B.A. Henrich

The use of energy models in heating transition decision making

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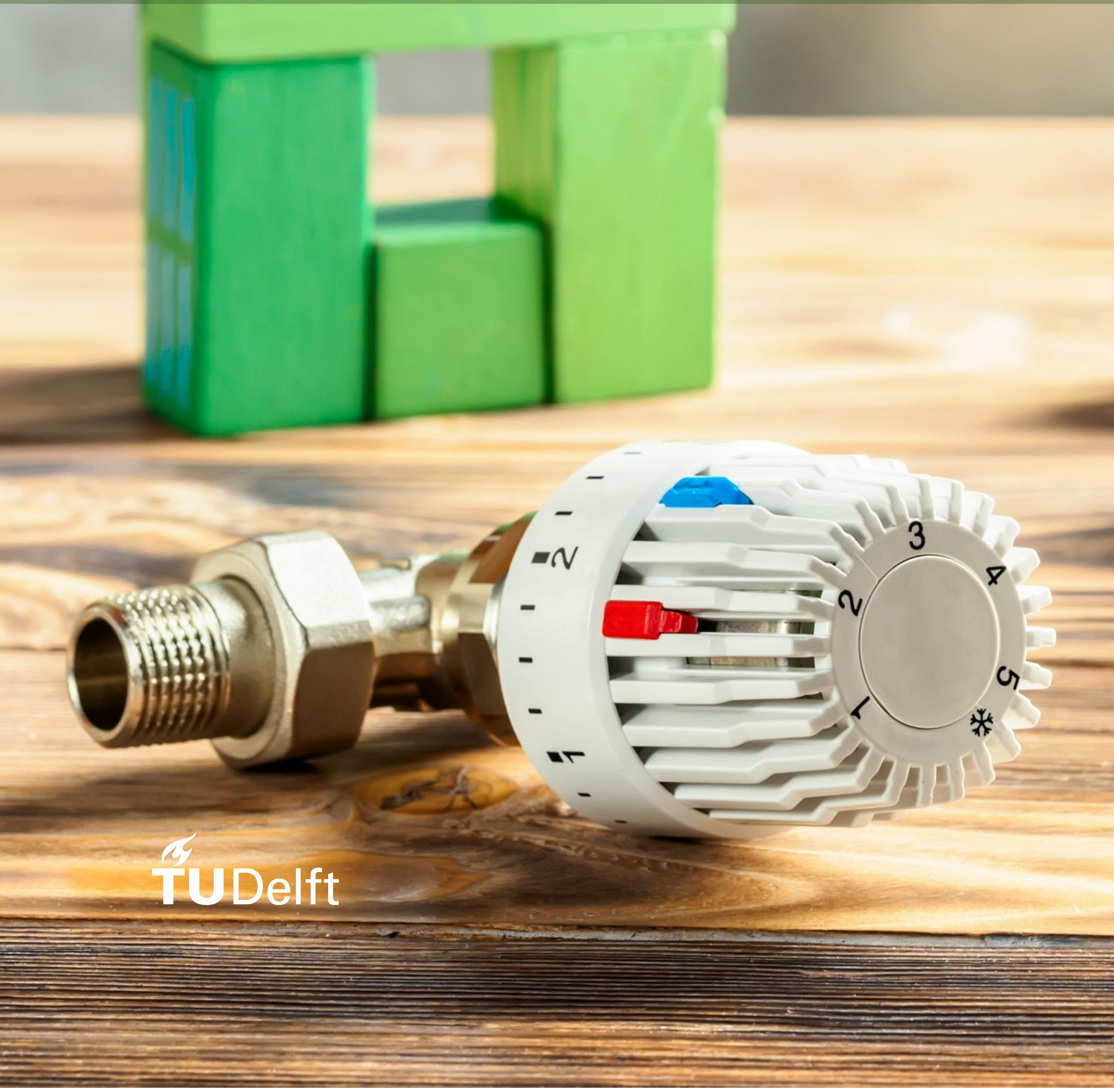

TU Delft

The use of energy models in heating transition decision making

Insights from ten municipal heating transition case studies in the Netherlands

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TU Delft

Preface & Acknowledgements

Before you lies the MSc thesis "The use of energy models in heating transition decision making: insights from ten municipal heating transition case studies in the Netherlands", a research based on embedded case studies into heating transition projects at ten Dutch municipalities. This thesis was written in fulfilment of the Complex Systems Engineering and Management programme at the Delft University of Technology and offers seven recommendations for more effective energy model use targeted at model developers and heating transition practitioners. I conducted this research between March and September 2020 and defended the thesis at October 21 2020 in Delft.

This research was undertaken during an internship at TNO and the research question was formulated together with my TNO supervisor, Devin Diran. During my studies, Devin was always available to answer my questions and to connect me with interesting contacts or projects relating to my studies. His practical mindset and his experience with academic research have greatly helped me during my study. Devin, thank you for your help and enthusiasm! To my other colleagues at TNO, thank you for your curiosity, for your knowledge and for involving me in your research projects.

Special thanks also go out to my supervisors from the TU Delft for their guidance and support during this project. Your feedback has greatly helped me to scope my research and to improve its academic value. Your constructive criticism has, I think, greatly improved my final product. Moreover, I would like to thank the interviewees of my research, without whose cooperation I could not have conducted this study. I thank all 23 interviewees for their time, their enthusiasm their interesting insights and for the fact that they were willing to adjust to the online situation that the Corona pandemic has put us in.

Finally, I would like to thank Anton and my parents. Who did not only provide support and tips, but who also never seemed to grow tired of my constant research related chatter! Your wise words always made me feel confident that I was moving in the right direction and helped me to gain some perspective whenever I would worry about my research.

I hope you will enjoy reading this thesis.

B.A. Henrich
Delft, October 2020

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Executive Summary

In March 2018, the Dutch national government announced its decision to end natural gas extraction from the Groningen gas field by 2030. To plan for a transition to sustainable heating within the built environment, municipalities need data and evidence to support decision-making processes. Adopting a data-driven approach using energy models can improve the decision-making process. The goal of the present study was to provide clear recommendations on how to use energy models for data-driven decision-making. The research question of this study was therefore as followed: "How can Dutch municipalities effectively use energy models within their data-driven decision-making processes regarding heating transition towards a gas-free heat supply?" To answer the research question embedded case studies were conducted at ten Dutch municipalities. The sources of evidence per case study that have been used were (1) governmental reports (2) interviews with practitioners and (3) interviews with model developers. Interview transcripts were analysed with thematic coding, using Atlas.ti 8 software. The empirical results were then used to test the ten theoretical propositions via pattern matching. Table 1 presents an overview of the tested theoretical propositions.

Table 1: An overview of the confirmed and rejected theoretical propositions.

Theoretical proposition	Confirmed/rejected
Different municipalities use different energy models (if any) with different aims.	confirmed
If energy models are complex to use, then practitioners will make limited use of them while planning for the heating transition.	confirmed
If energy models are not user friendly, then practitioners will make limited use of them while planning for the heating transition.	confirmed
If energy models do no integrate social or socio-economic factors, then practitioners will make limited use of them while planning for the heating transition.	rejected
If assumptions within energy models are uncertain, then this will decrease the trust within energy models for practitioners.	unclear
If data is uncertain or unavailable, then this will decrease the trust within energy models for heating transition decision making of practitioners.	unclear
Practitioners seek the help of external parties to use and interpret energy models.	confirmed
External parties have commercial reasons to not be transparent about their energy model design.	unclear
Practitioners need new (in-house) expertise to effectively use energy models	confirmed
Interactive visualization and different interfaces for different stakeholders could improve the usability of energy models.	confirmed

An unexpected finding of this study was that both model developers and practitioners had little desire to include social and/or socioeconomic factors within the current energy techno-economic models, since these models were focused on finding the lowest societal costs of different heating alternatives. Model developers and practitioners did claim that social and socio-economic factors were useful to prioritize neighbourhoods for the transition, to get a sense of how residents could be motivated and to identify coupling opportunities. Therefore, social and socio-economic data was gathered and presented by model developers and practitioners in heating transition projects alongside of modelling results as a means to start useful discussions.

Based on the results of the embedded case studies seven recommendations for more effective use of energy models were proposed:

1. **Develop and preserve knowledge, skills and competences regarding the use of energy modelling by municipalities**

The present study recommends developing practical and interactive training materials for practitioners focused on critically evaluating problem definitions, the modelling process, the use of models and how to prevent some common pitfalls. Knowledge and skill development should be done collectively where possible (as opposed to every municipality independently). Developing knowledge about available energy models and modelling processes will enable practitioners from municipalities to either model scenarios themselves or to correctly and critically interpret and reflect on modelling studies conducted by third parties.

2. **Provide more user-friendly models and/or model interfaces**

The present study recommends model developers to make energy models more user friendly and accessible for non-experts by offering interactive models or model interfaces. According to interviewees of this study, interactivity helps end-users, such as municipalities, with understanding the dependencies of variables and the sensitivities of parameters within energy models. It shows that modelling results do not provide absolute answers and that they are dependent on the underlying assumptions. Models should not only be made interactive to increase usability, but the entire modelling process should be an interactive process with a multitude of stakeholders involved, such co-creation could also improve the legitimacy and support of modelling results.

3. **Improve heat source, energy use and thermal insulation level data sets**

There is a need for improved heat source data, energy use data and thermal insulation level data for energy models to be more useful for heating transition projects, both for the residential and utility sector. Current heat source data sets are uncertain and incomplete, energy use data is only available in averages and insulation data is inaccurate. The present study recommends municipalities to invest in heat source studies and to involve potential heat suppliers, such as industrial facilities, in such studies to get more certainty about the availability, temperature and price of potential heat sources. Data set improvement should be done collectively where possible (as opposed to every municipality independently).

4. **Develop more efficient data collection processes at municipalities**

The present study showed that data collection at municipalities is important to ensure that the modelling study provides enough local detail and to define potential social or infrastructural coupling opportunities. However, both model developers and practitioners stated that the data collection process can be too time-consuming. Developing a more efficient data collection process at municipalities is recommended to enlarge the potential benefits of using an energy model. The present study proposes three suggestions to achieve this: 1)Set up covenants with stakeholders to share relevant data; 2) provide clear guidelines on how to store, access and share data; and 3) provide documentation on which data has been collected, from where, with what goal and under which conditions. Data collection should be done collectively where possible (as opposed to every municipality independently).

5. **Offer and demand transparent modelling processes**

The present study urges model developers and model users to be transparent about the input data, mathematical principles, assumptions, parameters and parameter sensitivities used within heating transition projects. It is recommended for both model developers and model users (municipalities) to follow standards of transparent evidence-based policy design when conducting modelling studies for heating transition projects or when using a third party to conduct the modelling process.

6. **Offer and demand comparative modelling studies**

Comparative studies provide robustness of modelling results by comparing the underlying assumptions, data and sensitivities and modelling results of different models/modelling studies. The myriad of models, that occasionally provide different results for the same research question, create confusion and uncertainty at municipalities. Offering comparative analysis ensures the myriad of models and modelling studies is used to create more certainty by showing for which neighbourhoods models provide the same results, where results differ and why? The present study recommends to perform more national comparative studies such and to conduct comparative analysis during heating transition projects.

7. Ensure that model developers collaborate and specialize

More collaboration between different model developers, where multiple models are used within one project, could save practitioners time and allows modelling results to be compared to one another immediately. The present study recommends specialization in other abstraction levels or on the connection with other industries for a share of energy models, as not all current models are needed for comparative analysis. To achieve this, model developers should position and improve current models or develop new models in such a manner that they offer specialized expertise, for example by showing the impact of heating choice on the electrical network. To make the most use of a range of specialized models the present study recommends to invest in multi-modal ecologies.

Finally, based on the outcomes of the present study, academics and practitioners are urged to consider when the use of energy models adds value to the decision-making process and when it unnecessarily increases the complexity of the decision-making process. The case studies presented heating transition projects in which energy models played a significant role in deciding a heating transition alternative, but also shed light on the characteristics of heating transition projects where no energy models were used to choose a suitable natural gas alternative.

Abbreviations & terms used

Table 2: Definition of key concepts and abbreviations used within this study.

Concept	Abbreviation	The definition used within this study
Energy model	Not applicable	A computer model of an energy system that introduces a structured way of thinking about the implications of changing parts of the system (Pfenninger et al., 2014). Outputs may include things such as financial costs, CO_2 emissions, resource use, energy efficiency, or system feasibility of the energy system that is investigated.
Startanalyse	SA	The Startanalyse (Start Analysis) is a national modelling study conducted with the Vesta MAIS model by PBL. The Startanalyse is presented together with guidelines for local analysis (Handreiking) in a guidebook (Leidraad) for Dutch municipalities.
Openingsbod	OB	The Openingsbod (opening offer) is a modelling study initiated by Stedin, a Dutch network operator. The study was developed as a tool to quicken decision-making in the Dutch heating transition. The study compares the modelling approach and the results of three different energy models.
Programme for Natural Gas-Free Districts	PAW	A joint programme of the Ministry of the Interior and Kingdom Relations, the Ministry of Economic Affairs and Climate Policy, the VNG, the IPO and the Association of Regional Water Authorities (UvW) that, among others, provides subsidies and requirements for the Test Beds for Natural Gas-Free Districts (Pilot projects) (Government of the Netherlands, 2019).
Regional Energy Strategy	RES	"Within the RES, public authorities work alongside social partners, network managers the business community and, where possible, residents to develop regionally supported choices. The aim of the RES is to realise the generation of renewable electricity (35 TWh), to realise the heating transition in the built environment (from fossil to sustainable sources) and to realise the necessary storage and energy infrastructure." (Government of the Netherlands, 2019).
Transition Vision Heat	TVW	The TVW is a policy document in which the municipal council has to establish a realistic schedule within which to transition away from natural gas (Government of the Netherlands, 2019). The focus of the first TVW is on the period until 2030 and every municipality has to show which building will become natural gas free or insulated, with which electrical infrastructure and when (PAW, 2020).
Neighbourhood Implementation plans	WUP	A WUP is the follow up of the TVW and indicates how a municipality will make a specific neighbourhood natural gas-free by transitioning to sustainable heating and cooking systems (Goes, 2020).
Heat network	Not applicable	Heat networks (also known as district heating or teleheating) is a system for distributing residual heat or heat generated in a centralized location through a system of insulated pipes for residential and commercial heating. HT= high temperature, MT = medium temperature and LT = low temperature.
Basic registration of addresses and buildings	BAG	In Dutch: "Basisregistratie Adressen en Gebouwen". The BAG-dataset is a national dataset. Municipalities are responsible for providing data for the BAG-dataset, the dataset is maintained by the Dutch Cadastre, Land Registry and Mapping Agency
Association of Netherlands Municipalities	VNG	The VNG is an organisation that unites the Dutch municipalities, including those overseas. The goal of this association is to strengthen the local governments to ensure municipalities are able to offer their residents optimal support.
Netherlands Enterprise Agency	RVO	RVO supports entrepreneurs, NGOs, knowledge institutions and organisations. RVO operates under the auspices of the Ministry of Economic and its activities are commissioned by the various Dutch ministries and the European Union.

1 Introduction

1.1 The Dutch Heating transition

The heating and cooling sector, which provides energy to warm and cool the built environment, is the largest energy consumer of the European Union, accounting for half of the EU's energy consumption in 2016 (Nava Guerrero et al., 2019). In the Netherlands, 53% of the national heat supply is provided by natural gas (RVO, 2017). In March 2018, the Dutch national government announced its decision to end natural gas extraction from the Groningen gas field by 2030 (Nava Guerrero et al., 2019) to help reach the climate goals of the Paris agreement and to reduce the negative impact of gas extraction in Groningen (RVO, 2017). The heating transition in the Netherlands is defined by RVO (Netherlands Enterprise Agency) as removing natural gas from the built environment (RVO, 2017). In addition, the climate agreement states that a sufficient level of sustainable heating must be made available to meet the target of 3.4 Mega ton of CO_2 emission reduction in the built environment. To reach this goal, 1.5 million existing residential houses have to be supplied with sustainable heating by 2030 (Government of the Netherlands, 2019). The Dutch built environment, therefore, has the challenging task of organizing a heat supply that is natural gas-free. However, decision-making and policymaking for this transition is not simple, as actors, technology and institutions interact in a complex manner (Nava Guerrero et al., 2019). The heating transition requires a change of the supply of renewable energy, the infrastructure, the residential heating systems and of the thermal insulation at residential houses, which all raise questions about the division of costs and the freedom of choice (Buttelaar & Heeger, 2018). Next to these dependencies, the Dutch heating transition poses significant financial challenges. Natural gas is currently in most cases cheaper than sustainable alternatives and residents do not always have sufficient funds to provide the needed investments or to deal with increased living expenses (Schellekens et al., 2019). To organize this challenging transition, the Dutch Environment and Planning Act for 2021 states that every municipality within the Netherlands should incorporate a Transition Vision Heat (TVW) and a plan of execution within their governmental plans, to show how they will organize a heat supply that is natural gas-free and affordable. This leading role in the heating transition is new for municipalities and requires new knowledge, expertise and competences. To this end, the Dutch government has set up Test Beds for Natural Gas-Free districts (pilot projects) and a knowledge and learning programme (KLP) to learn and experiment (Government of the Netherlands, 2019).

