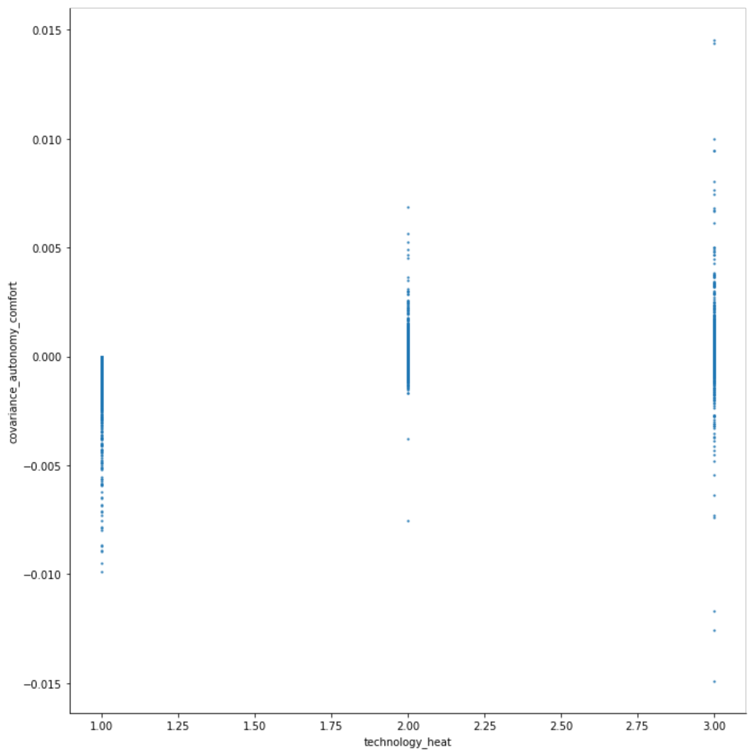


Figure 6.16: Sensitivity to Technical Design (x-axis: 1 = all electric, 2 = LT heat grid and 3 = HT heat grid) for Relation between Autonomy and Comfort (y-axis: negative = conflict and positive = no conflict).

When is determined if conflicts within the values arise, mainly conflicts within value autonomy and within value comfort can be identified. The conflicts within value autonomy *between* different conversion factor groups (and not within conversion factor groups) can be seen in Figure 6.18. The conflicts occur between the highest and the lowest income groups (mean = 2 and variance = high), the lowest and the middle income groups and the middle and highest income groups. The income of a household does not directly influence the value autonomy, but can cause that some technical designs are not feasible for some households which are feasible for other households. This can lead to conflicts between these groups. When looking at the factors to which the conflicts within autonomy are sensitive, some parameters with a low score arise. When looking at the dimensional stacking, it seems that the combination of different factors lead to these results and are not always the same. To understand the conflicts within autonomy better, it is necessary to conduct more analysis. The results of above mentioned points and the results for the conflicts within the value comfort can be found in Appendix G.

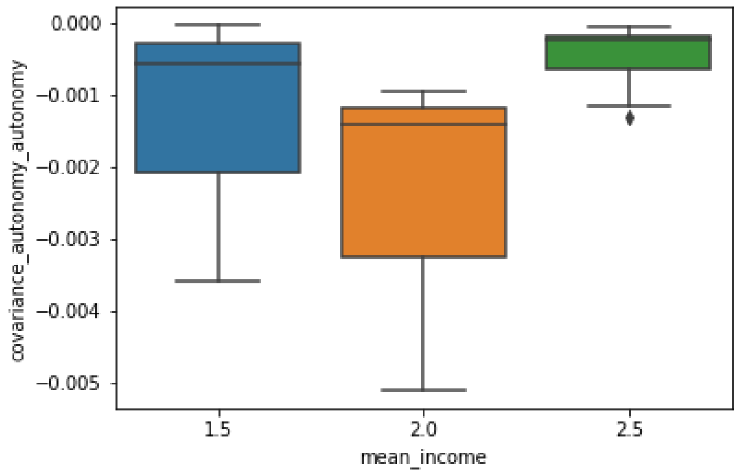


Figure 6.18: Box Plot: Conflicts between Autonomy and Autonomy (y-axis) between and within Income Groups (x-axis).

6.4.2 Conclusions

The goal of this chapter is to answer the second sub research question:

"Under what conditions (uncertainties and policies) do household value conflicts occur?"

For answering this question experiments and analyses are conducted in order to find out under what combinations of policies and uncertainties conflicts *between* and *within* conversion factor groups can be identified. The main findings are presented below.

Many cases can be identified for which conflicts occur *between* a group of households with a high income level and a group of households with a lower income level. Also, many cases exist for which a value conflict can be identified *between* a group of households with a energy efficient house and a group of households with a less energy efficient house. Income level and energy label form constraints for the households to have a feasible option and therefore conflicts *between* these different conversion factor groups arise.

Value conflicts can be identified *within* conversion factor groups, too. Two reasons can explain the occurrence of these conflicts. Firstly, because some conflicts are inherently conflicting (autonomy and affordability). Secondly, because the other conversion factors of the group differ. For example, some households in 'De Vruchtenbuurt' with a high income level might live in a house that is energy efficient and some households in 'De Vruchtenbuurt' with a low income level might live in a house that is energy efficient. This means that even if a conversion factor, like income or energy label, is the same for a group of households, other conversion factors can cause that households have different feasible options, and therefore certain values are conflicting. The same reasoning can be applied to the other conversion factor ownership.

The main conflicts are identified between autonomy and the traditional values that require cooperation, i.e. security of supply, affordability and sustainability. These conflicts were already revealed in the interviews and are therefore embedded in the conceptualization. Logically, in the experimentation these conflicts are identified, mostly *within* and *between* different income groups and *within* and *between* different energy label groups. However, when a group of households in 'De Vruchtenbuurt' do not have a feasible option at all, these inherent conflicts do not occur, because these households cannot fulfill any value (and therefore the values are not conflicting).

Furthermore, value conflicts between comfort and the more traditional values are identified. Furthermore, comfort is also in conflict with autonomy and inclusiveness. The conflicts of comfort in relation to security of supply, sustainability and autonomy are to some extent embedded in the conceptualization. The other conflicts are determined by the other conversion factors that differ for the group.

Also, value conflicts are identified between inclusiveness and the more traditional values. Furthermore, inclusiveness is also in conflict with comfort and autonomy. When in a larger community in 'De Vruchtenbuurt' many different households with different characteristics (in this research the inclusiveness is determined by the income) are present, this can influence the fulfillment of inclusiveness. This is also the case for the households that cannot join due to their conditions and the households that form a community on their own (because their conditions allow them). Since the households that cannot join the community are in many cases the households that have a low income level and the households that decide not to join are in many cases the households with a high income, the households that (have to) do the same (not joining together) are not always the households with the same income level. This influences the fulfillment of inclusiveness negatively. Other values might be fulfilled for the households with a feasible option and therefore conflicts with the value inclusiveness occur.

The conflicts are most sensitive to the combination of conversion factors and the chosen technical heat design (except for the value conflicts of autonomy in relation to affordability and inclusiveness). The value conflicts of comfort in relation to security of supply, sustainability and autonomy are partly caused by the conceptualization, since the fulfillment of comfort requires another technical heat design than the fulfillment of security of supply, sustainability and autonomy. However, the other conflicts are caused by the specifications of 'De Vruchtenbuurt'. For many households it is not feasible when the 'all electric' design is chosen. When a technical design is chosen that gives more households a feasible option, less conflicts are identified. It should be noted that the inherent conflicts between autonomy and the traditional values are expressed more cases when more households have a feasible option.

Chapter 7

Lessons and Implications

The aim of this chapter is to answer the following sub research question:

What are the effects of strategies on household value conflicts?

To answer this sub question it is important to first discuss the limitations of this research (7.1), in order to give well considered advice taking into account the scope and choices made in this research. Then the translation to the real world is made by giving advice, insights and lessons drawn from this research (7.2). The results of the experiments and the insights from the third 'implication' round of interviews are used to provide lessons for 'De Vruchtenbuurt'. In section 7.3 is discussed if the lessons can also be used for other city districts and maybe even on other levels (like municipalities). Finally, the use of the model is discussed (7.4). It is discussed to what extent the model fits the purpose and if it can be useful for other cases.

In this chapter information and data from interviews are used which is, as before, indicated by the interviewee or event between brackets placed behind the statement.

7.1 Limitations of the Research

Some of the limitations have to do with the scoping choices, but other limitations are identified during the process of the research and are important to take notice of. The limitations should be kept in mind when using the results for real world applications. Discussing the limitations of this research is done in four categories: meaning of the results (7.1.1), data and detail level (7.1.2), translation of the conceptual model (7.1.3) and development of city districts (7.1.4). On the important limitations is reflected in Chapter 9. Also, suggestions for future research are formulated in that chapter.

7.1.1 Meaning of the Results

The most important limitation in this research is that it is difficult to understand what the results actually imply. Since the problem is rather complex and includes many aspects that can be understood in different ways, it is very important to communicate thoroughly what questions can be answered, what lessons can be learned from this research and which questions remain unanswered. Three points illustrate this limitation and are explained in more detail.

The way the value conflicts are identified tells something about the relation between two values. However, when no conflict is identified between two values under certain conditions, it does not imply that both values are fulfilled. It is also possible that the values are aligned because they are both not fulfilled or because both vary independently. The aim of this research is to find value conflicts and therefore the focus was not on the fulfillment of individual values. **Results of experiments:** In 'De Vruchtenbuurt' some of the inherent conflicts are not expressed, since many households have no feasible option (due to their characteristics). It therefore seems that the inherent conflicts are not present in some cases, while it actually means that the households cannot fulfill any of its values. When policies and innovations are used to make sure all households have a feasible option, it is possible that the inherent conflicts show up in all cases.

Furthermore, when no conflict between two values is identified, it does not mean that the benefits and burdens are distributed equally. In the evaluation of the value inclusiveness the similarities in income for the households that perform the same are taken into account, but this neither implies how exactly the costs are divided nor what the distribution of the other burdens and benefits are. **Results of experiments:** Almost no cases with value conflicts within a group of households with a low income level can be identified in 'De Vruchtenbuurt', since in most of the cases these households do not obtain a feasible option. This means that even the inherent conflicts are not expressed in these cases.

Finally, in this research is tested under what conditions fulfilling the set of values of households is in conflict with fulfilling the set of values of other households. This does not imply that households will actually choose to fulfill their values and support the change to decentralized energy systems. It is important to note that the results of the experiments do not imply anything about the acceptance of decentralized energy systems in 'De Vruchtenbuurt' and in other city districts. **Results of experiments:** In 'De Vruchtenbuurt' even for households with a feasible option, conflicts arise (inherent or due to other conditions). However, it is possible that the households do not perceive the conflicts as a problem, such that they would still adopt the decentralized energy system. Furthermore, households might find other values (that do not relate to energy) more important, so they may not see these value conflicts on energy level as a big problem.

7.1.2 Data and Detail Level

Data on the city district properties, the type of decentralized energy systems and the values were difficult to collect and did not always provide the desired detail level. Nevertheless, a way was found to work around the detail level of the data and information. The conclusions from the results are consequently less detailed and should not be interpreted more detailed than they are. Three points illustrate this limitation and are explained below.

Firstly, the correlation between the conversion factors is not taken into account in this research (since no specific data are available on the correlations), while it is possible that some of the conversion factors are correlated (like income level and energy label). The results from the model, where conversion factors are assigned, can therefore lead to unrealistic results in some cases. When the conversion factors are assigned randomly to the households, favorable and unfavorable combinations can be created, which can lead to different results. The experiments run with the model were performed in replicates to determine the robustness of the results. Furthermore, interviews were conducted to check whether certain value conflicts are expected to happen in reality or not. The interviewees expected that most of the results reflect realistic scenarios. **Results of experiments:** In 'De Vruchtenbuurt' in many cases the conflicts are dependent on the combinations of conversion factors. Since many experiments were run, many different scenarios were identified. Due to privacy reasons it is not possible to retrieve exact information on the conversion factors of a household in 'De Vruchtenbuurt'. Testing many different scenarios is therefore the only way to generate possible outcomes for 'De Vruchtenbuurt'.

Secondly, when the options are compared to rank them for the evaluation per value, an ordinal scale is used, since it is not known how much better a certain option is than another. Therefore this research does not allow to rank the conflicts that are found in the analysis (as explained in Chapters 4 and 5). This is not a problem for identifying the value conflicts, it is however a problem when the results are interpreted as if a interval scale is used. **Results of experiments:** In 'De Vruchtenbuurt' some cases are identified where trade-offs have to be made between different values (for example: comfort and affordability). However, since an ordinal scale is used, the difference in comfort between two different technical designs might be smaller than the difference in affordability. This cannot be identified with this research.

Finally, the data on the characteristics of the households used to define the conversion factors of the households in the model were often divided in three or two groups, while in reality the characteristics of households are not divided in more than three groups. Since the results are generated per conversion factor group and not per individual household, the groups were useful to define the categories.

This is a limitation of the model, but it does give the possibility to access a lot of information in a more structured way. **Results of experiments:** In 'De Vruchtenbuurt' conflict are mainly identified within income level groups or energy label groups.. For example, cases are identified where a groups of households with a high income level have a conflict between security of supply and comfort. It remains the question whether this conflict is caused by the other household characteristics (like ownership and energy label), by the chosen technical heat design (the fulfillment of these values require another technical heat design) or by both.

7.1.3 Translation of the Conceptual Model

In this research the Capability Approach is used to structure the information in different building blocks and describe the relation between these blocks. However, the translation of these building blocks into a model resulted in some difficulties. Some choices have been made to make the translation feasible and in Chapter 5 the influence of these choices was tested. Three points illustrate this limitation and are explained in more detail. It is also explained how the limitation is dealt with.

Firstly, when a household tests if it can increase the level of its values, the options are compared by using the weighted average of all the values together. This evaluation criteria might be limited, since it prioritizes values indirectly. The prioritization of values can happen directly, but as explained here also indirectly. It is important for policymakers to know that prioritization of values often happens quickly, sometimes without being aware of it. **Results of experiments:** In 'De Vruchtenbuurt' more feasible options occur when the 'HT heat grid' design is chosen. For the fulfillment of some values, i.e. security of supply, sustainability and autonomy, the 'HT heat grid' design is not favorable. A feasible option is most important, but as a result some values are given less priority.

Secondly, the set of weights given to the values is equal in this research. The experiment that included different sets of weights showed different results when higher weights were assigned to the values security of supply, affordability and sustainability compared to the values autonomy, comfort and inclusiveness. In reality it is possible, for example due to politics, that some values are prioritized (get higher weights) over others. In the previous point, the indirect prioritization of values is discussed, but in this case values can be prioritized directly. **Results of experiments:** In 'De Vruchtenbuurt' conflicts arise under an equal set of weights for the values. However, as in the experiment conducted with different sets of weights, the results would differ when the more progressive values, i.e. autonomy, comfort and inclusiveness, retrieve higher weights. It is therefore important to find out which values the households in 'De Vruchtenbuurt' hold most important and if that complies with the opinion of the governments.

Lastly, in this research the covariance is used to identify the relations between the values, since all the values use the same scale. However, some of the values are influenced by more factors, which means that the scale of these values is divided into more steps (within the range of the scale). Since only the direction of the relation between values is used and not the strength of the relations, it is not expected that the above two points have an influence on the way the results are used for implications. **Results of experiments:** Some cases in 'De Vruchtenbuurt' have a very small negative covariance between two values. Since the covariance does not imply anything about the strength, it is not possible to perceive this conflict as less important than a conflict with a bigger negative covariance. However, it is logical to perceive a bigger negative covariance as a bigger conflict, but this research does not account for ranking the identified value conflicts.

7.1.4 Development of City Districts

It is important to understand that the relevant values, designs and conversion factors can change over time due to the development of the city district and its surroundings. This implies that different results can be found when this research is executed again in a couple of years. Furthermore, if the scope is extended and some of the surroundings are included in the model, the results can also be influenced. Four points that are related to this limitation are explained in more detail below.

Firstly, not a complete set of the values, designs and conversion factors is taken into account. This implies that the inclusion of more components and aspects could influence the results. However, to keep the research accessible, a selection is made and according to consulted experts and stakeholders the most important components are included. **Results of experiments:** In 'De Vruchtenbuurt' cases are identified that solely examine the values that have to do with 'energy'. In 'De Vruchtenbuurt' more aspects affect the well-being (like the traffic in the city district). It should be noted that 'energy' is just a part of the well-being of the households in 'De Vruchtenbuurt'.

Furthermore, in this research only one governance model and one technical design are used in a city district. However, in reality it is possible that multiple models and designs are used within one city district. In the Vesta MAIS model, developed by PBL (2018), this is possible. This could be an addition to this model. **Results of experiments:** In 'De Vruchtenbuurt' some households decide to form a community on their own (since their characteristics allows them to) and not to join the bigger community when the 'HT heat grid' design is chosen. It is likely that these households in reality would choose an individual option ('all electric') or would join the 'heat grid' option later and do not get the benefits of buying materials in a large order. In the model only one technical design can be used in 'De Vruchtenbuurt', while it is not realistic that a household would create a heat grid on its own.

The dimension 'time' is not included in this model, but many of the factors taken into account can change over time. It could be interesting to take this into account when research is conducted in a dynamic instead of static way. For example, it would be possible that the social cohesion (and therefore the social network) of a household increases when it joins a community (Local Initiator 2). It would also be possible that new buildings are built in the city district or that households move out and other households with different characteristics move in. Besides that, it is very likely that values and technology will evolve over time. **Results of experiments:** In 'De Vruchtenbuurt' many households do not have a feasible option due to the combination of their characteristics. Especially for households that live in old houses, technical heat designs like 'all electric' are not feasible. It is possible that due to innovations these technical options become feasible. Furthermore, it is also possible that the set of values change. For example, social cohesion could be a value that becomes important in the future.

Lastly, this research focuses on the households within a city district, but does not include any implications on the city district in a bigger picture. Since the city district 'De Vruchtenbuurt' is part of the municipality The Hague and the municipality is part of a province and a region there can be further implications. Therefore it is important that advice for the specific city district 'De Vruchtenbuurt' also includes the consequences it has on other city districts in the municipality and the region. **Results of experiments:** The 'HT heat grid' design causes the least context dependent conflicts (since most households have a feasible option for this design). However, this technical option requires heat sources that can also be used for other city districts. It is therefore possible that the most acceptable technical option for 'De Vruchtenbuurt' is not the most acceptable technical option in the bigger picture.

7.2 Real World Implications for 'De Vruchtenbuurt'

Firstly, specific lessons for city district 'De Vruchtenbuurt' are given and secondly, is determined whether these lessons also lead to participation and support of the change to a decentralized energy system in the city district. It is important to note that **both the interview results and the modelling results are used** to generate these lessons.

7.2.1 Lessons for 'De Vruchtenbuurt'

As once written by Giuseppe Tomasi di Lampedusa: *"for everything to stay the same, everything must change"*, this statement can also be applied to the change of a energy system. Since the surroundings, the politics, the mindset of people and much more are changing, it is not possible to keep the current energy system the way it is. Change is inevitable and this is also a mindset that is necessary to communicate to the households. However, since the new options are more expensive than natural gas (current technical option), the government has to provide support to the people who do not have a feasible option to use heat instead of gas. The results of the model show that households do not have a feasible option in many cases and probably need support to join the energy transition and to be included. Since heat is perceived as a basic necessity of life, everyone should be able to change to a new option. The national government has the obligation to make sure that all households receive this basic necessity of life.

The technical designs that can increase the level of sustainability, security of supply and autonomy are often not feasible for the houses in 'De Vruchtenbuurt'. This is mainly due to the fact that the buildings in 'De Vruchtenbuurt' are built before 1945 and have mainly the energy labels D, E or F. Furthermore, the costs of the renovations are often high or even not realistic. It is therefore important that first of all the feasibility of the options are secured and that the main factors that limit the feasibility which are the income and ownership of the household and the energy label (construction year) of the building the household is living in.

To increase the feasibility of the technical designs it is important to facilitate innovations by the national government, in order to make more technical designs feasible for different types of buildings. Also, innovations for renovations of the houses (like insulation materials) can help to create more feasible options, since renovating and insulating old houses is extremely expensive, but are desired to limit the energy use.

However, it should be noted that even through innovations and financial incentives value conflicts remain or actually will be expressed when more households have a feasible option. Some of the values are inherently in conflict, given the way they are conceptualized in this research (for example: affordability with autonomy and sustainability with comfort), which means these conflicts cannot be solved. Because of this, it is not realistic to search for solutions that do not cause any value conflicts. Instead the focus should be on thresholds (minimum and maximum) that should be met for every value (Energy Systems Expert 3). Maximizing all the values seems impossible, but focusing on solutions that at least fulfill all the values to some extent can be a way of working (Policymaker 6).

The previous paragraphs show again that the task of finding solutions that meet all the values is extremely difficult. So, it is expected that volunteers in 'De Vruchtenbuurt' cannot complete the whole project (analyzing, choosing, executing and evaluating) from beginning to end. It is expected that the municipality might adopt the idea of the community (Decentralized Government 1), since the volunteers in the city district do not have enough time to realize the decentralized energy system and cope with the other households in the city districts that did not join the community (Decentralized Government 1).

It is for the municipality helpful that volunteers who live in 'De Vruchtenbuurt' help in exploring solutions, since they know the characteristics of their city district the best and can find out what is important for the households in 'De Vruchtenbuurt'. It is recommended to the volunteers in 'De Vruchtenbuurt' to specify what values are important for them and to what extent they find the level of the values acceptable (minimum and maximum thresholds). In this way they make their trading position clear, as it is important for them to be seen as a professional partner in the project (Local Initiator 2).

Two remarks can be made on the support of volunteers in the city district. Firstly, when just a part of the city district is involved in exploring solutions, this group is probably not representative for the whole city district (Local Initiator 1). Secondly, when the city district comes with a technical heat design that does not fit in the bigger picture of the municipality of The Hague, more resistance can arise when the municipality of The Hague does not adopt the preferred solution of the active inhabitants of the city district.

Furthermore, the municipality of The Hague does not have the jurisdiction to shut off natural gas, but it is possible that the municipality gets this jurisdiction at some point in time. When the municipality decides to shut off the gas in a certain city district, it needs to provide an alternative solution though. It is therefore important to make a heat grid or another technical option feasible. It should be noted that at least 50 (and probably even more) households in the same street or block have to join (Decentralized Government 1) to make a connection feasible. In the model and also in reality, the households that are interested in joining together to change to a decentralized heat system are not all located in the same block or street. It is therefore important when not all households in a city district join for a collective option, that at least the technical design is still feasible for the amount of households that do join.

7.2.2 Support of Decentralized Energy Systems in 'De Vruchtenbuurt'

As can be seen in Figure 2.3 only part of the Capability Approach is addressed in the core of this research, so the part where the households translate their options to actions is not analyzed. However, it is interesting to identify what the identified value conflicts mean for the acceptance, participation and support of the change to decentralized energy systems.

Acceptance can be supported in two main ways: involvement in the process and support in the realization (Policymaker 4). The policies discussed so far support in the realization. In many interviews is highlighted that for participation the process towards the change to a decentralized energy system is of great importance as well. Involving the different actors in the process can increase the 'procedural justice' and also the 'recognition justice' (Jenkins et al., 2016).

Furthermore, to avoid protest about the distribution of the burdens and the benefits ('distributive justice'), compensation could be considered. It is hard to choose the principle of fairness that results in the highest acceptance though. The distribution of the costs for the climate policy differs per income group (CE Delft, 2017). So, even if all income groups can fulfill their values, it does not mean that the benefits and burdens are divided equally (and equally depends on the principle of fairness that is used), i.e. when considering that the households that invest as the first adopters in new decentralized energy technologies have to spend more and take more risk than households that wait. Often these are the households with a higher income level, one may wonder if these households still deserve subsidies. On the distributive justice and principles of fairness is reflected in Chapter 9.

In some interviews is mentioned that due to the uncertainty of the new governance and technologies many stakeholders are insecure about making decisions. Law and regulations are not up to date for the new energy system which increases insecurity even more. Furthermore, the different government levels are more transparent by showing their lack of knowledge nowadays. The municipality of The Hague has an idea on how to heat half of the city district, but does not know how it will heat the other half (Decentralized Government 1, Local Initiator 3). This uncertainty has a puzzling effect on households. Some households get the motivation to find solutions themselves and want to create security for themselves (the community members in 'De Vruchtenbuurt'), while many other households decide to wait and find it the responsibility of the government to recommend solutions.

It is expected that starting with ten varying districts creates good practices and examples to support the change of other city districts in The Hague too (Decentralized Government 1, Policymaker 1, Policymaker 4). The municipality of The Hague selected different types of city districts, so the lessons learned from these city districts can be considered representative for the remaining city districts (Decentralized Government 1). If any city district can be compared to another city district is still questionable though, because in most of the interviews is highlighted that every city district has very specific features (Policymaker 3 and Policymaker 5).

Since the national government has no precise knowledge on the different types of city districts within a municipality, it is not its task to find exact solutions for every city district. The national government can create frameworks and guidelines to support the municipalities to find solutions that also can be applied on a higher regional and national level (Policymaker 5, Policymaker 6, Local Initiator 2). It is important that the municipalities plan ahead and do not promise certain heat sources to certain city districts, in case other city districts need this source more urgently (due to their conditions). The same goes for the use of heat sources that other municipalities or regions want to use, it is important that all the decisions fit into the bigger picture (Policymaker 5 and Policymaker 6).

Finally, in the evaluation of pilot projects executed by TKI Urban Energy (2018) is highlighted that households prefer to get information from other inhabitants of the city district than from higher authorities. In 'De Vruchtenbuurt' inhabitants are educated to become energy coaches, so they can inform other households with their experiences of making their house more sustainable (for example the insulation of the house). The experiment conducted in 'De Vruchtenbuurt', where households decreased the temperature of their boiler to 70 degrees Celsius to explore experience and comfort with this temperature, resulted in more trust in the city district to change to a HT heat grid of 70 degrees Celsius (Local Initiator 1, Local Initiator 3).

7.3 Lessons for Other City Districts

In this section is considered whether the lessons for 'De Vruchtenbuurt' can be generalized and used for other city districts and maybe for other levels (like municipalities). The lessons are categorized in six subgroups and are presented in sections 7.3.1 - 7.3.6.

7.3.1 Feasibility of Designs

When looking at other city districts in The Hague that are selected as 'green energy' districts, the context of those city districts differ from 'De Vruchtenbuurt'. Main differences are the governance model applied (public model) and the income level of the households that is often lower in these city districts than in 'De Vruchtenbuurt'. The houses are in some cases less old and many of the houses are part of housing corporations. The factors mentioned above mean that some of the lessons learned from the analysis can be applied to the other city districts, but since the context is different, other policies and approaches could work differently than for 'De Vruchtenbuurt'.

It is expected that the ownership of the houses is a determining factor that is differentiating for the city districts a lot. For example in city district 'Bouwlust & Vredelust' 75% of the households rent their house (CBS, 2017), and therefore the municipality of The Hague is taking initiatives in this city district by collaborating with the housing corporations (Gemeente Den Haag, 2018). How the other households that own their house are to be involved needs to be considered in a different way (for example by gatherings with the stakeholders). On the other hand, it is also expected that in this kind of districts the minority can step in more easily when the majority already changed (Policymaker 1). It should however not be neglected that the remaining households can have old houses or not enough financial resources to invest in the technical design chosen by the housing corporation (System Operator 2). Then it is necessary for the government to step in and support with financial instruments, like subsidies. Also, options are available for 'Verening van Eigenaren (VvE's)' to ask for subsidies jointly (Policymaker 3, Local Initiator 1), that could help the house owning households with financing the desired changes. Furthermore, in the concept version of national Climate Agreement building-related investments are included, that allows the household to shift the pay-off burden to the next owner when leaving the house before the investment is earned back (NVB, 2018).

7.3.2 Inherent Conflicts and Thresholds

In the previous section is stated that some of the values are inherently in conflict with each other (for example: affordability with autonomy and sustainability with comfort). In the results of the experiments it became clear that these conflicts are not totally independent of the conditions of the households in a city district, since it matters if the household has a feasible option (otherwise it cannot fulfill any of its values and therefore no inherent conflict can be identified). It is expected that these conflicts also will occur in other city districts for the households that have a feasible option.

The same advice is given to 'De Vruchtenbuurt': use thresholds for the values to make sure the new energy system at least does not neglect any of the values fully. When all households have a feasible option, the inherent value trade-offs occur. Then it is important to find out what the minimum and maximum acceptable level of the values is in order to know how much can be given in on one value to meet the threshold of another value. However, it is difficult to specify indicators to evaluate if a new energy system is meeting the thresholds. This approach will lead to new discussions.

Furthermore, when multiple types of decentralized energy systems fulfill the thresholds, new trade-offs arise. It requires to prioritize values to make a decision. Lastly, it can be questioned if the thresholds are the same for all city districts. For example, when a higher authority decides what the thresholds of a city district are, it is questionable if all city districts agree with these thresholds.

7.3.3 City Districts in a Bigger Picture

It is important to consider a specific city district in a bigger picture. This advice relates to all city districts which includes the task of the municipality to facilitate this. It is the task of the region coordinator to place all the municipalities in a bigger picture and the task of the national government to put all the regions in an even wider picture.

It can be useful to zoom in on a city district to find out what the city district needs by considering the conditions of the households. However, it is very important to zoom out after this analysis to make sure that the favored solution for the city district also aligns with the favored solution of other city districts, municipalities and regions.

It is difficult to find the right balance between conducting analysis in detail and keeping the overview on a higher level. The municipality of The Hague can be a key actor in finding this balance. The national government is too far away from the city districts to know what a city district desires and a city district is too involved in its own city district to see the bigger picture. The municipality has the difficult in-between position to understand both levels.

7.3.4 Process and Distribution

It is expected that the lessons concerning the support of the change to decentralized energy systems work for all the city districts. However, it is questionable if city districts where the households have other priorities than the energy transition involvement can be expected (Policymaker 5), even though it is facilitated.

Von Wirth et al. (2018) argue that it is important to communicate the benefits to the users of the decentralized energy system. In 'De Vruchtenbuurt' energy coaches are explaining households in the city district what the benefits of the change to decentralized energy systems are. In other city districts this approach could work as well. However, it is questionable if in all types of city districts volunteers can be found to become energy coaches in their city district.