1.2 The need for a data-driven methodology

To enable a heating transition in the built environment, municipalities need data and evidence to support their decision-making processes (Brouwer, 2019). Questions such as, which heating source would lead to low end-user costs, low society costs and low CO_2 emissions need to be answered. One way to approach this is with the formulation of data-driven policies. According to the policy lab approach, as defined by van Veenstra & Kotterink (2017), a data-driven policy uses information and communication technologies (ICT) to capture (sensor) data and to facilitate collaboration with citizens to co-create. Using big and open data does not only offer the potential to create better policies but also to create more legitimacy for said policies. Currently, municipalities use little ICT to create policies, this is partly due to a lack of guidelines. New guidelines need to be developed that can make use of new data sources and ICT (van Veenstra & Kotterink, 2017). One form of ICT, that municipalities are trying to integrate when designing policy for the heating transition, is the energy model. Energy models have the ability to help analysts and policymakers to better understand the increasingly complex energy sector. Among others because they help in the formalization and categorization of dispersed knowledge and data about complex interactions within the energy sector. Energy modelling introduces a structured way of thinking about the implications of changing parts of the system (Pfenninger et al., 2014). However, a clear guideline on how to use these energy models while designing policies is lacking. This research aims to provide recommendations for effective use of energy models based on theories of data-driven policy design, such as described by van Veenstra & Kotterink (2017) and Androutsopoulou & Charalabidis (2018) and theories on good modelling practice, such as described by Nikolic et al. (2019a).

1.3 The usability of models and the integration of socioeconomic factors

Next to a lack of knowledge on how to integrate ICTs such as energy models, policymakers also experience challenges with energy models themselves, which hinder the use of these for policy design and decision-making. A Dutch research report mentions that different models provide different results for the same research question, which makes it difficult for policymakers to trust and interpret modelling results (Brouwer, 2019). Another challenge for policymakers when interpreting modelling results is that results are never a certainty, since it is unavoidable to make use of assumptions and estimates when modelling, which may not be valid under all circumstances (Herbst et al., 2012; van Beeck, 1999). These issues are also highlighted in the current literature, as described in chapter 2. Multiple studies (Erker et al., 2019; Sakellaris et al., 2018) state that many energy models are currently difficult to use for non-experts, such as most policymakers. This study aims to investigate how much of an issue this is at Dutch municipalities and how the usability of energy models could be improved.

Another significant challenge of current energy models is that they fail to take into account social aspects. This is problematic since the heating transition is highly dependent on humans and their intentions. Social aspects, such as behaviour and attitude of the public, affect proposed or implemented policies and should therefore not be ignored (Androutsopoulou & Charalabidis, 2018). One social challenge that was mentioned during a conference about the Dutch heating transition (Warmtenetwerk, 2020) and a meeting with a Dutch municipality (TNO & Gemeente Zoetermeer, 2020) is the participation of citizens. At present, building owners (either citizens or associations) have the right and responsibility to make investment decisions about the heating supply of their buildings (TNO & Gemeente Zoetermeer, 2020; Warmtenetwerk, 2020). In other words, building owners have to be incentivised to change their current gas-based heat supply, preferably to a more sustainable option. Building owners and local communities thus form an essential part of the heating system and their contribution to the heating transition, by deciding to adopt sustainable heating technologies and/or thermal insulation for their homes, is key in making the transition happen. Therefore, there is a need to develop, implement and test incentives that target building owners to make investments. One promising solution for this is co-creation with citizens and local stakeholders (Itten et al., 2019), which also fits in the earlier mentioned data-driven policy design of the policy lab approach (van Veenstra & Kotterink, 2017). Another solution, intertwined with co-creation is to incorporate coupling opportunities within heating transition policies (Warmtenetwerk, 2020)(TNO & Gemeente Zoetermeer, 2020). Coupling opportunities are sought after because for each area development, the municipality must consider what challenges it faces in a broader context and consider how these can be included (RVO, 2017). For example, if a road has to be opened up for the development of a heat network, this opportunity can be used to update the sewer system or vice versa. But opportunities can be more social as well, such as incorporating wishes of local residents regarding the layout of the neighbourhood. This study will assess opportunities for the integration of co-creation, social factors and coupling opportunities within the process of using energy models for heating transition decision-making.

1.4 Research questions

In summary, the use of energy models could improve the quality of data driven decision-making in the heating transition, however, the use of such models is currently limited . This is most likely due to a lack of guidelines, how and when do we use these tools? Due to the fact that energy models and their results are hard to understand and interpret for non-experts and due to the lack of integration of social factors, such as citizen preference and coupling opportunities. To investigate the use of energy models for heating transition decision-making, a study into the energy models that are used by policymakers was conducted. The goal of the present study was to provide clear recommendations on how to effectively use energy models for data-driven decision-making. The research question of this study was therefore as follows: How can Dutch municipalities effectively use energy models within their data-driven decision-making process regarding heating transition towards a gas-free heat supply?

Sub questions to answer this research questions were: 1) Which energy models are used while planning the heating transition and how?; 2) How can current energy models be improved to better support decision making in the heating transition? and; 3) What is needed, besides energy model improvements to facilitate effective use of energy models for decision making in the heating transition? To answer these questions an embedded multiple case study was conducted in which different heating transition projects at ten Dutch municipalities were investigated. Based on the results, recommendations on how policymakers can effectively use energy models while planning for the heating transition were formulated.

1.5 Document structure

This chapter introduced why there is a need for research regarding the use of energy models in the Dutch Heating transition. Chapter 2 entails a literature review that elaborates on the role of energy models in data-driven policy design and decision-making, the current advantages and challenges of using energy models, and the Dutch heating transition modelling landscape. Chapter 2 also identifies present knowledge gaps and theoretical propositions. Chapter 3 discusses the research approach and methodology to answer the research questions. This chapter presents the choice and design of the embedded multiple case studies that were used and elaborates on the data collection process. Chapter 4 discusses the results of the first empirical part of this study, the interviews with practitioners from municipalities. This chapter discusses the statements made by interviewees per code, divided over the three sub-questions. Chapter 4 ends with a summary of the most relevant findings per sub-question. Chapter 5 discusses the results of the interviews with model developers. Chapter 6 reflects on the empirical findings in light of the theoretical propositions proposed based on the literature review. Based on the results of the case studies, chapter 7 proposes seven recommendations to improve the use of energy models at Dutch heating transition projects. Chapter 8 discusses the results of this research compared to academic literature, reflects on the theoretical propositions used and identifies limitations of the present study. Chapter 9 concludes with an answer to the research questions, the societal and academic relevance of the present study, recommendations for future research and the link of the present study with the study programme of Complex Systems Engineering and Management of the Delft University of Technology

2 Literature review

This chapter discusses literature related to the use of energy models in heating transition projects. Section 2.1 focuses on academic literature on data-driven policy design, section 2.2 focuses on academic literature on the use of models for heating transition projects and section 2.3 focuses on grey literature about modelling in the context of the Dutch heating transition. Section 2.4 shows how the literature review has led to the design of the research question and introduces a conceptual model and theoretical propositions to guide research activities.

2.1 Data-driven policy design

8 articles were reviewed, an overview of the reviewed articles, their findings and how they were chosen can be found in Table 33, appendix A. The following sections review the findings of these articles.

2.1.1 The importance of ICT and data in policymaking

Justification for policies is usually connected to two main purposes, the search for effectiveness (instrumentality) and the construction of common acceptance (legitimacy). Providing evidence for the effectiveness of policy choices is one of the cornerstones of legitimate policymaking (Adam et al., 2018). Within the literature, one can recognize evidence-based policy design and data-driven policy design. According to van Veenstra & Kotterink (2017), the difference between these two is that data-driven policy focuses on the integration of big and open data sources. They define data-driven as a policy that uses information and communication technologies (ICT's) to capture (sensor) data and to facilitate collaboration with citizens to co-create. According to their study, this integration of data and stakeholders creates the aforementioned legitimacy. Based on the concept of data-driven policy design, van Veenstra & Kotterink developed the policy lab approach. They state that information and communication technologies (ICT's) can enhance different phases of the policy cycle (agenda setting, policy formulation, decision making, implementation, evaluation) by capturing new data and by supporting collaboration with different stakeholders. One of the ICT's mentioned in this approach is energy models. To integrate these and other relatively new ICT's, new methodologies need to be designed. Such methodologies would help in effectively integrating new data sources and technologies in policy design (van Veenstra & Kotterink, 2017).

The importance of ICTs in policymaking is also recognized by Koussouris et al. (2015). They state that ICTs will simplify decision-making processes, even under the most complicated conditions, by facilitating the opportunity to model complex processes and the opportunity to collaborate with different actors involved. Based on analysis of four case studies, they expect that ICTs will help in the acceleration of the engagement of citizens in the policymaking process Something that is highly sought after (Koussouris et al., 2015). Besides, they expect that high quality and open data will improve the accuracy, transparency and efficiency of policymaking processes. However, to ensure this, policymakers should constantly seek for reliable, updated and machine-understandable data sources. Because good models only operate well as long as the data they are fed with is excellent. According to Diran et al. (2020), this is currently not the case in the Dutch energy sector. The use of data for public decision making is currently underdeveloped and especially the energy sector is lacking behind in promoting open and reproducible data and methods. Diran et al. (2020) suggest that within the Dutch heating transition there is currently data with uncaptured value, such as citizen preference for natural gas alternatives and dwelling details (Diran, Hoppe, et al., 2020).

Koussouris et al. (2015) also expect that visualization and social computing will convey policy messages smoother. A large obstacle for the adoption of policy models (such as energy models) is the increased complexity that comes with sophisticated models and methods. Their case studies reveal that interactive visualization holds the key to explain in an understandable and digestible way the operation and the results of complex models. Furthermore, they suggest that models are being understood differently by different stakeholders and that is therefore important to offer infrastructures that bridge this gap in understanding. This can be realised by offering different interfaces to different target groups. Lastly, this study concludes that policymakers must adopt research teams within their organisations to break down barriers of communication and context understanding when it comes to using new ICTs for policy development.

2.1.2 The changing role of policymakers

Janssen and Helbig (2015) also investigate the impact of new ICTs on policymaking and identify the changing role of policymakers. They state that policymakers often use models to formulate their policies and to do this, they rely not only on their research but also on research conducted by third party experts (e.g. research agencies, consultancy firms, academic institutions). Usually, stakeholders are only minimally involved in this process, however, Janssen & Helbig (2018), like van Veenstra & Kotterink (2017) propose that more participative approaches could help in understanding the needs from and perceptions of stakeholders. Moreover, their study states that policymakers now have to assure the quality of engagement, legitimacy of the process and usability of data and information. They must create processes for checking complex simulations, falsify arguments and validate and verify the models they use. In addition, policymakers will take on the role of aggregating and reporting vast amounts of data collected through new forms of connection and communication. According to Janssen & Helbig (2018), new expertise within governmental organisations is needed to deal with these new responsibilities caused by advances in ICTs (Janssen & Helbig, 2018).

This concern whether governmental organisations have the capabilities to facilitate data-driven policies is also highlighted by Poel et al. (2015), who investigated emerging opportunities for data-driven policymaking. One of their findings is that there are pressing concerns about the availability of relevant skills in governmental organisations related to data collection, data analysis and interpretation of data. Moreover, they shed light on the risk that a data-driven approach can reduce transparency for the policy process, especially if data collection and data analytics are not fully understood by policymakers and other stakeholders. Another interesting finding of this study is that it identifies the need for strategies to ensure policymakers are informed about the tools (such as energy models) that are being developed in research projects (Poel et al., 2015).

2.1.3 Guidelines for data-driven policy design

One study within this sample attempted to design a methodology for data-driven policy design (Androutsopoulou & Charalabidis, 2018). Within their study, they developed a framework for evidence-based policymaking. Their framework incorporates open big data and could, therefore, by the definition of Van Veenstra & Kotterink (2017), be defined as a data-driven approach. Their methodology, like the policy lab approach, mentions the value of modelling and machine intelligence. They state that dynamic modelling has the potential to reduce the uncertainty of complex social issues, as they allow for proactive analysis of socio-economic impacts of initiatives if they rely on the appropriate evidence. However, they also state that most existing models fail to take social aspects into account. The study concludes that there is a lack of systematic approaches that consider not only the objective facts but also people's behaviour, people's attitude towards these facts and the effect that these behaviours and attitudes will have for the implemented policies. One key goal of the data-driven methodology as proposed by Andoutsopoulou & Charalabidis (2018) is to enable the combination of objective facts coming from statistical databases with subjective data revealing the public opinion and people's behaviour (Androutsopoulou & Charalabidis, 2018).

Another study that attempts to offer guidelines for evidence-based policy design, regardless of which method one uses to design, is Argyrous (2012). This study, although possibly not focused on data-driven approaches (types of data used are not mentioned), states that transparency and accountability are necessary to design any sort of evidence-based policy. They define a transparent process as a process that is open to scrutiny, and state that accountability requires those engaged in evidence-based policy to actively seek out ways in which evidence can be assessed. The study provides seven standards for transparency, see Table 3. For accountability, they suggest one should at least provide evidence to those affected by the policy, to those who hold a different conceptual framework and to independent experts. An important notion to their guidelines is that the author of this study acknowledges that the extent to which these standards are to be followed is dependent on the ethical and practical considerations of the context (Argyrous, 2012). Within the context of the Dutch heating transition and the use of energy models, especially analytical assumptions and choices and the relationship with past research seem to be important transparency standards.

Table 3: Seven standards for transparent evidence-based policy design (Argyrous, 2012).

#	The standard for transparent evidence-based policy design
1	Ensure that raw data is accessible
2	Ensure that the data collection instrument is accessible
3	Ensure that metadata is accessible
4	Explicitly explain analytical assumptions
5	Explicitly explain analytical choices and their testing
6	Acknowledge and declare the relationship with past research
7	Acknowledge and declare financial and other interests

2.1.4 Summary Data-driven policy design

This short overview shows that most studies agree that using a data-driven approach using new data sources and technologies can improve policymaking practices (Adam et al., 2018; Androutsopoulou & Charalabidis, 2018; Janssen & Helbig, 2018; Koussouris et al., 2015; Poel et al., 2015; van Veenstra & Kotterink, 2017), but that a systematic approach to do so is still missing (Androutsopoulou & Charalabidis, 2018; van Veenstra & Kotterink, 2017). Moreover, many studies agree that the involvement of stakeholders is beneficial for policymaking and that new ICTs can support this involvement (Androutsopoulou & Charalabidis, 2018; Janssen & Helbig, 2018; Koussouris et al., 2015). However, multiple studies do express concerns about the capabilities of policymakers (and stakeholders) to deal with new data sources and technologies (Janssen & Helbig, 2018; Koussouris et al., 2015; Poel et al., 2015). No academic literature was found on how the use of new ICTs, such as energy models, would affect practitioners within the Dutch heating transition, indicating a research gap. This research gap is strengthened by the claim of Diran et al. (2020), who state that the use of data for public decision making is currently underdeveloped, especially in the energy sector. Moreover, multiple studies call for more clear guidelines for the use of new ICTs at governmental institutions. Argyrous (2012) offers some guidelines on ensuring transparency and accountability, but only Koussouris et al. (2015) offer concrete suggestions for policymakers besides ensuring the governmental organisation has the right expertise. This research will therefore concentrate on concrete improvement suggestions for the effective use of data and new ICTs in policymaking, with a focus on the use of energy models in the Dutch heating transition.

2.2 The use of models for the heating transition

Academic literature regarding the use of energy models to support policy-making in the heating transition shows that there is a large variety of models, modelling methodologies and tools being used to support decision making within the energy (and/or heat) transition and few comparisons are being made between these models, modelling methodologies and tools. An overview of the literature found describing different modelling methodologies used for a sustainable heating transition is shown in Table 34, Appendix B (full description) and Table 4 (relevant findings for this study). The final sample (see Appendix B on how this sample was identified) consisted of 23 articles and discusses three types of modelling methodologies (according to the typology of Hirt et al. (2020)). First, integrated assessment modelling (IAM) methodologies, which are global-level modelling methodologies that are designed to support climate policy by uniting long-term climate goals and the evolution of the economy, technology and the environment. Second, Energy System Modelling (ESM) methodologies which can be applied at all spatial scales and quantify the transition with a focus on technical feasibility and interactions between energy, economy, environment and policy. Third, socio-technical transition modelling methodologies, such as Socio-Technical Energy Transition (STET) methodologies, System Dynamics (SD) methodologies or Agent-based modelling (ABM) methodologies, this type of methodologies are designed to model the coevolution of technology and society. In other words, these modelling methodologies include the behaviour and interactions of diverse actors (Hirt et al., 2020).

2.2.1. Socio-technical transition models

Three studies in this sample (Nava Guerrero et al., 2019) (Busch et al., 2017) (Sopha et al., 2011) use Agent-Based Models (ABMs) to investigate challenges regarding the heating transition. According to Nava Guerrero et al. (2019), ABMs are "computational models that can be used to represent and explore the complexity of systems where individuals and organizations, and technology interact in complex ways through rules and regulations" which can be used to understand plausible futures, trends and behaviours under specific circumstances. Nava Guerrero et al. (2019) developed an ABM to study the transition to a gas-free heating system in the Netherlands. Their study provided insights into the interactions between actors, institutions and technology but the model was still subject to large simplifications such as bounded rationality of agents (the agents were not able to select cost-effective alternatives) and social network effects (transition of the neighbourhood was only dependent on individual choices of households). Bush et al. (2017) used an ABM to investigate heat network development in the UK and they had similar challenges regarding simplifications. Nevertheless, this study concludes that modelling methodologies that go beyond techno-economic energy system modelling are necessary within the energy transition and that a model such as proposed helps in identifying policy implications and potential interventions. Sopha et al. (2011) used an ABM to identify potential intervention for the uptake of wood-pellet heating in Norway. Within this study, the issue of unavailable information was raised regarding future replacement time. The authors conclude that due to this lack of information the model cannot predict future diffusion quantitatively, but the model is able to show possible development paths as a result of policy strategies.