Lastly, this research is not able to identify if the benefits and burdens are distributed equally over the households in 'De Vruchtenbuurt', but it is expected to be an important aspect for the acceptance of a new energy system (for all city districts). In Chapter 9 is reflected whether an acceptable decentralized energy system is also a 'fair' energy system or not.

7.3.5 Distrust in the Government

It is expected that possible distrust in the government plays a role in all city districts. The government is expected to be transparent nowadays and therefore shows its lack of knowledge about the energy transition to the society. Some of the households in city districts (like 'De Vruchtenbuurt') see it as motivation to explore solutions themselves. Other households decide to wait until the government comes with a feasible solution, which is more likely to happen in city districts where households do not prioritize the energy transition (Decentralized Government 2).

In city districts like 'Bouwlust & Vredelust' it is not expected that the households are taking a lot if initiatives themselves and do not mind to wait until the government finds a solution for them. The advantage of the understanding of the city district that can be given by the households that live in the city district, cannot be applied here though.

7.3.6 Good Practices and Local Experiences

The municipality of The Hague selected different types of city districts to change to decentralized energy systems first. It is expected that the ten selected 'green energy' city districts can form a good example and stimulate the other city districts that still have to change.

However, it can be questioned to what extent city districts can be classified in types. In the conducted interviews different answers on this question were given. Some of the interviewees mentioned that it is possible to create an approach for a certain type of city district and repeat this approach for the same type of city districts. When this is true, it would make the change to decentralized energy systems more efficient when the first city district of a certain type has changed. Other interviewees mentioned that it is not possible to categorize city districts in types and it is very important to analyze every city district in detail, as every city district has its own remarkable characteristics.

As shown in 3.1, the municipality of The Hague identifies the notable characteristics per city district, which indicates that all city districts are different to some extent. However, if all these differences also influence the change to decentralized energy systems is hard to predict upfront.

7.4 Use of the Model for Policymakers

When discussing the use of the model, it is important to keep in mind the limitations that are mentioned in section 7.1. The model should be used with the same purpose as it is used in this research, which is explained in Chapter 4. As stated by Box (1976): *"every model is wrong, but some models are useful"*. By being aware of the limitations of the model, it is possible to see to what extent the model is credible and applicable.

If this model is used for other city districts, then the conversion factors have to be changed for the specific data of the city district. If another governance model is applied in the city district, then the structure of the model might have to be changed. For example, when the municipality of The Hague takes the initiative (as with city district 'Mariahoeve'), and not a community (as with city district 'De Vruchtenbuurt').

Furthermore, it should be noted that this model is not designed to link or add to another model. It might be probably designed differently by any other researcher. Even though the model code is well documented and the interface is user friendly (as explained in Appendices D and E), most probably additional efforts have to be performed in training others to work with the model. In order to include a big number of households further design work has to be executed to make the model ready for fast decision-making. The way the model can be found is explained in Appendix H.

Chapter 8

Conclusions

Firstly, in this chapter a short summary of the research is given (8.1). Secondly, the answers to the sub research questions are provided (8.2) in order to answer the main research question (8.3).

8.1 Short Summary of the Research

This research has been performed to help the Dutch government with the decisions and choices it has to make in order to meet the requirements of the Paris Agreement and the Climate Agreement. Decentralized energy systems can be a solution for meeting these requirements, however trade-offs have to be made between different system criteria, which are evaluated as values in this research. The aim of this research is to find out what strategies can reduce and deal with value conflicts that can be identified when designing a decentralized energy system considering the properties of a city district. A specific city district is analyzed, i.e. 'De Vruchtenbuurt' in The Hague, the Netherlands. The research starts with an identification of values, conversion factors, governance models and technical designs which are important when changing to a decentralized energy system in 'De Vruchtenbuurt'. Following the Capability Approach is used to structure the different components and the relations between them. Subsequently, a translation of the components into a simulation model is made, using the values to evaluate the acceptability of the capabilities. By analyzing the values that are conflicting (for different conversion groups) for different input parameter settings, insights are gained about possible value conflicts that can emerge in 'De Vruchtenbuurt' and possibly also in other city districts. Finally, an analysis on strategies is developed that can be effective to limit the emergence of the identified value conflicts and therefore possibly support the change to a decentralized energy system in 'De Vruchtenbuurt' and in other city districts.

8.2 Answer to the Sub Research Questions

The sub research questions are answered below.

1. What household values are important in decentralized energy system and what household characteristics and design choices for the energy system influence these values?

Existing literature on values and changes in energy systems is used as input for the first round of orientation interviews. After the first round of interviews a selection of a set of values is made. The selection of this set is used as input for the second round of validation interviews. When the process values and the privacy and data security layer are not taken into account, the main values that are found to be relevant in this research for the change to a decentralized energy system in 'De Vruchtenbuurt' are: (1) security of supply, (2) affordability, (3) environmental sustainability, (4) autonomy, (5) comfort and (6) inclusiveness.

The Capability Approach is a normative framework which allows to evaluate the acceptability of the capabilities (options and chances for a household) with the above mentioned values. However, in order to use the Capability Approach also the other components of the framework have to be identified that influence the values and capabilities: (1) good and services and (2) conversion factors.

The components that influence the values are the type of decentralized energy system (good and services) used in the city district (specified in governance model and technical design) and the household characteristics (conversion factors). The conditions that appear to be important in existing literature, local documents and interviews are: (1) income, (2) ownership, (3) social network, (4) type of household, (5) energy label and (6) type of building. It should be noted that this list of conditions it not exclusive, but considered as most relevant here. Furthermore, in this research is focused on governance community models, since in the 'De Vruchtenbuurt' a community is taking the initiative to change to a decentralized energy system. Moreover, in this research is focused on technical heat designs, since 'De Vruchtenbuurt' focuses on the heat transition in first instance. Three heat designs are considered: (1) all electric, (2) low temperature heat grid and (3) high temperature heat grid.

2. How can the design choices for the energy system, household values and characteristics of 'De Vruchtenbuurt' in The Hague be specified in a simulation model?

To create a simulation model that can evaluate the relation between the values under different conditions, the identified components of the Capability Approach (see the answer on previous sub research question) have to be conceptualized and specified. The objective of the model is to identify under what combinations of the conversion factors, governance 'community' models, technical 'heat' designs and other policies and innovations value conflicts occur (given the uncertainty of the conceptualization). The key performance indicators that match with this objective are: (1) the fulfillment of the values per household (categorized in conversion factor groups) and (2) the relation between these values.

To achieve the model objective it is important to identify how the different combinations of aspects influence the evaluations of the values. In the model, households test if changing from community given their conditions and the chosen technical design can increase the overall fulfillment of their values and if changing is feasible for them. Whether a value is fulfilled or not is done by comparing the options and ranking them from best to worse. It should be noted that the ranking and scoring is done using an ordinal scale with the same minimum and maximum for every value. Since only the direction of the value conflicts is taken into account, and not the strength, it is expected that using an ordinal scale is not limiting to reach the aim of the model. Furthermore, it is important to note that conversion factors are assigned randomly and no correlation between the conversion factors is taken into account in this research.

3. Under what conditions (uncertainties and policies) do household value conflicts occur?

Firstly, it is important to note that some of the conflicts are inherent and already revealed by conducting the interviews, which is embedded in the conceptualization. Mainly, inherent conflicts can be identified between the more traditional values, i.e. security of supply, affordability and sustainability and the more progressive value, i.e. autonomy. This conflict is related to the requirement of collective solutions for the fulfillment of traditional values, which contradicts with the fulfillment of the value autonomy.

However, conflicts that result specifically from the conditions of the case 'De Vruchtenbuurt' are identified by modelling. Mostly conflicts between the more traditional values and the more progressive values, i.e. autonomy, comfort and inclusiveness are identified in 'De Vruchtenbuurt'. Also, cases can be observed in which autonomy is in conflict with comfort and inclusiveness and cases in which comfort is in conflict with inclusiveness. In 'De Vruchtenbuurt' most conflicts arise *between* and *within* income groups and *between* and *within* energy label groups, due to the diversity of income levels of the households and the diversity of energy labels of their houses. For example, in some cases a low income level group of households cannot fulfill the value inclusiveness for an all electric design (too expensive), while a high income level group of households can fulfill the value sustainability by applying the all electric design (most sustainable design). Another example, in some cases a group of households with an energy efficient house cannot fulfill both the values security of supply and comfort when the all electric design is chosen. One reason can be the properties of the design, since it supports the fulfillment of security of supply and opposes the fulfillment of comfort (which is embedded in the conceptualization and is not context dependent). Another reason can be the other characteristics of the households (income or ownership) that differ within the discussed household group.

As can be seen in the examples, the choice for the technical design (in 'De Vruchtenbuurt' less conflicts occur when the 'HT heat grid' is chosen as technical design that the 'all electric' design) together with the combinations of conversion factors (in 'De Vruchtenbuurt' not all the households that have a high income level live in an energy efficient house) are determining the conflicts the most. To summarize, the technical design is a determining policy and the combination of conversion factor is a determining uncertainty that form together the conditions that determine the value conflicts the most.

4. What are the effects of strategies on household value conflicts?

As can be concluded from the previous sub research question, many conflicts emerge due to the households not having a feasible option given their conditions. It is therefore important that the costs of the new technical designs are reduced in order to make it affordable for all the households. Furthermore, innovations are important to decrease the costs of renovations or to increase the compatibility of technologies with all types of buildings. Lastly, if the ownership of the house cannot be changed and therefore the households that rent their house should communicate with their owner to join the energy transition. Most of the households in city district 'De Vruchtenbuurt' own their house, but in other city districts more households might rent their house instead.

Even though some of the conflicts can be reduced when innovations and subsidies are applied, still other conflicts can occur. Some values are inherently in conflict and it is questionable if any policy can help to reduce these inherent conflicts. Because of this, it is not realistic to search for solutions that do not cause any value conflicts. Instead the focus should be on determining thresholds for each value to be met.

Hence it is questioned if other ways can support the change to decentralized energy systems, even though some value conflicts exist. A process where households are seriously concerned is initially helping to make these households participate in the energy transition. It is expected that it depends on the city district though, that the households in a less wealthy city district might not prioritize the energy transition and will more rely on the municipality taking initiatives and decisions for the change to decentralized energy system.

8.3 Answer to the Main Research Question

The main research question is answered below.

"How can household value conflicts be identified and reduced when designing decentralized energy systems?"

The identified value conflicts can be observed *between* and *within* different income groups and energy label groups and are mostly caused by the technical design and the combinations of household characteristics in 'De Vruchtenbuurt'. Many households have characteristics (e.g. low income level and low energy label) that constrain the feasibility of some technical designs (e.g. all electric). For those households it is not possible to join a community when specific technical designs are chosen, and consequently cannot fulfill their values. These households are in conflict with households that have characteristics (e.g. high income level and high energy label) that do not form a constraint. It is recommended to reduce the context dependent value conflicts by creating more feasible options for the heterogeneous households in 'De Vruchtenbuurt', by using financial instruments and by supporting innovations.

Even though value conflicts can be limited by these policies, not all value conflicts can be eliminated. The value autonomy is inherently in conflict with the more traditional values, i.e. security of supply, affordability and sustainability, since the fulfillment of these values require cooperation which contradicts the fulfillment of the value autonomy. Furthermore, the value comfort is inherently in conflict with the values security of supply, sustainability and autonomy, since the fulfillment of comfort requires another technical design than the other values. It is therefore important to find ways to deal with inherent value trade-offs. For example, by defining thresholds for every value in order to decide on design options that at least meet the thresholds of all the identified values.

Besides limiting the value conflicts and dealing with the remaining value conflicts, it is also important to focus on the process towards the change to decentralized energy systems. It depends on the type of city district which process works best, but it is expected that including the households from the beginning in the process can help to identify what thresholds most probably will be accepted by the households. Furthermore, including households in the process may result in less resistance and a higher degree of participation.

Chapter 9

Reflection, Contribution and Recommendations

The goal of this chapter is to reflect on the used concepts, frameworks and methods, the scoping and modelling choices and the research process (9.1 - 9.4). By contemplating on the previous mentioned points, it is also possible to identify the societal and scientific contribution of this research. Besides that, also recommendations for future research are given, for policymakers and for academic researchers. This chapter is considered as one of the most important chapters of this research report, since it gives insight in the credibility of the research and it reveals which research choices appeared to be wise and which did not.

9.1 Reflection on the Concepts and Frameworks

The Capability Approach is used in this research to make the problem accessible and to structure the conceptualization of the case. This normative value theory made it possible to take the type of decentralized energy systems into account as goods and services, the households characteristics as conversion factors and the households values to evaluate the acceptability of the capabilities. However, it can be questioned if another framework could also be used and if such other framework would lead to different results. The use of the Capability Approach and the assumption that the values are equally important are discussed in this section, following by arguing if this research contributed to the societal and academic knowledge gap. Lastly, recommendations for policymakers and academic researchers are given on the use of the Capability Approach.

9.1.1 From Capabilities to Functionings

In this research only a part of the Capability Approach framework is included. This research focused on the acceptability of decentralized energy systems and not specifically on the acceptance of decentralized energy systems. This means that the quantitative analysis has not taken into account if the households that have the option to join a community also will make this choice. This choice is influenced by many factors, i.e. personal preference, social influences, personal history, psychology and decision-making mechanisms (as shown in Figure 2.3). However, many interviews revealed that the process and the way households are informed and consulted in this process are of great importance.

It is important to note that households might have a feasible option to change to a decentralized energy system, but still do not make the decision to change. The many reasons why a household can decide to adopt their options are not examined in this research. However, it is expected that creating more feasible options for the households to change, and therefore limit at least some of the value conflicts, is a step in the right direction.

9.1.2 Is Acceptability Also Fairness?

In a research on the fairness of the energy transition by CE Delft (2017) the different principles of justice are discussed. CE Delft (2017) reveals that the new energy system has a larger impact on the households with a low income than on the households with a higher income. This shows that the distribution of the burdens is not equal, which is not taken into account in the research discussed in this report.

Furthermore, Jenkins et al. (2016) specified three types of 'energy justice' (Table 9.1): distributional, recognition and procedural justice.

Table 9.1: The Evaluative and Normative Contributions of Energy Justice (Jenkins et al., 2016).

Tenets	**Evaluative**	**Normative**
Distributional	Where are the injustices?	How should we solve them?
Recognition	Who is ignored?	How should we recognise?
Procedural	Is there fair process?	Which new processes?

The procedural and recognition justices are not thoroughly taken into account in the research in this report, since this research did not focus on the process towards the change to a decentralized energy system. However, not taking into account distributional justice in this research needs further discussion.

In the core of the research value conflicts say something about the possibility that the fulfillment of different values are in conflict. This does not mean that the values are also distributed equally. This research tested if all households have the option to join the change to a decentralized energy system and have the option to fulfill their values without being in conflict with other values of other households or other values of themselves. The detail level of the evaluation of the values is too abstract and the clustering of the households were the reasons that it is impossible to imply something about distributive justice.

Furthermore, this research does not take into account if the new energy system is acceptable towards the ones that are not included in the city district. The households (or city districts) that are the first ones in a municipality to become sustainable have advantages, but also disadvantages. The first households (or city districts) have more technical options (enough grid capacity and sources like geothermal heat are available). On the other hand, also a lock-in situation is created for these households (or city districts), since it is possible that new (not yet existing) technologies cannot be applied by them anymore. Furthermore, it is more expensive to be the first one to invest. Therefore subsidies can help those households (or city districts) to make the investment affordable. However, it can be questioned if all investors should get the same amount of subsidy, or should less wealthy households (or city districts) with a lower level of income get more subsidy? Moreover, it is important that the lessons learned from the first investors are communicated well, so not every district or household has to find out the same again. A last point, when the electricity grid has to be changed because of the new electricity demand, everyone who is connected to the grid has to pay for that, not only the ones that 'cause' the investment in the grid. This is seen as 'unfair' too.

Finally, the dimension 'time' is not considered in this research. Therefore intergenerational justice is also not taken into account. The question whether it is 'unfair' that the generation who lives now influences the climate, while this has a big influence on the next generations. The notion of intergenerational justice is not taken into account specifically, but is to some extent captured in the value 'sustainability'.

9.1.3 Direct and Indirect Prioritization of Values

This research intended not to prioritize any of the values, but during the research it became clear that not prioritizing values is rather difficult. Even though no direct prioritization is applied, it is very possible that values are prioritized indirectly. The traditional values, i.e. security of supply, affordability and sustainability retrieved a higher score when a household would join together in a large community. However, this meant that the fulfillment of the value autonomy was decreased. This example shows that the traditional values were indirectly prioritized.

On the other hand, in reality it is very likely that direct prioritization of values takes place, because of households perceiving some values more important than others. Nowadays the value autonomy is perceived as very important and therefore it is possible that some households do not mind to give in on the other values when they can fulfill their value autonomy. Also, the politics can influence which values are perceived important by the country.

It is expected that value conflicts remain, since values are inherently in conflict with each other. A way to deal with these remaining conflicts is to focus on thresholds for every value. Van de Poel (2009) discusses the method 'satisficing' to deal with value conflicts. However, the problem with satisficing is that thresholds of values have to be defined (which is not easy) and that it is possible that more cases meet the thresholds and then still prioritization has to take place to chose between the cases.

Furthermore, besides forming minimum thresholds for the values, it is also important to form maximum thresholds. For example, maximum thresholds can be set for the economies of scale that can be reached with a large community. In this way the value affordability is 'reached' at some point and then it is better for the fulfillment of the value autonomy to not join together in a even larger community.

9.1.4 Contribution of this Research

This research applies only a part of the Capability Approach, but made it possible to apply this part thoroughly. Applying the full approach would probably result in a high level of abstractness, since it was already difficult to make this part of the Capability Approach in this research specific.

In scientific literature and in interviews is revealed that mostly is spoken about participation and acceptance when discussing the social side of energy systems. Therefore this research focused on the determination of acceptability and gives understanding in the possible underlying explanation of non-acceptance.

This research did not contribute in identifying the distributive fairness of decentralized energy systems. Robeyns (2016) argue that *"the capability approach is often wrongly taken to be an egalitarian theory or a theory of social or distributive justice"*. Another theory is necessary to analyze the distributive justice.

A contribution for the ethics field is that in this research an attempt is made to conceptualize values, even though Sen (2009) states the following about value incommensurability: *"a much-used philosophical concept that seems to arouse anxiety and panic among some valuational experts"*.

9.1.5 Recommendations For Policymakers

As explained in previous chapters, some conflicts are inherent and therefore hard to solve. However, it is questionable if the households also perceive these value conflicts as a problem. Interviews revealed that often the process is more important than the outcome, therefore it might be wise to not only focus on the outcome, since it is highly possible that a fully social responsible energy system cannot be found.

For example, more research on the political preference, since it is expected that this is going to have a big influence on the acceptance of new energy systems and can be the main problem of failing when concerning the energy transition (Local Government 1, Policymaker 1, Policymaker 4, Policymaker 5).

Furthermore, this research identifies that autonomy has a high potential of being in conflict with other values and is also highly influenced by the conditions of a household. Therefore further research on this specific value can be useful to find out what different households exactly mean with autonomy and how important households perceive autonomy. In the current situation households can only pick the gas supplier, so not a lot of freedom of choice can be identified in the current energy system. Do households really mind if they are not able to pick their own heat supplier anymore or is it more about the idea of having an influence on the new energy system? These are interesting questions to conduct further research on.

Lastly, the perceptions of having more autonomy is sometimes more important than actually having more autonomy. Therefore it is interesting to look better into the perceptions households have of values like autonomy, to see whether households actually really want and need autonomy to accept the change to decentralized energy systems. This leads to defining a threshold for autonomy that the new energy systems should meet. By defining what level of autonomy is acceptable and accepted (which is not easy), it is possible to test if certain designs are meeting this threshold.

9.1.6 Recommendations For Academic Researchers

The Capability Approach allows to identify value conflicts for a real world case and takes into account the conditions of the households. Other frameworks, like resourcism, do not take the characteristics of the households into account and therefore it would not be possible to identify the value conflicts between different conversion factor groups. So, when conducting research focusing on the conditions of actors, it is recommended to use the Capability Approach framework over the resourcism framework.

It would be interesting if analysis can be done on the full Capability Approach framework to identify the relation between acceptability and acceptance of decentralized energy systems. However, it is expected that applying the full Capability Approach framework is very time consuming.

The question if the benefits and burdens are distributed fairly remains. This research was not able to identify whether the values are also divided equally, but non-acceptance can result from an unfair distribution of the benefits and burdens. It should be noted that creating a fair energy system is expected to be impossible, since every household (and actually every individual within a household) is affected differently. Furthermore, the Capability Approach is not a full theory of justice (Robeyns, 2016), it did not allow to analyze the distributive justice in this research.

It is expected that value conflicts remain and therefore the focus should be on thresholds (minimum and maximum) that should be met for every value. Further research can be conducted in defining these thresholds. Due to value incommensurability it can be hard to define a concrete threshold, but evaluating if an energy system meets the thresholds can be a way of dealing with the remaining value trade-offs.

9.2 Reflection on the Methods

In this section the used methods are discussed. Since it was possible to use other methods, it is discussed if the use of other methods would potentially lead to other results. The contribution of this research related to the used methods is then discussed. Finally, recommendations for policymakers and academic researchers are given.

9.2.1 Interviews

The snowball sampling technique was used to find experts and stakeholders to interview. At some point, the same kind of components (values, conversion factors, etc.) was given which lead to the decision that enough information was gathered. However, it is uncertain if due to this technique some important experts and stakeholders were not reached. How big may the impact be if other people were interviewed? It means that other values and conversion factors could have been identified as more important than the values taken into account in the core of the research now. This could have a big influence on the results. However, it depends on the choices related to scoping, which values and conversion factors were taken into account as well.

9.2.2 Agent-Based Modelling and Exploratory Modelling and Analysis

Agent-Based Modelling and Exploratory Modelling and Analysis are used as modelling method in this research. On the use of these methods is reflected below.

Agent-Based Modelling is mostly used for models that contain heterogeneous agents that interact with each other. It is expected that other methods would not have been able to include the diversity of households into the model. Furthermore, methods like 'system dynamics' and 'discrete-event simulation' are especially used for simulations over time, which is not the case in this research.

Furthermore, the Exploratory Modelling and Analysis method is used to conduct many experiments and it is not expected that another method would lead to different results. Another sampling method (than Latin Hypercube) could have been used, but it is not expected that the sampling method would result in major differences. Since the direction of the relation between the values is used only (and not the strength of the conflicts), it is not expected that different analysis would lead to extremely different results. Different analysis supported by the Exploratory Modelling and Analysis are used to analyze the results with almost all showing similar outcomes.

9.2.3 Contribution of this Research

Agent-Based Models often include complex entities which makes it difficult to specify and quantify these entities in order to develop a model. In this research the heterogeneous households are the complex entities. This research developed a way (conceptualizing and specifying the households in the case following the

Capability Approach) to deal with the complexity and spend a long time on qualitative research to get a better insight in the households.

Categorizing the households in groups made it possible to interpret a lot of results in a structured way. When only looking at the results generated with the Agent-Based Model, it is difficult (if not impossible) to draw conclusions from the results. In the Agent-Based Model it is only doable to see the overall fulfillment and relations of the values and not the fulfillment and relations of the values on household level.

9.2.4 Recommendations For Policymakers

The use of modelling methods allows to test many different scenarios. When applying qualitative methods to examine the change to decentralized energy systems in the Netherlands only, possible scenarios may be overlooked.

The use of modelling techniques is not easy when it is never used before. It is therefore questionable if it is efficient to let policymakers apply modelling techniques. However, the systematic thinking that is necessary before developing the model can be helpful in conceptualizing the case and can lead to thorough analysis of the components that are important to take into account in the change to decentralized energy systems.

9.2.5 Recommendations For Academic Researchers

It would be interesting to let someone else conduct the same research and see whether the results and conclusions of that research would be in line with the results and conclusions of this research. Especially when someone would conduct interviews with different experts and stakeholders this can lead to different insights.

Agent-Based Modelling is a helpful method when it is desired to take into account the heterogeneity and interaction of agents. Other modelling methods are expected to be less appropriate for taking the diversity of the households into account (which was an important component of this research).

It is recommended to link the Agent-Based Model to another modelling method like Exploratory Modelling and Analysis, since this makes it possible to analyze the results of the agents in categories. In this way (a part of) the heterogeneity of the agents is maintained and the amount of results can be analyzed in a structured way. However, categorizing the households has consequences for the determination of the distributive justice (as discussed in section 9.1).

9.3 Reflection on the Scoping and Modelling Choices

To keep this research accessible in the limited amount of time scoping and modelling choices had to be made. To make choices that do not prevent reaching the goal of the research was the most challenging part of the research. Some of the main scoping and modelling choices are discussed below. It is questioned if the decisions are wise in the end or if other choices would lead to better results.

9.3.1 Conceptual Simplifications

The simplistic way of comparing technical heat designs with each other in this research can be seen as a limitation, but on the other hand an integration of the technical, economic and social side has been made. The integration causes that not all parts can be very detailed. Other models, like the Vesta MAIS model of PBL (2018), focus on the technical and economic side. Therefore this model can be used next to the Vesta MAIS model to identify if the technical and economic solutions lead to possible value conflicts.

The way the households make choices in the used model are rather simplistic, since the actual choices of the households are not examined in this research. This research focuses on the options and chances that the households have to fulfill their values and not on the decisions to make use of their options and chances. Since the decisions of the households influence the conditions of the households, it was necessary to include some kind of decision-making of the households in the model. Again, this does not mean that these choices actually materialize (in reality).

Lastly, it can be questioned if the conceptualization and specification of the values are in line with the definitions given to the values. Even though most of the aspects mentioned in the definition are also used to conceptualize and specify the values, some choices had to be made to keep the research manageable. This means that in some cases the definition of a value includes more than the conceptualization and specification. For example, the value inclusiveness is defined as: *"the extent a household is able to participate in the change to a decentralized energy system and sacrificing the same as the other households to participate in that change"*, but the second part of the definition is only conceptualized using the different income levels of the households. It is possible that more factors have to be sacrificed to participate in the change to a decentralized energy system than just income.

9.3.2 Scoping Simplifications

The focus on one city district made it possible to make this problem manageable to research, but resulted in the risk of losing the bigger picture. However, to let this research lead to specific lessons, focusing on one case was necessary. It should be noted that the lessons for the specific city district have to be considered in the bigger picture. For example, when 'De Vruchtenbuurt' wants to apply a certain heat design with a certain heat source, the consequences for other city districts should be taken into account too.

In this research only the values of households are taken into account, which can be seen as a limitation. It can be questioned if the values that are identified for the households also can be used for other stakeholders. In one of the interviews is mentioned that similar discussions are being conducted on national and regional level (Policymaker 6). This implies that possibly the same values can be applied for stakeholders that represent the households on higher levels (municipalities, regions, provinces and national government). Furthermore, it is questionable if the values also apply to other stakeholders, like the system operator and energy suppliers. For example, does it matter for a system operator if the new energy system is comfortable? And does it matter for an energy supplier if everyone is included?

Furthermore, in this research only the acceptability and well-being of the households concerning 'energy' are taken into account. However, the well-being of a household goes beyond that. In general, it should be noted that this research only focuses on 'energy' and therefore does not imply anything about other aspects. It is therefore questionable how important the set of values concerning 'energy' are perceived when the full set of values to evaluate the well-being of a household would be identified.

Lastly, values and technologies are evolving over time and therefore the identified technologies and values in this research can be changed when time passes. It is therefore important to realize that the components and relations taken into account in this research might be different when this research would be performed again in a few years. For example, the value comfort became implicit after the gas transition, but is perceived as important when evaluating decentralized energy systems.

9.3.3 Contribution of this Research

For the system engineering field this research shows how to cope with values and value conflicts in new engineering systems. Not many studies have been done specifically on the change to decentralized energy systems on city district level before. This research goes beyond the technical and economic side of new engineering systems and makes an integration between the technical, economic and social side of the change to decentralized energy systems. However, due to the complexity only one city district is specified and no connection is made with other city districts.

This research was able to give insight in the possible social concerns when changing to a decentralized energy system on the level of a city district. The social side is complex, since it requires to take into account the heterogeneous households which are hard to understand for other stakeholders (like the national government).

It is not possible to conclude if the same values apply to the other stakeholders, since this is not included in this research. The stakeholders that represent the households (the different level of governments) have discussions about the same kind of values and it can be expected that a similar set of values occur when the values were defined for the municipality of The Hague. However, no further research is conducted to prove this.

9.3.4 Recommendations For Policymakers

This research shows how possible value conflicts can be identified given that many uncertainties remain. This research learns that even with many uncertainties an analysis can be conducted.

It should be noted that the analysis was time consuming and only one city district is analyzed thoroughly. To put the results of this research in a broader perspective, it could help to analyze other city districts and see if the same conflicts under the same conditions emerge. When multiple analyses have been conducted it might be possible to find patterns in value conflicts and specific conditions of a city district. This could make it easier to assign an approach to a type of city district. Furthermore, when all city districts in a municipality are analyzed and the technical design that results in the least value conflicts can be determined per city district, the municipality can check whether the preferred technical design of the city district is in conflict with other city districts or even with other municipalities.

In this research not all the possible combinations of governance models and technical designs are worked out in detail. Furthermore, also not all technical heat designs are considered (like green gas). When this research is used to analyze other districts, it might be necessary to add extra governance models and technical designs (when these options are considered in the city district).

Furthermore, in this research it is only possible that one governance model and one technical design are used at the same time. However, in reality within a city district different governance models and technical designs may be used. In the Vesta MAIS model, developed by PBL (2018), not every household has to use the same technical design. This can mean that within one city district some households use the 'all electric' design and other households the 'HT heat grid' design. This option could be added to the used model to see if different value conflicts emerge. When the households with an energy efficient house use the 'all electric' heat design, insulation is already done to some extent and can fulfill the values sustainability, security of supply and autonomy values. When other households live in older houses that are less energy efficient, it is better for these households to go for a collective heat grid design. However, in this case not all the values are fulfilled, but at least more households have a feasible heat option.