Next to ABM, there is another modelling methodology that tries to incorporate social factors into the analysis of energy systems, Socio-Technical Energy Transition (STET) modelling. In 2015, a review of STET models (Li et al., 2015) concluded that the development of STET models was necessary because many other modelling methodologies were criticized for their limited treatment of socio-political dynamics and the poor representation of the co-evolving nature of society and technology. Especially optimization models tend to simplify their depiction of societal and political factors, which can make it difficult to use them for policy design (Li & Strachan, 2019). STET models try to integrate both quantitative modelling and conceptual socio-technical transitions (Li et al., 2015). According to Li et al. (2015), one of the challenges of the use of STET models for policy development is the trade-off between breadth and depth. Due to computational constraints or data availability, for example, STET models are likely never going to be as detailed in any single domain as their counterparts who do not try to integrate techno-economic details, actor heterogeneity and transition pathway dynamics. Similar to the STET models, one study (Ziemele et al., 2016) in this sample tried to incorporate behavioural aspects by developing models based on the system dynamics (SD) theory. The SD theory is based on the complex system that analyses behaviour over time by identifying elements within the system and their mutual correlations. Ziemele et al. (2016) used this model to analyse three policy instruments for district heating in Latvia.

One study in this sample (Bauermann, 2016) tried to incorporate more behavioural aspects by combining a building stock model with a discrete choice model (nested logit approach). The rationale behind this dynamic model was that a combined model that explicitly considers the decision making process is needed while “it is the decision-maker who translates regulation into market reality”. Fotiou et al. (2019) also used a discrete choice model to incorporate behaviour in their modelling approach but they combined it with the PRIMES (Price-Induced Market Equilibrium System) model, which is a hybrid economic-engineering model based on microeconomic theory. The model combined discrete choice theory with dynamic programming and was made to assess policies for the building sector through the comparison of decarbonisation scenarios (Fotiou et al., 2019). Even though the use of discrete choice models in this context is still subject to some serious limitations (such as imprecise parameter estimations and the use of a single energy price scenario) (Bauermann, 2016), it could shed light on the motivations of building owners to invest in different heating options. This PRIMES model was also used by Connolly et al. (2014), who used it in combination with GIS-(Geographical Information Systems)mapping to analyse district heating options in Europe. Although the same model was used, this study does not seem to involve social or behavioural aspects. Their energy system analysis quantifies the impact a heat network could have on the EU energy system based on the inputs from the GIS-mapping (Connolly et al., 2014).

Although there is a potential of incorporating behavioural, social and political aspects into energy models, only a share of the sample was found to incorporate such aspects into their modelling approach. The rest of this sample consists of studies that use modelling methodologies focused on mostly techno-economic factors.

2.2.2 Integrated Assessment Models & Energy System Models

By far the largest share of the studies found use optimization models to make policy recommendations for the heating sector. Optimization models show the optimal solution under certain conditions and are used to investigate and evaluate the performance of a system. Worldwide, MARKAL and TIMES are the most used optimization models (Åberg & Henning, 2011). Three studies in the sample use the TIMES energy model (Kerimray et al., 2018; Sarbassov et al., 2013; Venturini et al., 2019), which stands for The Integrate Markal EFOM System. The TIMES model is a partial equilibrium, bottom-up, dynamic, linear programming optimization model. It is a long-term model that defines investments, operation modes of the energy system, production and consumption of fuel, materials and energy services and their prices. It defines these investments and goods in such a manner that production equals consumption (Kerimray et al., 2018). The main advantage, according to Kerimray et al. (2018) is that the TIMES models provide an elaborate description of possible scenarios for the development of energy systems by considering interregional, intertemporal and intersectoral relations. Sarbassov et al. (2013) mention that the maximum surplus assumption used in the model is challenged, especially in regards to energy and environmental matters where oil prices are strongly influenced by the OPEC cartel, which causes information asymmetry between consumers and suppliers. To solve this issue, modellers can choose to relax the pure economic equilibrium assumptions and, for example, add socio-political constraints. Venturini et al. (2019) tried to improve the TIMES model by combining it with Balmoral-Optiflow. This allowed them to assess different pathways for the optimal use of residual biomass in Denmark. The different models were linked to benefit from the distinctive strengths of each energy model in terms of process coverage and spatio-temporal resolution. Balmorel uses a more realistic image of investments under uncertainty and avoids extremely high computational times.

Next to the TIMES optimization models, a large variety of optimization models and tools were found in this sample (Åberg & Henning, 2011; Nakata et al., 2005; Nässén & Holmberg, 2013; Qadrdan et al., 2019; Siraganyan et al., 2019; Zvingilaite & Klinge Jacobsen, 2015). Within these studies, we can see, as Siraganyan et al. (2019) notice as well, that most models and tools currently used do not provide both economic and environmental analysis of energy systems, which can lead to the design of sub-optimal systems. Siraganyan et al. (2019) try to solve this issue by developing a flexible and modular simulation tool called Eco-sim which is used in combination with the Homer optimization model. Zvingilaite & Klinge Jacobsen (2015) also notice that most models have a purely cost optimizing focus and they decide to integrate health damage costs in private heating choice while optimizing. Because indoor wood stoves, for example, can have an impact on indoor air quality. One important conclusion of this study is that the optimum private solution may deviate from the socio-economic optimal solution. The authors suggest incentivising individuals to make choices that are more in line with the socio-economic optimal situation (Zvingilaite & Klinge Jacobsen, 2015). An important conclusion we can draw from this collection of optimization studies is that the results of the model will always depend on the focus of the optimization and that there are not many models yet that can incorporate economic, environmental and social factors at the same time. When using modelling results for policy choices, one has to ask which solution is desired, for example, a socio-economic optimum solution or a private optimum solution. Such considerations, especially about individual costs versus society costs, are already seen as challenging in the Netherlands (TNO & Gemeente Zoetermeer, 2020; Warmtenetwerk, 2020).

One study within this sample (Sakellaris et al., 2018) uses the METIS (Markets and Energy Technologies Integrated Software) model. This model is developed by the European Commission in the context of improving evidence-based policymaking in the energy field. The underlying mathematical model is also based on optimization. One of the main goals of developing this model, according to the authors, was to provide a transparent model that was user-friendly, so that non-experts could use the model and interpret its results. The aim was to bring policymakers closer to the quantitative tools used to support energy policymaking. This focus seems to suggest that a current understanding of quantitative tools by policymakers is missing. This view seems to be shared by the study of Erker et al. (2019). This study developed a holistic planning model (the Eco.District.heat-kit) which stays adaptable to user and regionally specific requirements. The model was developed to assess the possibilities and limits of district heating systems in urban areas. Just like Sakellaris (2018), this study (Erker et al., 2019) attempted to make the model usable for non-experts. They applied a straightforward approach and focused on basic parameters so that energy suppliers, urban-planners and decision-makers could use the model and its results at the beginning of the planning process. The study of Novikova et al. (2018) went even further and involved policy-makers into their model development to make sure all stakeholders involved could run and modify the model themselves and even modify it according to their needs. Their model was a bottom-up simulation model (with leap software) to analyse different low carbon scenarios in Eastern Europe. One disadvantage of this modelling approach was that it had a large sensitivity for a multitude of assumptions (Novikova et al., 2018).

This challenge of developing 'usable' models also comes forward into the study of Sousa et al. (2017) who compare 27 Housing Stock Energy Models (HSEMs) used in the UK to support the formulation of policies regarding the energy transition. HSEMs are models that start with basic abstractions of energy flow pathways of single dwellings, which are then replicated for a given housing stock (Sousa et al., 2017). This study concludes that many HSEMs are lacking in transparency and modularity and that they are limited in scope and limited in their utility. Moreover, the study states that behavioural responses, more specifically the parameters that affect behaviour, are blurred in HSEMs. The fact that HSEMs are at this moment unable to analyse dynamic processes, such as socio-economic processes that influence household decisions, undermines their functionality according to Sousa et al. (2017).

Table 4: An overview of the literature sample including their modelling approach and relevant findings for this research.

Modelling approach	Study	Relevant findings
Agent-based modelling methodology	(Nava Guerrero et al., 2019) (Busch et al., 2017) (Maya Sopha et al., 2011)	These studies emphasise the importance of trying to incorporate social factors within modelling.
TIMES energy model (linear optimization)	(Kerimray et al., 2018) (Venturini et al., 2019) (Sarbassov et al., 2013)	The maximum surplus assumption used in the model is often challenged.
Simulation model (using LEAP)	(Novikova et al., 2018)	All stakeholders involved could run and modify the model themselves and even modify it according to their needs. The model has a large sensitivity for a multitude of assumptions
METIS simulation model	(Sakellaris et al., 2018)	A current understanding of quantitative tools by policymakers is missing
HOMER optimization	(Siraganyan et al., 2019)	Most models and tools currently used do not provide both economic and environmental analysis of energy systems, which can lead to the design of sub-optimal systems
Housing Stock Energy Model	(Sousa et al., 2017)	Many HSEMs are lacking in transparency and modularity and that they are limited in scope and limited in their utility. Behavioural responses are blurred in HSEMs.
Optimization modelling methodology	(Nakata et al., 2005) (Qadrdan et al., 2019) (Nässén & Holmberg, 2013) (Åberg & Henning, 2011) (Zvingilaite & Klinge Jacobsen, 2015)	The results of the model will always depend on the focus of the optimization and that there are not many models yet that can incorporate economic, environmental and social factors at the same time.
Dynamic system modelling methodology	(Ziemele et al., 2016)	Analyzes behaviour over time by identifying elements within the system and their mutual correlations.
PRIMES model	(Connolly et al., 2014)	The study does not seem to involve social or behavioural aspects. Analysis of energy systems is based on the inputs from GIS mapping.
Eco-district heat kit optimization model	(Erker et al., 2019)	This study attempted to make the model usable for non-experts.
STET modelling methodology	(Li et al., 2015) (Li & Strachan, 2019)	(Optimization) Models tend to simplify their depiction of societal and political factors. STET models try to integrate both quantitative modelling and conceptual socio-technical transitions
Discrete choice modelling methodology	(Bauermann, 2016) (Fotiou et al., 2019)	The model has some serious limitations (such as imprecise parameters) but a combined model that explicitly considers the decision-making process is needed.
Area-based modelling methdology	(Calderón et al., 2019)	Emphasises the importance of modelling at the sub-city scale as this enables, among others, more accurate quantification of demand increases.
Econometric modelling methodology	(Fu et al., 2014)	Suggests that we should combine spatial attributes with econometric models.

Some studies suggest we should look past socio-economic factors when determining heating options. Fu et al. (2014) use an extended spatial econometric model to study the reduction options for solid fuel that is used for home heating and they find that proximity to a solid fuel resource is the most significant determining factor. They suggest that policies should focus on proximity aspects when trying to decarbonise the heat sector, for example by introducing or expanding smoky coal ban areas. To accomplish the formation of useful policies, this study suggests that we should combine spatial attributes with econometric models. Calderón et al. (2019) also focus more on spatial attributes when modelling. Their study (Calderón et al., 2019) used an area-based model to investigate the electrification of the heating sector in the UK. A bottom-up community energy building model based on the BREDEM-12 domestic energy modelling method was used. The authors of this study state that in terms of energy planning models and policy, bottom-up and spatially referenced methods such as the one they present a more robust way of modelling local area characteristics such as building details or socio-economic data. This study suggests that such models are therefore better able to estimate domestic energy demand in sub-city areas. Calderón et al. (2019) therefore emphasise the importance of modelling at the sub-city scale as this enables, among others, more accurate quantification of demand increases.

2.2.3 Summary on the use of energy models for the heating transition

Modelling methodologies have the potential to reduce the uncertainty of complex social issues but there is no systematic approach yet on how to apply models to make policy decisions and how to consider not only objective facts but also social and socio-economic factors. The sample shows a large variety of modelling methodologies and models that are currently used, based on different theories and mathematical principles, but there is little comparison between these different approaches. However, a few common challenges can be recognized. First of all, the correctness and sensitivity of assumptions. Second, the transparency and usability for policymakers. Third the need to integrate both economic, environmental and social factors. Another interesting aspect that comes forward within this literature overview is the lack of energy modelling research in the Dutch heating transition. Only one study within this sample was focused on the Dutch heating transition (Nava Guerrero et al., 2019).

2.3 Context of the Dutch heating transition

To provide a more complete image of the current knowledge base regarding the use of energy models, Grey literature on this topic is shortly reviewed as well. Dutch municipalities often rely on energy models as tools to analyse (proposed) policies. Energy models are therefore an important instrument in the current Dutch heating transition (Brouwer, 2019). Models are simplified representations of reality. They are based on assumptions and are reliant on parameter choices and the availability of data (Wesselman, 2019). Popular models used to support decision making in the Dutch heating transition are the CEGOIA model, the Vesta MAIS model, the Warmtetransitiemodel (WTM), the Energy Transition Model, DWA models and the Caldomus model (Brouwer, 2019). Large modelling studies conducted in the Netherlands focused on the heating transition are the Openingsbod (OB), and the Startanalyse (SA). The following sections briefly introduce these models and modelling studies. Thereafter, some Dutch studies focused on energy models or good modelling practice are discussed. Table 35 in Appendix C shows an overview of the discussed documents.

2.3.1 The Dutch heating transition model landscape

Table 5 shows an overview of the six models often used within the Dutch heating transition. The sections below discusses these six models.

Table 5: An overview of the six models discussed.

Model	Developer	Type of model	Format	Availability	Geographical scope
Vesta MAIS	PBL	Techno-economic optimization	C++ (GeoDMS software + Crimson Editor)	Open access	National, regional, city, neighbourhood
CEGOIA	CE Delft	Techno-economic optimization	Excel model	Model owned by CE Delft	National, regional, city, neighbourhood
Energietransitie model (ETM)	Quintel	Techno-economic simulation	Website	Open access	International, national, regional, city
Warmtetransitie model (WTM)	Over Morgen	Techno-economic optimization	Unknown	Model owned by Over Morgen	Unknown
Integraal kostenmodel (IKM)	DWA	Techno-economic optimization	Excel model	Model owned by DWA	Regional, city
Wijkwarmtemodel (WWM)	DWA	Techno-economic optimization	Excel model	Model owned by DWA	Neighbourhood
Caldomus	Innoforte	Techno-economic optimization	Excel model	Model owned by Innoforte	Regional, city, neighbourhood

All models shown in Table 5 can be classified as techno-economic optimization models, with the exception of the ETM, which can be classified a techno-economic simulation model. The difference is that optimization modelling provides a recommendation for action in a specific action, it finds the optimal solution under a set of rules and assumptions, whereas a simulation models allows the end-user to explore how a system responds with different inputs as to better understand how it operates (River logic, 2020).

The CEGOIA model is developed by CE Delft, a Dutch consultancy firm. With this model, one can calculate the costs of sustainable heating options throughout the full value chain; production, distribution, energy savings and consumption. CEGOIA calculates which heat option would have the lowest costs for which neighbourhood, currently and in the future. The model was developed to provide insight to policymakers and planners in regards to possible developments due to the energy transition in residential areas and infrastructures. The model incorporates specific details of neighbourhoods such as thermal insulation levels, the density of the built environment and the type of buildings. Furthermore, the model incorporates the potential for different technologies, such as distance to residual heat sources, geothermal wells or thermal energy storage. The model runs in Excel and results are presented in reports, spreadsheets and GIS-maps. The Excel model is owned by CE Delft (CE Delft, 2019).

The Vesta MAIS (Multi-Actor Impact Simulation) model is developed by PBL and is an open-source and open access model. The model is programmed in C++ and can be used by downloading the GeoDMS software and Crimson Editor. The Vesta MAIS model can calculate the energy use and the CO_2 emissions of the built environment (among other residential houses, offices, shops and hospitals) and the horticulture industry. The potential costs and building improvements (such as isolation and heat pumps) and district policies (such as district heating networks fed by residual heat from the industry, geothermal production or thermal storage) can be calculated and the effects on CO_2 emissions, energy use, investment costs and financial gain of actors can be shown. The model is focused on technical-economic factors which are crucial for decision making (Schepers et al., 2019). As a first step, the model calculates the costs of measures to save energy for individual buildings compared to the profits of those measures. These measures, in turn, influence the heat demand. This heat demand is then used to calculate the areas where heating alternatives are profitable, profitable in this sense means cheaper than the current heat supply with natural gas (Schepers et al., 2019).

The Energy Transition Model (ETM) is developed by Quintel, a Dutch consultancy firm and is an open-source and open access model. The ETM describes the entire energy system of a country, differentiating between sectors such as residential, transport, industry and energy. Demand and supply within these sectors. The ETM can calculate the impact and costs of infrastructures for gas, electricity and heat. The ETM uses a merit order based approach to match demand and supply, based on 15-minute intervals. The ETM is available for seven countries and the EU-27. A large share of the ETM results and sources are based on the energy balances of the International Energy Agency (IEA). All sources, data, analyses and assumptions are publicly available. The user interface of the ETM entails much background information and explanation. Results are shown via an interactive dashboard, graphs and tables. The ETM is publicly available via a website (Netbeheer Nederland, 2020). The ETM offers support in exploring the options for a specific region and allows it's users to change over four hundred variables. The impact of variable changes are visible within seconds, there are no hidden assumptions within the models, such as learning curves of prices and technologies. It is a static model if nothing is changed the future looks the same as the start date (Quintel Intelligence, 2020). The ETM is not an optimization model, users can look for their own optimal solutions (Netbeheer Nederland, 2020).

DWA, a Dutch consultancy firm, has developed two models that they use within their heating transition consultancy projects. The Integral Costs Model (IKM) and the Neighbourhood Heat Model (WWM). Both models run in Excel, are owned by DWA and are only available for consultants of DWA. The IKM calculates integral costs of the transition, i.e. all costs are totalled into societal costs. This includes investments to residences, network investments, maintenance and yearly energy costs. The IKM is used by DWA as support for the developments of TVWs, it provides input for a vision but does not provide enough detail for concrete decision-making processes. The WWM provides a more detailed analysis and is usually used after analysis is conducted with the IKM, for example for the development of a WUP (DWA, 2020).