9.3.5 Recommendations For Academic Researchers

More research on the conceptualization of conversion factors as constraints and the evaluation of the values can be conducted, as in this research only the options are compared using an ordinal scale. It might be interesting to conduct more research on the exact conceptualization and specification of the conversion factors as constraints and the evaluation of the values, because then more precise comparison and trade-offs can be made. Furthermore, also more research can be done to identify the correlations between conversion factors, so the outcomes of the model are less dependent on the random assignment of the conversion factors to the households.

It is important to conduct further research on the identification of the co-evolution of values and technology. This research is static and therefore does not include the co-evolution. However, if a method can be found that can evaluate the acceptability of decentralized energy systems over time, this research can be even more useful for policymakers.

9.4 Reflection on the Research Process

In general the research process went well and most phases of the project went as expected. However, the translation of a qualitative case into a quantitative model was very challenging. Identifying which values, conversion factors and types of decentralized energy systems were important to take into account, took a lot of time. Even though a specific case was selected, collecting information by consulting scientific literature and conducting interviews was not easy. It is felt that this struggle had to do with the involvement of multiple disciplines in this research, which are described below.

9.4.1 Bringing Multiple Disciplines Together

First of all, the change to decentralized energy systems affects many disciplines. The social side of decentralized energy systems is often related to the ethics field and the technical and economic side is often related to the system engineering field. Bringing these two fields together, by also using a modelling approach, is challenging.

Second of all, the change to decentralized energy systems affects many stakeholders. Many stakeholders are influencing the energy transition and therefore it is difficult to find out who should be included as interviewees in this research. It was beneficial to bring different stakeholders together to make a comprehensive analysis, but it was hard to explain all the components of the research to the different experts and stakeholders. It took a lot of time to make the goal and vision of the research clear to the interviewees.

Furthermore, many insights were gathered before starting the modelling process, the process of retrieving the input for the model was already worth it to use a modelling approach. However, when no model would have been developed, no experimentation with the uncertainties and policies could have been done. The modelling approach had therefore an added-value in two ways:

- It is a trigger to understand the complexity of decentralized energy systems
- It made it possible to execute experiments with the different policies to come to policy advice and the uncertainties that are inherently linked to the complexity of decentralized energy systems

9.4.2 Contribution of this Research

The contribution of this research on this specific part is that multiple disciplines are brought together and the integration is made, not only concerning the topic itself (technical, economic and social side of energy systems) but also concerning academic fields (ethics, modelling and system engineering). The studies specified on decentralized energy systems are missing a thorough integration of the technical, economic and social side. This research focuses specifically on this integration. Furthermore, not in many scientific studies the integration is made between the fields of ethics, modelling and system engineering. In many studies ethics and engineering are not brought together. Van de Poel (2009) states that values are embedded in engineering systems though. This research can be seen as an example that links the ethics and system engineering field together by using a modelling approach.

Furthermore, by including many different stakeholders and experts in this research a very comprehensive view on the social side of decentralized energy systems is developed. To understand what really happens in the city district makes it possible to do specific research. This research covers a local problem, but the conclusions and lessons drawn from this research might be useful for different levels (regional, national and international). As Teisman (2019) argues that the energy transition is something that affects all levels of society and therefore it is expected that this research on local level also provides lessons for other levels.

9.4.3 Recommendations For Policymakers

The systematic approach used in this research to analyze a case can be a useful approach for policymakers. Even though it is not expected that policymakers will use a modelling approach for decision-making for the time being, tackling a case as if it is being translated into a model can be beneficial. It will help to bring the expertise of different experts and stakeholders together in order to conceptualize a problem (components and relations).

9.4.4 Recommendations For Academic Researchers

This research process shows how a study on values can have a qualitative start, a quantitative core and a qualitative end. Many studies in the ethics field are fully qualitative and therefore this research can be seen as setting an example.

It does not mean that a quantitative research always is better than a qualitative research, but this research shows that more insights are gained due to the quantitative part of the research. It would not have been possible to identify value conflicts under different conditions *between* and *within* conversion factor groups if no modelling approach was used, now it was possible to run the model for multiple scenarios.

References

Adil, A. M., & Ko, Y. (2016). Socio-technical evolution of Decentralized Energy Systems: A critical review and implications for urban planning and policy. *Renewable and Sustainable Energy Reviews*, *57*, 10251037. doi: 10.1016/j.rser.2015.12.079

Atkin, E. (2018). *Frances yellow vest protesters want to fight climate change.* Retrieved from `https://newrepublic.com/article/152585/frances-yellow-vest-protesters-want-fight-climate-change`

Augusiak, J., van den Brink, P. J., & Grimm, V. (2014). Merging validation and evaluation of ecological models to evaludation: A review of terminology and a practical approach. *Ecological Modelling*, *280*, 117-128. doi: https://doi.org/10.1016/j.ecolmodel.2013.11.009

Bohli, J. M., Sorge, C., & Ugus, O. (2010). A privacy model for smart metering. Paper presented at the Communications Workshops (ICC). *2010 IEEE International Conference*.

Box, G. (1976). Science and Statistics. *Journal of the American Statistical Association*, *71*.

Briggs, A., Weinstein, M., & Fenwick, E. (2012). Model Parameter Estimation and Uncertainty: A Report of the ISPOR-SMDM Modeling Good Research Practices Task Force-6 . *Value in Health*, *15*, 835842. doi: https://doi.org/10.1016/j.jval.2012.04.014

CBS. (2016). *Buurtkompas vruchtenbuurt.* Retrieved from `http://www.weetmeer.nl/buurt/'s-Gravenhage/Vruchtenbuurt/05181953/bagview`

CBS. (2017). *Cbs is uw buurt.* Retrieved from `http://www.cbsinuwbuurt.nl`

CBS. (2018). *Inkomen per gemeente en wijk, 2015.* Retrieved from `https://www.cbs.nl/nl-nl/maatwerk/2018/03/inkomen-per-gemeente-en-wijk-2015`

CBS. (2019). *Kerncijfers wijken en buurten 2017.* Retrieved from `https://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=83765NED&LA=NL`

CE-Delft. (n.d.). *Lt-warmtenet.* Retrieved from `https://www.ce.nl/assets/upload/image/Plaatjes%20themapagina's/Duurzame%20stad/CE_Delft_5R19_Factsheet_warmtenet_LT_Def.pdf`

CE-Delft. (2017). *Rechtvaardigheid en inkomenseffecten van het kli-*

maatbeleid. Retrieved from https://www.ce.nl/publicaties/1930/rechtvaardigheid-en-inkomenseffecten-van-het-klimaatbeleid

Chrisman, L. (2014). *Latin hypercube vs. monte carlo sampling.* Retrieved from http://www.lumina.com/blog/latin-hypercube-vs.-monte-carlo-sampling

David, N. (2009). *Validation and verification in social simulation: Patterns and clarification of terminology.* Springer, Berlin, Heidelberg.

Demski, C., Butler, C., Parkhill, K. A., Spence, A., & Pidgeon, N. F. (2015). Public values for energy system change. Global Environmental Change . *Global Environmental Change*, *34*, 59-69. doi: https://doi.org/10.1016/j.gloenvcha.2015.06.014

Der-Spiegel. (2014). *Energiearmut: Im dunklen deutschland.* Retrieved from https://www.spiegel.de/wirtschaft/soziales/energiearmut-reportage-ueber-menschen-ohne-stromversorgung-a-964258.html

de Wildt, T. E., Chappin, E. J. L., van de Kaa, G., & Herder, P. M. (2018). A comprehensive approach to reviewing latent topics addressed by literature across multiple disciplines. *Applied Energy*, *228*, 2111-2128. doi: https://doi.org/10.1016/j.apenergy.2018.06.082

Duurzaam-Nieuws. (2017). *De dunkelflaute: wat is dat precies?* Retrieved from https://www.duurzaamnieuws.nl/de-dunkelflaute-wat-is-dat-precies/

EBN. (2019). *Energie in nederland 2019.* Retrieved from https://www.ebn.nl/wp-content/uploads/2019/03/EBN_Infographic-2019_14MRT19.pdf

ECN, & RIGO. (2013). *Energiebesparing: Een samenspel van woning en bewoner - analy-se van de module energie woon 2012.* Retrieved from https://www.rijksoverheid.nl/onderwerpen/onderzoeken-over-bouwen-wonen-en-leefomgeving/documenten/rapporten/2013/12/02/energiebesparing-een-samenspel-van-woning-en-bewoner-analy-se-van-de-module-energie-woon-2012

Ecofys. (2018). *Kostprijs van zon-pv en wind in 2030.* Retrieved from http://www.nvde.nl/wp-content/uploads/2018/06/NVDE_Kostendalingen-zon-PV-en-wind.pdf

European-Parliament. (2010). *Decentralized energy systems.* Retrieved from https://www.europarl.europa.eu/document/activities/cont/201106/20110629ATT22897/20110629ATT22897EN.pdf

Friedman, J. H., & Fisher, N. I. (1999). Bump hunting in high-dimensional data . *Statistics and Computing*, *9*, 123-143. doi: https://doi.org/10.1023/A:1008894516817

Gemeente-Den-Haag. (2015). *Wijkprogramma vruchtenbuurt 2016-2019.* Retrieved from https://www.denhaag.nl/nl/in-de-stad/stadsdelen/segbroek/wijkprogramma-segbroek-vruchtenbuurt-2016-2019.htm

Gemeente-Den-Haag. (2018). *Programmaplan energietransitie den haag.* Retrieved from https://denhaag.raadsinformatie.nl/document/

6177290/1/RIS299076_Bijlage_2_Basisversie_programmaplanf

Goulden, M., Bedwell, B., Rennick-Egglestone, S., Rodden, T., & Spence, A. (2014). Smart grids, smart users? The role of the user in demand side management . *Energy Research Social Science*, *2*, 21-29.

HIER. (2017). *Wat kunnen we leren van denemarken.* Retrieved from https://www.hieropgewekt.nl/kennisdossiers/wat-kunnen-we-leren-van-denemarken

HIER. (2018). *Waarom aardgas geen schone brandstof is.* Retrieved from https://www.hier.nu/themas/stroom-en-gas/waarom-aardgas-geen-schone-brandstof-is

Hillerbrand, R. (2018). Why affordable clean energy is not enough. A capability perspective on the sustainable development goals. *Sustainability*, *10*(7). doi: 10.3390/su10072485

IF-Technology. (2018). *Haalbaarheidsstudie teo, ted en geothermie-retour - vruchtenbuurt in den haag.* Retrieved from https://www.warmindewijk.nl/images/Haalbaarheidsstudie-TEO-TED-en-Geothermie-retour---ex-fin.compressed.pdf

IRENA. (2018). *Renewable power generation costs in 2017.* Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf

Jenkins, K. E. H., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. W. M. (2016). Energy justice : a conceptual review . *Energy Research and Social Science*, *11*, 174-182. doi: 10.1016/j.erss.2015.10.004

Klimaatakkoord. (2018). *Ontwerp van het klimaatakkoord.* Retrieved from https://www.klimaatakkoord.nl/documenten/publicaties/2018/12/21/ontwerp-klimaatakkoord

Klimaatmonitor. (2018). *Klimaatmonitor.* Retrieved from https://klimaatmonitor.databank.nl/dashboard/Dashboard/Woningen/

Kunneke, R. W., Mehos, D. C., Hillerbrand, R. C., & Hemmes, K. (2015). Understanding values embedded in offshore wind energy systems: Toward a purposeful institutional and technological design . *Environmental Science Policy*, *53*(1), 118-129. doi: https://doi.org/10.1016/j.envsci.2015.06.013

Kwakkel, J. H. (2017a). *Open exploration with the exploratory modeling workbench [blog post].* Retrieved from https://waterprogramming.wordpress.com/2017/11/19/open-exploration-with-the-exploratory-modeling-workbench/

Kwakkel, J. H. (2017b). *Using the exploratory modeling workbench [blog post].* Retrieved from https://waterprogramming.wordpress.com/2017/11/01/using-the-exploratory-modelling-workbench/

Kwakkel, J. H. (2017c). The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making. *Environmental Modeling Software*, *96*, 239-250. doi: https://doi.org/10.1016/j.envsoft.2017.06.054

Kwakkel, J. H., Haasnoot, M., & Walker, W. (2016). Comparing Robust Decision-Making and Dynamic Adaptive Policy Pathways for model-based decision support under deep uncertainty . *Environmental Modeling Software*, *86*, 168-183. doi: 10.1016/j.envsoft.2016.09.017

Kwakkel, J. H., & Pruyt, E. (2013). Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty . *Technological Forecasting and Social Change*, *80*(2), 419-431.

Le-Figaro. (2018). *Emmanuel macron promet des aides pour le chauffage et le carburant.* Retrieved from `http://www.lefigaro.fr/conjoncture/2018/11/06/20002-20181106ARTFIG00073-emmanuel-macron-promet-des-aides-pour-le-chauffage-et-le-carburant.php`

Lempert, R. J., Popper, S., & Bankes, S. (2003). *Shaping the next one hundred years: new methods for quantitative, long-term policy analysis.* Rand Corporation. Santa Monica, CA.

Ligtvoet, A., van de Kaa, G., Fens, T., van Beers, C., Herder, P. M., & van den Hoven, J. (2015). Value sensitive design of complex product systems. *Policy Practice and Digital Science*, *10*, 157-176. doi: https://doi.org/10.1007/978-3-319-12784-2_8

Liu, J., Xiao, Y., Li, S., Liang, W., & Chen, C. P. (2012). Cyber security and privacy issues in smart grids. *IEEE Communications Surveys Tutorials*, *14*(4), 981-997.

Macal, C. M., & North, M. (2010). Tutorial on agent-based modelling and simulation. *Journal of Simulation*, *4*(3), 151-162.

Mikulecky, D. (2001). The emergence of complexity: science coming of age or science growing old? *Computers and Chemistry*, *25*(4), 341348.

Milchram, C., Hillerbrand, R., van de Kaa, G., Doorn, N., & Kunneke, R. (2018a). Energy justice and smart grid systems: evidence from the Netherlands and the United Kingdom . *Applied Energy*, *229*, 1244-1259. doi: 10.1016/j.apenergy.2018.08.053

Milchram, C., van de Kaa, G., Doorn, N., & Kunneke, R. (2018b). Moral values as factors for social acceptance of smart grid technologies . *Sustainability*, *10*(8), 2703. doi: https://doi.org/10.3390/su10082703

Munda, G. (2004). Social multi-criteria evaluation: Methodological foundations and operational consequences . *European Journal of Operational Research*, *158*(3), 662677.

NeoSmart. (n.d.). *De nieuwe energie transitie.* Retrieved from `https://www.neosmart.nl/city-zen`

Nu.nl. (2017). *Achtergrond: De financile gevolgen van daling van gaswinning.* Retrieved from `https://www.nu.nl/gaswinning-groningen/4945004/achtergrond-financiele-gevolgen-van-daling-van-gaswinning.html`

Nussbaum, M. (2011). *Creating capabilities: The human development approach.* Harvard University Press. Cambridge, MA.

NVB. (2018). *Ontwerp-klimaatakkoord neemt drempels voor gebouwgebonden financiering weg.* Retrieved from https://www.nvb.nl/nieuws/ontwerp-klimaatakkoord-neemt-drempels-voor-gebouwgebonden-financiering-weg/

OnsAardgas. (n.d.). *Bron van welvaart.* Retrieved from https://www.onsaardgas.nl/alles-over-aardgas/

Oreskes, N., Shrader-Frechette, K., & Belitz, K. (1994). Verification, validation, and confirmation of numerical models in the Earth sciences. *Science*, *263*, 641646. doi: 10.1126/science.263.5147.641

PBL. (2014). *Energiecoperaties: ambities, handelingsperspectief en interactie met gemeenten. de energieke samenleving in praktijk.* Retrieved from https://www.pbl.nl/sites/default/files/cms/publicaties/PBL_2014_Energiecooperaties-ambities-handelingsperspectief-interactie_1371.pdf

PBL. (2018). *Technisch en economisch potentieel voor een aardgasvrije gebouwde omgeving in de regio drechtsteden.* Retrieved from https://www.omgevingsweb.nl/cms/files/2018-11/pbl-2018-technisch-en-economisch-potentieel-aardgasvrije-gebouwde-omgeving-drechtsteden-3419.pdf

PBL. (2019). *Effecten ontwerp klimaatakkoord.* Retrieved from https://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2019-effecten-ontwerp-klimaatakkoord_3619.pdf

PwC. (2006). *Customer engagement in an era of energy transformation.* Retrieved from https://www.pwc.nl/nl/assets/documents/pwc-customer-engagement-in-an-era-of-energy-transformation.pdf

Rahmandad, H., & Sterman, J. (2008). Heterogeneity and Network Structure in the Dynamics of Diffusion: Comparing Agent-Based and Differential Equation Models. *Management Science*, *54*, 998-1014. doi: 10.1287/mnsc.1070.0787

Railsback, S. F., & Grimm, V. (2012). *Agent-based and individual-based modeling: A practical introduction.* Princeton University Press.

Rawls, J. (1971). *A theory of justice.* Cambridge, MA: Harvard University Press.

RES. (n.d.). *Nationaal programma res.* Retrieved from https://www.regionale-energiestrategie.nl/default.aspx

RLI. (2018). *Warm aanbevolen.* Retrieved from https://www.rli.nl/sites/default/files/advies_warm_aanbevolen_-_def.pdf

Robeyns, I. (2016). *The capability approach.* Retrieved from https://plato.stanford.edu/archives/win2016/entries/capability-approach

Rogers, E. (1962). *Diffusion of innovations.* Free Press, London, NY, USA.

Rokeach, M. (1973). *The nature of human values.* Free Press.

RVO. (2012). *Beoordeling van systeemconcepten voor duurzame gebieden.* Retrieved from https://www.rvo.nl/sites/default/files/2014/

10/Beoordeling%20van%20systeemconcepten%20voor%20duurzame%20gebieden.pdf

RVO. (2018). *Samenvatting smart grid groene mient.* Retrieved from https://www.rvo.nl/sites/default/files/2018/11/Samenvatting%20Smart%20Grid%20Groene%20Mient.pdf

Sen, A. (1993). *Capability and well-being.* Oxford Clarendon Press.

Sen, A. (2009). *The idea of justice.* The Belknap Press of Harvard University Press Cambridge, Massachusetts.

Stedin. (2015). *Usef: nieuw marktmodel maakt handel in flexibel energiegebruik mogelijk.* Retrieved from https://www.stedin.net/over-stedin/pers-en-media/persberichten/nieuw-marktmodel-maakt-handel-in-flexibel-energiegebruik-mogelijk

Stedin. (2018). *Layered energy system.* Retrieved from https://www.energy21.com/2018/12/layered-energy-system-exploring-a-new-energy-market-model/

Stedin. (2019). *Stedin start met andere netbeheerders uniek initiatief met gopacs.* Retrieved from https://www.stedin.net/over-stedin/pers-en-media/persberichten/stedin-start-met-andere-netbeheerders-uniek-initiatief-met-gopacs

Taebi, B. (2017). Bridging the Gap between Social Acceptance and Ethical Acceptability. *Risk Analysis*, *37*(10), 1817-1827. doi: 10.1111/risa.12734

Teisman, G. (2019). *Energietransitie gediend bij slim georganiseerde regionale tussenruimtes.* Retrieved from https://www.topsectorenergie.nl/sites/default/files/uploads/Algemeen/Essay%20Energietransitie%20en%20tussenruimte%202019.pdf

TKI-Urban-Energy. (2018). *Inspiratieboek maatschappelijk verantwoord ondernemen.* Retrieved from https://www.topsectorenergie.nl/sites/default/files/uploads/Urban%20energy/publicaties/Inspiratieboek%20maatschappelijk%20verantwoord%20innoveren%20-%20TKI%20Urban%20Energy%20.pdf

TNO. (2015). *Virtual infrastructure operating system (vios).* Retrieved from https://projecten.topsectorenergie.nl/storage/app/uploads/public/5a0/485/597/5a0485597c8d1065181051.pdf

TNO. (2018). *Tno webinars : Hoe maken we nederland aardgasvrij? 10 december en 15 en 22 november 2018.* Retrieved from https://www.tno.nl/nl/aandachtsgebieden/ecn-part-of-tno/roadmaps/naar-een-energie-producerende-gebouwde-omgeving/succesvolle-wijkaanpak-motiveer-bewoners/tno-webinars-hoe-maken-we-nederland-aardgasvrij/

United-Nations. (n.d.). *Decentralized energy system.* Retrieved from https://www.unescap.org/sites/default/files/14.%20FS-Decentralized-energy-system.pdf

United-Nations. (2015). *Paris agreement.* Retrieved from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

Valentine, S. V. (2014). *Wind power politics and policy.* Oxford University Press.

van Dam, K. H., Nikolic, I., & Lukszo, Z. (2013). *Agent-based modelling of socio-technical systems.* Springer Science & Business Media.

van de Poel, I. R. (2009). Values in Engineering Design. *Philosophy of Technology and Engineering Sciences*, *9*, 973-1006. doi: https://doi.org/10.1016/B978-0-444-51667-1.50040-9

van de Poel, I. R. (2016). A coherentist view on social acceptance and moral acceptability of technology . *Philosophy of Technology after the Empirical Turn*.

van der Schoor, T., & Scholtens, B. (2015). Power to the people: Local community initiatives and the transition to sustainable energy. *Renewable and Sustainable Energy Reviews*, *43*, 666-675. doi: https://doi.org/10.1016/j.rser.2014.10.089

Vangheluwe, H., & de Lara, J. (2002). *Meta-models are models too.* San Diego, California, USA, Proceedings of the 2002 Winter Simulation Conference.

van Kempen, R., & Bolt, G. (2009). Social cohesion, social mix, and urban policies in the Netherlands. *Journal of Housing and the Built Environment*, *24*(4), 457-475. doi: https://doi.org/10.1007/s10901-009-9161-1

von Wirth, T., Gislason, L., & Seidl, R. (2018). Distributed energy systems on a neighborhood scale: Reviewing drivers of and barriers to social acceptance. *Renewable and Sustainable Energy Reviews*, *82*(3), 2618-2628. doi: https://doi.org/10.1016/j.rser.2017.09.086

WarmInDeWijk. (2017). *Warm in de wijk, duurzame warmte in de vruchtenbuurt.* Retrieved from http://www.warmindewijk.nl/

Wijkberaad-Vruchtenbuurt. (n.d.). *Duurzaamheid.* Retrieved from https://wijkberaad-vruchtenbuurt.nl/category/duurzaamheid/

WonenInDenHaag. (2015). *Vruchtenbuurt.* Retrieved from https://wonenindenhaag.nl/wijken/vruchtenbuurt/

Wuebbles, D. J., & Jain, A. K. (2001). Concerns about climate change and the role of fossil fuel use. *Fuel Processing Technology*, *71*(1-3), 99-119. doi: https://doi.org/10.1016/S0378-3820(01)00139-4

Wustenhagen, R., Wolsink, M., & Burer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy*, *35*(5), 2683-2691. doi: https://doi.org/10.1016/j.enpol.2006.12.001

Zhang, T., & Nuttall, W. J. (2007). An agent based simulation of smart metering technology adoption.
doi: https://doi.org/10.17863/CAM.5130

Appendix A

Interview Questions

Different rounds of interviews were organized and underneath the questioned that were used as support for the interviews are presented. The interviews were in most cases unstructured. During the conversation was checked if all necessary questions were answered.

A.1 Round 1: Orientation

The first round of interviews were orientation interviews in order to understand the context of decentralized energy systems in the Netherlands and in specific in 'De Vruchtenbuurt'. A set of values and conversion factors is identified with the results of these interviews. Also, the different governance models and technical designs are discussed in these interviews.

- What is your role in the energy transition?
- With what other parties are you working together? What other parties are critical in this problem?
- What is your link to decentralized energy systems?
- What is your link to 'De Vruchtenbuurt'?
- What would you describe as remarkable aspects of this city district?
- What are aspects (values) that should be taken into account when is changed to a decentralized energy system?
- What specific characteristics of households are important to take into account when looking at the change to a decentralized energy system?
- How do you think these different characteristics influence the values?

- What do you expect to be the biggest obstacle when changing to a decentralized energy system?
- Which governance and technologies do you expect to have much potential?
- What do you expect from bottom-up initiatives? Is there enough support for these initiatives?
- Do you expect that a general approach for city districts to change to a decentralized energy system can be identified?

A.2 Round 2: Validation

In the second round of interviews is tested if the chosen values, conversion factors, governance models and technical designs are approved. These interviews are important to make sure that no crucial components are missed. Also, discussions about the scope of the research are held. Some of the interviewees mentioned that certain aspects could be taken into account, like data security and privacy and process values. However, it is decided that the focus of this research should not be on these parts of the transition in order to keep the research manageable. The first questions are the same as in the first round, since it is always useful to understand the context of the interviewee.

- What is your role in the energy transition?
- With what other parties are you working together? What other parties are critical in this problem?
- What is your link to decentralized energy systems?
- What is your link to 'De Vruchtenbuurt'?
- Do you agree with the chosen values? Are any important values missing?
- Do you agree with the chosen conversion factors? Are any important conversion factors missing?
- Do you agree with the chosen governance models and technical design? Are any models or designs missing?

A.3 Round 3: Implications

In the third round of interviews the results are discussed with different policy-makers, a researcher and a local initiator. This is done to verify the model output and to test the credibility of the research in order to make the translation to real world implications. The results of this interviews are mainly used in Chapter 7 and Chapter 9. Firstly, the researcher presented a summary of the research and shows the components taken into account in the research. Then the following question was discussed.

- Looking at the values, conversion factors, governance models and technical designs taken into account, what possible conflicts do you expect to emerge?

The researcher presented a summary of the results of the research. Then the following questions were discussed.

- Given the results from this research, do you expect that the identified value conflicts can be found in reality?
- Under which conditions do you expect that these value conflicts can occur?
- Are the identified value conflicts expected to occur in more cases (other city districts)?
- Do these value conflicts also lead to non-acceptance and protest?
- What strategies could help to reduce the value conflicts and do these strategies also result in more acceptance?

Appendix B

Stakeholder Identification

The actor scan is executed to identify the position of the different actors. Even though this research is not about the interests of the actors, it is useful to have an overview of the different actors (and their perceptions, objectives, interests and resources) that play a role in this problem (Table B.1 and B.2). Even though is mainly focused on the households (and are the only stakeholders that are modelled as agents), it is still important to understand the actor field to find out how other stakeholders can influence the households. Also, because different stakeholders are consulted for interviews and the actor scan helps to understand the position of the interviewees.

In Table B.1 and Table B.2 is revealed that especially the national government, the system operators and the decentralized governments have a strong position, besides the households and other users of the energy system in the built environment. Even though the focus of this research is on the households in the built environment, the actors that have power should be taken into account because of their instruments to influence and steer the energy system in a desired way. These critical actors (households, national government, region, municipality and system operator) are therefore further discussed below the tables.

Table B.1: Actor Scan (Part 1).

Actor	Problem Perception	Objective(s)	Interest(s)	Causes of Problem	Resources	Position
Households	Change in energy system without knowing what to choose and what the consequences are	Receiving affordable, reliable and sustainable energy	Depends per consumer, some people want to change, others are skeptical (heterogeneity)	Change of existing systems due to set targets	Protest and not adopting the new system	Strong (many households together)
Companies and Utility Sector	Change in energy system without knowing what to choose and what the consequences are	Receiving affordable, reliable and sustainable energy	Depends per company, some people want to change, others are skeptical (heterogeneity)	Change of existing systems due to set targets	Protest and not adopting the new system	Strong (but are not taken into account in this research, since the focus is on households)
Environmental Organizations (NGOs)	Share of renewable energy is too low in the Netherlands and carbon dioxide reduction targets might not be met	Promoting and supporting the change to renewable energy	High	Targets might not be met, which means that the climate change continues	Protest and lobbying	Medium
System Operators	The grids have to be compatible with the changes in the system	Maintaining a reliable and affordable grid	High	Current grids cannot handle the electricity peaks and the national government holds them responsible	Deciding on how to make the grids compatible	Strong

Table B.2: Actor Scan (Part 2).

Actor	**Problem Perception**	**Objective(s)**	**Interest(s)**	**Causes of Problem**	**Resources**	**Position**
Energy Suppliers	What products should they sell for what price?	Providing attractive products for the prosumers and consumers	High	Different technologies and resources are possible and the buyers have different desires	Deciding on which products are provided on the market	Medium
National Government	The Netherlands needs to meet its targets, but how can they make sure that all parties work together?	Supporting all stakeholders, so the new energy system is acceptable	High	Paris Agreement targets and Climate Agreement targets	Policy instruments	Strong
Decentralized Governments	Have to contribute in the energy transition, since they have to create Regional Energy Strategies (RES) and transition plans on municipality and district level	Creating strategies that are suitable for the specific region, municipality and district	Depends, some local governments see the urge of the energy transition, others have different priorities	Goals from higher governments and it is unclear how to govern the diversity of the areas	Policy instruments	Strong

B.1 Households

For the households many aspects change in their living environment the ones that have to change to a new energy system, while these households do not have to have any affinity with the new technologies that come along with the change to a decentralized energy system. Furthermore, some households do not have the right conditions to change to these new technologies. As explained before in Chapter 2, the citizens in the households are heterogeneous and therefore it is harder to make policies that do not lead to protests and delays. While other stakeholders in this problem situation (see next section and Appendix B) display the conflicts they experience, often households do not have all the information and therefore do not know what the energy transition means for them and what conflicts might occur. Even though, the households are not the ones that asked for a change in the energy system, they are the ones that have to deal with the consequences of the change. For policymakers it is hard to get a grip on the impacts on the households and can be seen as a blind spot (Policymaker 1). Therefore it is interesting to explore and evaluate the values of the households when is changed to a decentralized energy system.

In this research the characteristics of households and the houses the households live in are taken into account. However, it should be noted that with the characteristics in this research is meant the personal, social and environmental conditions of a household and not its preferences, perceptions and believes. For example, the level of income is a characteristic that is taken into account, but the drive to live sustainable not. Nevertheless, it does not mean that the conditions or characteristics of households cannot be related to the preferences and perceptions. For example, the participants of pilot projects are mostly the innovators (Figure B.1), but this is only a small amount of the households that change to a decentralized energy system. The households that change to new technologies later are different from the innovators and have possibly different characteristics. These differences can be the preferences, perceptions and believes why these households choose for new energy technologies (not included in the core of this research), or the conditions of these households and the houses these households live in. When a household has a high level of income, this household has the option to afford the investments that have to be made to change to a decentralized energy system (included in the core of this research), but can have the preference to spend its income on buying a new car (not included in the core of this research). To answer the questions of this research, it is important to identify the varying conditions of (Dutch) households, specified by their personal, social and environmental characteristics and the houses they live in. When value conflicts arise in the specific case 'De Vruchtenbuurt', this does not mean that the same value conflicts are applicable for another city district. Further in the research is reflected on the implications for other city districts when looking at the specific results of city district 'De Vruchtenbuurt'.