The Caldomus model is developed by Innoforte, a Dutch consultancy agency. The model runs in Excel and is owned and used by Innoforte in heating transition consultancy projects. It calculates and compares the costs and CO_2 emissions of 15 different sustainability routes per building. Costs include capital costs (investments, lifetime, interest), maintenance costs and energy costs (Mans et al., 2017).

The Warmtetransitiemodel (WTA/WTM) is developed by Over Morgen, a Dutch consultancy agency, and is owned and used by Over Morgen for heating transition consultancy projects. It is used mostly for TVW and WUP projects, it is deemed too detailed for RES projects. The WTM only uses public data such as the BAG dataset. The WTM uses two different thermal insulation levels, minimum and basic. The WTM does not include heat source data and is therefore not limited by heat source data. The model assumes infinite sources. The OB is a modelling study initiated by Stedin, a Dutch network operator. The study was developed as a tool to quicken decision making in the Dutch heating transition. The study compares the modelling approach and results of three different models; Vesta MAIS, CEGOIA and the ETM (Stedin, 2020a). By using different models, this study can compare modelling studies under different conditions, by doing this the study can make conclusions about the degree of certainty of results. Which in turn provides a starting point for discussions at municipalities (Stedin, 2020b).

The SA is a modelling study conducted with the Vesta MAIS model by PBL. The SA is presented together with guidelines for local analysis (Handreiking) in a guidebook (Leidraad) for Dutch municipalities. The guidebook is supposed to help municipalities with the development of their TVW, use of the guidebook is not compulsory, however, its use is recommended by the Dutch Expert Centre of Heat (ECW). The SA provides a techno-economic analysis of the costs of becoming natural gas free on the neighbourhood level for five different strategies. To do this the SA uses national averages, so-called key figures. However, the analysis does take into account local conditions such as the type of houses, building year of houses and the presence of heat sources. PBL and ECW recommend municipalities to adjust and supplement the data and assumptions of the SA to fit the local situation. The guidelines for local analysis published by ECW explain the SA and how to enrich and adjust the data and assumptions to fit the local situation (ECW, 2019).

Netbeheer Nederland, a branch organization of all Dutch electricity and gas network operators, published an overview of available energy models in the Netherlands, as shown in Figure 1. Although this overview is more extensive, one can already see that the models developed by DWA and Innoforte that were mentioned are not included in this overview. Nevertheless, it shows the great variety of energy models that are available within the Netherlands.

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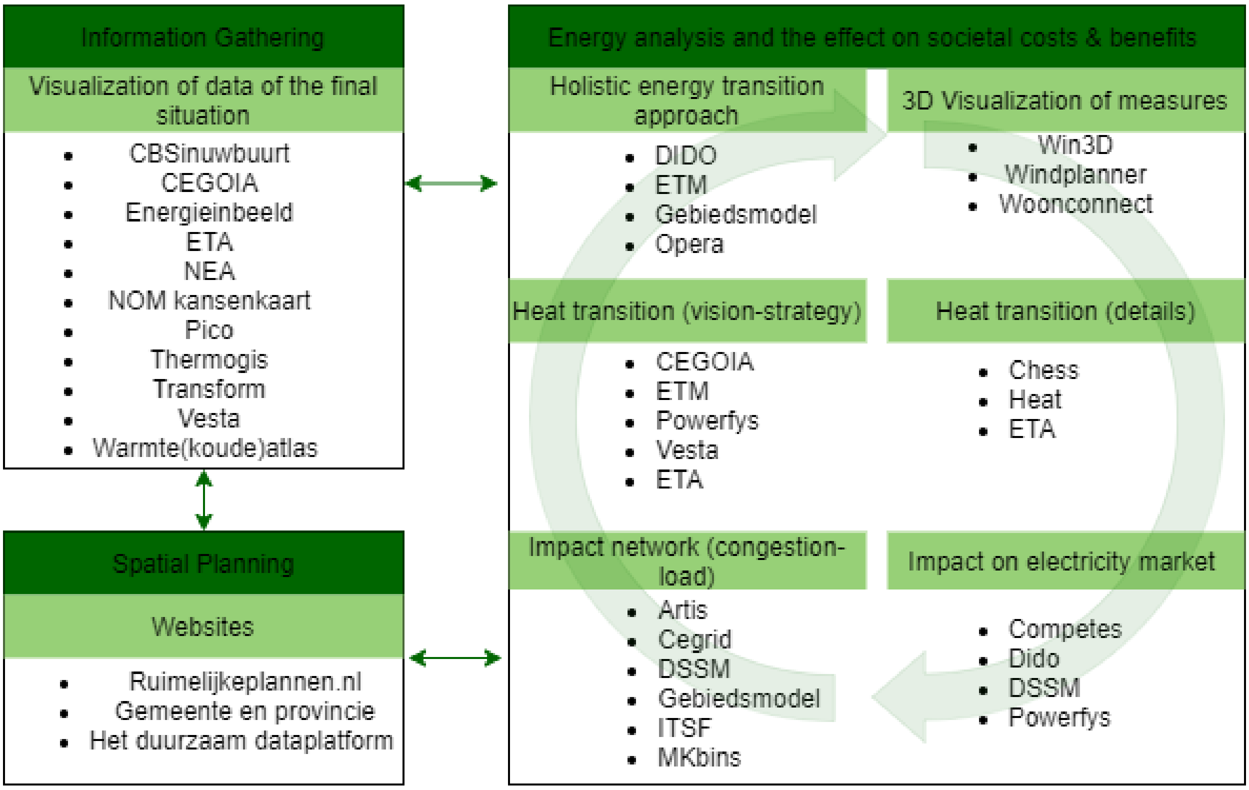

Figure 1: An (incomplete) overview of Dutch energy models, translated and adapted from Netbeheer Nederland (Expertgroep Energietransitie Rekenmodellen, 2019)

2.3.2 Comparative studies of Dutch heating transition models

A 2019 study of the province of Zuid-Holland (Brouwer, 2019) compared six different models as shown in figure 2, focused on the Dutch heating transition, that were used by municipalities. This study found significant differences in outcomes between models. Some models, for example, found that the most cost-effective solution for a neighbourhood was a high-temperature heat network whereas other models would find that an all-electric network would be more cost-effective. Differences like these make it hard for policymakers within municipalities to create public support for certain new policies (Brouwer, 2019). According to this study, the differences in results were due to a lack of standardisation of data, due to differences in approach and due to differences in assumptions (Brouwer, 2019). A more concrete overview of possible sources of differences, as defined by Brouwer (2019) is shown in Table 6.

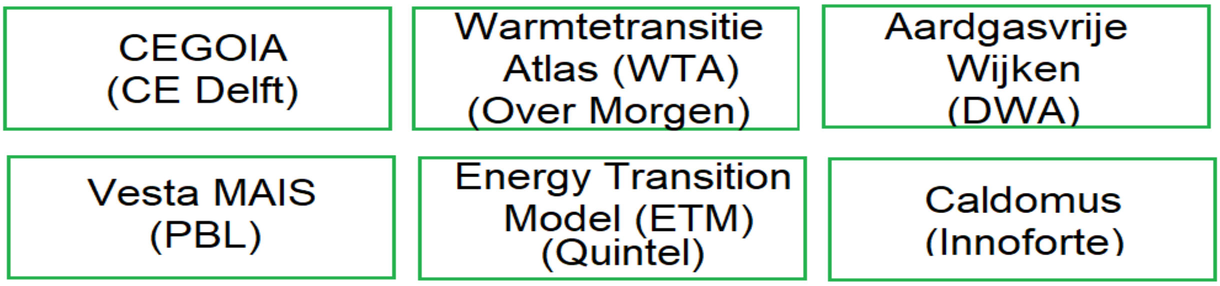

Figure 2: The six different models that were investigated (Brouwer, 2019). It is unclear whether the DWA model mentioned in this study is the same as the IKM or the WWM mentioned earlier.

Table 6: An overview of factors that cause different outcomes when modelling within the heating transition (Brouwer, 2019).

Factors within models that cause different results	Explanation
Building types and geographical borders	Differences in whether buildings count as residential or whether the heating type is clustered by city, neighbourhood or a different area.
Individual vs project approach	Project approach gives lower end-user costs.
Renovations to improve past label B	For example; just isolating vs inclusion of renewable energy sources.
Differences in costs of all-electric networks	Differences in heat pump costs cause the costs of all-electric networks to vary strongly.
The specific research questions determine the optimization	For example low costs for end-user vs low costs for society.
The overall ambition affects the technologies that will be used in the model	For example; the ambition to have low CO_2 emissions, to be energy neutral or to be free of natural gas.
The order of steps within the approach.	For example; do you reduce demand and then make supply more sustainable or do you start with sustainable sources and then try to reduce demand?
Assumptions regarding the scarcity of sources	Some models assume an infinite supply of some heating sources whereas others assume it to be finite.
Assumptions regarding learning curves	There is great variety in the 'term' of learning curves, i.e. the time it takes for new technologies to become cheaper.

A Report of the Association of Netherlands Municipalities (VNG) compared multiple analysis tools used in the Dutch heating transition among which were three energy models, the Vesta MAIS model, the ETM and the CEGOIA model. According to this report, the Vesta MAIS model is developed for users that are modelling experts and the CEGOIA model is the only model of the three that is privately owned and able to provide insight for projects that require more detail than the initial vision (Brand & Konijnenberg, 2019). Table 7 shows the model comparison results of the VNG.

Table 7: A comparison of the ETM, the Vesta MAIS model and the CEGOIA model (Brand & Konijnenberg, 2019).

Model	Developed for:	Data use:	Transition phase used:	Availability
ETM	Policymakers & Experts	Residence characteristics Residence ownership Energy use Area characteristics	Development of visions	Open-source
Vesta MAIS	Experts	Residence characteristics Residence ownership Energy use Area characteristics	Development of visions	Open-source
CEGOIA	Policymakers & planners	Residence characteristics Residence ownership Energy use Area characteristics	Development of visions, programs and project plans.	Privately owned

A 2018 report of RVO (Valk et al., 2018) also provided a comparison of tools that are being used by Dutch municipalities for the heating transition, models focused on the heating transition mentioned by this report and their prime users and scale level are shown in Table 8. This is the only report of this sample that mentions the IF-model developed by Stedin.

Table 8: A comparison of the CEGOIA model, the IF-model and the WTA (Valk et al., 2018).

Model	Developed by:	Used by:	Scale level
CEGOIA	CE Delft	Municipalities, provinces and network operators	Neighbourhood
Infrastructural Footprint (IF) model	Stedin	Policymakers	Neighbourhood
WTA	Over Morgen	Policymakers	Neighbourhood

2.3.3 Requirements for Dutch heating transition models

A white paper from the Delft University of Technology (Nikolic et al., 2019a) summarizes the state of the art in good modelling practice. This document was published to help parties to align and clarify expectations regarding modelling projects and to increase the overall quality and usefulness of modelling efforts. According to Nikolic et al. (2019a), models and simulations are useful tools in supporting decision making. However, creating them is a complex and time-consuming task and if a model or its results are incorrect, one might be worse off than when not using a model to start with. Since models are such complex tools, a non-expert in modelling might find it hard to identify wrong, substandard or broken models, especially when they produce desirable results. Nikolic et al. (2019a) provide five general principles for good modelling practice, as shown in Table 9.

Table 9: Five general principles of energy modelling as proposed by Nikolic et al. (2019a)

#	Principle	Explanation
1	"All models are wrong, but some are useful"	Every model is by definition wrong since it is a simplification, but how can you simplify in a useful manner. Too little and the model is too complex to use, too much and the model cannot provide useful answers.
2	"Modelling is making choices and assumptions"	A model is a collection of assumptions with a run button. Much detail does not improve the model and overly detailed models may suggest a closeness to the reality that is not there if details are irrelevant.
3	"Garbage in = Garbage out"	If incorrect data or assumptions enter the model, then modelling results will be incorrect as well.
4	"Re-run, Repeat, Reproduce, Reuse, Replicate"	A model should be developed and used in such a way that the results can be reproduced.
5	"Openness is essential"	It is of paramount importance to have the model and the data it uses as transparent as possible. Many public organisations have already adopted open source/ open access guidelines.

Moreover, Nikolic et al. (2019) provide a few red flags that indicate inadequate modelling practice:
- Lack of a clear modelling question that was mutually agreed on.
- Incapacity or reluctance to clarify the choice for a modelling formalism.
- Not explicitly discussing or demonstrating input data uncertainties.
- Not explicitly discussing or demonstrating the parameter sensitivities.
- Not consciously varying parameters within plausible ranges when testing the effect of a policy/decision.
- If (some) outcomes cannot be satisfactorily explained in terms of (1) the assumptions used, (2) the properties of the model/model type (3) and the experiment conducted.
- Incapacity to answer the 'Why is this happening' inquiry.

Nikolic et al. (2019a) state that there are guidelines for good modelling practice. However, their study suggests that these guidelines need to be made more practical and easier to communicate. Most practitioners do not have time to read lengthy and abstract guideline descriptions. Nikolic et al. suggest that offering practical training materials on how to critically evaluate problem definition, modelling process, the use of models and how to prevent some common pitfalls would be useful for both model developers and model users. Finally, Nikolic et al. (2019a) suggest that there is a gap in methodological knowledge between academia and practitioners and that closer interaction between these worlds could be beneficial. The practitioners could provide realistic problems and case material for methodology development and academia could provide more sophisticated modelling methods and practices.

The Dutch General Audit Office (Algemene Rekenkamer), an independent organisation that checks the legality and effectiveness of the expenses of the Dutch government, has researched the policy processes in the Dutch heating transition, with a focus on the situation in Amsterdam (de Ridder et al., 2019). Their research concluded with eight recommendations, one of those recommendations is related to the use of energy models in the heating transition. The researchers suggest that municipalities should develop more internal knowledge. The report states that specific knowledge is of extra importance for the energy transition, due to the fast developments and the complex context of this transition. Knowledge should be developed regarding available heating technologies, energy markets, societal transitions and energy models. The latter is relevant because it provides insight into the underlying assumptions of the energy models used, which in turn could provide insight into whether the modelling results reflect the desired societal effect. Moreover, energy models require its users to make choices regarding which factors to include and how these factors will be weighted. This requires knowledge and expertise about these energy models at the organisation. The report concludes that municipalities need to develop processes to gather and secure knowledge and need to share this knowledge between different departments of the organisation (de Ridder et al., 2019).

A report developed by a collaboration of Dutch knowledge institutes focused on the information supply in the energy transition also provides some information on the Dutch energy models used in the heating transition, more specifically about their data needs (Diran, van Veenstra, et al., 2020). This report states that there is a large variety of models and that their data demand is highly dependent on the research question of the end-user. Table 10 shows the data needed for the use of energy models. One of the most important shortcomings of the current data supply for techno-economic energy models, according to this study, is data regarding utility. Much about energy use, thermal insulation levels and thermal installations of the Dutch utility is unknown. Network operators have data on energy use available but are currently not able to share this data due to privacy restrictions. Moreover, forecasts and plans of individual companies are not known. These unknowns make it difficult to map potential residual heat sources. A second shortcoming mentioned by this report is the lack of data regarding the social and cultural context of neighbourhoods. In the preparation and execution of heating transition projects, there is a high demand for this data.

Table 10: Data needed for energy models (Diran, van Veenstra et al., 2020).

Data theme	Data sets needed for energy models
Building data	Thermal insulation levels, Energy use (residential), Energy use (utility), Type of energy connection, The capacity of energy connections Renovation plans (residential & utility), New housing estate plans
Infrastructure	Current Infrastructure for gas, electricity & heat Infrastructure replacement & renovation plans Current electrical network capacity , Key figures about the implications of network changes Available & potential heat sources (for heat networks)
Energy production	Current fossil energy production (regional level), Current renewable gas production (regional level)
Standardisation	Technical key figures, Building types coupled with BAG data

2.3.4 Summary context of the Dutch heating transition

This section showed that even though there is almost no academic literature available on Dutch models for the heating transition, there is an abundance of grey literature. This section discussed energy models developed by consultancy agencies such as CE Delft, DWA, Over Morgen, Quintel and Innoforte and models and modelling studies developed by network operators (Stedin) and knowledge institutes (PBL). The comparative studies discussed show that different models have different target users (ranging from modelling experts to policymakers), different geographical scopes, different formats and calculation methods.

The study of the province of Zuid-Holland (Brouwer, 2019) even showed that models provide significantly different results for the same research question due to differences in assumptions and approach. The study of Nikolic et al. (2019a) offered general principles for good modelling practice and red flags that indicate inadequate modelling practices. This study concludes that there is a need for modelling guidelines that are more practical and easier to communicate and that there is a need for more interaction between academia and practitioners. Both Nikolic et al. (2019a), and De Ridder et al. (2019) suggest that municipalities need to develop more internal knowledge to understand and make use of models (de Ridder et al., 2019). Finally, this review suggests that sufficient access to data in the themes of buildings, infrastructure and energy production is needed to utilize current energy models for the heating transition (Diran, van Veenstra et al., 2020).

2.4 Conceptual model & theoretical propositions

Chapter 2.1 concluded that there is a lack of literature that considers how new ICTs, such as energy models, affect practitioners. Clear guidelines for the use of new ICTs for policy design are missing and there are serious concerns about the lack of expertise regarding new ICTs at governmental organizations. Chapter 2.2 concluded that among energy models that are currently used for policy design, there are challenges regarding the correctness and sensitivity of assumptions, regarding the transparency and usability for practitioners (such as policymakers) and regarding the need to integrate more social factors. Moreover, this section showed that even though there is grey literature available, there is still a clear lack of academic research about Dutch energy models. To bridge these knowledge gaps, a study into the energy models that are used by policymakers in the Dutch heating transition was conducted. The goal of this study was to provide clear recommendations on how to use energy models for data-driven policymaking, which led to the research question: "How can Dutch municipalities effectively use energy models within their data-driven decision making processes regarding heating transition towards a gas-free heat supply?"

To guide research activities needed to answer this research questions a conceptual model was designed. The conceptual model is shown in figure 3 and shows an overview of the explanatory variables of the relationship between the use of energy models and the complexity of the heating transition decision making process. Explanatory variables identified in literature were the expertise of practitioners regarding data and models and the quality of the modelling approach. Variables of influence on the quality of the modelling approach were the usability for non-experts of the model, the quality of the modelling results and the degree of transparency of the approach. The present study seeks to test the relations shown in this figure in order to provide substantiated recommendations on how to effectively use energy models in the heating transition decision-making process. To scope the research to a manageable project, ten theoretical propositions were defined that focus on the variables outlined in bold in figure 3. Variables were included based on their prevalence in literature (more prevalent variables were chosen) and on the expected knowledge about these variables of practitioners. It was, for example, expected that practitioners would have limited input about the effect of underlying mathematical or economic theories of energy models. In Table 11 an overview of the ten theoretical propositions is presented.

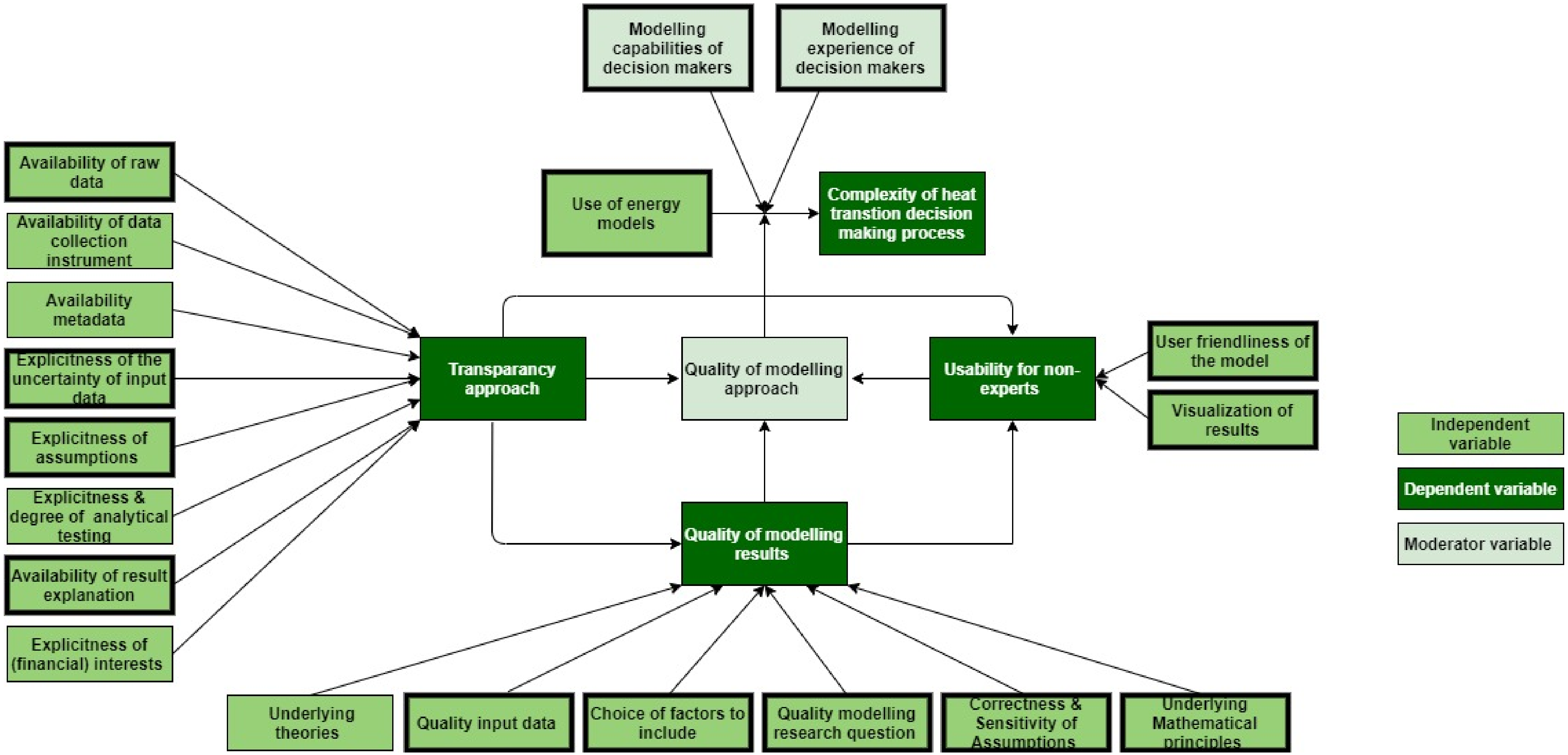

Figure 3: A conceptual model showing the variables found in the literature that could influence the relationship between the use of energy models and the complexity of heating transition decision making.

Table 11: An overview of theoretical propositions and their justification based on the literature review

	Theoretical proposition	Justification
1	Different municipalities use different energy models (if any) with different aims.	Due to the large share of energy models available in the Netherlands (see chapter 2.3), that use different approaches and assumptions and that have different focusses (Brouwer et al., 2019), it is expected that different municipalities will use different energy models with different aims.
2	If energy models are complex to use, then practitioners will make limited use of them while planning for the heating transition.	Current energy models are not usable for non-experts such as practitioners (Erker et al., 2019; Sakellaris et al., 2018). It is therefore expected that practitioners make limited use of energy models due to the complexity of energy models.
3	If energy models are not user friendly, then practitioners will make limited use of them while planning for the heating transition.	Current energy models are often not usable for non-experts such as practitioners (Erker et al., 2019; Sakellaris et al., 2018). It is therefore expected that practitioners make limited use of energy models due a lack of user-friendliness of energy models.
4	If energy models do no integrate social or socio-economic factors, then practitioners will make limited use of them while planning for the heating transition.	The complexity of heating transition projects is partly due to the dependency on social factors such as human behaviour and that models which consider not only-objective but also social and socio-economic factors could increase the value of modelling approaches in heating transition projects (Androutsopoulou & Charalabidis, 2018; Busch et al., 2017; Li & Strachan, 2019; Li et al., 2015; Nakata et al., 2005; Qadrdan et al., 2019; Nässén & Holmberg, 2013; Åberg & Henning, 2011; Zvingilaite & Klinge Jacobsen, 2015). It is therefore expected that practitioners currently make limited use of energy models because current Dutch energy models do not include social factors.
5	If assumptions within energy models are uncertain, than this will decrease the trust within energy models for practitioners.	The correctness and sensitivity of assumptions has an impact on the trust and willingness of practitioners to use energy models (Brouwer et al. 2019) in their heating transition projects.
6	If data is uncertain or unavailable, then this will decrease the trust within energy models for heating transition decision making of practitioners.	There is more data needed in the themes of buildings, infrastructure and energy production to utilize current energy models for the heating transition (Diran, van Veenstra et al., 2020).
7	Practitioners seek the help of external parties to use and interpret energy models.	Current energy models are often not usable for non-experts such as practitioners (Erker et al., 2019; Sakellaris et al., 2018). It is therefore expected that practitioners seek external expertise when using an energy model.
8	External parties have commercial reasons to not be transparent about their energy model design.	According to the data-driven approach and good modelling practices discussed, models and modelling studies require a high degree of transparency (Argyrous, 2012; Nikolic et al. 2019a). Since many Dutch energy model developers are commercial parties it is expected that external parties occasionally have commercial reasons to not be fully transparent.
9	Practitioners need new (in-house) expertise to effectively use energy models	Municipalities need to develop more internal knowledge and expertise to understand and make use of models (Janssen & Helbig, 2018; Koussouris et al., 2015; Poel et al., 2015; Nikolic et al., 2019a; De Ridder et al., 2019)
10	Interactive visualization and different interfaces for different stakeholders could improve the usability of energy models.	The literature review suggested that interactive visualization can help in making models and their results more understandable for non-experts (Koussouris et al., 2015).

3 Methodology & research approach

This chapter outlines the chosen research approach of this study. Chapter 3.1 discusses the choice of embedded case studies, chapter 3.2 discusses the case selection, chapter 3.3 discusses how data was linked to the theoretical propositions and chapter 3.4 discusses data collection, data treatment and data analysis.

3.1 Research approach: embedded case study research design

To answer the research questions an embedded case study research design was chosen. One of the reasons case studies were deemed an appropriate research approach for this study is because case studies provide an empirical method that investigates a phenomenon in depth and within its real-life context. This is especially useful for research topics where the boundaries between the phenomenon (the case) and the context are not clearly evident (Yin, 2018), as is the case in the Dutch heating transition. Case studies allow for analysis of a set of decisions; why they were taken, how they were implemented and with what result. Moreover, case studies allow for analysis of situations where there will be more variables of interest than mere data points. The embedded case study as a research method, therefore, relies on multiple sources of evidence, with data needing to converge in a triangulating fashion. Theoretical propositions, as introduced in chapter 2, guided design, data collection and analysis (Yin, 2018). The goal of conducting the case studies was to empirically test these propositions, which in turn helped in answering the research questions.

Yin (2018) defines four different types of case studies, in which single-and multiple case study designs are variants within the same methodological framework. Based on criteria proposed by Yin (2018), an embedded multiple-case design was deemed to be most suitable for the present study. In addition, this choice was made because evidence from multiple cases is considered more compelling and more robust (Yin, 2018). In the present study, multiple cases represented different heating transition projects within Dutch municipalities and embedded units of analysis can be identified as 1) heating transition practitioners and 2) model developers. The embedded multiple-case design used is shown in figure 4. The types of data per case study that used were 1) governmental reports (for example heating transition implementation plans), 2) in depth interviews with practitioners from municipalities and 3) in depth interviews with model developers. Practitioners, such as policymakers and project managers, had to be closely involved in the heating transition pilot project of the municipality and/or in the development of the TVW. Model developers had to be involved in the development of a model that was used by one or more of the municipalities of the sample during heating transition projects. The interviews were semi-structured, meaning there was a set of pre-defined questions (see appendix E) but interviewees were given freedom to explore questions in greater depth and to introduce new topics. This type of in depth interviews, according to Roller et al., increased the credibility of the data by reducing response bias (distortion due to tendency of interviewees to provide answers that are considered socially accessible), by reducing satisficing (providing an easy 'I don't know' answer) and the amount of non-responsive answers (Roller 2020). In addition, semi-structured in-depth interviews offer flexibility which allowed tailoring the order of questions, the question wording and to ask follow-up questions (Roller 2020).

The information of these three sources was converged in a triangulating fashion, e.g. information from governmental reports was compared to information from the interviews and statements from the fourteen practitioner interviews were compared to the statements of the seven model developer interviews and vice versa. The combination of this information was then used to design recommendations for more effective use of energy models. As a final step of this research, these recommendations were validated with in-depth interviews with two independent experts of the Dutch heating transition. An overview of the research activities conducted is shown in Figure 5.

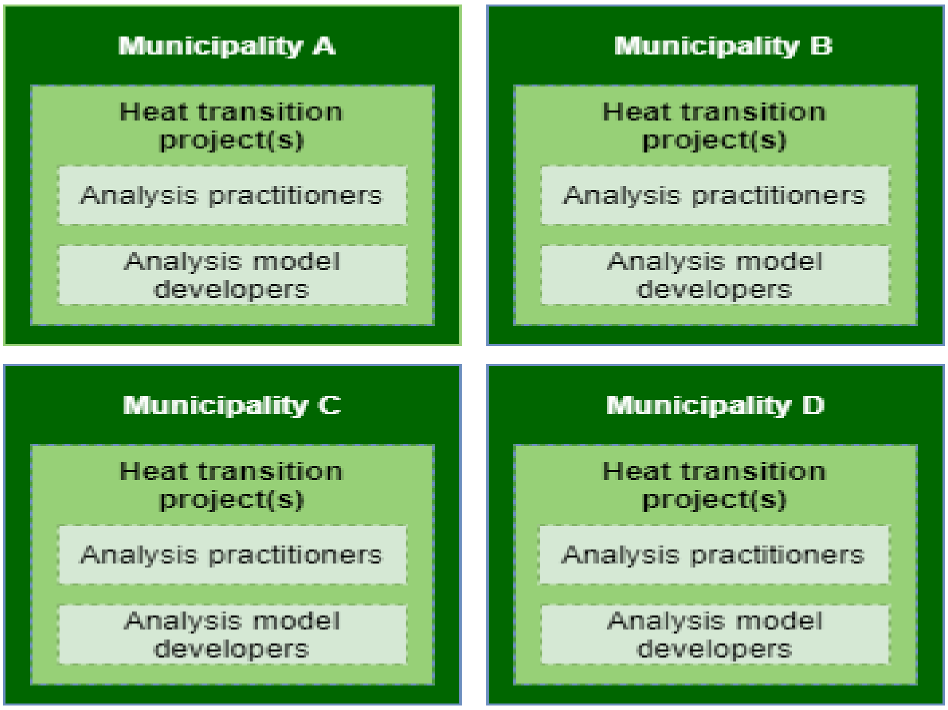

Figure 5: The embedded multiple case study design used in this study.

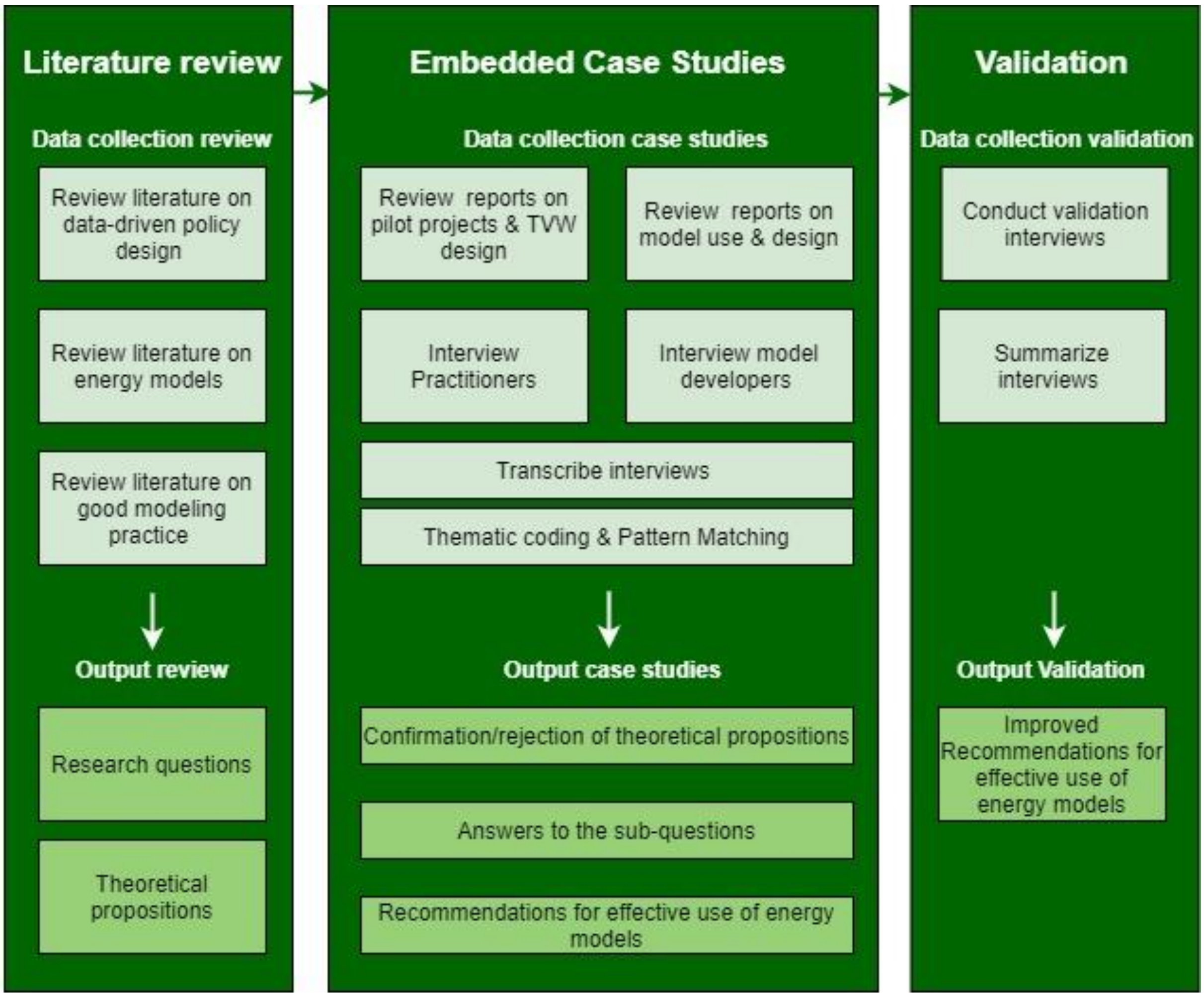

Figure 4: An overview of the research activities conducted, shown in a research flow diagram.

3.2 Case Selection

Within a case study approach, each case must be selected so that the individual cases either predict similar results (literal replication) or predict contrasting results but for anticipatable reasons (theoretical replication). Moreover, sufficient access to cases is needed to conduct research activities.