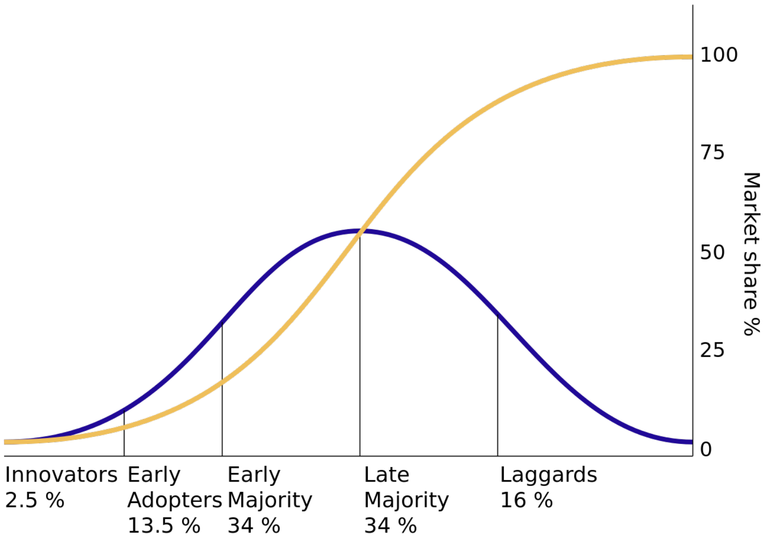


Figure B.1: Diffusion of Innovations (Rogers, 2003).

B.2 Other Stakeholders

A stakeholder scan is executed (Appendix B) to identify which stakeholders are most critical. The scan shows that especially the national government, the governments of a lower level and the system operator have a strong position, besides the households and other users (the companies and utility sector are not taken into account in this research) of the energy system in the built environment. Even though the focus of this research is on the households in the built environment, the actors that have power should be taken into account because of their instruments to influence and steer the energy system in a desired way. Therefore these critical actors are elaborated on.

B.2.1 National Government

The national government and especially the Ministry of Economic Affairs and Climate Policy have the obligation to meet the goals set in the international Paris Agreement and the national Climate Agreement. However, as mentioned by Teisman (2019), the energy transition is not a national project, but a project that reaches out over multiple levels (districts, municipalities, regions, but also international levels). Besides that, the energy transition is not only about 'energy', but also about other domains (social justice, spatial integration, ecology and economic growth). This means that the energy transition cannot be handled by the Ministry of Economic Affairs and Climate Policy only, since it has to deal with other ministries (Ministry of the Interior and Kingdom Relations, Ministry of Infrastructure and Water Management and Ministry of Agriculture, Nature and Food Quality). Furthermore, it means that the energy transition cannot be handled by the national government only. The national government has a difficult task to communicate with the different levels and should not forget to make sure the goals are achieved. Furthermore, it is the task of the national government to make decisions and take actions that are socially responsible and to take care of their citizens (Policymaker 1, Policymaker 4, Policymaker 5). The national government has therefore a difficult position in the energy transition.

B.2.2 Region and Municipality

Decentralized governments have different operating levels concerning the energy transition in the built environment. In the Climate Agreement 30 regions are specified, in these regions the municipalities, water authorities and provinces work together with the stakeholders to create a Regional Energy Strategy (RES). This is a platform to make decisions together on the generation of sustainable electricity, the heat transition in the built environment and therefore also the desired energy storage and infrastructure (RES, n.d.; Policymaker 6). The decisions that are made on national and regional level have influence on the districts on a lower level.

Municipalities have to create a transition vision (focused on heat) in 2021 and implementations plans on district level have to be defined. The municipality of The Hague wants to be energy neutral in 2040. It therefore selected ten green energy districts, where De Vruchtenbuurt is also included, that should be the first districts to become sustainable and give an example to the districts following thereafter. Some districts differ more from each other than other districts, but what makes 'De Vruchtenbuurt' interesting is that it is totally initiated by the inhabitants of the neighbourhood and therefore can lead to new lessons learned. For other districts the municipality leads the districts and for this research it is interesting to compare De Vruchtenbuurt with those districts (different governance model) (Gemeente Den Haag, 2018).

B.2.3 System Operator

The system operators have a powerful position in this problem situation, since they have a monopoly on the electricity (and gas) grids. When more renewable resources are going to be used, like solar and wind energy, it means that the electricity grid needs an upgrade (TNO, 2015; System Operator Expert 1; System Operator Expert 2). This is due to the fluctuating character of these resources. The system operators are the ones that are responsible that the grid is improved in such a way that it can be used with the new energy resources. Creating enough storage opportunities, energy saving and smart technologies can help in solving the flexibility problem (Policymaker 2). In some pilot projects subsidies are used to change the grid and connections, so the households do not have to pay for the transition to a new energy system. When on a larger scale the system operators have to change the grids, the costs are going to be paid by the households (or other users) that are connected to the grid.

Appendix C

Governance Models and Technical Designs

In this appendix the governance models (C.1) and technical designs (C.2) that are not used in this research are explained in more detail. These models and designs can be used to explore the acceptability of other types of decentralized energy systems.

C.1 Governance Models

In this section the commercial governance model (C.1.1) and the public governance model (C.1.2) are explained.

C.1.1 Commercial

A model where households buy the product(s) to adopt a decentralized energy design themselves because it is profitable for them. The households can be seen as consumers is this case. In multiple interviews, the essay of Teisman (2019) and the webinars of TNO (2018) on 'natural gas free districts' is mentioned that it is important that besides the innovations of products (solar panels, heat pumps, batteries etc.) and services (leasing of solar panels, using the roof of other households to install solar panels etc.), also packages of products and services have to be developed. With these packages is meant that an integral approach is available to make a house energy neutral or more sustainable. In the webinars of TNO (2018) is mentioned that changing to the new energy system should be an 'one-shop-stop', in order to make it comfortable for the households and not costing too much effort. Not many households have 'energy' as a hobby and therefore should be focused on easy accessible options (TKI Urban Energy, 2018). The focus should be on the extra benefits (besides 'energy' reasons) that can be reached by buying the 'package of products and services'. Extra benefits can be financial reasons or the feeling of inclusion when contributing in the energy transition (TKI Urban Energy, 2018). Different providers provide the products and competition between the providers create better service, quality and price. Market mechanisms create the incentive for providers to improve their products. In this model it is possible to choose your own supplier, this is the same for the current energy system (Stedin, 2018).

C.1.2 Public

A model where a public organization (like the municipality) takes the initiative to bring different parties together to make the change to decentralized energy systems happen. Sometimes incentives, often financial, are used to make the first households change. Also, focused is on including the different stakeholders in the process of changing. However, it is difficult to get a representative group of stakeholders together (Decentralized Government 1). The approach of public organizations (on different levels) often take the approach of focusing on particular pilot projects, districts or regions and try to draw useful lessons from these pilots and implement these pilots on a larger scale taking the lessons into account. However, it is questionable if the lessons learned from specific pilots can also be used in other situations where the context is different. Even within a city district the way a heat grid can be connected differs per block or street (Local Initiator 1).

C.2 Technical Designs

In this section the 'decentralized energy generation' design (C.2.1) and the 'flexibility' design (C.2.2) are explained.

C.2.1 Decentralized Energy Generation

To reduce the carbon dioxide emissions, one of the solutions is to use renewable energy sources (like solar and wind) for generating energy. However, the security of supply of these sources is different from the current conventional energy sources (like natural gas and coal), because of 'Dunkelflaute', the German word for moments when no sun and no wind are present (Duurzaam Nieuws, 2017). Furthermore, the renewable energy technologies are rather new and in development the costs of these technologies are higher than the conventional technologies. However, Solar PV is one of the renewable sources that achieved unexpected cost reductions (Klimaatakkoord, 2018; IRENA, 2018). IRENA (2018) mentions three drivers for cost reduction: (1) technology improvements, (2) competitive procurement and (3) a large base of experienced, internationally active project developers. It is uncertain how much cost reduction is possible in the future due to innovations.

Furthermore, not all households has to generate energy themselves. It is also possible that household A shares a roof with another household that does not want to place solar panels on its roof. Therefore household B buys the electricity from household A, that does have its own roof and generates enough to share it with household B.

C.2.2 Flexibility

As already mentioned in the previous section, it is necessary to strengthen the electricity grid, but this requires high investment costs and time. Therefore solutions are required that can create flexibility. Some possible solutions to create flexibility are: storage, demand control and conversion. The system operators have to make sure that the electricity and other grids can handle the capacity. Flexibility is expected to provide the solution to reach this (TNO, 2015).

Platforms are developed that make flexibility possible. For example, the USEF framework is constructed to integrate all smart energy products and services. USEF unlocks the value of flexible energy use by making it a tradable commodity (Stedin, 2015). Other platforms, like GOPACS, Flexiblepower Alliance Nework (FAN) and Energy Flexibility interface (EFI), create interoperability of smart appliances and help to limit the congestion in the system (Stedin, 2019; Technical Experts 2). However, it should be noted that more data of the users are shared for these services and that privacy issues might occur and should be evaluated (Policymaker 3; Technical Experts 1; Technical Experts 2).

On city district level it is possible to place storage batteries in the houses or a collective battery in the city district (TKI Urban Energy, 2018). Furthermore, it is expected that electric vehicles are going to be used to provide flexibility (Policymaker 1; Policymaker 3). However, in the field of electricity storage still a lot of research and innovation is to be conducted. It is uncertain how the market for storage and conversion is going to develop (Technical Experts 2).

Furthermore, the energy market in the Netherlands is currently demand driven and the new energy system asks for a change to a more supply driven system. This requires a shift in behaviour of the users (System Operator Expert 1). As also mentioned in Chapter 1, the end-users become central players, which also means that the users have a different role and different obligations (System Operator Expert 1).

Appendix D

Model Formalization and Specification

In this appendix is elaborated on the way the model is formalized and specified. Firstly, the assumptions and simplifications made in order to build the model are explained (C.1) and secondly, the pseudo-code of the model is given (C.2).

D.1 Assumptions and Simplifications

In this section the assumptions and simplifications of the different components of the model are explained. The number of households are retrieved from CBS (2017) and the initial size of the community from Warm in de Wijk (2017) and Local Initiator 1. The model is run for half of the households, since the model is running very slow when all households are included. With this amount of households there are still enough households that have a feasible option to join the initial community.

The other assumptions and simplifications are divided in two sections, conversion factors (C.1.1) and policies and innovations (C.1.2).

D.1.1 Conversion Factors

- Three income groups are identified and no variation within an income group is made. The income of a household can be a constraint for the household to change to a option that highers the overall level of values. The data for the income levels is retrieved from CBS (2018).
- Two ownership groups are identified and no variation in the group of households that rent their house is made (no division is made if the households is renting from a particular house owner or a housing corporation). The households that own their house have a feasible option to change from community

(if no other conversion factors constrain the households). The ownership also influences the value autonomy of the household, when the household is owner of its house, it influences the value autonomy positively and when the household is renting its house, it influences the value autonomy negatively. The data for the ownership is retrieved from CBS (2017).

- No clear information is retrieved on the social network of the households in 'De Vruchtenbuurt'. An assumption is therefore made. The social network of a household is determined by the income levels of the households that are surrounding the household. When a high amount of households (default large social network is equal or greater than 25 other households) in a certain surrounding (default radius = 2) have the same income level as the specific household, the social network is high (level 3). When a medium amount of households (default medium social network is equal of greater than 10 other households and smaller than 25 other households) in a certain surrounding (default radius = 2) have the same income level as the specific household, the social network is medium (level 2). When a small amount of households (default small social network is smaller than 10 other households) in a certain surrounding (default radius = 2) have the same income level as the specific household, the social network is low (level 1).
- The type of household is divided in three groups, while the households can also be specified in more detail. However, the type of household is used to say something about the size of the households and therefore the energy use. The data for the type of household is retrieved from CBS (2017).
- The energy label is used to determine how energy efficient a building is. Since not all buildings in 'De Vruchtenbuurt' have a energy label, the distribution of the energy labels that are specified are used. This means that in reality the estimated energy labels can be more or less efficient than taken into account in this research. The data for the energy labels is retrieved from Klimaatmonitor (2018).
- The type of building is divided in two groups, one family buildings and multiple family buildings. The type of buildings can be specified in more detail, but the type of building is in this research used to determine whether a households has to argue with other households to make changes in the building or not. The data for the type of building is retrieved from CBS (2017).
- The possible correlation between certain conversion factors are not taken into account in the analysis. For example, in the research of ECN & RIGO (2013) is specified that a correlation between the income of a household and the energy label of the house exists. Possibly more correlations exist, which should be kept in mind when analyzing the results.

D.1.2 Policies and Innovations

The conceptualization of the conversion factors as constraints and the evaluation of the values are already explained in the main text. The way the policies and innovations are conceptualized are not given in the main text and explained below. It should be noted that the specification is quite simplistic, as can be seen in Figure D.1. However, the aim is to see how the model behaviour changes when these policies or innovations are applied and not to give exact implications. The outcomes are used as input for the third round of interviews with the policymakers, researcher and local initiator.

- **Subsidies**
  When subsidies are applied it means that 16.7% (10% less than the default setting) of the households have a low income level and 45.1% (the same as the default setting) of the households have a middle income level and 38.2% (10% more than the default setting) of the households have a high income.

- **Technologies more sustainable**
  When innovation is supported to make the technical designs more sustainable can increase the fulfillment of sustainability for the LT heat grid design and also the HT heat grid designs. For example, when less energy is lost and used during transport, the heat grid designs get more sustainable. The evaluation of sustainability is different when innovations on the sustainability of technologies are supported and reached. The sustainability for all three technical designs are equal and the sustainability is only dependent on the size of the community.

- **Renovations cheaper**
  When the renovations get cheaper (for example because of innovations on the insulation materials and techniques). When this happens the affordability of the technical designs where renovations are crucial, which are the all electric design and the LT heat grid design. The evaluation of affordability is increased for the all electric design and the LT heat grid design by 1/3 (since this is the smallest step on the scale of evaluating affordability) compared to the evaluation without the cheaper renovations.

- **Companies and utility sector for flexibility**
  When the companies and utility sector in the city district are used for flexibility, the fulfillment of security of supply increases. The evaluation of security of supply is changed by + 0.5 (since this is the smallest step on the scale of evaluating security of supply) compared to the evaluation without the use of the companies and utility sector for flexibility. When the evaluation was already the maximum (+ 1), nothing changes.

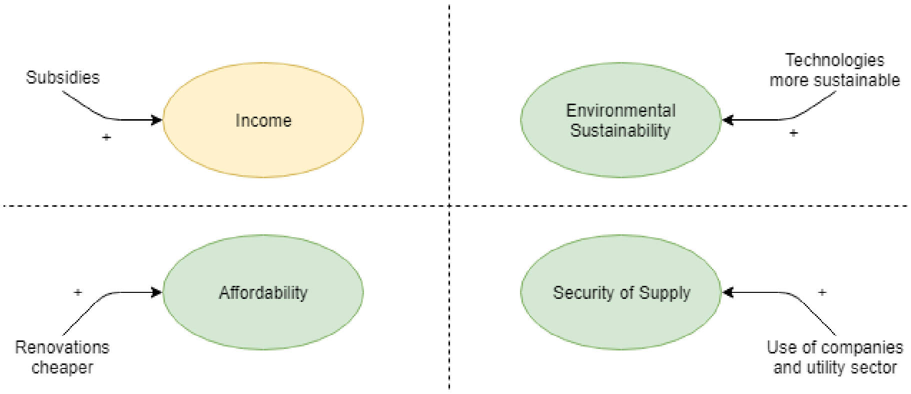


Figure D.1: The Influence of the Policies and Innovations.

D.2 Pseudo-code

In this section the pseudo-code of the model is given, by starting with the set-up phase, followed by the main procedure and the sub procedures.

D.2.1 Set-up Phase

The following procedures are used to set-up the model according to the given input parameters (or default settings).

Globals

The following action happen once on observer level.

1. Set time 0
2. Create the amount of households
3. Set the chosen heat technology
4. Set the chosen community model
   - If community model is 'two smaller communities', set initial size of community / 2
5. Set the chosen weighting of the values
6. Set the locations of the households

Households

The following actions happen per household in a random order.

1. Set the level of income
2. Set the ownership
3. Set the social network
4. Set the type of household
5. Set the energy label
6. Set the type of building

Initial Communities

The following actions happen once on observer level.

1. Set assignment of community false
2. **Check the community model: if 'one big community' go to 3, if 'two smaller communities' go to 11**
3. Set counter community equal to initial size community
4. Set counter households checked equal to number of households
5. While counter community is greater than 0 and counter households checked is greater than 0, ask households with assignment of community = false:
   - Set community number 1 of asked household and set assignment of community true
   - Check feasibility of option by checking if the income, ownership or energy label forms a constraint
   - If option is feasible, set feasibility true, set counter community - 1 and set counter households checked - 1
   - If option is not feasible, set feasibility false, set assignment of community false, set community number 0 and set counter households checked - 1
6. Set counter community number 2
7. Ask households with assignment of community = false: set assignment of community true, set community number equal to counter community number and set counter community number + 1
8. Check feasibility of option by checking if the income, ownership or energy label forms a constraint

9. If option is feasible, set feasibility true
10. If option is not feasible, set feasibility false and set option 'alone in community not feasible' true (**go to 22**)
11. Set counter community equal to initial size community
12. Set counter households checked equal to number of households
13. While counter community is greater than 0 and counter households checked is greater than 0, ask households with assignment of community = false:
    - Set community number 1 of asked household and set assignment of community true
    - Check feasibility of option by checking if the income, ownership or energy label forms a constraint
    - If option is feasible, set feasibility true, set counter community - 1 and set counter households checked - 1
    - If option is not feasible, set feasibility false, set assignment of community false, set community number 0 and set counter households checked - 1
14. Set second counter community equal to initial size community
15. Set second counter households checked equal to number of households
16. While second counter community is greater than 0 and second counter households checked is greater than 0, ask households with assignment of community = false:
    - Set community number 2 of asked household and set assignment of community true
    - Check feasibility of option by checking if the income, ownership or energy label forms a constraint
    - If option is feasible, set feasibility true, set second counter community - 1 and set second counter households checked - 1
    - If option is not feasible, set feasibility false, set assignment of community false, set community number 0 and set second counter households checked - 1
17. Set counter community number 3
18. Ask households with assignment of community = false: set assignment of community true, set community number equal to counter community number and set counter community number + 1
19. Check feasibility of option by checking if the income, ownership or energy label forms a constraint

20. If option is feasible, set feasibility true
21. If option is not feasible, set feasibility false and set option 'alone in community not feasible' true
22. Ask households to evaluate their values with the size of its assigned community (see sub procedures)
23. Assignment of colors (see sub procedures)

KPIs

The following actions happen once on observer level.

1. Create empty lists for the KPIs (to track the fulfillment of the values later)
2. Ask households: create empty lists for the KPIs (to track the fulfillment of the values later)
3. Statistics (see sub procedures)
4. Update data per agent(group) (see sub procedures)

D.2.2 Main Procedure

The following procedures contain actions that happen every time step (when the model starts running). First of all, the time is set equal to ticks, then the following procedures are started respectively:

Selection of Capability

1. Update the size of my community
2. If the the size of my community is larger than 1:
   - Check feasibility of option by checking if the income, ownership or energy label forms a constraint
   - If option is feasible, set feasibility true and if option if not feasible, set feasibility false
   - Calculate the overall value level of the current option
3. If the the size of my community is larger than 1 and the option 'alone in community not feasible' = false:
   - Create a new community with the size 1
   - Evaluate their values with the size of its assigned community (see sub procedures)

- Calculate the overall value level of this option

4. If another household has a larger community:
   - Assign the community number of the larger community and the size of my community of the larger community + 1
   - Evaluate their values with the size of its assigned community (see sub procedures)
   - Calculate the overall value level of this option

5. Set the choice current, when the overall value level of this option is the highest

6. Set the choice alone, when the overall value level of this option is the highest

7. Set the option new group, when the overall value level of this option is the highest

Feasibility of Capability

1. If choice = current, do nothing

2. If choice = alone, check feasibility of option by checking if the income, ownership or energy label forms a constraint

3. If choice = new group, check feasibility of option by checking if the income, ownership or energy label forms a constraint

Change to Selected Capability

1. If choice = alone and the option is feasible:
   - Let community number counter 0
   - While any other household has community number equal to community number counter, set community number counter + 1
   - Set my community number equal to community number counter
   - Set the size of my community 1
   - Set feasibility true

2. If choice = new group and the option is feasible:
   - Set my community number equal to the tested community (see procedure 'options' step 4)
   - Set the size of my community equal to the tested size (see procedure 'options' step 4)
   - Set feasibility true

3. If choice = alone and the option is not feasible: set choice = current and set option 'alone in community not feasible' true
4. If choice = new group and the option is not feasible: set choice = current
5. Set the level of values equal to the level of the values that belong to the choice (current, alone or new group)
6. Assignment of colors (see sub procedures)
7. Statistics (see sub procedures)
8. Update data per agent(group) (see sub procedures)

Stop

1. If the stop condition = true and ticks greater or equal to the report time, stop the model
2. Tick

D.2.3 Sub Procedures

The following procedures are invoked in the procedures specified above.

Evaluation of the Values

The following actions happen per household with the size of community that is requested to be evaluated.

1. Evaluation of the value security of supply
2. Evaluation of the value affordability
3. Evaluation of the value environmental sustainability
4. Evaluation of the value autonomy
5. Evaluation of the value comfort
6. Evaluation of the value inclusiveness

Assignment of Colors

These actions are used to display a certain type of visualization.

1. If type of visualization = communities:
   - Let community counter 0 and let initial color black
   - While community counter is smaller or equal to the maximum community number, ask households with the same community number: set color initial color, set initial color different and set community number + 1

2. If type of visualization = feasibility:
   - Ask households: if feasibility = true, set color green
   - Ask households: if feasibility = false, set color red

3. If type of visualization = income
   - Ask households: set color blue (lighter for lower income, darker for higher income)

4. If type of visualization = energy label
   - Ask households: if energy label = A to A++, set color dark green - Ask households: if energy label = B, set color bright green
   - Ask households: if energy label = C, set color light green
   - Ask households: if energy label = D, set color yellow
   - Ask households: if energy label = E, set color light orange
   - Ask households: if energy label = F, set color orange
   - Ask households: if energy label = G, set color red

5. If type of visualization = value security of supply
   - Ask households: if the level of the value is greater than 0, set the color green
   - Ask households: if the level of the value is 0, set the color black
   - Ask households: if the level of the value is smaller than 0, set the color red

6. If type of visualization = value affordability
   - Ask households: if the level of the value is greater than 0, set the color green
   - Ask households: if the level of the value is 0, set the color black
   - Ask households: if the level of the value is smaller than 0, set the color red

7. If type of visualization = value sustainability
   - Ask households: if the level of the value is greater than 0, set the color green
   - Ask households: if the level of the value is 0, set the color black

- Ask households: if the level of the value is smaller than 0, set the color red

8. If type of visualization = value autonomy
   - Ask households: if the level of the value is greater than 0, set the color green
   - Ask households: if the level of the value is 0, set the color black
   - Ask households: if the level of the value is smaller than 0, set the color red

9. If type of visualization = value comfort
   - Ask households: if the level of the value is greater than 0, set the color green
   - Ask households: if the level of the value is 0, set the color black
   - Ask households: if the level of the value is smaller than 0, set the color red

10. If type of visualization = value inclusiveness
    - Ask households: if the level of the value is greater than 0, set the color green
    - Ask households: if the level of the value is 0, set the color black
    - Ask households: if the level of the value is smaller than 0, set the color red

Statistics

1. Add the mean of the fulfillment of the value per household to the list
2. Calculate per value the mean of the list
3. Calculate the covariance between the different values (overall)

Update Data per Agent(group)

1. Divide the households over different conversion factor groups
2. Create a list with the means of the conversion factor groups
3. Create a list with the variances of the conversion factor groups
4. Create a list with the fulfillment of the values per conversion factor group.
5. Calculate the covariance of all the lists (see sub-sub procedure)

Covariance Calculation (Sub-sub Procedure)

1. Calculate the covariance of two lists

Appendix E

Use of Model

In this appendix is explained how the model can be used. Firstly, the interface of the model is explained (D.1) and then the steps for using the model are presented (D.2). After that, more detailed explanation is given about the parameters (D.3) and the monitors and graphs (D.4).

E.1 Explanation of the Interface

In Figure E.1 a display of the interface of the Agent-Based Model used in this research is given. All the colored blocks in the display have a different meaning and are explained in this section.

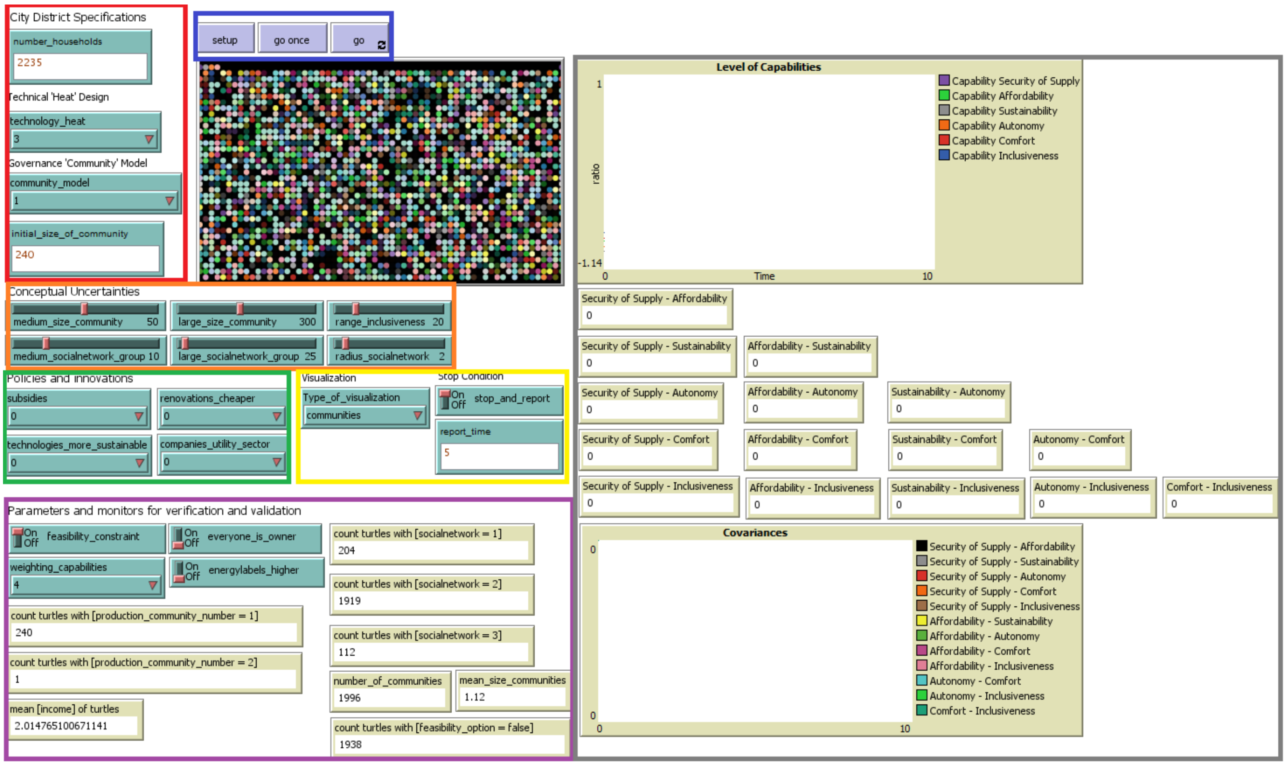


Figure E.1: Interface of the Agent-Based Model.

- Red block: these inputs and choosers can be used to specify the city district characteristics
- Blue block: these buttons can start the procedures specified in the code of the model. The setup button can be used to initialize the model, the go once button can be used to run one tick of the model and the go button can be used to start running the model (until the stop condition is met).
- Orange block: these sliders can be used to vary the conceptual uncertainties of the model. The base case settings are the default settings.
- Green block: these choosers can be used to vary the policies and innovations.
- Yellow block: this input, chooser and switch can be used to decide which type of visualization is displayed and specify the stop conditions.
- Purple block: these switches, chooser and outputs are used to verify the model and are not recommended to change when using this model.
- Grey block: these monitors and graphs show the outcomes of interest of the model.

E.2 Steps for Using the Model

1. Adjust the parameters (see next section) or use the default settings
2. Press the 'setup' button
3. Press the 'go' button, the simulation will start. When pressing the 'go once' button, only one time step of the model is run.
4. Look at the interface, monitors and graphs to see how the the households change from communities, how the level of values develop and how the covariance between the values develops.

E.3 Parameters

- number_households: the amount of households specified in the model can be adjusted with this parameter.
- technology_heat: the technical heat design can be specified with this chooser (1 = all electric, 2 = LT heat grid and 3 = HT heat grid).
- community_model: the governance community model can be specified with the chooser (1 = one big community and 2 = two smaller communities)
- initial_size_of_community: the initial size of the community can be specified in this input. It is important that the initial size of the community cannot be bigger than the number of households.
- medium_size_community: with this slider the medium size of a community (where the first scale benefits can be reached) can be specified. It is important that the parameter cannot be larger or equal to the large size of a community.
- large_size_community: with this slider the large size of a community (where large scale benefits can be reached) can be specified. It is important that the parameter cannot be smaller or equal to the medium size of a community.
- range_inclusiveness: with this slider the range that is used to define the value inclusiveness can be specified. This parameter entails what percentage the income level of a household can differ from the average income level of the households that do the same.
- medium_socialnetwork_group: with this slider the medium size of a social network group can be specified. It is important that the parameter cannot be larger or equal to the large size of a social network group.

- large_socialnetwork_group: with this slider the large size of a social network group can be specified. It is important that this parameter cannot be smaller or equal to the medium size of a social network group.