The Dutch government has started the Programme for Natural Gas-Free Districts (PAW). The PAW aims gain more knowledge and experience for municipalities to transition their neighbourhood to feasible and affordable natural gas-free heating sources. Within the PAW, 27 municipalities have received a governmental subsidy to transition one of their neighbourhoods to a natural gas-free heat supply. These are so-called pilot projects, the national government has provided a total of 120 million euros to these 27 pilot projects (RVO, 2018). The first generation of PAW pilots, consisting of 27 municipalities served as an initial source of case study selection. The following argumentation was used for this: first of all, it was predicted that these cases would produce similar results or contrasting results for anticipatable reasons. All of these projects have started at a similar time in 2018, have received government funding and have a similar manner of publicly documenting their progress. The latter offered easier access to data. Moreover, pilot projects are generally more open for collaboration in research projects. Differences in results between these projects were expected to be based on the size of the municipality, based on specific neighbourhood characteristics of the pilot projects and on different energy models that are being used.

All 27 municipalities that have PAW pilot projects were asked to participate in the study. 10 of these 27 municipalities agreed to participate in the study. This provided a final sample of three large municipalities (>100,000 residents), five medium-sized municipalities (>30,000 residents) and two small municipalities (<30,000 residents), spread over ten different provinces, with ten different approaches to natural gas alternatives analysis and a variety of different chosen heating alternatives. Table 12 shows an overview of the ten municipalities and the analysis tools used to analyse potential alternatives for natural gas for their respective pilot projects, based on the information that was published in the implementation reports of 2018.

Table 12: An overview of the municipalities that provided cases for the present study, including their size, and the identified natural gas alternatives and analysis tools used for their heating transition pilot projects.

#	Municipality	Residents Municipality (CBS[1], 2019)	Natural gas-free heat supply proposed for the pilot project	Analysis tools identified in implementation plans
1	Loppersum	9,614	Heat network, heat pumps and thermal energy storage	Energie-omgevingsplan (EOP) (Gemeente Loppersum, 2018)
2	Tytsjerksteradiel	31,780	Individual heat pumps	Energy Scan + Software RVO (Gemeente Tytsjerksteradiel, 2018)
3	Assen	67,963	unknown	Asser Servicekosten Model (Gemeente Assen, 2018) Roadmap Sustainability (Gemeente Assen, 2018)
4	Noordoostpolder	46,849	Heat network	Unclear (Gemeente Noordoostpolder, 2018)
5	Katwijk	65,302	Aquathermic solution, MT Heat Network	Business case IF technology (Gemeente katwijk, 2018)

[1] CBS: Central Bureau of Statistics of the Netherlands.

6	Rotterdam	644,618	HT Heat Network (possible later MT)	Caldomus model (Gemeente Rotterdam, 2018) Infrastructure footprint model (Stedin, 2017)
7	Utrecht	352,866	HT heat network and heat pumps	Infrastructure footprint model (Stedin, 2017) Routekaart Eneco (Gemeente Utrecht, 2018)
8	Eindhoven	231,642	Heat Network	CEGOIA model CE Delft (Gemeente Eindhoven, 2018)
9	Brunssum	28,103	LT Heat network	Unclear (Gemeente Brunssum, 2018)
10	Middelburg	48,544	HT Heat network	Feasibility study DWA (Gemeente Middelburg, 2018)

3.3 Linking data to theoretical propositions

The objectives and design of the case study were based on the theoretical propositions proposed in chapter 2, which in turn reflected a set of research questions and a literature review. The propositions have therefore shaped case identification and the data collection process. To link data from the empirical study to the theoretical propositions a technique called pattern matching was used. According to Yin (2018) pattern matching is one of the most desirable techniques used in case study analysis. Pattern matching entails comparing empirically based patterns with the predicted patterns made before collecting data, e.g. the theoretical propositions. ATLAS.ti 8 software (ATLAS.ti, 2016) was used to support the process of pattern matching, as detailed in chapter 3.4. As this was an explanatory case study, the patterns related to the how's and why's of the case study (how and why are energy models used?). Where empirical and predicted patterns were found to be similar to the theoretical propositions, the internal validity of the case study was strengthened (Yin, 2018). As there is a risk of collecting too little data with this approach (Yin, 20198), data was also collected on emerging themes that were not identified in the conceptual model as influencing the relationship between the use of energy models and the complexity of heating transition decision-making such as coupling opportunities, resident motivation and collaboration between model developers. After the empirical study was conducted, the theoretical propositions were reviewed and confirmed or rejected based on the empirical results.

3.4 Data collection, treatment & analysis

3.4.1 Data collection

Within the case studies two types of data collection were used, document studies and interviews. The documents (such as implementation plans and model guidelines) provided secondary data that was used to structure the interviews. Only publicly available documents were used.

In depth interviews provided primary data in the case studies. All 23 (expert) interviewees were provided with informed consent forms (see Appendix D) and all interviewees provided, among others, permission for the use of their statements for the present study. All 23 interviews were conducted via video call or telephone and audio was recorded. Interviews with practitioners (14) and model developers (7) were transcribed verbatim, validation interviews with experts (2) were summarized. Transcripts/summaries were provided to the interviewees after the interviews and interviewees were given ample opportunity to read and alter the transcripts/summaries. All 23 interviews were conducted between the first of May and the first of September of 2020. The average duration of individual interviews was 55 minutes. The interviews were semi-structured with open-ended questions to allow for in-depth analysis. The questionnaires used to structure the interviews can be found in appendix E and were communicated to interviewees in advance of the interviews.

The data collection process, including the informed consent forms, was approved by the Ethical Committee of the Technology, Policy and Management faculty of the Delft University of Technology.

3.4.2 Data analysis

Analysis of the interview transcripts was completed by thematic coding. Atlas.ti 8 (ATLAS.ti, 2016) (computer-aided qualitiative data analysis software) was used to execute the coding process and to create coding reports. Thematic coding is a method of identifying, analysing and reporting themes within data. According to Braun and Clarke (2006) a theme captures something important about the data in relation to the research questions. For the present study a semantic analysis was conducted, meaning that data was coded at face value, i.e. at the explicit meaning. This is the most evident type of thematic coding that shows patterns that exist in data that are organized in the forms of content and interpreted meanings (Javadi & Zarea, 2016). Thematic coding is viewed as a relatively simple qualitative method that offers a high level of flexibility. Moreover, the results of this method are understandable for non-academic public (Javadi & Zarea, 2016), which was one of the main reasons for choosing the data analysis method. The thematic coding was realised in three phases, similar to the thematic coding phases described by (Friese et al., 2018).

Phase 1: Pre-analysis

The first phase was focused on immersing in the data and getting a sense of its meaning. All interviews were transcribed and then reread, which allowed for pre-analysis.

Phase 2: Material exploration

The second phase was aimed at gaining a deeper understanding of the meaning of the data, e.g. the transcripts. At this stage quotations were created based on the theoretical propositions and the research questions and a code was assigned to each quotation. As proposed in standards for theoretical thematic analysis (Friese et al., 2018), an initial set of codes was set-up to guide analysis of the transcripts. Codes such as ‘limitations model: Vesta MAIS’, ‘lack of user friendliness’ and ‘coupling opportunities’ were proposed in the code frame. The code frame, as expected, did not fully cover all aspects related to the topic and was adapted and supplemented where needed with codes such as ‘motivation residents’ and ‘not familiar with energy models’. These adaptations were made inductively, meaning that the ‘open coding’ function of Atlas.ti was used to add codes during the first round of coding. After this first round of coding, all codes and their frequency were assessed to see whether splitting or merging of codes was necessary. For example, codes having a low frequencies would be merged with more abstract codes. After multiple rounds of coding, recoding, merging and splitting the 13 interviews with practitioners (14 interviewees) yielded 820 quotes, divided over 36 thematic codes. The 7 interviews with model developers (7 interviewees) yielded 561 quotes divided over 53 thematic codes. An overview of the used codes and their respective occurrence can be found in appendix H.

Phase 3: Interpretation

This phase was focused on transforming the raw data into meaningful information. All quotes were given an English title, code groups were created to show the relation between several codes and so-called network figures were created (see appendix F and G) to show the focus of different quotes within one code. Moreover, code-occurrence tables (see appendix F and G) were made to quantify the findings. The thematic codes were then divided over the three sub-questions in order to utilize the quotes to confirm or reject the theoretical propositions and to answer the research questions.

3.4.3 Data storage

After conclusion of this study, on the 21st of October, all audio files of interviews were deleted. Consent forms and anonymized transcripts and summaries are available at the research repository of the Delft University of Technology (http://repository.tudelft.nl/). Atlas.ti 8 (Atlas.ti, 2016) coding reports with quote titles (English) and quotes (Dutch) of the interviews with practitioners and model developers can also be found at this repository.

4 Results of the interviews with Dutch heating transition practitioners

This chapter discusses the results of the interviews with practitioners conducted within the embedded case studies. Chapter 4.1 introduces the cases and the interviewees. Chapter 4.2 discusses results relating to sub-question 1, which energy models are used while planning for the heating transition and how? Chapter 4.3 discusses results relating to sub-question 2, how can the energy models be improved to better support decision making for the heating transition? Chapter 4.4 discusses results relating to sub-question 3, what is needed, besides energy model improvements, to facilitate effective use of energy models for decision making in the heating transition? Chapter 4.5 concludes with a summary of the relevant findings.

4.1 Case description

14 interviewees participated in 13 interviews. Table 13 shows an overview of municipalities and interviewees. The interviews yielded 820 quotes divided over 36 thematic codes. An overview of codes and code frequency is shown in Table 37 in Appendix H. This chapter provides a short description of the case studies which includes the quotes relating to envisioned natural gas alternatives. The quotes relating to the other codes will be discussed in the next chapters.

Table 13: An overview of the participating municipalities and interviewees.

	Municipality	Interviewee (function)
1	Tytsjerksteradiel (Garyp)	Part-time project leader pilot project
2	Eindhoven	Project leader pilot project Project manager TVW
3	Katwijk	Environment manager pilot project
4	Loppersum (Westeremden)	Project leader pilot project
5	Utrecht	Project manager TVW Project leader pilot project
6	Brunssum	Project manager pilot project Project manager TVW
7	Noordoostpolder (Nagele)	Project leader pilot project
8	Rotterdam	Process director pilot project
9	Middelburg	Project leader pilot project Project manager TVW
10	Assen	Project leader pilot project

The application for the first round of pilot projects was in 2018, here municipalities had to present a heating alternative for their pilot neighbourhood. In 2021 every municipality has to deliver the TVW in which they show which heating alternative is most suitable for all neighbourhoods in the city and when they are planning to implement these alternative systems. A so-called prioritization of neighbourhoods has to be proposed to show which neighbourhood will become natural gas-free at what time. None of the municipalities from this sample had finished their TVW at the time of the interviews. However, some had already chosen a heating alternative for natural gas for the pilot project. Ten out of thirteen interviews provided information about the (envisioned) alternative heating supply for the pilot projects. A total of 36 quotes was collected, an overview of these quotes is shown in Figure 11, Appendix F. The next section discusses the findings.

Brunssum, Assen, Utrecht – No alternative chosen for pilot project

The municipality of Brunssum, Assen and Utrecht had not chosen a natural gas alternative for their respective pilot projects yet In 2018 the municipality of Brunssum planned to change the heating system of the pilot project to a Low Temperature (LT) heat network where the heat source would be mining water and possibly residual heat. However, the interviewee of Brunssum claimed that the municipality was currently not executing this plan because the municipality felt that it would be better to wait for the results of the analysis conducted for the TVW. Similarly, in Assen, the municipality planned in 2018 to provide the pilot project with all-electric solutions and better thermal insulation. However, this approach had little public support, partly due to high costs. Because of this reason the municipality of Assen was reassessing the heating options for the pilot project at time of the interviews. The municipality of Utrecht was assessing the costs of different heating alternatives with the CEGOIA model and had not made a definitive choice for a heating alternative yet.

Rotterdam – Heat network for large shares of the city including the pilot project

According to the TVW analysis in Rotterdam, a large share of the city of Rotterdam could be heated with a heat network, however, the heat source still had to be defined. The city has an abundance of sources available, ranging from residual, geothermal and aqua-thermal, but there was still discussion within the municipality on which ones to use. The TVW analysis of Rotterdam also showed some small areas where individual all-electric solutions would be suitable.

Middelburg, Loppersum, Katwijk, Eindhoven – Heat network for the pilot project

In Middelburg, the plan was that the pilot project would get a High Temperature (HT) heat network that was fed with residual heat from a nearby company. The municipality was reinvestigating the financial feasibility of this plan. For the rest the TVW, analysis was being conducted. A similar HT heat network was proposed in Katwijk, fed by the heat of surface water and waste water, i.e. aqua-thermic sources. At the start, no houses would be insulated because these sources could provide HT heat. However, the plan was to gradually insulate the houses as well. In Eindhoven, the municipality planned to extend their current city HT heat network into the pilot neighbourhood and the municipality was investigating alternative approaches to do this. The pilot project in Loppersum consisted of part of the village of Westeremden. In the pilot project in Loppersum, the municipality also opted for an HT-heat network because this was minimally invasive for the houses of residents and because no extra thermal insulation was needed. Insulating houses in Loppersum was difficult because many residents were waiting on the renovations that will be realised by the Earthquake Renovation Programme[2].

Tytsjerksteradiel – Individual all-electric solutions for the pilot project

The pilot project in Tytsjerksteradiel consisted of part of the village of Garyp. Garyp was the only pilot neighbourhood in this sample where the municipality had chosen for an individual approach in which all houses could opt for an individual all-electric solution. Garyp consisted mostly of detached houses with poor insulation, which was thought to render a heat network financially unfeasible.

[2] The Earthquake Renovation Programme (Dutch: Meerjarenprogramma Aardbevingsbestendig en Kansrijk Groningen) includes concrete measures to reinforce residential and public building in the Groningen region that have been affected by the earthquakes caused by natural-gas extraction of the Groningen gas field. The 2015 plans outlined that these reinforcement measures would be combined with energy improvements of residential buildings and improvement the overall quality of living in affected areas (Nationaal Coördinator Groningen, 2015).

Noordoostpolder– Solar collectors with seasonal storage for the pilot project
The pilot project in Noordoostepolder consisted of part of the village of Nagele. In Nagele, the municipality planned to use thermic solar collectors on flat rooftops in combination with underground seasonal storage. This was an innovative solution that had never been applied collectively, as planned here, before. The dimensions of the storage were highly dependent on the amount and size of collectors and the demand, balancing this was difficult. A gradual shut down of natural gas was foreseen.

Conclusion
The municipalities are still assessing the different heating options available but heat networks are the most favoured option for densely populated areas. HT-heat networks were considered easier to implement for residents than other heating alternatives, as they usually did not require extra thermal insulation at residential houses. However, the challenging aspect of heat networks was to find suitable heat sources to feed the network. The results of these interviews show that in less densely populated areas municipalities opted for other heating alternatives than heat networks, such as individual all-electric solutions or solar collectors.

4.2 Which energy models are used while planning for the heating transition and how?

4.2.1 The use of energy models

All thirteen interviews provided information about the use of models and/or modelling studies (such as the SA or the OB) while developing heating transition plans and/or conducting heating transition projects. A total of 61 quotes was collected, an overview of these quotes is shown in Figure 12, Appendix F. The results are discussed below, Table 14 shows an overview of energy usage mentioned during the interviews.

Table 14: An overview of energy usage mentioned during the interviews with practitioners.

Energy model usage mentioned	# case studies
Models/modelling studies used for the pilot project	6/10
Models/modelling studies used for TVW	7/7
Vesta MAIS model usage mentioned	3/7
CEGOIA model usage mentioned	4/7
DWA model(s) usage mentioned	2/7
Caldomus model usage mentioned	2/7
WTM usage mentioned	1/7
ETM usage mentioned	1/7
Startanalyse (SA) usage mentioned	4/7
Openingsbod (OB) usage mentioned	3/7

Tytsjerksteradiel, Noordoostpolder and Loppersum – No use of energy models for pilot projects

The interviewees from Tytsjerksteradiel and Noordoostpolder (both project leaders deployed by local energy cooperatives) were not familiar with energy models. However, the interviewee of Tytsjerksteradiel was familiar with the SA. According to the interviewee, no model was used for the pilot project in Tytsjerksteradiel since the decision for a heating system could be made with 'common sense'. In Noordoostpolder the energy cooperative organised a national contest to find a new heating concept for the village. In Loppersum the interviewee also stated that there had been no model involved in the choice for a heating alternative in the pilot project. No information was gathered on the development of the TVW for Tytsjerksteradiel, Noordoostpolder and Loppersum. It is therefore not known whether for the development of the TVW these municipalities were planning to use models or modelling tools.

Utrecht - CEGOIA, SA, Vesta MAIS

In Utrecht, the CEGOIA model was used to calculate the societal costs and end-user costs of different heating alternatives for the pilot project in the pilot project. This project was the first project where the CEGOIA model was used to calculate end-user costs. CE Delft has also used/compared the results of the OB and the SA while analysing the options for this pilot project. The TVW in Utrecht was being developed based on calculations within the Vesta MAIS model. The municipality in Utrecht had an internal team with expertise in modelling and data that utilized the Vesta MAIS model to provide scenarios and calculations for the design of the TVW. Scenarios made with the Vesta MAIS model in Utrecht were also compared to the results of the SA.

Eindhoven - CEGOIA, DWA models, SA

The CEGOIA model was used in Eindhoven to calculate the lowest societal costs per heating alternative. However, the results of the CEGOIA model were deemed too abstract for the pilot project in Eindhoven and DWA, another Dutch consultancy firm, was hired to conduct more detailed calculations and a business case. DWA, most likely used the IKM and the WWM for this. The results of the CEGOIA model, as used for the pilot project, had not provided input for the TVW yet. For the TVW the interviewee of Eindhoven felt obliged to use the SA.

Brunssum- SA, Caldomus

The Caldomus model supported the development of the RES in the region of Brunssum. The TVW for Brunssum was being developed by EnTra Management. The interviewee of Brunssum responsible for the TVW thought EnTra Management was predominantly using the SA as input for the TVW. No model had been used to support the pilot project, however, the pilot neighbourhood was included in the analysis that was being conducted for the TVW.

Katwijk - CEGOIA

In Katwijk the CEGOIA model was used in a regional setting, where municipalities collaborated and hired CE-Delft together to calculate societal costs for different heating alternatives for individual neighbourhoods. In Katwijk this served as input for the plan of the pilot project.

Assen - Vesta MAIS, DWA models

In Assen KAW, a Dutch architectural and consultancy agency looked into multiple scenarios of the Vesta MAIS model, but these provided similar results to their internal analysis. DWA was investigating the different heating alternatives for the pilot project. DWA also supported the development of the TVW in Assen, for both projects, DWA was most likely using the IKM and/or the WWM.

Middelburg - SA, CEGOIA,ETM, WTM, OB

In the pilot project of Middelburg, no model was used to find the most suitable heating alternative. Over Morgen, a Dutch consultancy agency, was hired by the municipality of Middelburg to help with the design of the TVW. The interviewee of Middelburg responsible for the design of the TVW also stated that the OB had been a useful modelling study for designing the TVW.

Rotterdam - Caldomus model, Vesta MAIS, OB

Rotterdam had a team of data and modelling experts that collaborated with Innoforte to utilize the Caldomus model for scenarios and calculations that served as input for the choice of a heating alternative in the TVW and the pilot project. In the past, this team collaborated with Over Morgen, who had used the WTM to support heating transition projects. Moreover, the team tried to stay up to date with current models and modelling tools available, such as the OB. One of the employees that had previously worked on the development of the Vesta MAIS model at PBL, was providing the team with knowledge on the Vesta MAIS model and the SA.

Conclusion

Six out of ten municipalities interviewed used models or modelling studies to support the decision-making process regarding a natural gas alternative for their pilot project. Four out of ten of the municipalities interviewed did not use models or modelling studies for this, of three of those no information was gathered on the development of the TVW. From the seven municipalities that provided information about the development of the TVW, all indicated that they did use models or modelling studies at some point during the decision-making process. All municipalities had access to the SA but only one municipality seemed to be planning on using this as the focus for analysis of the TVW, others were using it in a comparative manner next to other modelling approaches. From this sample four municipalities (Rotterdam, Katwijk, Utrecht and Middelburg) had access to the OB. Three of these municipalities mentioned using the OB. From this sample, it seemed that larger municipalities, with more resources, were more likely to use models and modelling studies in their heating transition decision making processes than small municipalities. Rotterdam and Utrecht, the two largest municipalities of this sample, had internal teams with expertise on data and modelling, which allowed them to rely less on consultancy agencies for model usage or result interpretation. All three villages represented in this sample (Nagele, Loppersum and Garyp) did not use models to support their decision for a natural gas alternative in the pilot neighbourhood. These villages were part of the smallest, second smallest and fourth smallest municipality (in terms of the number of residents).

4.2.2. Approach & Decision making process

All thirteen interviews provided information about their approach and/or decision-making process within heating transition projects. A total of 149 quotes was collected, an overview of quotes can be found in figure 13, in Appendix F. The general modelling approach and decision-making process differed greatly between municipalities and not all quotes collected were relevant for the research question of this study, relevant aspects are discussed below.

Analysis at a regional level

Smaller municipalities of this sample (Katwijk, Brunssum & Middelburg) collaborated on a regional level to analyse natural gas alternatives. CE Delft was for example hired by the region of Holland-Rijnland, which is a collection of municipalities that included Katwijk, to utilize the CEGOIA model to compare different heating options. Brunssum collaborated with seven other municipalities in a joint organisation, this organisation hired one heat coordinator that was responsible for designing the TVWs for the seven municipalities. Moreover, this heat coordinator was also involved in the design of the RES. In Zeeland, a collection of municipalities, including Middelburg, had collectively hired Over Morgen to support the municipalities in the design of their TVW.

Connection RES, TVW, WUP

The interviewee of Brunssum mentioned that it was difficult to match up plans at different abstraction levels, among others, because the RES, the TVW and the pilot project all had different deadlines. Because the plans on different abstraction levels influenced each other, the heat coordinator in Brunssum was involved in both the development of the TVW and the RES. After these two would have been concluded, the municipality of Brunssum was planning on choosing a definitive heating solution for their pilot project. Moreover, the interviewee of Brunssum stated that the TVW did not provide enough detail for Neighbourhood Implementation plans (WUPs).

In Utrecht, the CEGOIA model was used for the pilot project and the TVW design was being made, among others, with results of the Vesta MAIS model. The interviewees of Utrecht stated that the pilot was more detailed, focused on execution and more intense due to the involvement of residents whereas the TVW design was more abstract. The municipality organised meetings to check whether both projects (TVW and pilot) were still in line with each other and to assess how they influenced each other. In Assen, the municipality also assessed the relationship between the RES, the TVW and the pilot project. The municipality and KAW assessed how these three were connected and how one can go from an abstract level to a more concrete level. According to the interviewee, this was especially clarifying for the council. In Assen, the analysis for the TVW and the pilot project were both conducted in collaboration with DWA, who provided a coupling between the two projects.

Inclusion of social and socio-economic factors

In Middelburg, the municipality was trying to include social factors, such as resident motivation, into the design of the TVW. In Middelburg, they did not prioritize their neighbourhoods (where do you start with your heating transition projects) based on social factors such as income yet, the interviewees were unsure whether they should do this or not. The interviewee of Utrecht stated that it would likely be easier to start heating transition projects in neighbourhoods with an average low income because these usually have more property of housing corporations. The interviewee of Rotterdam agreed that it would likely be easier to start in neighbourhoods where there is a housing corporation property. In addition, the interviewee of Rotterdam claimed that it would likely be easier to convince higher-income neighbourhoods to participate but that this had the risk of increasing the wealth gap between different neighbourhoods.

The interviewee of Eindhoven mentioned that the municipality used to be overly focused on the technical aspects of heat networks and that the municipality wanted to change this approach for the TVW by incorporating social factors, such as resident perspective and the motivation of residents. Eventually, the municipality of Eindhoven would like to design the TVW together with stakeholders in an interactive process with attention for both the techno-economic and social aspects. The interviewee of Assen also stated that for the pilot project in Assen, the 'kind of residents that are living in a neighbourhood' was one of the two leading variables in assessing different heating alternatives.

Conclusion

To conduct a modelling study, smaller municipalities often collaborated in a regional setting. This is in line with the findings discussed in chapter 4.2.1. For the approach and decision-making process, this chapter showed that it could be difficult to match up plans made on different abstraction levels because different plans have different deadlines and they constantly influence each other. Three municipalities of this sample stated that they were trying to overcome this challenge by facilitating overlap and collaboration between heating transition (modelling) projects at different abstraction levels. Finally, this chapter showed that municipalities used social and socio-economic factors. However, municipalities did not integrate such factors into current models, but rather presented them alongside modelling results to help with the prioritization of neighbourhoods. There did not seem to be a desire from practitioners to integrate social or socioeconomic factors within current techno-economic models, as it was not clear how such factors should influence the choice of a heating alternative.

4.3 How can current energy models be improved to better support decision making for the heating transition?

4.3.1 Added value and limitations of energy models

Added value energy models

Six out of thirteen interviews provided information about the advantages of using models and/or modelling studies while developing heating transition plans and/or conducting heating transition projects. A total of 28 quotes, divided over 5 codes was collected. An overview of quotes can be found in figure 14 in Appendix F. An overview of advantages mentioned by interviewees is shown in Table 15.

Table 15: Advantages of using an energy model as mentioned by practitioners.

Added-value of using an energy model	Mentioned by
Provides perspective for action	Rotterdam
Provides financial insights (such as societal/end-user costs)	Katwijk, Utrecht
Provides transparency & legitimacy	Utrecht
Sparkes useful discussions	Katwijk
Provides a concrete proposition to residents	Katwijk, Eindhoven

Caldomus: Perspective for action & Socio-economic insights

The interviewee of Rotterdam stated that the results of the Caldomus model provided perspective for action for stakeholders and residents that wanted to start with the heating transition. The interviewee mentioned that the Caldomus model provided a high degree of detail, whereas other energy models tended to use national data that was more generalized.

CEGOIA: Financial insights, transparency, ignites useful discussions

Interviewees of Katwijk and Utrecht provided comments about the added value of the CEGOIA model. Both interviewees of Utrecht stated that the CEGOIA model had been useful in the pilot project to determine societal and end-user costs. Moreover, one interviewee stated that it helped in creating transparency towards residents. The interviewee of Katwijk claimed that use of the CEGOIA model had provided useful insights into the needed investment and in societal costs, which in turn had helped in communicating potential offers to residents. Moreover, the interviewee stated that the results of the CEGOIA model calculations were helping the municipality to get a grip on the financial aspects of the plan, such as feasibility, financial responsibility and ownership. Another important benefit mentioned by the interviewee of Katwijk was that the process of using the CEGOIA model sparked some useful discussions about aquathermic solutions, which also led to adaptations in the CEGOIA model.

DWA model(s): Concrete proposition

The modelling process that DWA applied in Eindhoven was useful, according to the interviewee of the pilot project Eindhoven, because it offered a concrete proposition for residents. According to the interviewee, the approach and models of DWA had offered integral insight into the needed investments along the entire chain, from source, infrastructure to supply.

OB: Offers robustness of different modelling results

According to the interviewee of Middelburg, the OB had proven to be a very practical modelling study for the TVW in Middelburg. The interviewee valued the comparison of modelling results offered in the

OB and stated that it was useful to see which neighbourhoods received similar results across different models. According to the interviewee, this OB provided robustness and trustworthiness of modelling results by providing comparisons and statistical analysis. If three models provided the same results for one neighbourhood, that solution, with current circumstances, was most likely the best.

SA: Validation

The interviewee of the pilot project in Eindhoven stated that the municipality was planning on using the SA because it offered validation of the analysis that was already conducted. In Loppersum the municipality was likely use the SA in the future because it offered clear guidelines on analysis. In Utrecht, the SA offered the municipality an opportunity to compare the results of the local Vesta MAIS analysis with the results of the SA.

Limitations of energy models

Eight out of thirteen interviews provided information about the limitations of using models and/or modelling studies while developing heating transition plans and/or conducting heating transition projects. A total of 57 quotes, divided over 6 codes, was collected. An overview of quotes can be found in figure 15, Appendix F

Interviewees from Rotterdam, Assen, Brunssum and Middelburg provided some comments about the limitations of energy models in general. An overview is shown in Table 16.

Table 16: Limitations of using energy models, as mentioned by practitioners.

Limitation energy models in general	Mentioned by
Does a model have added value?	Assen
Not all technologies included	Brunssum
Assumption of energy label B	Middelburg
Cascading of heat not included	Rotterdam
Odd results for the utility sector	Rotterdam
No clustering	Rotterdam

Limitations of energy models in general

The interviewee of Assen stated that models did not always have added value over other types of analysis. At the start of the project, KAW, the consultancy agency that the interviewee from Assen worked for, tried to assess whether the use of an energy model or a modelling study would provide added value to other types of (data) analysis. The interviewee of Brunssum stated that a big limitation for the use of energy models in Brunssum was that the specific technology the municipality had foreseen for the pilot project, was not taken into account in the existing models, which made it difficult to compare this option to other options. The interviewee of Middelburg stated that most models assumed that all houses would be insulated up to energy label B. She stated that this was an unrealistic assumption. Finally, the interviewee of Rotterdam mentioned multiple aspects that currently limit existing models. First of all, most energy models were focused on residential areas and could not provide useful results for utility and industrial areas. Second of all, models did not include the cascading of heat and the clustering of buildings, which could be practical.

CEGOIA

Interviewees from Eindhoven, Utrecht and Katwijk provided statements about limitations of the CEGOIA model. An overview is shown in Table 17:

Table 17: Limitations of using the CEGOIA model, as mentioned by practitioners.

Limitation CEGOIA model	Mentioned by
Availability of heat sources missing	Eindhoven
Lack of aquathermic options (has been improved)	Katwijk
Too abstract	Eindhoven
No end-user costs (has been improved, was available for Utrecht)	Katwijk, Eindhoven
Effect of (existing) heat networks on results	Katwijk
Statistics Netherlands (CBS) neighbourhood definitions	Utrecht
Quantification of other aspects than costs	Utrecht

The interviewee responsible for the pilot project in Katwijk stated that results of a model should never be taken literally, as energy models could never include all aspects from a sustainable transition. This interviewee mentioned, for example, that the CEGOIA model missed the temporal aspect of the heating transition. Specifics of the model that were limiting for its use in the pilot project of Katwijk, were the sensitivity of results to nearby heat networks, the lack of integration of aquathermic solutions and the fact that user costs were not clear. The latter two limitations have improved since the CEGOIA model was applied to Katwijk. The interviewee of Eindhoven also mentioned that the limited insight into end-user costs was a disadvantage of the CEGOIA model. Furthermore, the interviewee from Eindhoven stated that the CEGOIA model missed aspects, such as the availability of heat sources, which hindered it's usefulness for collective solutions such as heat networks which are dependent on the availability of heat sources. According to the interviewee, the CEGOIA modelling results did not provide sufficient insights into the availability of heat sources in Eindhoven. To gain insight into this the municipality of Eindhoven performed another study into available heat sources. Eventually, the municipality of Eindhoven only used the CEGOIA model briefly, because the municipality believed that the model was too abstract. The interviewee responsible for the pilot project in Utrecht stated that one limitation of the CEGOIA model was the Statistics Netherlands (CBS) neighbourhood definitions it used. These definitions can be quite random and not logical when looking at building characteristics and energy use. Another limitation mentioned by this interviewee was that it was hard to quantify other factors than costs with the model, such as how ‘future proof’ a certain heating alternative would make a residential house.

Vesta MAIS

Interviewees from Utrecht, Rotterdam and Assen mentioned some limitations of using the Vesta MAIS model. An overview is shown in Table 18.

Table 18: Limitations of the Vesta MAIS model, as mentioned by practitioners.

Limitation Vesta MAIS Model	Mentioned by
Complexity of usage	Utrecht
Simplification of neighbourhoods	Utrecht
Too general for local analysis	Rotterdam
Reality check needed	Utrecht, Rotterdam
The high sensitivity of variables/parameters	Utrecht
Odd results for utility & industrial areas	Utrecht, Rotterdam
Effect of (existing) heat networks on results	Rotterdam
No insight into end-user costs	Utrecht, Assen
Unclear when to stop modelling	Utrecht

The interviewee of Utrecht mentioned that the Vesta MAIS model is quite complex in its use. The fact that only Utrecht and Rotterdam used the Vesta MAIS model internally and that other municipalities, such as Middelburg, Brunssum and Assen relied on consultancy agencies to model scenarios in Vesta or to interpret results of the SA, might validate this claim. Moreover, the interviewee from Utrecht stated that the Vesta MAIS model tends to oversimplify neighbourhoods. For example; if for a neighbourhood 50% of houses were already connected to the heat network, then the model assumed that the whole neighbourhood was connected to the heat network. The municipality of Utrecht provided this feedback to PBL as well and in collaboration, the municipality of Utrecht was able to change these assumptions within the Vesta MAIS model. Moreover, another simplification that can be troublesome was that the Vesta MAIS model only looked at averages of neighbourhoods. Especially in older neighbourhoods in Utrecht, this provided odd results according to the interviewee of Utrecht.

The interviewee of Utrecht also stated that the Vesta MAIS model occasionally produced results for certain neighbourhoods that were not in line with general knowledge of the city, the results therefore always required a reality check. This limitation was also mentioned by the interviewee of Rotterdam. To check these results, data from other sources was needed, for example, knowledge from area managers who have in-depth knowledge about a neighbourhood or data about current buildings and infrastructure. One theme where the Vesta MAIS model often provided 'odd' results was for industrial areas. The interviewee of Rotterdam agreed to this and stated that most energy models were focused on residential houses and did not offer useful results for other objects such as care facilities, offices or industry. Moreover, the interviewee of Rotterdam stated that the calculations made with the Vesta MAIS model were often too general because they were made based on national key figures and assumptions, which did not provide enough detail for local analysis.

The interviewees from Utrecht and Assen would have liked to gain insight into end-user costs because societal costs were too general and provided too little insight for residents. Another limitation mentioned by the interviewee of Rotterdam was that the Vesta model did not take the effect of existing, developing and future heat networks into account sufficiently. If a neighbourhood has a heat network then the most logical thing to do is to extend this heat network to the neighbouring heat network, but the Vesta MAIS model does not use this as a variable. Another important limitation mentioned by the interviewee of Utrecht was that some variables of the model were highly sensitive when one tries to optimize, which makes the modelling results less trustworthy. This was also related to another point mentioned by this interviewee, namely when to stop modelling? According to the interviewee, it was hard to pinpoint a moment in time to stop the modelling process because there was always something that could be calculated differently or better. According to the interviewee of Utrecht, once the limitations of the model are reached one just has to stop the analysis and start the discussions with the results, which can then be checked and redefined with common sense.

Caldomus

The interviewee of Rotterdam mentioned limitations of using the Caldomus model. An overview is shown in Table 19.

Table 19: Limitations of the Caldomus model, as mentioned by practitioners.

Limitation Caldomus model	Mentioned by
Statistics Netherlands (CBS) Neighbourhood definitions	Rotterdam
Reality check and refinement needed	Rotterdam

The Caldomus model used the Statistics Netherlands (CBS) neighbourhood definitions, occasionally these were not logical for an energy system, as mentioned earlier. According to the interviewee of Rotterdam you always had to check the results from the model, because due to things such as illogical neighbourhood definitions, further refinement might be needed.