- radius_socialnetwork: with this slider the radius of the social network of the households is specified.

- subsidies: with this chooser can be specified if subsidies are used in the model

- renovations_cheaper: with this chooser can be specified if the renovations became more affordable due to innovations or not.

- technologies_more_sustainable: with this chooser can be specified if the technologies became more sustainable due to innovations or not.

- companies_utility_sector: with this chooser can be specified if the benefits for flexibility of the companies and utility sector are used.

- type_of_visualization: with this chooser the type of visualization can be specified.

- stop_and_report: with this switch can be decided if the stop condition is used or not.

- report_time: when the stop condition is switched on, the model stops running when the amount of ticks in this input passed.

E.4 Monitors and Graphs

- Level of Values: in this graph the development of the mean of the fulfillment of the values is displayed,

- Covariances (monitors): these monitors show the covariances between the fulfillment of the different values is shown.

- Covariances (graph): in this graph the covariances between the fulfillment of the different values is displayed.

Appendix F

Verification and Validation

In this appendix supportive explanation and figures are given for the verification and validation of the model, as presented in Chapter 5.

F.1 Stochastic Uncertainty

In the software Netlogo it is possible to conduct experiments and to run different repetitions. While using the reference and zero policy settings 50 repetitions are run. Below the results of these 50 runs are given per covariance between two values. Since the stochastic uncertainties are determined using the Netlogo 'behavioural space', only the overall covariance between the values is determined and not between the different conversion factor groups. Also, because of this reason, the covariance within one value is not given. However, it is expected that this way of testing is sufficient to see if stochastic uncertainties influence the model behaviour or not.

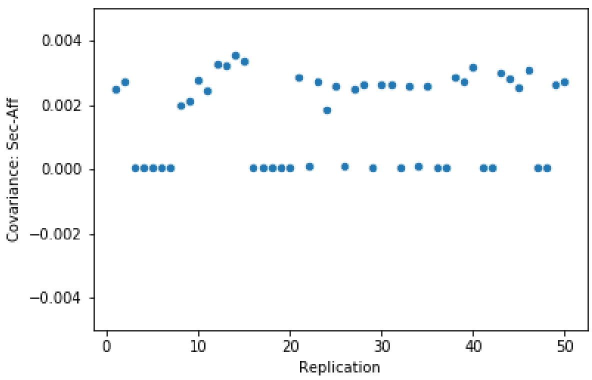


Figure F.1: Covariance between Security of Supply (Sec) and Affordability (Aff) (y-axis) for 50 Replications (x-axis).

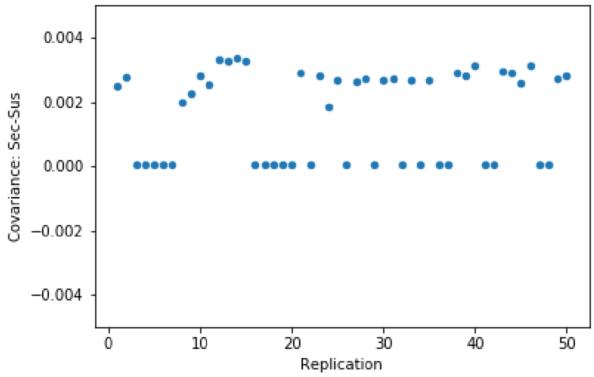


Figure F.2: Covariance between Security of Supply (Sec) and Sustainability (Sus) (y-axis) for 50 Replications (x-axis).

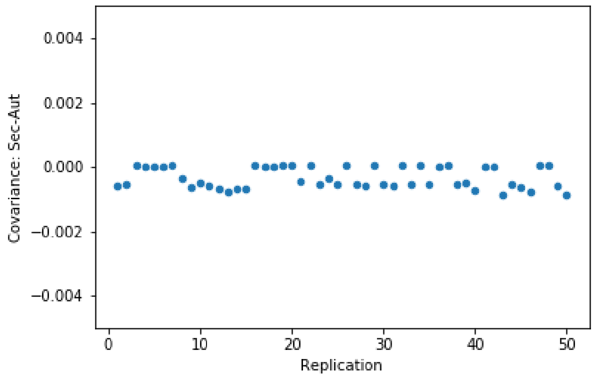


Figure F.3: Covariance between Security of Supply (Sec) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis).

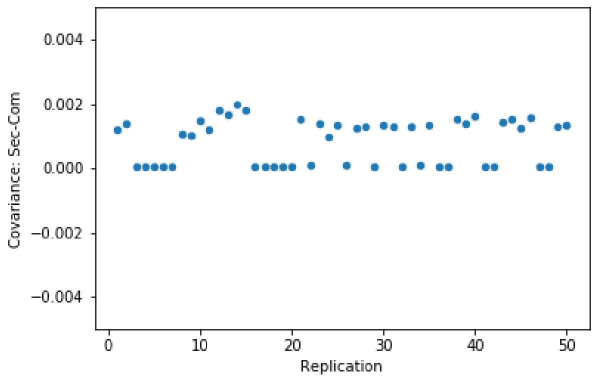


Figure F.4: Covariance between Security of Supply (Sec) and Comfort (Com) (y-axis) for 50 Replications (x-axis).

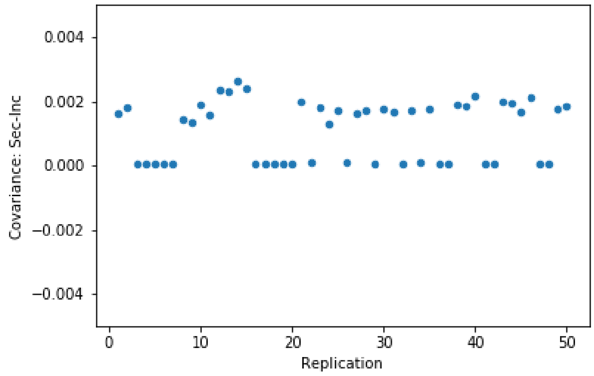


Figure F.5: Covariance between Security of Supply (Sec) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis).

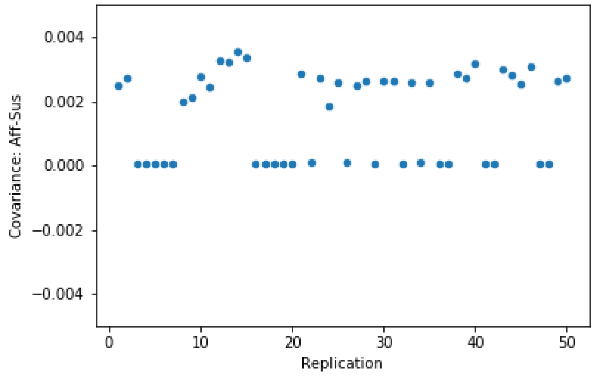


Figure F.6: Covariance between Affordability (Aff) and Sustainability (Sus) for (y-axis) 50 Replications (x-axis).

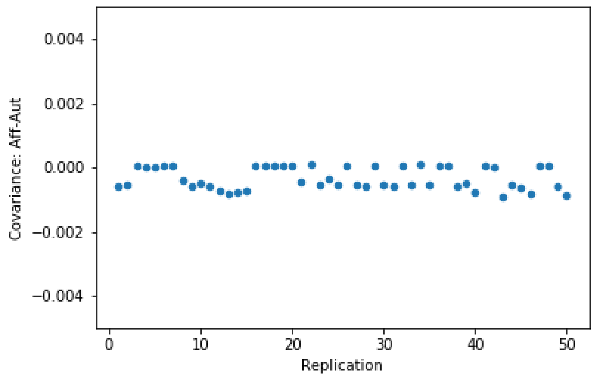


Figure F.7: Covariance between Affordability (Aff) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis).

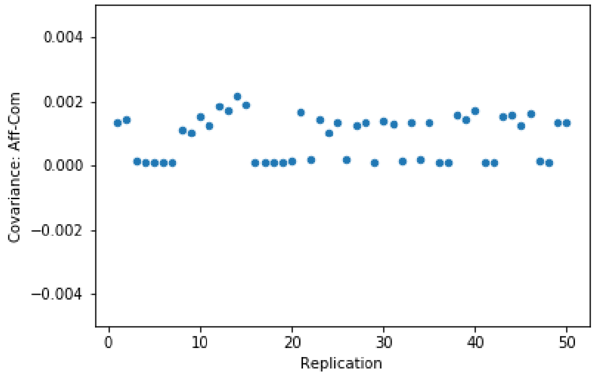


Figure F.8: Covariance between Affordability (Aff) and Comfort (Com) (y-axis) for 50 Replications (x-axis).

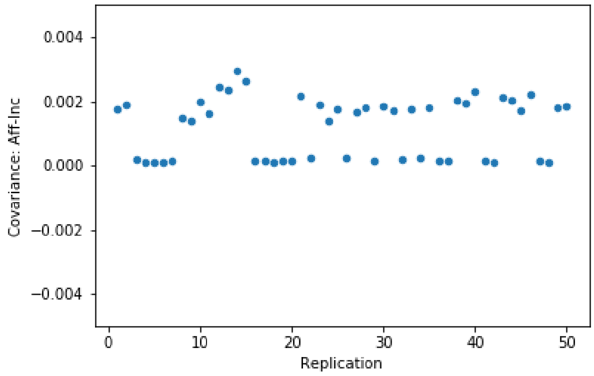


Figure F.9: Covariance between Affordability (Aff) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis).

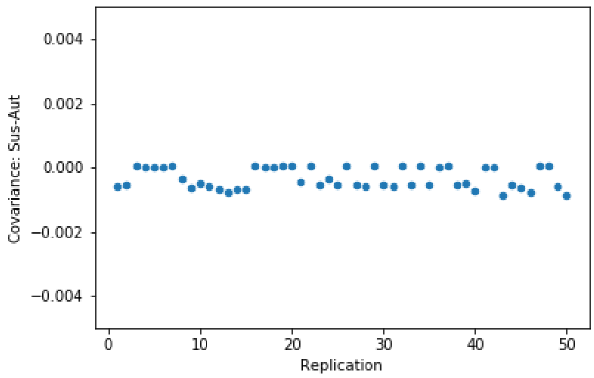


Figure F.10: Covariance between Sustainability (Sus) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis).

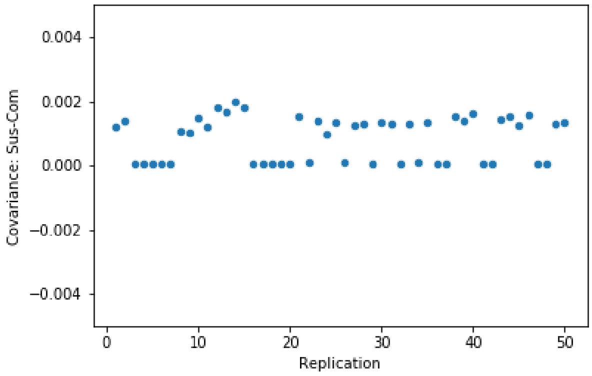


Figure F.11: Covariance between Sustainability (Sus) and Comfort (Com) (y-axis) for 50 Replications (x-axis).

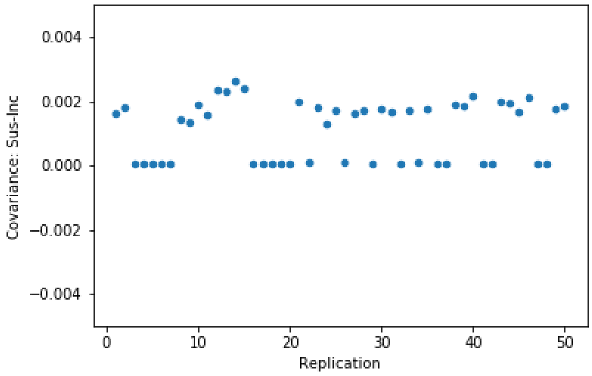


Figure F.12: Covariance between Sustainability (Sus) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis).

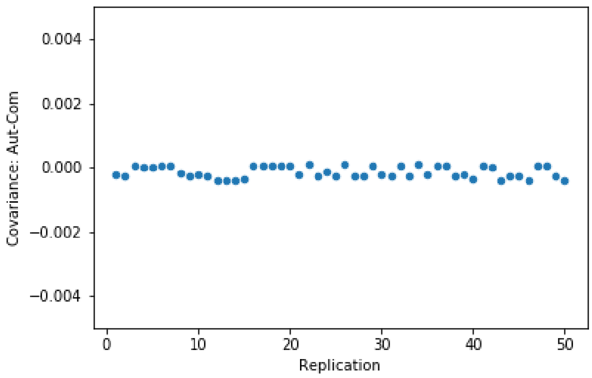


Figure F.13: Covariance between Autonomy (Aut) and Comfort (Com) (y-axis) for 50 Replications (x-axis).

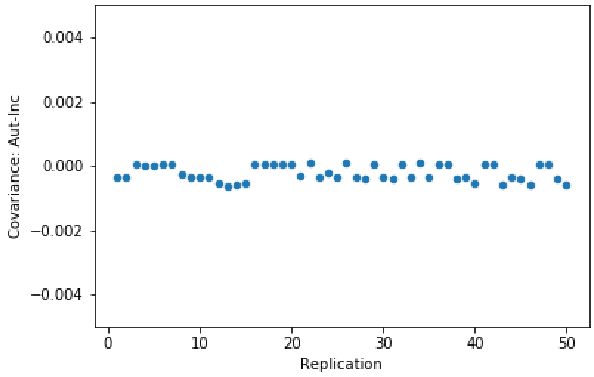


Figure F.14: Covariance between Autonomy (Aut) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis).

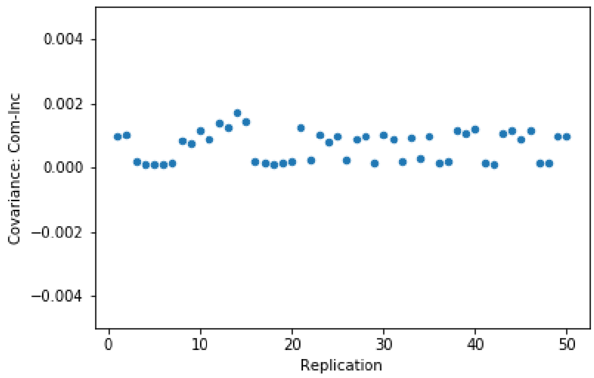


Figure F.15: Covariance between Comfort (Com) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis).

In Figures F.1 to F.15 the results concerning the different replications can be seen. In this research only the results where the covariance is negative are interesting (since a negative covariance implies a value conflict). The results do not show that in some situations the covariance between two values is negative and in other situations the covariance is positive. What can be seen is that in some situations the covariance between two values has a clear direction and in other situations the covariance is almost zero. It is expected that this is related to the random assignment of the conversion factors and the way they are divided over the households.

It is expected that the way the conversion factors are divided over the households is the main stochastic uncertainty and causes the differences in the results. It is therefore possible that in some replications more favorable or less favorable combinations of conversion factors are assigned to the households than in reality can be found. It is therefore important to include model replications in the experiments conducted with this model, in order to determine the robustness of the results. To be sure, also interviews are conducted to validate if the identified value conflicts are also expected to emerge in the real world.

F.2 Conceptual Model Evaluation

In the software Netlogo it is possible to conduct experiments and this possibility is used to run 200 experiments with four different sets of weights of the values. The different sets of weights of the values are presented below.

- Weight set 1:
  - Weight of value security of supply: 1
  - Weight of value affordability: 1
  - Weight of value sustainability: 1
  - Weight of value autonomy: 1
  - Weight of value comfort: 1
  - Weight of value inclusiveness: 1

- Weight set 2:
  - Weight of value security of supply: 0.5
  - Weight of value affordability: 0.5
  - Weight of value sustainability: 0.5
  - Weight of value autonomy: 1.5
  - Weight of value comfort: 1.5
  - Weight of value inclusiveness: 1.5

- Weight set 3:
  - Weight of value security of supply: 1
  - Weight of value affordability: 2
  - Weight of value sustainability: 1
  - Weight of value autonomy: 2
  - Weight of value comfort: 2
  - Weight of value inclusiveness: 1

- Weight set 4:
  - Weight of value security of supply: 1.5
  - Weight of value affordability: 1.5
  - Weight of value sustainability: 1.5
  - Weight of value autonomy: 0.5

- Weight of value comfort: 0.5
- Weight of value inclusiveness: 0.5

Below the results of these 200 runs are given per covariance of two values. Since these experiments are executed by using the Netlogo 'behavioural space', only the overall covariance between the values is determined and not between the different conversion factor groups. Also, because of this reason, the covariance within one value is not given. However, it is expected that this way of testing is sufficient to see if the weighting of the values influences the model behaviour.

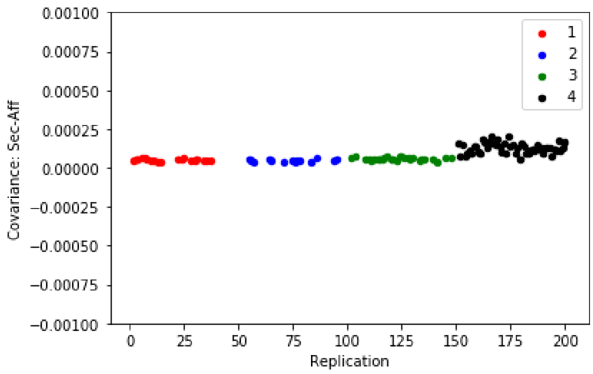


Figure F.16: Covariance between Security of Supply (Sec) and Affordability (Aff) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

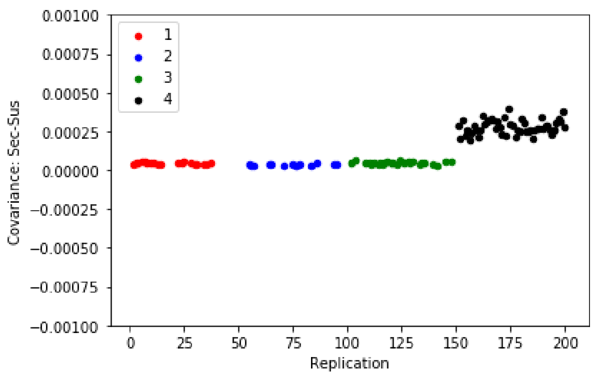


Figure F.17: Covariance between Security of Supply (Sec) and Sustainability (Sus) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

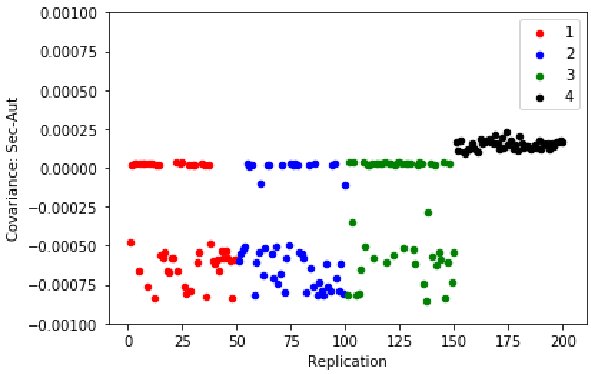


Figure F.18: Covariance between Security of Supply (Sec) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

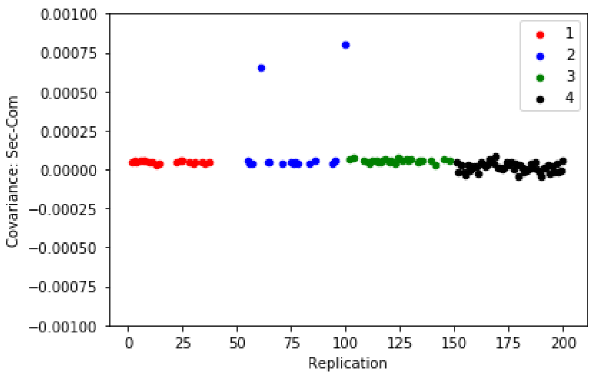


Figure F.19: Covariance between Security of Supply (Sec) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

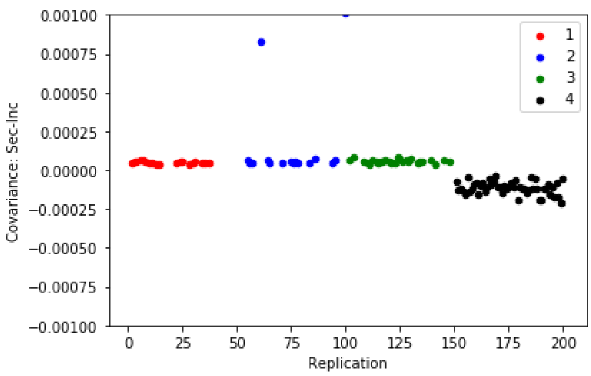


Figure F.20: Covariance between Security of Supply (Sec) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

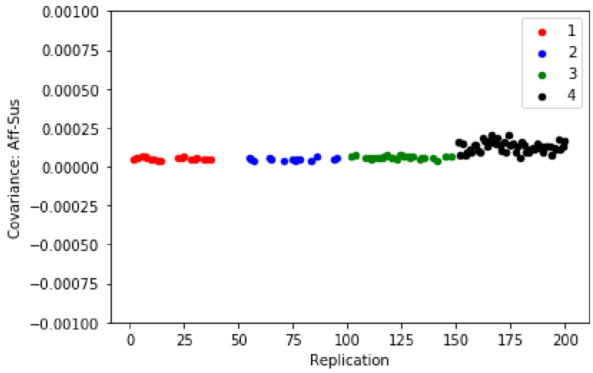


Figure F.21: Covariance between Affordability (Aff) and Sustainability (Sus) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

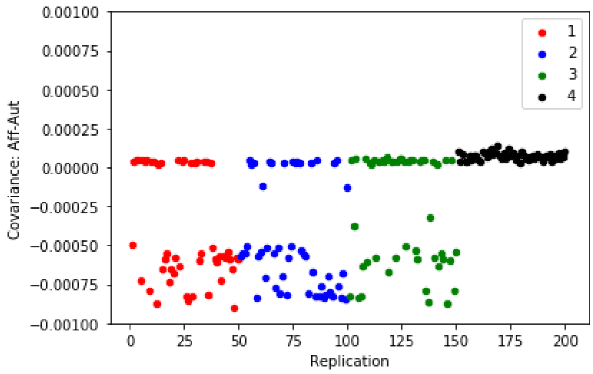


Figure F.22: Covariance between Affordability (Aff) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

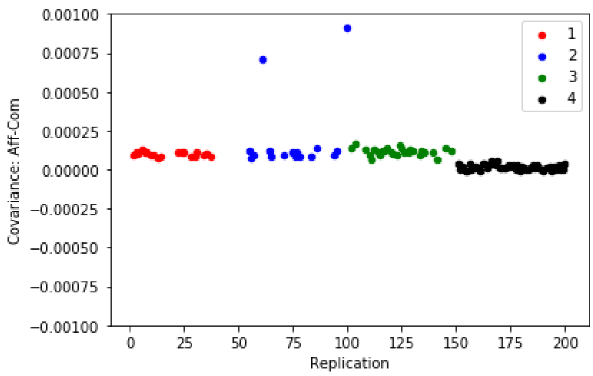


Figure F.23: Covariance between Affordability (Aff) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

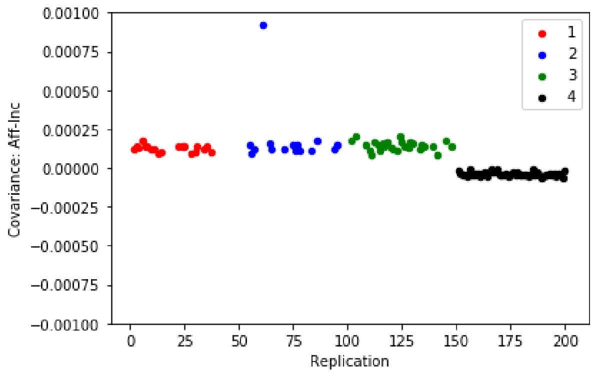


Figure F.24: Covariance between Affordability (Aff) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

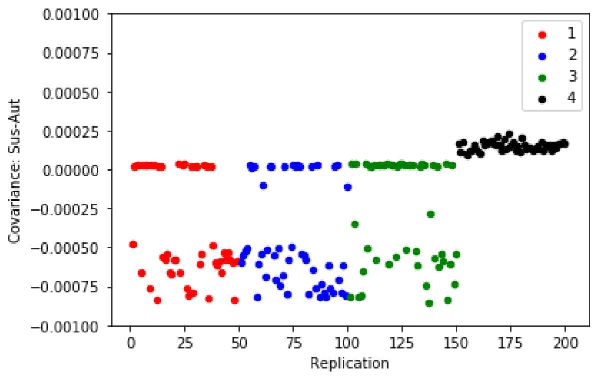


Figure F.25: Covariance between Sustainability (Sus) and Autonomy (Aut) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

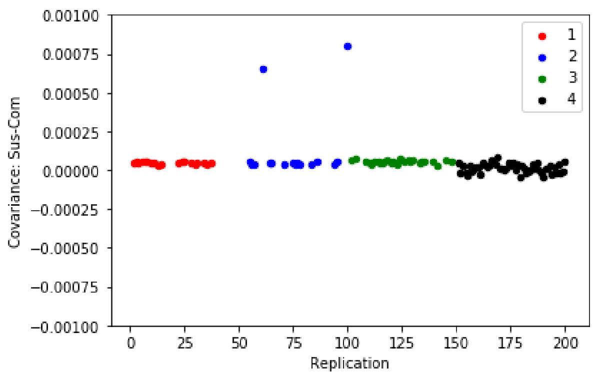


Figure F.26: Covariance between Sustainability (Sus) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

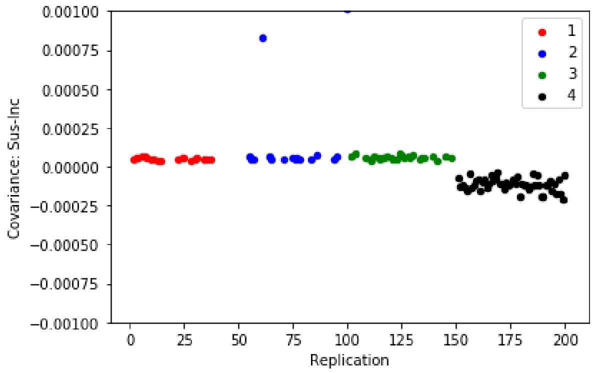


Figure F.27: Covariance between Sustainability (Sus) and Inclusiveness (Inc) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

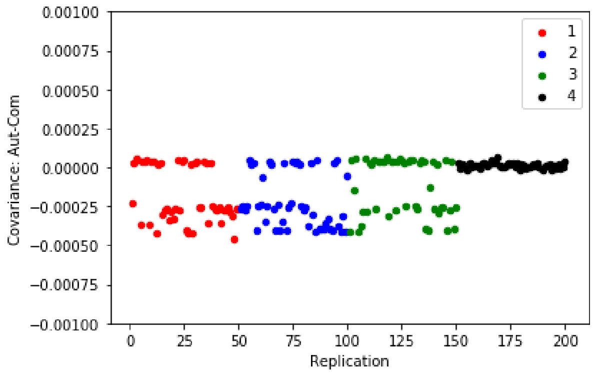


Figure F.28: Covariance between Autonomy (Aut) and Comfort (Com) (y-axis) for 50 Replications (x-axis) with Different Sets of Weights (colors).

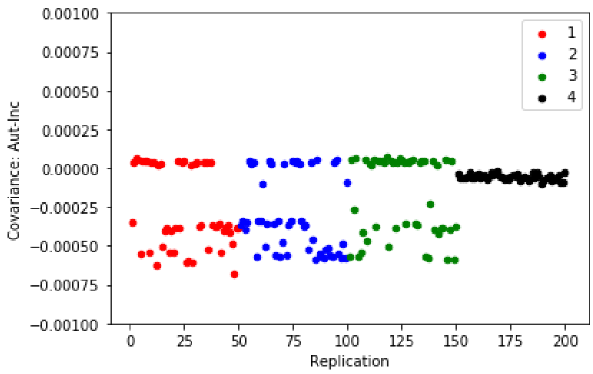


Figure F.29: Covariance between Autonomy (Aut) and Inclusiveness (Inc) for 50 Replications (x-axis) with Different Sets of Weights (colors).

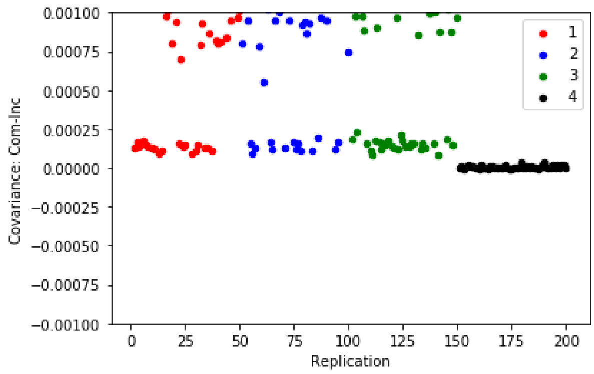


Figure F.30: Covariance between Comfort (Com) and Inclusiveness (Inc) for 50 Replications (x-axis) with Different Sets of Weights (colors).

In Figures F.16 to F.30 the results concerning the different weighting sets can be seen. The results for the first three sets of weights are similar as the results where the stochastic uncertainty is tested. However, the results are rather different for the fourth set of weights. In this set of weights security of supply, affordability and sustainability get a weight of 1.5 and autonomy, comfort and inclusiveness get a weight of 0.5. Since in this results only the overall conflicts can be seen and not the conflicts between conversion factors, no further conclusions can be drawn. However, it is important to note that weighting the more traditional values higher than autonomy, comfort and inclusiveness effects the results.

Since in this research no further time has been spent on the importance (the weight) of the values, no further real world conclusions can be given. However, it should be noted that prioritization of values can happen without being aware of it. In Chapter 9 is reflected on the influence of the embeddedness of indirect and direct prioritization of values.

F.3 Implementation Verification

In this section tests to fulfill the implementation verification step from the 'eval-udation' method are displayed. The four ways of verification presented by Van Dam et al. (2013) are applied to conduct the implementation verification step and are presented in section E.3.1 - E.3.4.

F.3.1 Tracking of Agent Behaviour

In this section the recording and tracking of agent behaviour is displayed, which allows to see if the operationalization is done right by monitoring the output variables.

In multiple ways is tested whether the agents behave the way the agents are supposed to behave. Some of the tests are shown below.

- If the governance model is ’one big community’, community number 1 has the size of 240 households. As can be seen in Figure F.31, 240 households have community number 1 after the set-up procedure is executed. **Confirmed**

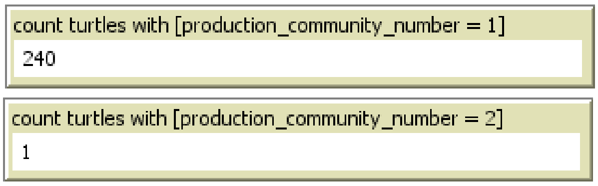


Figure F.31: Number of Households with Community Number 1

- If the governance model is ’two smaller communities’, community number 1 has the size of 120 households and community number 2 has the size of 120 households. As can be seen in Figure F.32, 120 households have community number 1 and 120 households have community number 2 after the set-up procedure is executed. **Confirmed**

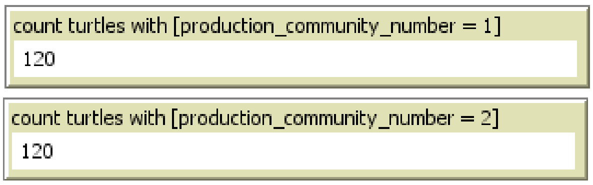


Figure F.32: Number of Households with Community Number 1 and Community Number 2

- The conversion factors are divided randomly over the households and over the interface. As can be seen in Figures F.33 and F.34, the conversion factors are randomly divided over the households and over the interface. **Confirmed**

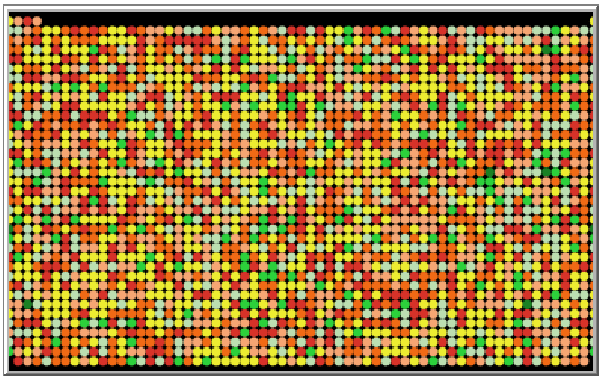


Figure F.33: Energy Label of Households

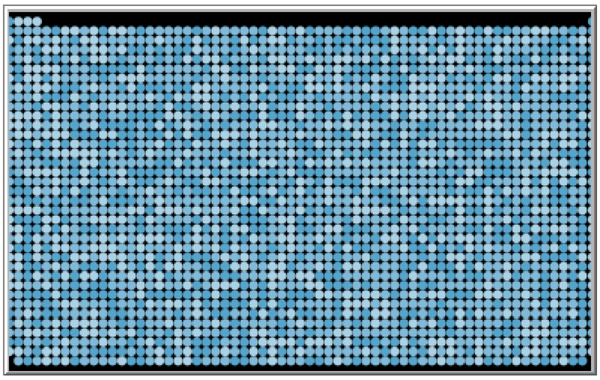


Figure F.34: Income Level of Households

- The conversion factor distributions are assigned in the right way. To start with, in Figure F.35 can be seen that 26.7% of the 2,235 (= 597) households have income level 1, 45.1% of the 2,235 (= 1008) households have income level 2 and 28.2% of the 2,235 households have income level 3. In Figure F.36 the distribution of the conversion factor social network is shown for the default setting. In Figure F.37 the distribution of the conversion factor social network is shown for radius = 3 and the distribution shows that the households have a higher social network (as intended). In Figure F.38 the distribution of the conversion factor social network is shown for radius = 1 and the distribution shows that the households have a lower social network (as intended). **Confirmed**

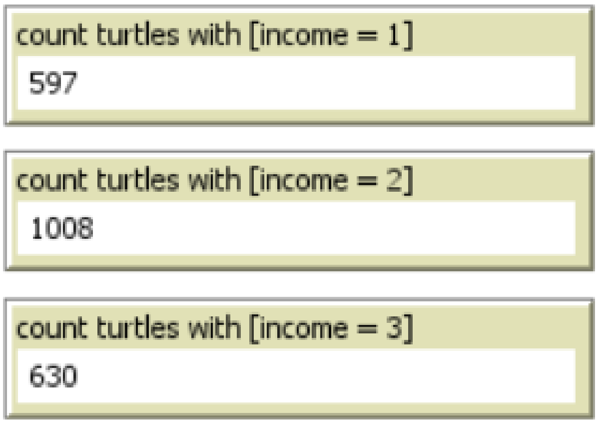


Figure F.35: Distribution of Conversion Factor Income

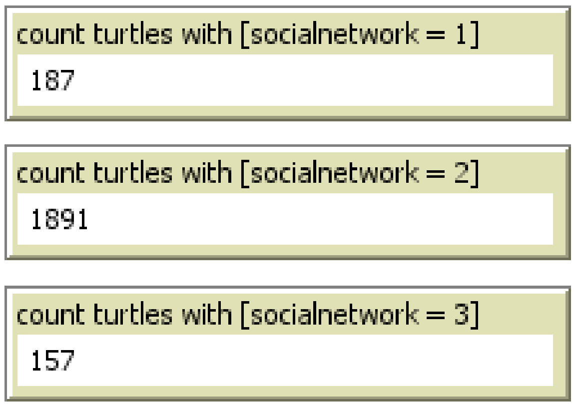


Figure F.36: Distribution of Conversion Factor Social Network (Default)

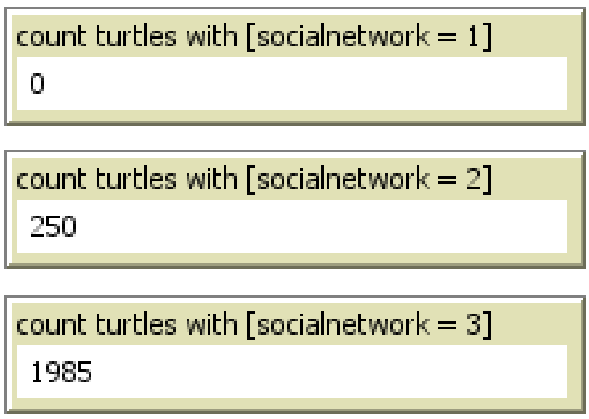


Figure F.37: Distribution of Conversion Factor Social Network (Radius = 3)

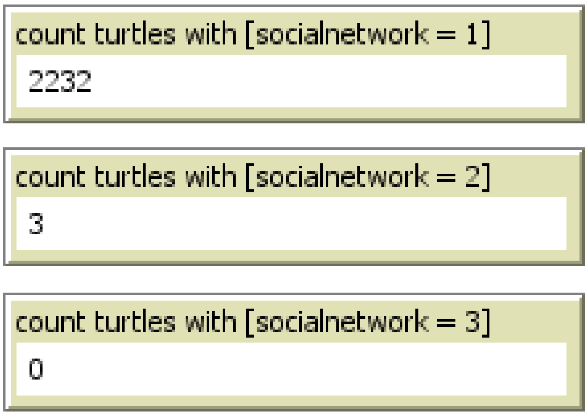


Figure F.38: Distribution of Conversion Factor Social Network (Radius = 1)

- The conversion factor groups contain the right households. When printing the conversion factor groups that are used for further analysis in the EMA workbench in the command center of Netlogo, the same amount of households are assigned to the conversion factor groups as the distribution of the conversion factors indicates. **Confirmed**

F.3.2 Single-agent Verification

In this section the single-agent verification is displayed, which allows to identify if the agent behaves the way the modeller intended it.

The behaviour of different households is tested by checking households individually. Below, most of the time the results of one household are shown, but for more households the same tests are executed.

When one of the conversion factors makes the assigned option unfeasible for the household, its feasibility is set on false. The assigned conversion factors of different households are checked and when one or more conversion factors formed a constraint, the feasibility of these households were set false. **Confirmed**

When the household does not have a feasible option, the evaluation of the values is -1. In Figure F.39 can be seen that the feasibility of this household is false and the level of all the values is - 1. **Confirmed**

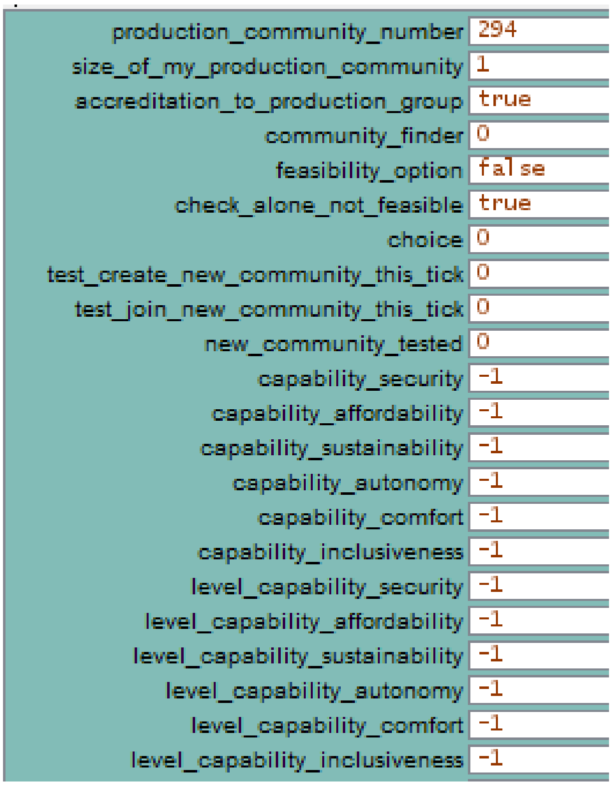


Figure F.39: Feasibility and Level of Values of a Household

The household selects the choice with the highest overall level of the values. A household is checked during a tick and the households chose for the option with the highest overall level of the values. **Confirmed**

When the chosen option (alone or new group) is not feasible, the current option is assigned again. A household is tracked during a tick and when a household chose firstly for 'alone', but this option was not feasible, within the same tick the choice was set on 'current'. **Confirmed**

The level of the values are the level of values that fit with the chosen option (when assigned feasible). After a tick the level of the values of the different options for a household and the choice the household made are checked. Then is checked if the level of the values corresponding to the chosen option are also the level of values assigned to the values of the household. This was the case. **Confirmed**

The evaluation of the values fit with the chosen technical design and the conversion factors of the household. In a run were the technical design 'HT heat grid' was used, a household was alone in a community, was living in a household without children and the evaluation of the value affordability is 0. This is in line with the score this option should get according to the model specification. **Confirmed**

The right color is assigned to the household in the different types of visualization. A household that has a red color in the feasibility visualization should also have a red color in the visualization of the values. A household is checked for different types of visualizations and all were in line with each other. **Confirmed**

F.3.3 Minimal Model Interaction Verification

In this section the minimal model interaction verification is displayed, which allows to test whether the interactions between a limited amount of agents in the model is correct or not.

To test if the model is still working when a limited amount of households are created in the model, the model is initialized with 5 households. However, an error occurred when the average of the conversion factor groups, created for further analysis with the EMA workbench, was requested. This has probably to do with the occurrence of one household in a group with this small amount of households. It is therefore necessary to at least run the model with 16 or more households.

The model is also tested with 100 households and 10 as initial size of community. The model works well, except that not enough households have a feasible option to join the initial community. However, when the conditions of the conceptual uncertainties 'medium-size-community', 'large-size-community', 'medium-socialnetwork-group' and 'large-socialnetwork-group' are decreased, enough households have a feasible option to join the initial community. The parameters that have to do with the size of the community or the size of the social network are set for the base case, so the parameter settings result in strange output when a very low number of households is used.

F.3.4 Multi-agent Verification

In this section the multi-agent verification is displayed, which allows to test whether the model behaviour on an overall level is in line with the expected behaviour.

To conduct the multi-agent verification different runs are executed with varying parameter settings. No implementation errors were found. Furthermore, the model behaviour is sensitive to some of the parameters (as also is mentioned in section 5.7, where the sensitivity analysis of the model is displayed). For example, the chosen technical design is a parameter that influences the model behaviour a lot. The determining parameters are used for further analysis in the experiments with the EMA workbench (see Chapter 6).

F.4 Model Output Verification

Most of the model output can be found in the next appendix, where the output of the experiments executed with the EMA workbench are displayed. Besides that an test is executed in Netlogo and is displayed below.

To test observation 4: "the composition of a city district influences the value conflicts. For example, the ownership and the construction year distribution influence the conflicts in a city district" (see Chapter 5), the conversion factors ownership and energy label (which includes the construction year) are changed to find out how this change influences the amount of households having a feasible option initially. In Figure F.40 the feasibility of the households for the default settings can be seen. In Figure F.41 the feasibility of the households where the houses are 10% more efficient than in the default settings. In Figure F.42 the feasibility of the households where all the households are owner.

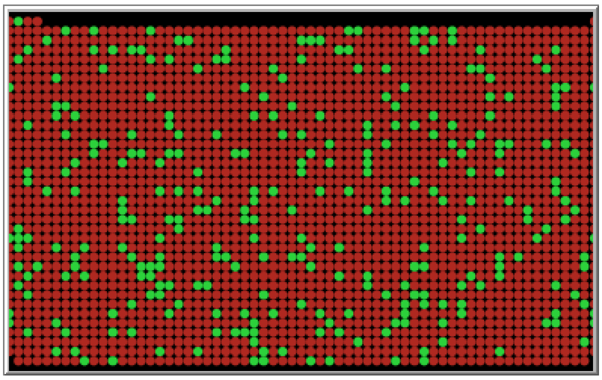


Figure F.40: Feasibility: Base Case

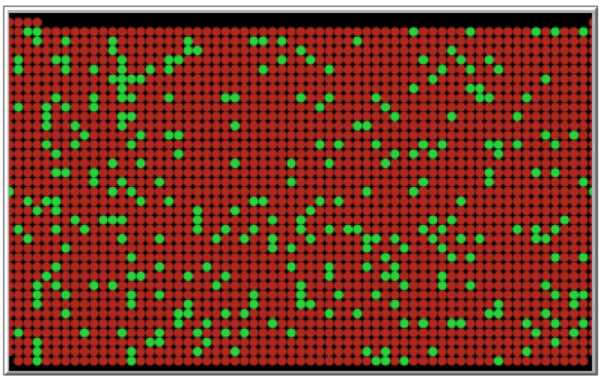


Figure F.41: Feasibility: Houses 10% More Efficient

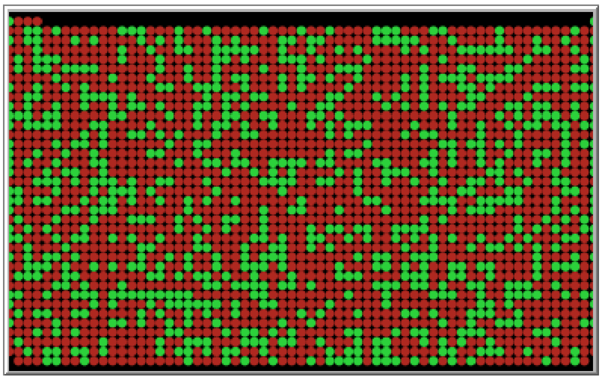


Figure F.42: Feasibility: Everyone is Owner

In the results can be seen that the amount of households that have a feasible option is varying. It is therefore important to keep in mind that the composition of another city district can be totally different. When making generalizations of the results, where the specific distributions of city district 'De Vruchtenbuurt' are used, this is important to mention.

F.5 Model Analysis

In section 5.7 the results of the sensitivity analysis, for the runs where only the conceptual uncertainties are taken into account and the runs where also the policies are taken into account, are displayed. In this section the results of the sensitivity analysis, for the runs where only the policies are taken into account, are displayed (see Figure F.43). The results show that especially the technical heat design determines the model outcomes.

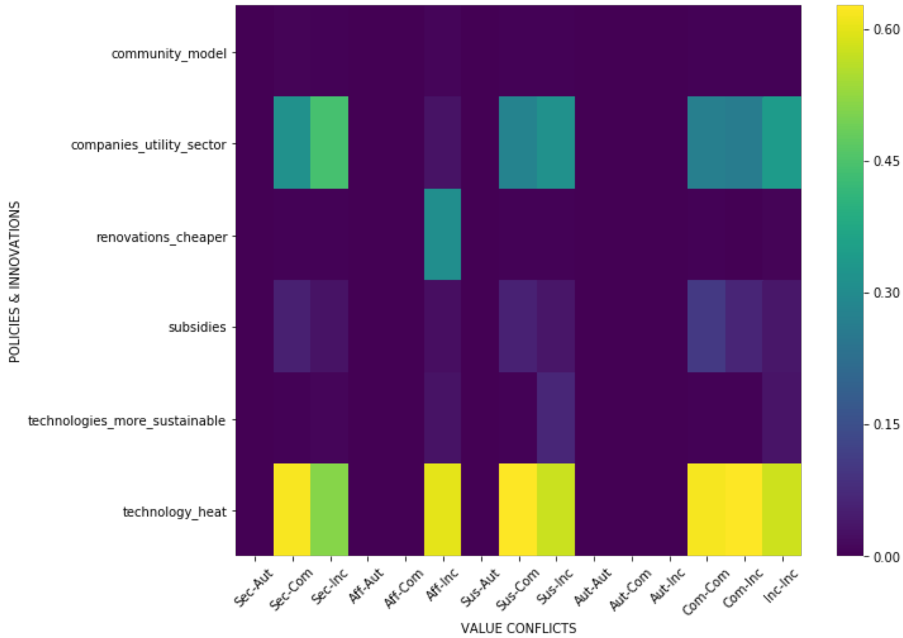


Figure F.43: Feature Scoring: Policies. When the result is more yellow in the feature scoring, the outcome of interest is more sensitive for this parameter.

Appendix G

Experiments and Data Analysis

In this appendix supportive explanation and figures are given for the experiments that are conducted with the model, as presented in Chapter 6. The results of PRIM and the regional sensitivity analysis are not presented in this appendix, since similar results occurred as with the use of dimensional stacking (which is shown below).

G.1 Traditional Values and Autonomy in Conflict

In this section the results from the experiments concerning the value conflicts between the values that require cooperation: security of supply, affordability and sustainability and the value autonomy.

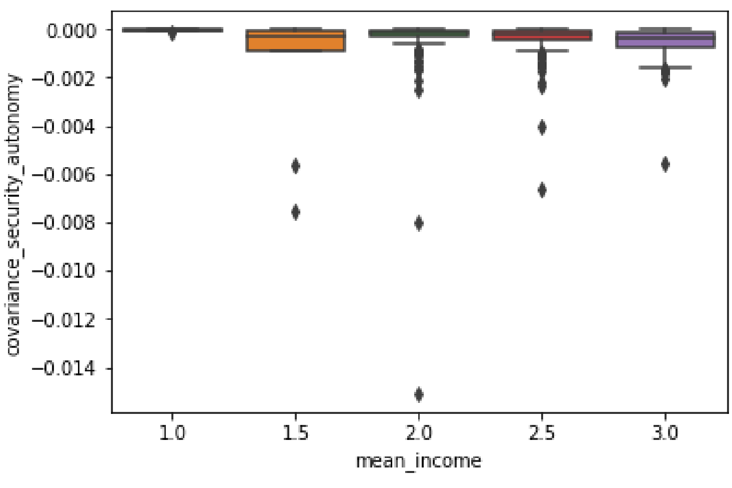


Figure G.1: Box Plot: Conflicts between Security of Supply and Autonomy (y-axis) between and within Income Groups (x-axis).

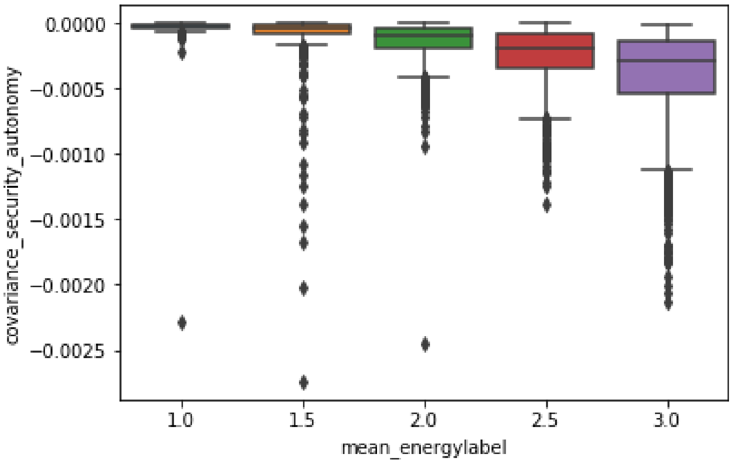


Figure G.2: Box Plot: Conflicts between Security of Supply and Autonomy (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.496145
radius_socialnetwork	0.155311
companies_utility_sector	0.116766
technologies_more_sustainable	0.038696
medium_socialnetwork_group	0.032724
range_inclusiveness	0.030248
large_socialnetwork_group	0.028989
large_size_community	0.028633
medium_size_community	0.027168
subsidies	0.020820
community_model	0.012595
renovations_cheaper	0.011906

Figure G.3: Ranking of Determining Factors for Conflicts between Security of Supply and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

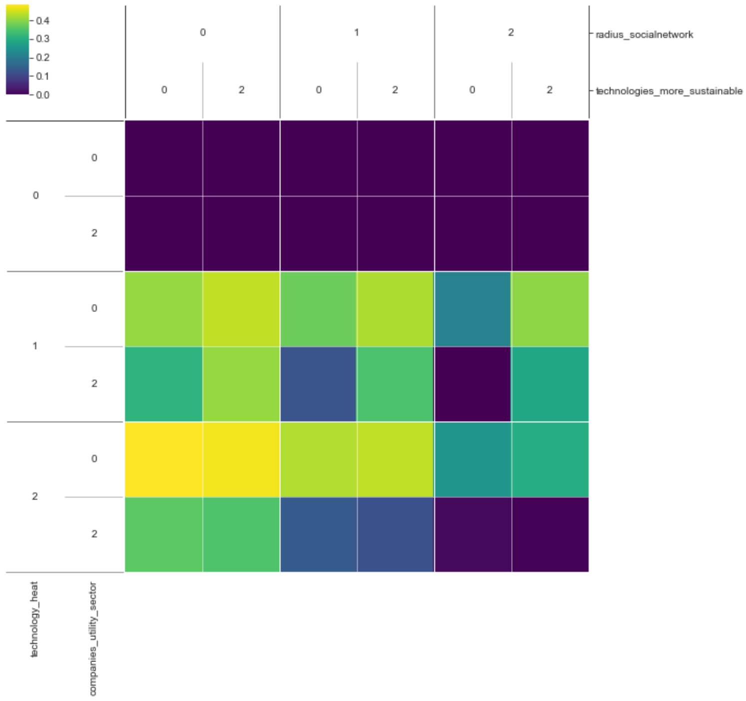


Figure G.4: Dimensional Stacking of the Conflicts between Security of Supply and Autonomy. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

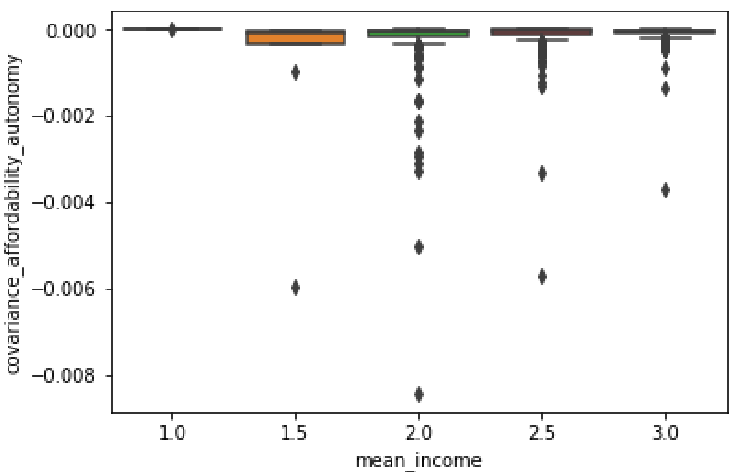


Figure G.5: Box Plot: Conflicts between Affordability and Autonomy (y-axis) between and within Income Groups (x-axis).

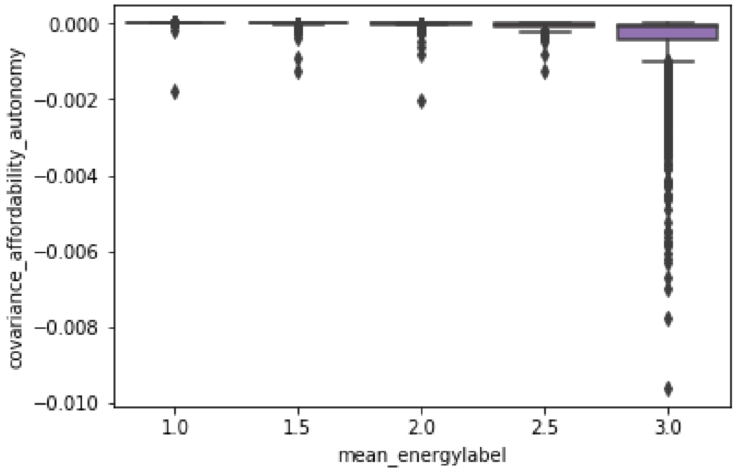


Figure G.6: Box Plot: Conflicts between Affordability and Autonomy (y-axis) between and within Energy Label Groups (x-axis).

radius_socialnetwork	0.188669
technology_heat	0.180468
technologies_more_sustainable	0.169029
companies_utility_sector	0.124451
medium_socialnetwork_group	0.051619
renovations_cheaper	0.051605
range_inclusiveness	0.046536
large_size_community	0.046200
large_socialnetwork_group	0.045910
medium_size_community	0.045568
subsidies	0.030180
community_model	0.019765

Figure G.7: Ranking of Determining Factors for Conflicts between Affordability and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

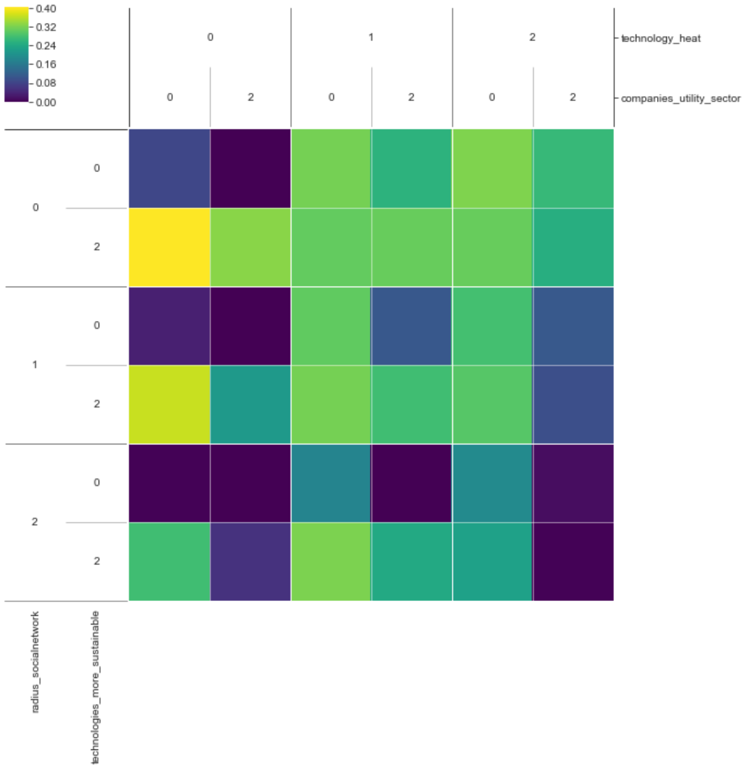


Figure G.8: Dimensional Stacking of the Conflicts between Affordability and Autonomy. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

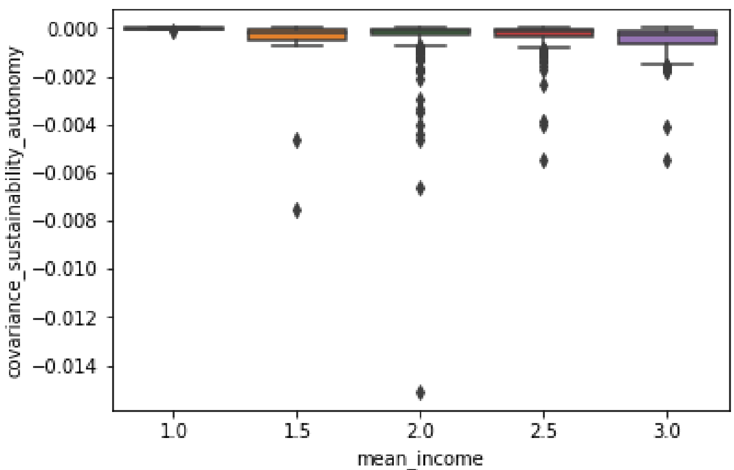


Figure G.9: Box Plot: Conflicts between Sustainability and Autonomy (y-axis) between and within Income Groups (x-axis).

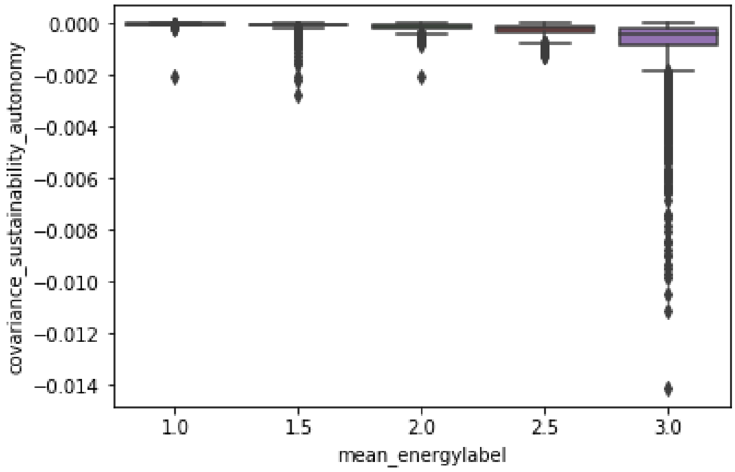


Figure G.10: Box Plot: Conflicts between Sustainability and Autonomy (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.234448
radius_socialnetwork	0.200123
technologies_more_sustainable	0.170387
companies_utility_sector	0.150830
medium_socialnetwork_group	0.041122
large_socialnetwork_group	0.035559
large_size_community	0.034567
range_inclusiveness	0.034486
medium_size_community	0.034261
subsidies	0.028813
renovations_cheaper	0.020700
community_model	0.014704

Figure G.11: Ranking of Determining Factors for Conflicts between Sustainability and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

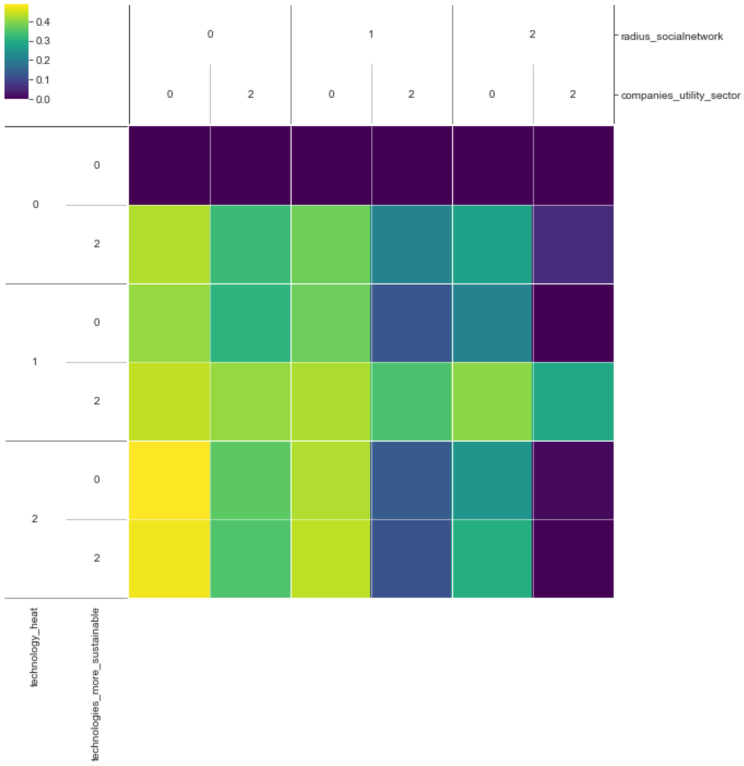


Figure G.12: Dimensional Stacking of the Conflicts between Sustainability and Autonomy. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

G.2 Traditional Values and Comfort in Conflict

In this section the results from the experiments concerning the value conflicts between the values that require cooperation: security of supply, affordability and sustainability and the value comfort.

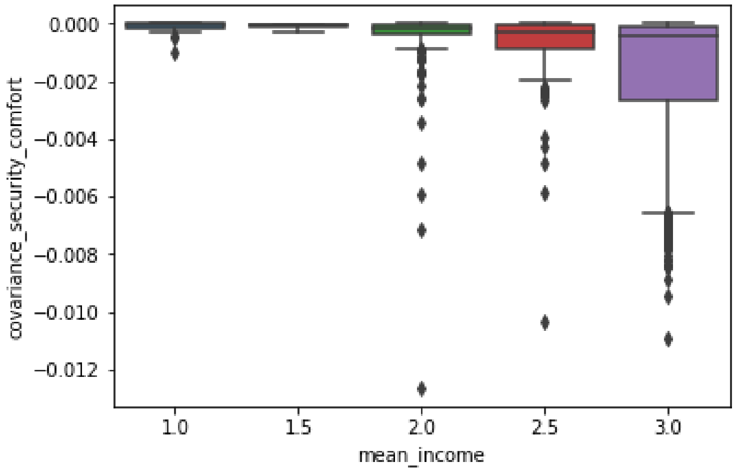


Figure G.13: Box Plot: Conflicts between Security of Supply and Comfort (y-axis) between and within Income Groups (x-axis).

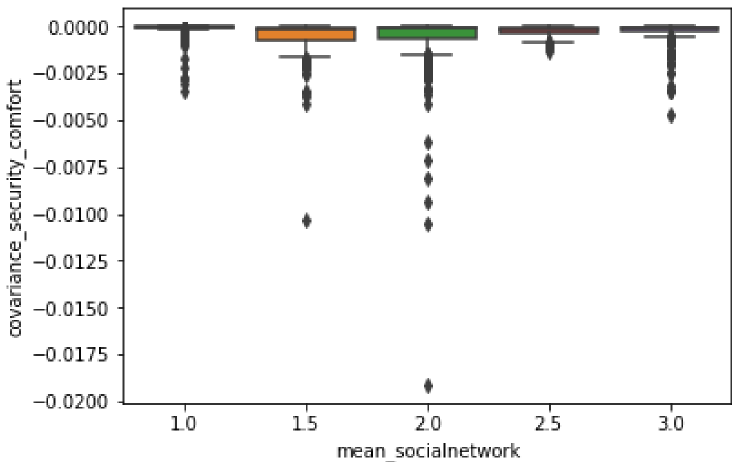


Figure G.14: Box Plot: Conflicts between Security of Supply and Comfort (y-axis) between and within Social Network Groups (x-axis).

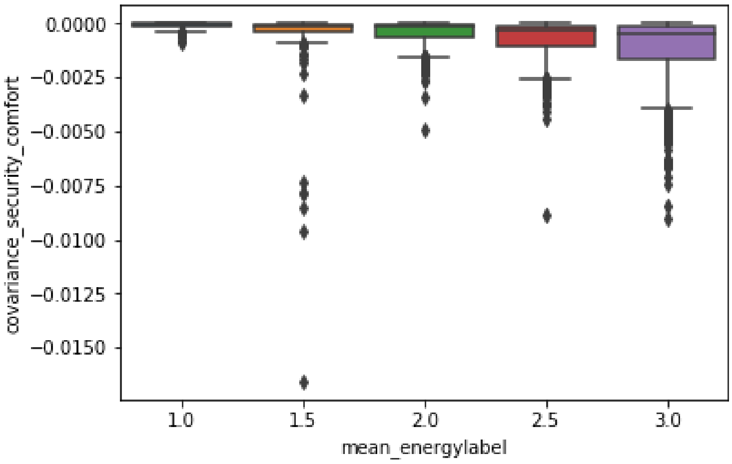


Figure G.15: Box Plot: Conflicts between Security of Supply and Comfort (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.500752
radius_socialnetwork	0.150343
companies_utility_sector	0.092232
medium_socialnetwork_group	0.042387
technologies_more_sustainable	0.038928
large_socialnetwork_group	0.031133
range_inclusiveness	0.030485
large_size_community	0.030186
medium_size_community	0.029703
subsidies	0.022296
renovations_cheaper	0.018704
community_model	0.012851

Figure G.16: Ranking of Determining Factors for Conflicts between Security of Supply and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

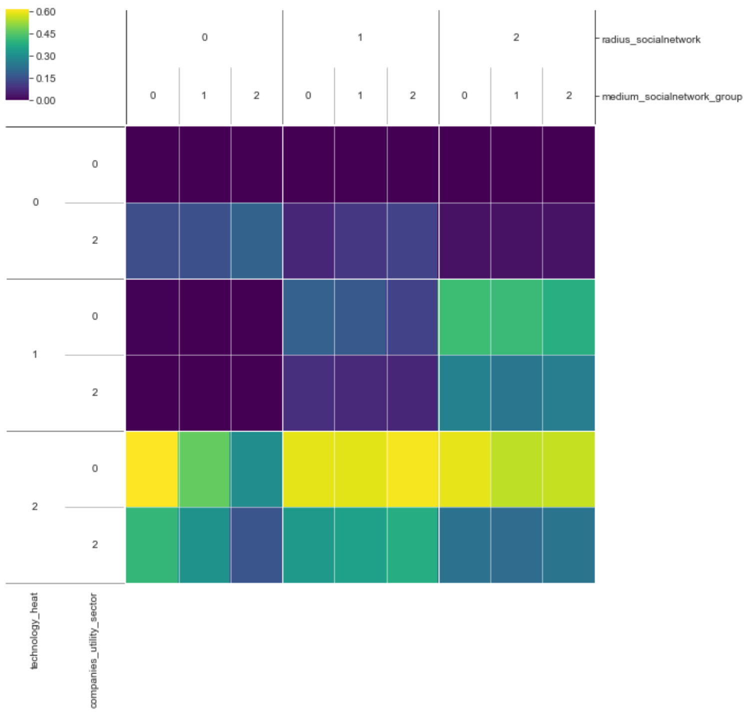


Figure G.17: Dimensional Stacking of the Conflicts between Security of Supply and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

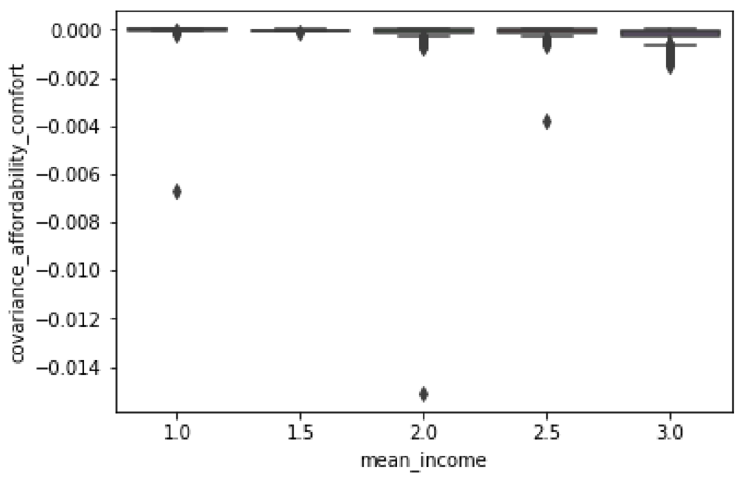


Figure G.18: Box Plot: Conflicts between Affordability and Comfort (y-axis) between and within Income Groups (x-axis).

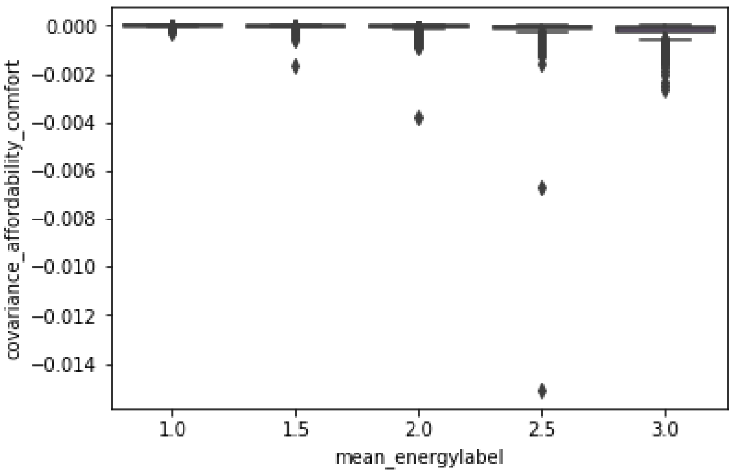


Figure G.19: Box Plot: Conflicts between Affordability and Comfort (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.525992
radius_socialnetwork	0.134493
companies_utility_sector	0.052949
medium_socialnetwork_group	0.046608
large_socialnetwork_group	0.038751
range_inclusiveness	0.037562
large_size_community	0.037345
medium_size_community	0.037105
renovations_cheaper	0.031822
subsidies	0.022910
technologies_more_sustainable	0.018833
community_model	0.015629

Figure G.20: Ranking of Determining Factors for Conflicts between Affordability and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

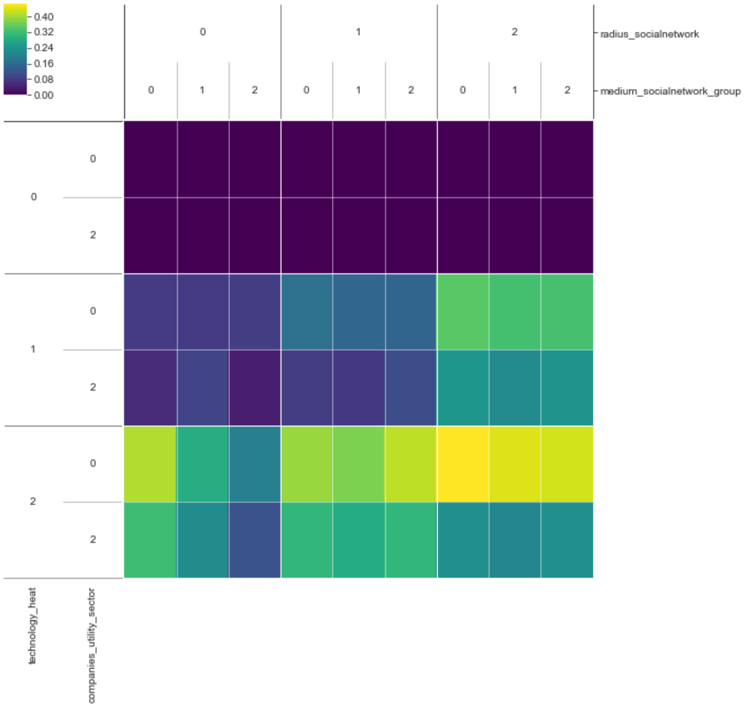


Figure G.21: Dimensional Stacking of the Conflicts between Affordability and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

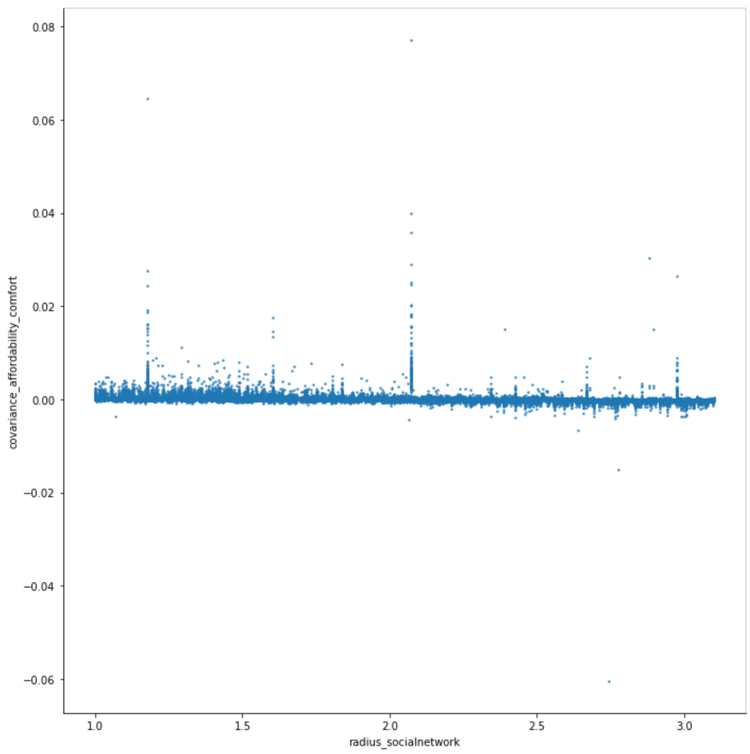


Figure G.22: Sensitivity to Radius Social Network (x-axis) for Relation between Affordability and Comfort (y-axis: negative = conflict and positive = no conflict).

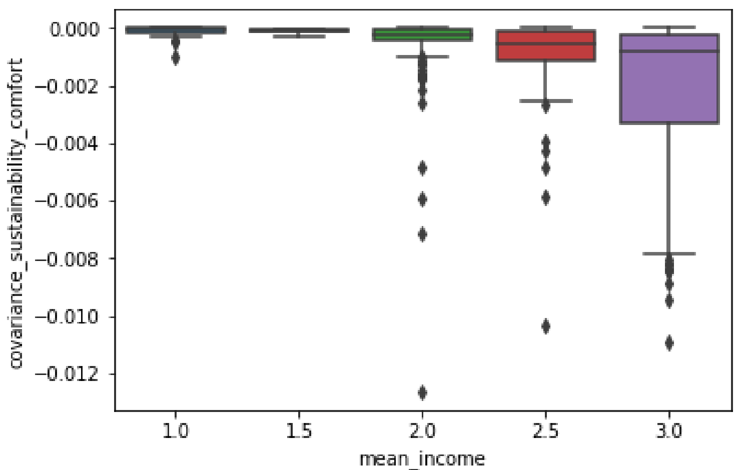


Figure G.23: Box Plot: Conflicts between Sustainability and Comfort (y-axis) between and within Income Groups (x-axis).

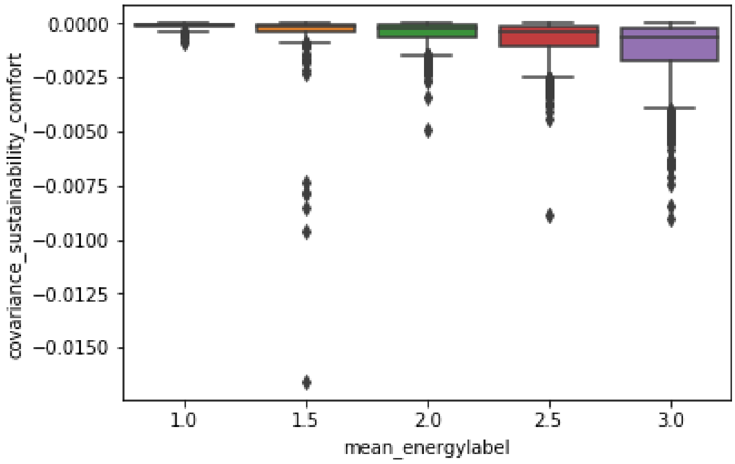


Figure G.24: Box Plot: Conflicts between Sustainability and Comfort (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.565758
radius_socialnetwork	0.135154
companies_utility_sector	0.086724
medium_socialnetwork_group	0.038815
large_socialnetwork_group	0.028821
range_inclusiveness	0.028375
medium_size_community	0.027327
large_size_community	0.026317
subsidies	0.021852
technologies_more_sustainable	0.015112
renovations_cheaper	0.014376
community_model	0.011369

Figure G.25: Ranking of Determining Factors for Conflicts between Sustainability and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

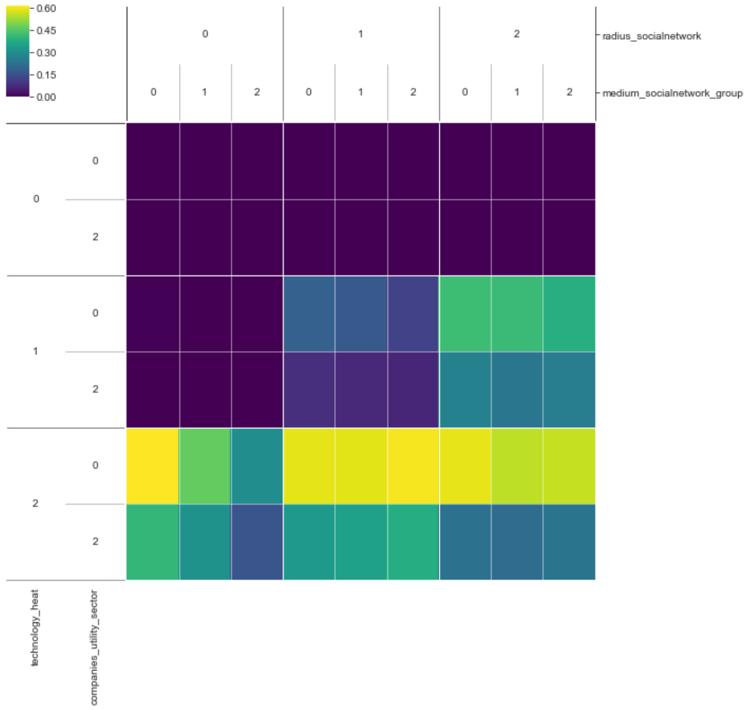


Figure G.26: Dimensional Stacking of the Conflicts between Sustainability and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

G.3 Traditional Values and Inclusiveness in Conflict

In this section the results from the experiments concerning the value conflicts between the values that require cooperation: security of supply, affordability and sustainability and the value inclusiveness.

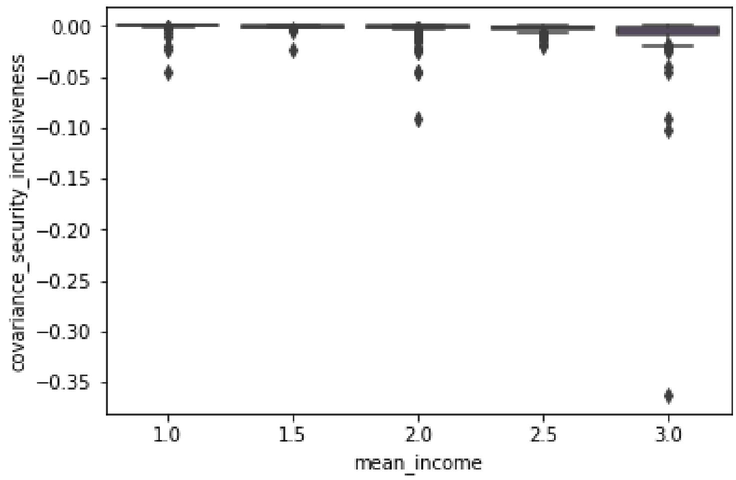


Figure G.27: Box Plot: Conflicts between Security of Supply and Inclusiveness (y-axis) between and within Income Groups (x-axis).

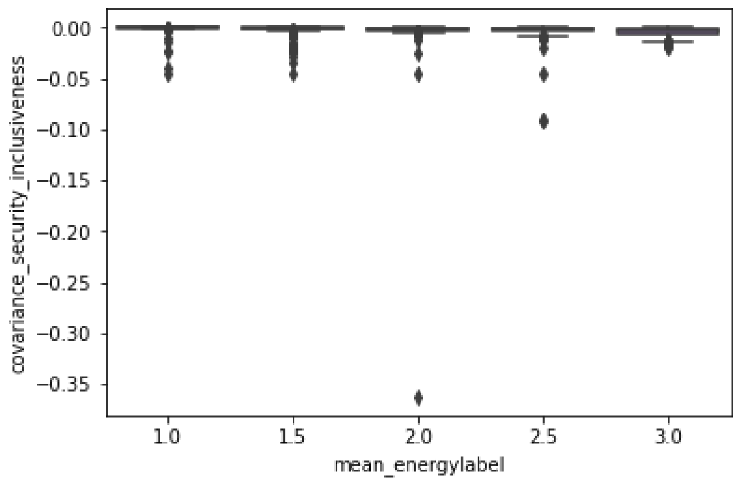


Figure G.28: Box Plot: Conflicts between Security of Supply and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.784625
radius_socialnetwork	0.065810
companies_utility_sector	0.036838
medium_socialnetwork_group	0.016107
range_inclusiveness	0.015553
large_socialnetwork_group	0.015415
large_size_community	0.015093
medium_size_community	0.014405
subsidies	0.013227
technologies_more_sustainable	0.009662
renovations_cheaper	0.006816
community_model	0.006450

Figure G.29: Ranking of Determining Factors for Conflicts between Security of Supply and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

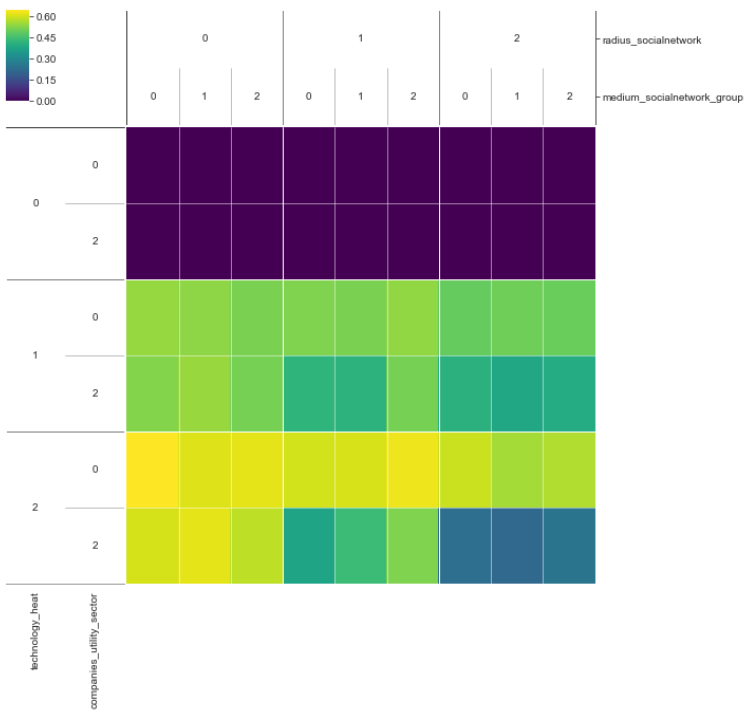


Figure G.30: Dimensional Stacking of the Conflicts between Security of Supply and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

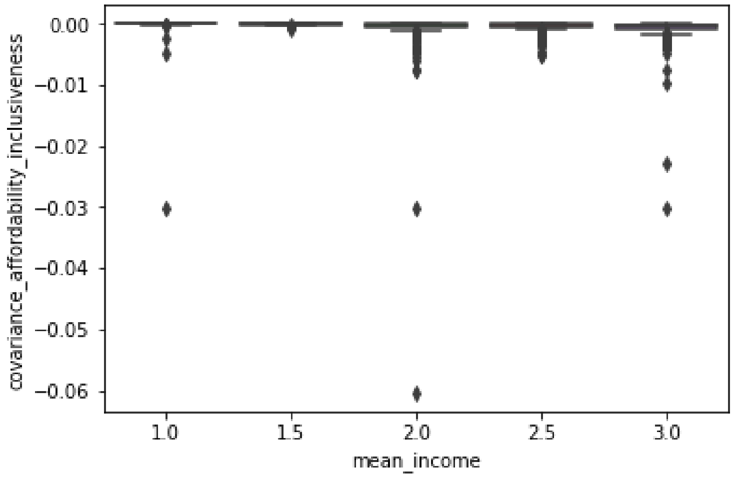


Figure G.31: Box Plot: Conflicts between Affordability and Inclusiveness (y-axis) between and within Income Groups (x-axis).

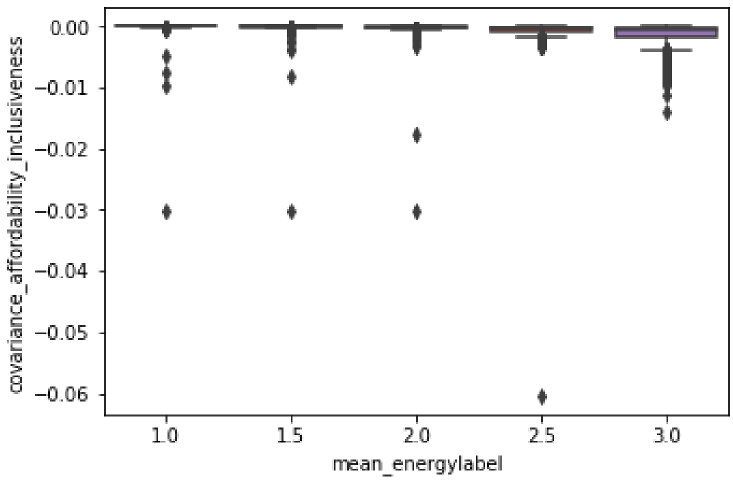


Figure G.32: Box Plot: Conflicts between Affordability and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.446167
technologies_more_sustainable	0.114252
radius_socialnetwork	0.100230
renovations_cheaper	0.053072
companies_utility_sector	0.044236
range_inclusiveness	0.042094
medium_socialnetwork_group	0.040449
large_socialnetwork_group	0.039920
medium_size_community	0.039906
large_size_community	0.039724
subsidies	0.023846
community_model	0.016107

Figure G.33: Ranking of Determining Factors for Conflicts between Affordability and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

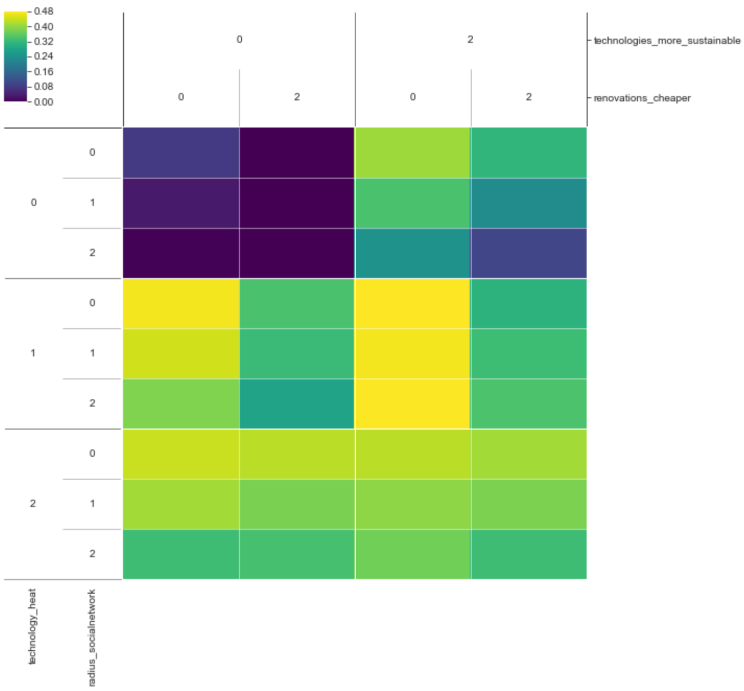


Figure G.34: Dimensional Stacking of the Conflicts between Affordability and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

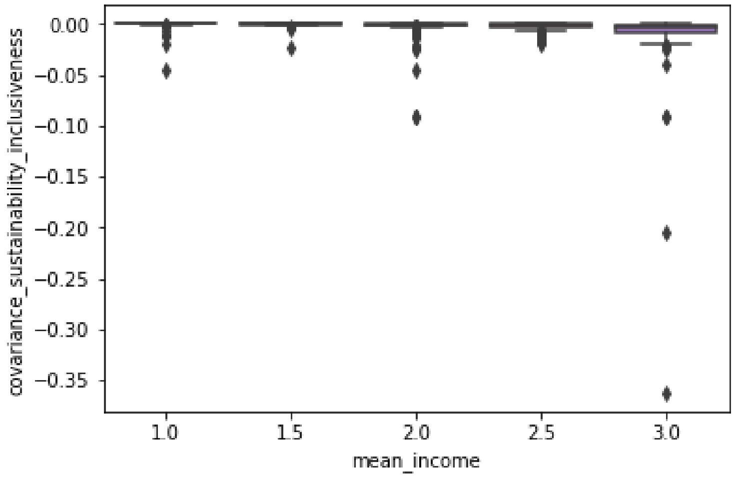


Figure G.35: Box Plot: Conflicts between Sustainability and Inclusiveness (y-axis) between and within Income Groups (x-axis).

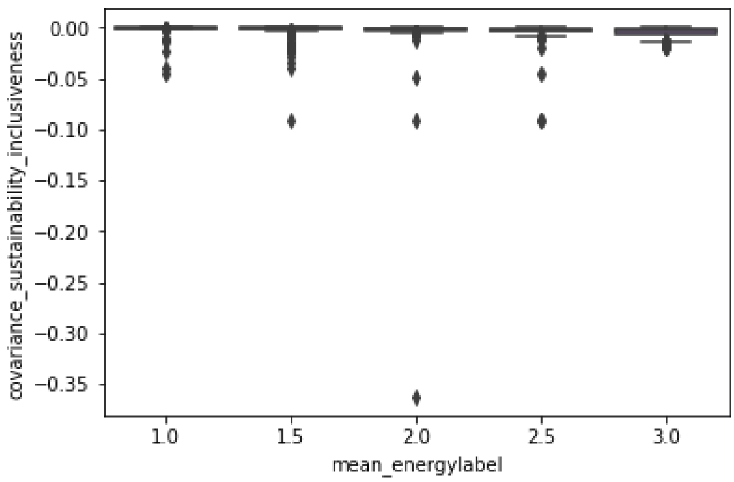


Figure G.36: Box Plot: Conflicts between Sustainability and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.571893
radius_socialnetwork	0.104873
technologies_more_sustainable	0.098823
companies_utility_sector	0.061402
medium_socialnetwork_group	0.025719
large_socialnetwork_group	0.024491
range_inclusiveness	0.023786
large_size_community	0.023166
medium_size_community	0.022231
subsidies	0.019626
renovations_cheaper	0.014115
community_model	0.009876

Figure G.37: Ranking of Determining Factors for Conflicts between Sustainability and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

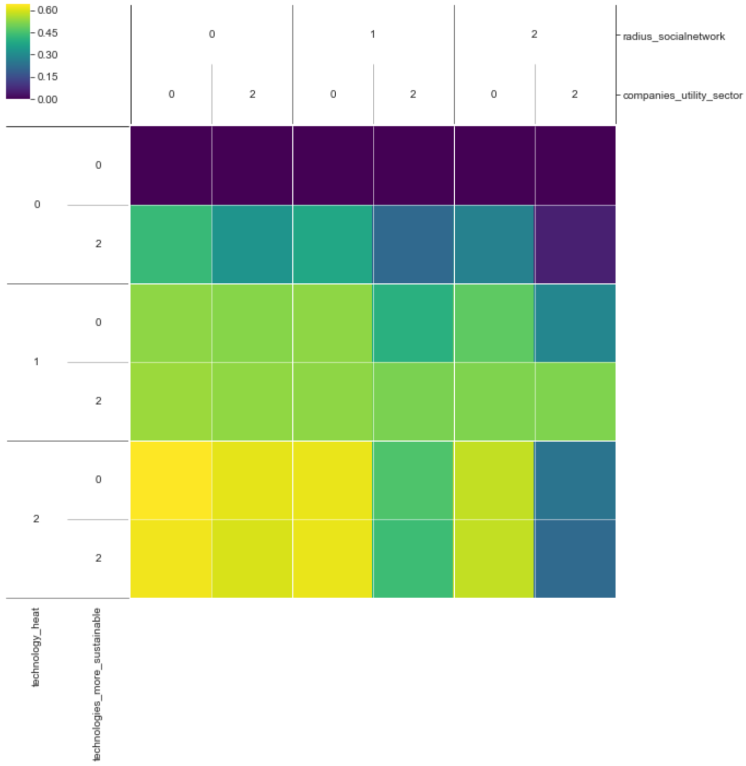


Figure G.38: Dimensional Stacking of the Conflicts between Sustainability and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

G.4 Autonomy, Comfort and Inclusiveness in Conflict

In this section the results from the experiments concerning the value conflicts between the values autonomy, comfort and inclusiveness.

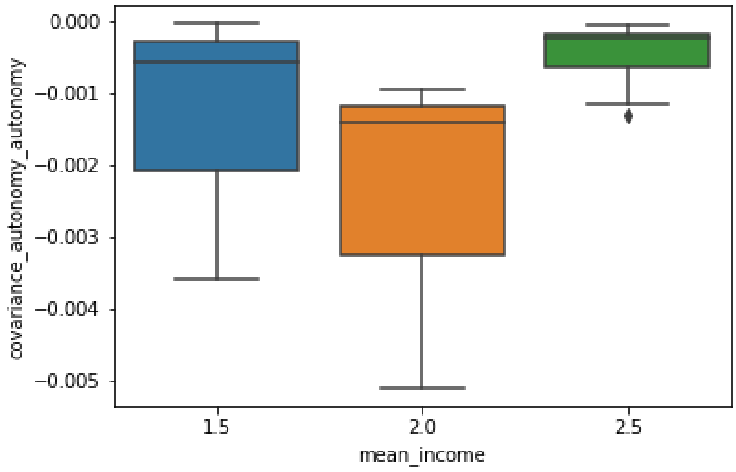


Figure G.39: Box Plot: Conflicts between Autonomy and Autonomy (y-axis) between Income Groups (x-axis).

radius_socialnetwork	0.141974
range_inclusiveness	0.140771
large_socialnetwork_group	0.133787
medium_size_community	0.130924
large_size_community	0.129302
medium_socialnetwork_group	0.124797
technology_heat	0.058653
subsidies	0.036875
technologies_more_sustainable	0.035033
companies_utility_sector	0.028888
community_model	0.025650
renovations_cheaper	0.013345

Figure G.40: Ranking of Determining Factors for Conflicts between Autonomy and Autonomy. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

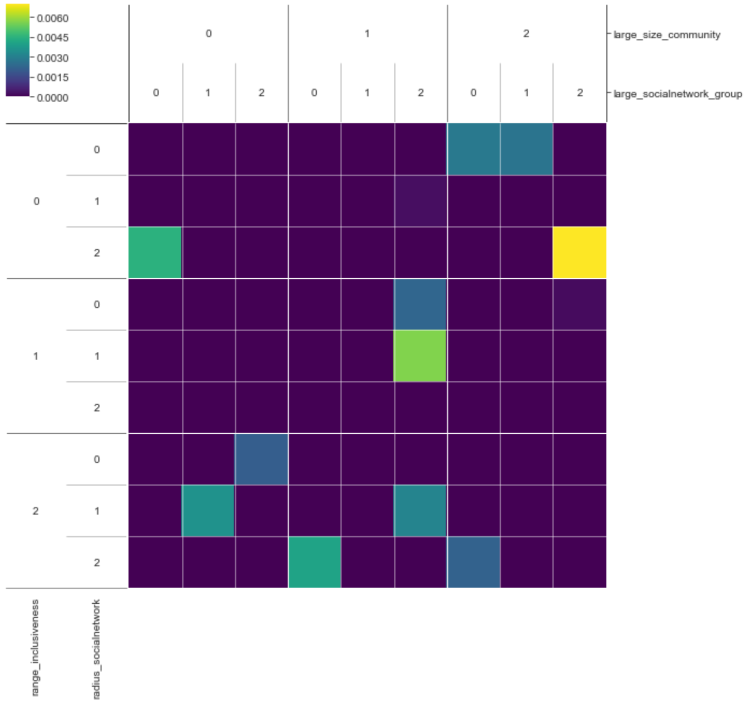


Figure G.41: Dimensional Stacking of the Conflicts between Autonomy and Autonomy. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

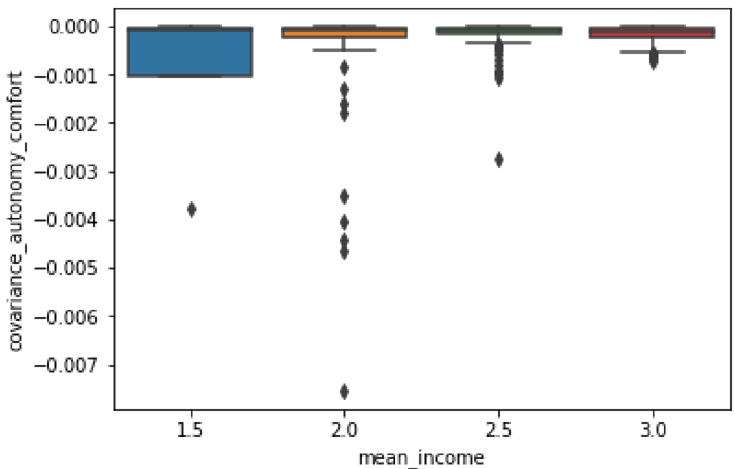


Figure G.42: Box Plot: Conflicts between Autonomy and Comfort (y-axis) between and within Income Groups (x-axis).

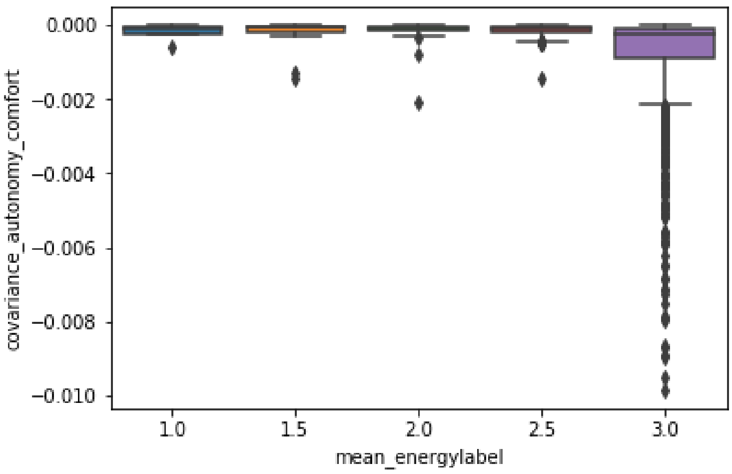


Figure G.43: Box Plot: Conflicts between Autonomy and Comfort (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.372259
radius_socialnetwork	0.244830
technologies_more_sustainable	0.093040
medium_socialnetwork_group	0.051058
large_size_community	0.037755
large_socialnetwork_group	0.036980
range_inclusiveness	0.036119
medium_size_community	0.035921
companies_utility_sector	0.031406
subsidies	0.023008
renovations_cheaper	0.021884
community_model	0.015740

Figure G.44: Ranking of Determining Factors for Conflicts between Autonomy and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

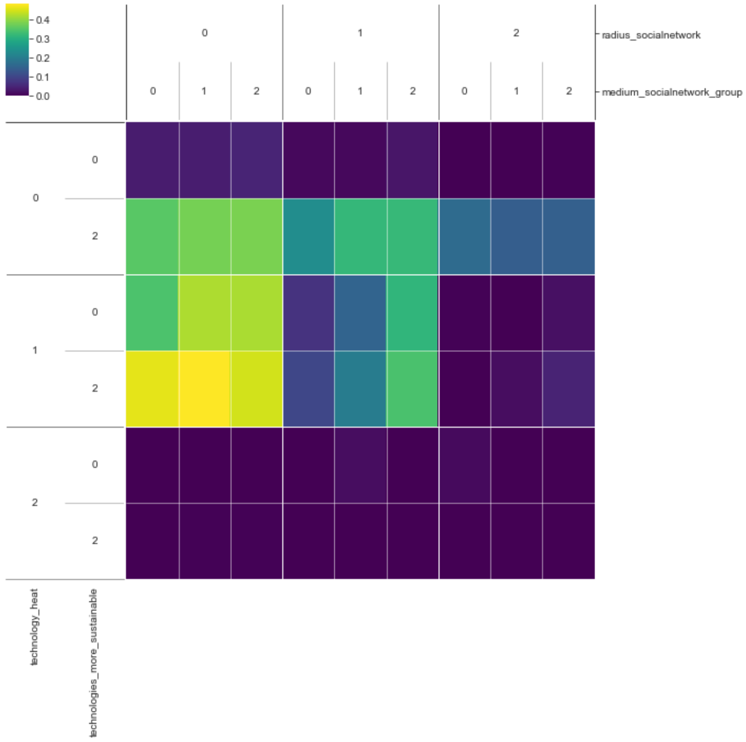


Figure G.45: Dimensional Stacking of the Conflicts between Autonomy and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

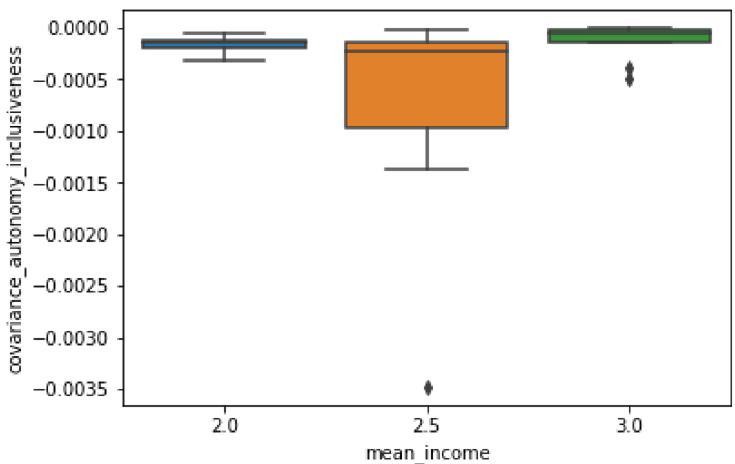


Figure G.46: Box Plot: Conflicts between Autonomy and Inclusiveness (y-axis) between and within Income Groups (x-axis).

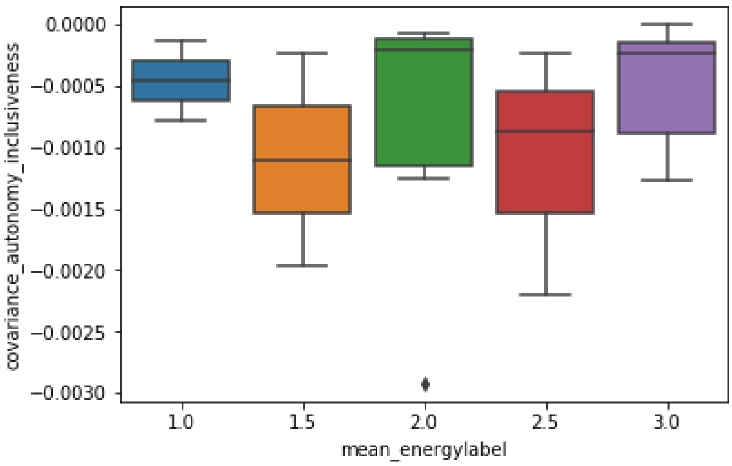


Figure G.47: Box Plot: Conflicts between Autonomy and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis).

radius_socialnetwork	0.160471
medium_size_community	0.141703
large_size_community	0.137960
large_socialnetwork_group	0.118367
range_inclusiveness	0.117903
medium_socialnetwork_group	0.117357
technology_heat	0.049797
subsidies	0.040175
renovations_cheaper	0.035884
technologies_more_sustainable	0.031865
companies_utility_sector	0.028264
community_model	0.020255

Figure G.48: Ranking of Determining Factors for Conflicts between Autonomy and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

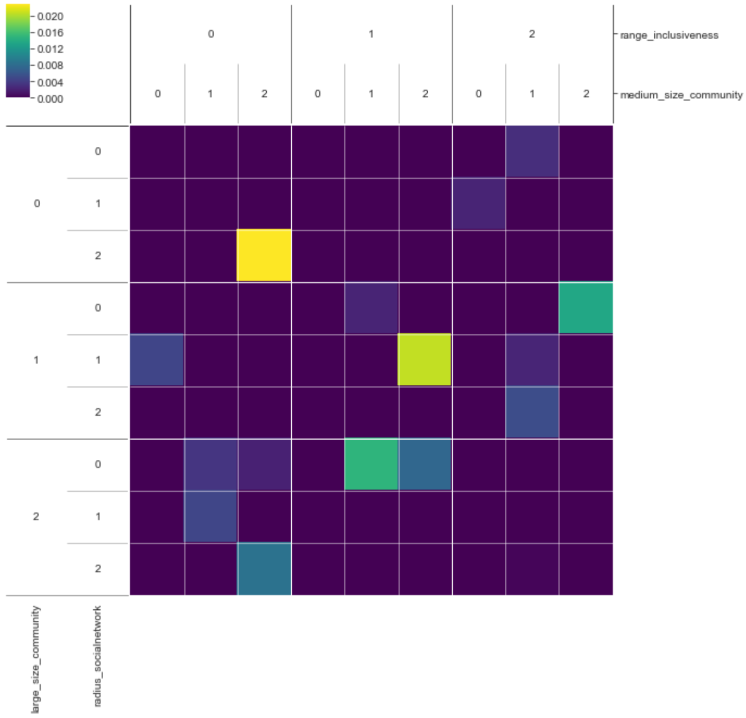


Figure G.49: Dimensional Stacking of the Conflicts between Autonomy and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

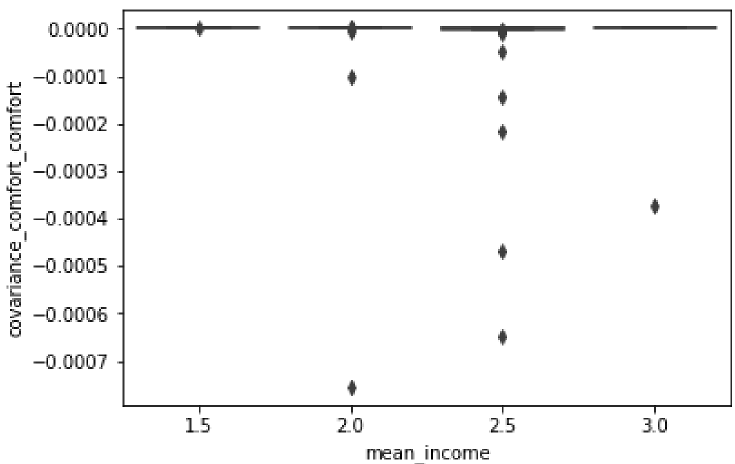


Figure G.50: Box Plot: Conflicts between Comfort and Comfort (y-axis) between Income Groups (x-axis).

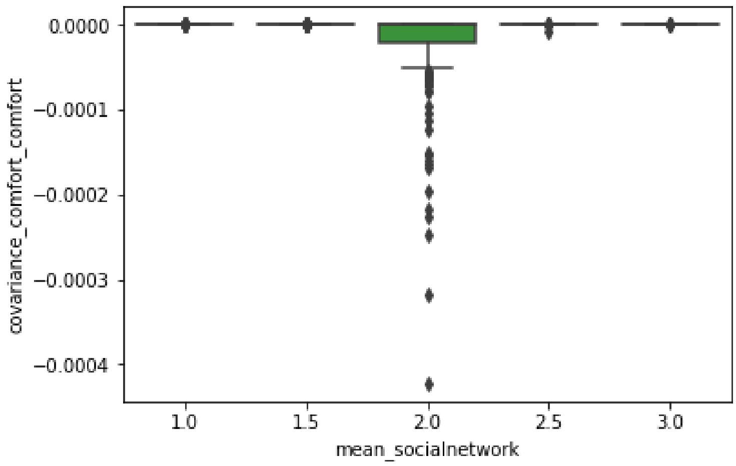


Figure G.51: Box Plot: Conflicts between Comfort and Comfort (y-axis) between Social Network Groups (x-axis).

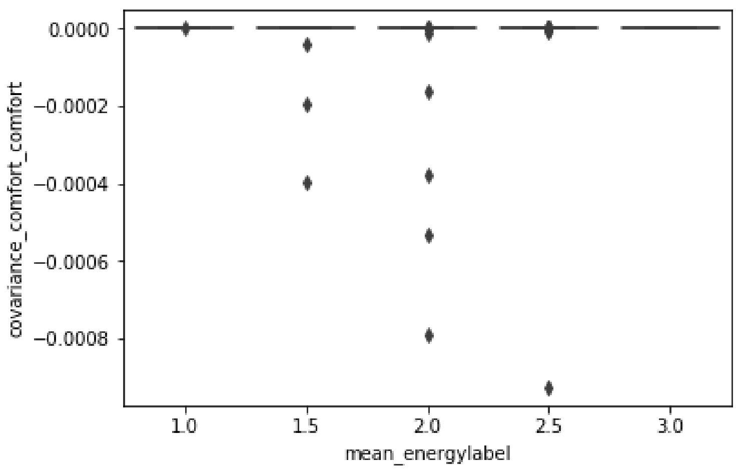


Figure G.52: Box Plot: Conflicts between Comfort and Comfort (y-axis) between Energy Label Groups (x-axis).

radius_socialnetwork	0.154198
medium_socialnetwork_group	0.136433
technology_heat	0.119192
large_size_community	0.101964
range_inclusiveness	0.100335
large_socialnetwork_group	0.099971
medium_size_community	0.096397
subsidies	0.050345
community_model	0.041234
renovations_cheaper	0.034303
companies_utility_sector	0.034120
technologies_more_sustainable	0.031508

Figure G.53: Ranking of Determining Factors for Conflicts between Comfort and Comfort. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

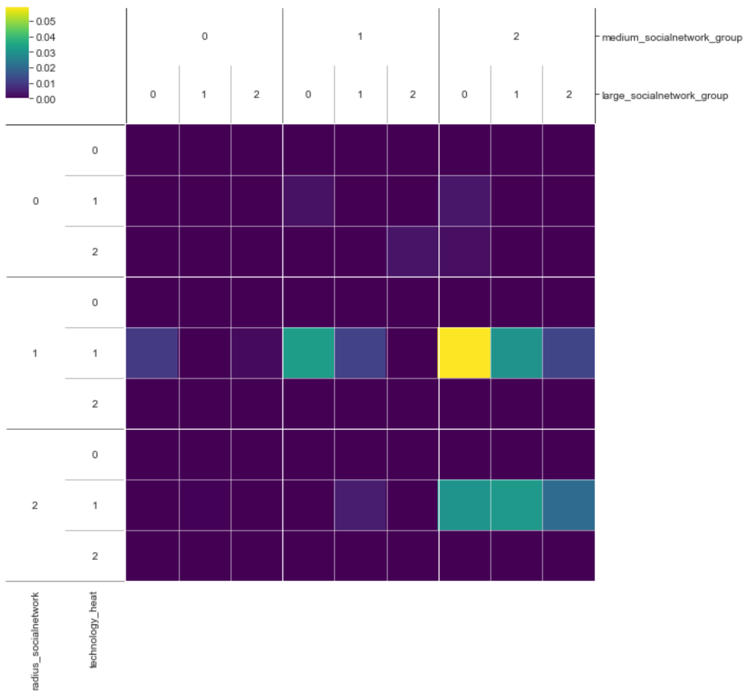


Figure G.54: Dimensional Stacking of the Conflicts between Comfort and Comfort. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

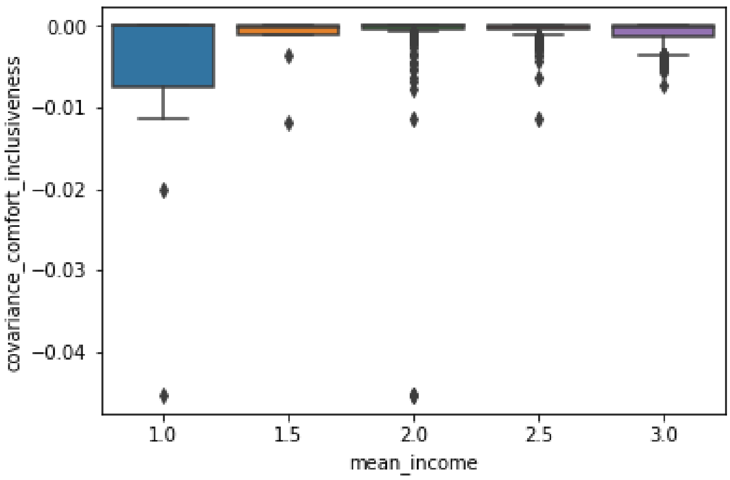


Figure G.55: Box Plot: Conflicts between Comfort and Inclusiveness (y-axis) between and within Income Groups (x-axis).

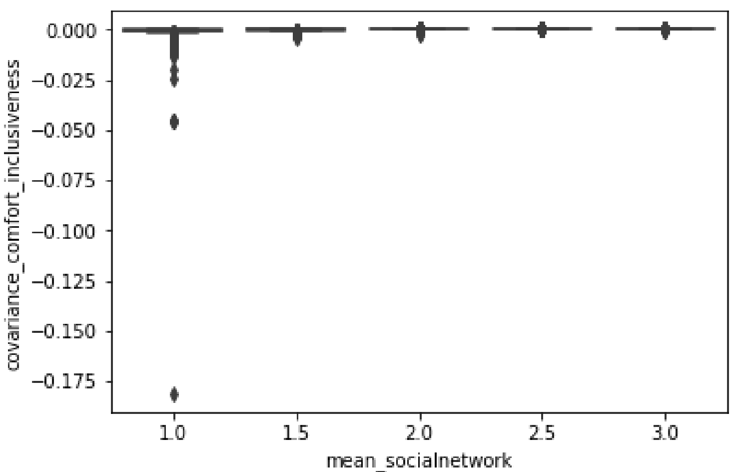


Figure G.56: Box Plot: Conflicts between Comfort and Inclusiveness (y-axis) between and within Social Network Groups (x-axis).

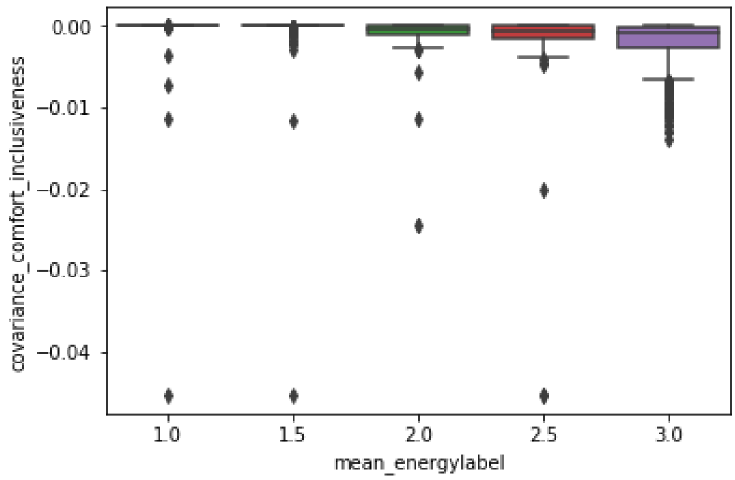


Figure G.57: Box Plot: Conflicts between Comfort and Inclusiveness (y-axis) between and within Energy Label Groups (x-axis).

technology_heat	0.412797
radius_socialnetwork	0.253119
technologies_more_sustainable	0.071129
medium_socialnetwork_group	0.048494
large_size_community	0.034476
medium_size_community	0.034236
range_inclusiveness	0.033507
large_socialnetwork_group	0.033054
companies_utility_sector	0.023482
subsidies	0.022580
renovations_cheaper	0.019111
community_model	0.014015

Figure G.58: Ranking of Determining Factors for Conflicts between Comfort and Inclusiveness. The policy or uncertainty that has the highest value is the most determining factor for the conflict.

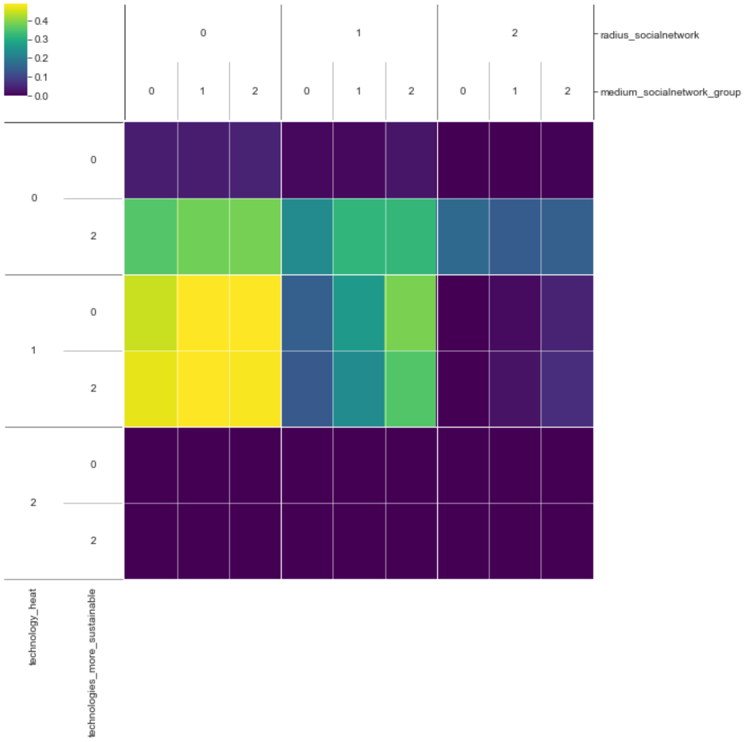


Figure G.59: Dimensional Stacking of the Conflicts between Comfort and Inclusiveness. When the result is more yellow in the dimensional stacking, the conflict is determined by the combination of the factors on the axis.

Appendix H

Model Files

It is chosen to put the files used for the analysis in a GitHub folder. All the files, except the model (Netlogo file) and the files to set-up the experiments, can be extracted from this folder. The model is not shared in the folder, since it is confidential. The files to set up the experiments are not shared in the folder, because they require a lot of changes in the EMA workbench to make them compatible. It is not recommended to do this without explanation of the author. When interested in using the model and running experiments with this model in EMA Workbench, please send an e-mail to `a.r.boijmans@student.tudelft.nl`.

The following link leads to all the files used for this research: `https://github.com/aboijmans/master-thesis`.

- Stochastic Uncertainty (csv file and jupyter notebook file)
- Weighting Values (csv file and jupyter notebook file)
- Data files (uncertainties and policies, uncertainties only and policies only)
- Open Exploration (jupyter notebook file)
- Sensitivity Analysis (jupyter notebook file per data file)
- Scenario Discovery (jupyter notebook file)