DWA models

The interviewee responsible for the pilot project in Eindhoven mentioned limitations of using the model(s) of DWA. An overview is shown in Table 20.

Table 20: Limitations of DWA models, as mentioned by practitioners.

Limitation DWA model(s)	Mentioned by
Standardisation vs. Specification	Eindhoven
No insight into the impact on the electrical network	Eindhoven
Uncertainty about financial and legal development	Eindhoven

The interviewee of Eindhoven stated that it would have been useful if the DWA model could have taken the effect of heating alternatives on the electrical network into account when analysing solutions. Moreover, the interviewee stated that the current modelling results still provided rather insecure results due to uncertainties regarding the development of financial and legal developments, such as Warmtewet (heat legislation) 2.0. Lastly, the interviewee of Eindhoven stated that when modelling, you always have some discrepancy between standardisation and specification. You want a model that works in different situations and locations, but you also want to provide a custom fit advice to residents. According to the interviewee, there will always be tension between these two goals.

SA

The interviewee responsible for the TVW in Eindhoven and the interviewee responsible for the pilot project in Utrecht mentioned limitations of using the SA. An overview is shown in table 21.

Table 21: Limitations of the SA, as mentioned by practitioners.

Limitation SA	Mentioned by
Not user friendly	Utrecht
Technocratic approach	Eindhoven
Green gas assumption	Eindhoven, Utrecht
Availability of heat sources	Eindhoven

The interviewee of Eindhoven felt obligated to use the SA for development of the TVW, however, she had doubts about the results because she found the approach too technocratic. For example, she had serious doubts about the assumptions made regarding the availability of green gas and heat sources. The interviewee of Utrecht also had severe doubts about the assumption of green gas used in the SA and claimed the SA was not useful for the pilot project in Utrecht because it suggested green gas for approximately 75% of the pilot neighbourhood, which was not available yet. Moreover, the interviewee of Utrecht stated that the SA was not particularly 'user friendly'.

Conclusion

According to literature, Energy modelling can aid in decision making and policymaking because it introduces a structured way of thinking about the implications of changing parts of the system (Pfenninger et al., 2014). The interviews provided some more concrete benefits and limitations of using energy models for decision making in the Dutch heating transition. Practitioners stated that the use of energy models within heating transition projects provided perspective for action, provided financial insight, provided transparency and legitimacy, sparked useful discussions and provided concrete propositions to residents. Most of these advantages seem related to creating public support for policy choices. Besides, practitioners stated that nationally available modelling studies provided validation and robustness of (other) modelling results. Practitioners also mentioned the limitations of using energy models. Interviewees claimed that modelling results were too abstract, too general or too simplified for local analysis and that models were not user-friendly and complex. Practitioners mentioned that modelling results provided no insight into available heat sources, limited insight into the impact of nearby heat networks and no insight into end-user costs. Another challenge mentioned was that Statistics Netherlands (CBS) neighbourhood definitions did not always provide a logical division of the city, which, among others, created the need to conduct a reality check after modelling to filter out odd results, especially for the utility sector. Finally, there was disagreement regarding the different assumptions regarding green gas in different models and modelling studies.

4.3.2 Data use & Data availability

Ten out of thirteen interviews provided information about the use of data and data availability for Dutch heating transition plans and projects, a total of 42 quotes was collected. An overview of quotes can be found in figure 16 in Appendix F.

The role of data in the heating transition

Data seemed to play an important role for municipalities in making heating transition plans. If municipalities chose to use a model, this model proved to be more useful if it was fed with local data. All models (except for the ETM), and studies such as the SA, use key figures which are based on national averages or assumptions. If one has local data, one can adjust these key figures to better represent the situation under investigation. Next to input for models, data was also gathered by municipalities with other aims. Municipalities, for example, gathered data about building typologies to gain insight into potential heating alternatives. This data was then for example presented in simple Excel files or GIS-maps. Another example was data gathered about social and socio-economic factors and coupling opportunities. Occasionally this was gathered next to model calculations and at times this was used in combination with data collection on other factors, such as building typology. When such maps were produced next to model calculations, the social, socio-economic, and coupling opportunity insights were used for the prioritisation of neighbourhoods for the TVW.

Privacy restrictions & Aggregated data

When asked about data availability the interviewee responsible for the TVW in Utrecht stated: "You always want more data, but some data is simply not accessible due to privacy restrictions, such as energy use per connection". The interviewee responsible for the pilot project in Utrecht agreed with this, stating that the municipality was having difficulties in Utrecht because the aggregated data on energy use that they were forced to use was found to be very unrealistic. In Utrecht, the municipality solved this issue by hiring a third party to conduct a study that would produce more accurate assumptions of energy use per connection based on building typology.

Building Typology data

All interviews showed the importance of building characteristics. Factors such as the degree of thermal insulation can have a great impact on the range of feasible options for heating. A prominently used data set to gain insight into building typology was BAG data. This data was publicly accessible and transparent. However, as the interviewee of Rotterdam stated, the BAG data set could be somewhat corrupted. According to the interviewee of Rotterdam, one needs more detailed data than the BAG data set offered to make decisions about heating options. The interviewee of Assen also mentioned this issue, he stated that energetic measures, such as thermal insulation levels, are often not captured well in data and that the municipality needed conversations with residents to uncover which energetic measures have been applied to houses. Most likely practitioners encountered this issue in Noordoostpolder as well, as the project leader decided to conduct house visits here to uncover the specifics of different houses in the pilot project.

Socio-economic data

The Handreiking (national guidelines to use the SA, presented by ECW) advised municipalities to include socioeconomic factors in the analysis of heating options (ECW, 2019) but the interviewee responsible for the TVW in Utrecht wondered on which factors you should then base your decision. For example, if one has the average income of a neighbourhood, what kind of effect should this have on the choice of heating option and the priority of neighbourhoods? In Rotterdam, the municipality was using socio-economic data from Statistics Netherlands (CBS) to identify pioneers: people who were likely to participate early on in energy or heating transition projects. The interviewee of Rotterdam stated that this data was useful for the prioritization of neighbourhoods as it indicated where it might be easier or more difficult to start with the heating transition. However, he did mention that this data was sensitive and that the municipality had to be very careful when using it.

Data for coupling opportunities

All municipalities interviewed mention the importance of coupling opportunities. Data about infrastructure planning was used to identify potential coupling opportunities. This data was usually internally available at municipalities and relatively easy to access. Data of housing corporations and network operators, about their renovation plans, was collected to identify coupling opportunities as well.

Sufficient data, but how to use it?

Five interviewees mentioned that there was not necessarily a lack of data or that a lack of data was not problematic. As the interviewee of Assen stated, there was often an abundance of information, but it was not always clear how to use it. Moreover, the interviewee of Eindhoven mentioned that even if there is plenty of data available, you also need the expertise to find it, to analyse it, to judge its trustworthiness and to visualize it.

Missing data

In terms of missing data, the interviewee of the pilot project in Eindhoven mentioned that it would be nice to gain insight into needed electrical network reinforcements. Both interviewees from Utrecht would like to gain more insight into the energy use per connection and the interviewee from Assen mentioned that there was no data on the willingness to pay available yet.

Conclusion

Data seems to play an important role for municipalities in making heating transition plans. If municipalities chose to use a model, this model proved to be more useful if it was fed with local data. Next to input for models, data was also gathered about socio-economic factors and coupling opportunities. The social, socio-economic, and coupling opportunity insights were then used for the prioritisation of neighbourhoods for the TVW. Five interviewees stated that there was no lack of data or that a lack of data was not problematic. However, interviewees did mention data that was currently not available that might be useful: data for needed network reinforcements, data about the energy use per connection and data on the willingness to pay.

4.4 What is needed, besides energy model improvements, to facilitate effective use of energy models for decision making in the heating transition?

4.4.1 Analysis tools used next to energy models

Twelve out of thirteen interviews provided information about the use of analysis tools other than energy models alongside or instead of energy models while developing heating transition plans and/or conducting heating transition projects. A total of 51 quotes was collected, an overview of quotes can be found in figure 17 in Appendix F. The results are discussed below. Table 22 shows an overview of used tools.

Table 22: An overview of the analysis tools, besides energy models, that were used in the heating transition case studies.

Energy tool	Used by (at least):	Used to:
Energy scan	Loppersum Tytsjerksteradiel Future: maybe Brunssum	Assess which energy technologies and/or thermal insulation options are possible for houses.
Business cases	Middelburg Katwijk Assen Eindhoven Noordoostpolder	Provide more details on the financial aspects of the proposed solution. Business cases are usually made after applying models or modelling studies.

Heat source studies	Eindhoven Rotterdam Middelburg	To provide an overview of available heat sources for heat networks.
Resident Questionnaire	Katwijk Brunssum Noordoostpolder	To gain the perspective of residents towards heating transition plans.
Participatory Value Assessment (A specific sort of resident questionnaire)	Utrecht	To investigate the preferences of individual residents regarding the allocation of public resources and personal income
Geographical Information Systems (GIS)	Middelburg Katwijk Assen Eindhoven Rotterdam Utrecht Brunssum	To visualize data sets or the modelling results.
Non-energy models and tools (Susteen, optical fibre models, climate adaptation tools)	Eindhoven Rotterdam Brunssum	-To calculate the costs of an all-electric solution for a certain house - To optimize the lay-out of the heat network - To express the value of certain climate adaptation coupling opportunities

Conclusion

Energy models only provided part of the analysis needed for heating transition projects and plans. Municipalities of this sample used an array of other analysis tools/studies. These tools/studies were targeted at gaining more insight into the perception of residents, gaining more insight into the financial feasibility of heating alternatives, gaining insight into available heat sources or gaining insight into the CO_2 impact of different alternatives.

4.4.2. Third-Party Expertise

All thirteen interviews provided information about the use of expertise from third parties while developing heating transition plans and projects, a total of 79 quotes was collected. An overview of quotes can be found in figure 18 in Appendix F. The results are discussed below. Figure 6 shows an overview of the parties that provide expertise to municipalities or regions.

Eindhoven pilot: CE Delft, Over Morgen, DWA, Buurkracht

For the pilot project in Eindhoven, CE Delft was hired to model the lowest societal costs per heating alternative per neighbourhood. Eindhoven missed data on the availability of heat sources in this model, so the municipality hired Over Morgen to conduct a study into available heat sources, to enrich the CEGOIA model of CE Delft. In Eindhoven, the municipality stopped using the CEGOIA model because they found it too abstract. After this, the municipality of Eindhoven hired DWA to conduct a technological and financial analysis of different heating alternatives, which included model calculations and a business case. For the pilot project in Eindhoven, the municipality also hired Buurkracht to guide residents in the heating transition. Buurkracht had the expertise to organise resident activities and they provide neighbourhood coaches and an online resident platform.

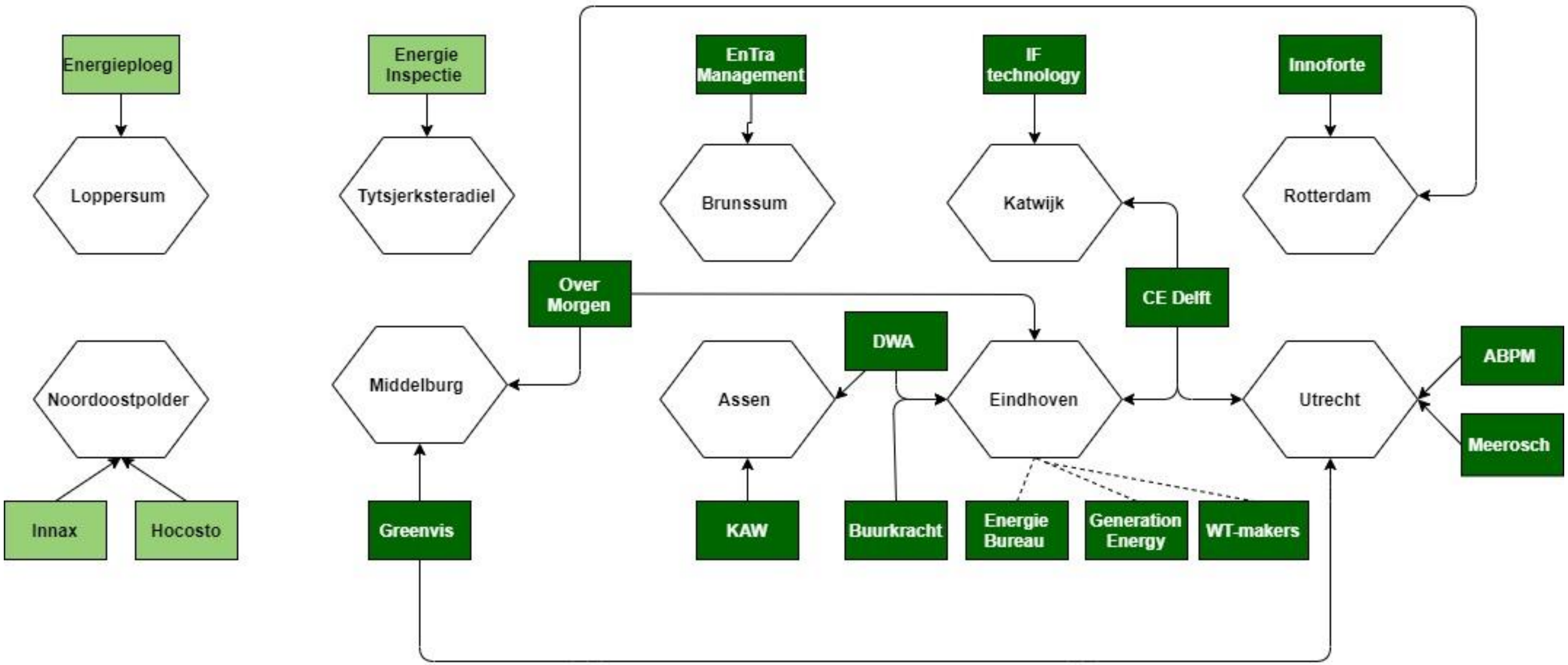

Figure 6: An overview of the parties that provided expertise to municipalities or regions. Dark green boxes indicate that the municipality that was supported used an energy model, light green boxes indicate that the municipality did not use an energy model.

Eindhoven TVW: CE Delft, the Warmtetransitiemakers, Generation Energy, Energie Bureau

The municipality of Eindhoven was searching for a third party to help them improve their TVW. The interviewee of Eindhoven would like someone to compare the results of the SA against other modelling approaches, would like to get more insight into the effects on electrical networks and would want a party that pays attention to social aspects, such as which residents have 'energy' to change. The interviewee of Eindhoven approached CE Delft, the Warmtetransitiemakers, Energie Bureau and Generation Energy for this (all Dutch consultancy agencies).

Utrecht pilot: CE Delft + ABPM, Merosch

CE Delft, in collaboration with ABPM, was hired by the municipality of Utrecht to support the pilot project. CE Delft conducted a technical-economic analysis with the CEGOIA model in which they compared the societal costs and end-user costs of different heating alternatives. CE Delft provided modelling results and result interpretation, ABPM led the discussions based on this information between stakeholders and practitioners. Merosch was hired to research energy use of different building types because the data on energy use was deemed not useful due to aggregation. The results of this study were fed back into the CEGOIA model.

Utrecht TVW: Greenvis

For the TVW in Utrecht, the municipality conducted model calculations in the Vesta MAIS model. To enrich this model the municipality hired Greenvis to conduct a study into available heat sources.

Katwijk pilot: CE Delft, IF-technology, Warmtetransitiemakers

The interviewee of Katwijk was working for both the municipality and for Warmtetransitiemakers, which is a heating transition consultancy agency. On a regional level (Holland-Rijnland), CE Delft was hired to conduct technical-economic analysis for the whole region. The results of this were also used for the pilot project in Katwijk. Moreover, expertise from IF-technology was hired to conduct a case study into the proposed aquathermic heating solution.

Middelburg pilot & TVW: Over Morgen, DWA, Greenvis,

Over Morgen was hired by a collaboration of municipalities in the region of Zeeland to develop TVW's for those municipalities. Over Morgen conducted, among others, modelling calculations for Middelburg for their TVW. The municipality of Middelburg felt unburdened by this and the interviewee of Middelburg experienced the process with Over Morgen as transparent. For the pilot project in Middelburg, the municipality hired DWA to conduct feasibility studies for heating alternatives. Greenvis provided a detailed business case for the pilot project.

Rotterdam pilot & TVW: Innoforte, Over Morgen

The municipality of Rotterdam had a short collaboration with Over Morgen for regional analysis, this collaboration ended because Rotterdam was not content with the degree of transparency in the process of Over Morgen, especially regarding the design of their respective model. After this, the municipality of Rotterdam hired Innoforte to support the development of the "WHAT-roadmap" for Rotterdam, which was input for the TVW and provided information on which heating solution would be suitable for which neighbourhoods. Innoforte, in collaboration with engineers from the municipality of Rotterdam, conducted calculations with the Caldomus model from Innoforte.

Brunssum TVW: EnTra Management, Innoforte

The RES in the region of Brunssum was developed with the help of Innoforte, who used the Caldomus model for this. The TVW for Brunssum was being developed by EnTra management. EnTra management is a small consultancy firm which was hired by a regional collaboration of seven municipalities, among which was Brunssum. EnTra management was involved in the RES of this region and was responsible for the TVWs of all seven municipalities. EnTra management used, possibly among other models and studies, the SA.

Assen: DWA, KAW
The interviewee of Assen, who was the project leader of the pilot project, was employed at KAW, which is an architectural and consultancy firm. KAW supported the municipality of Assen in developing a proposal for the pilot project in Assen. KAW had experience in city and neighbourhood transformations. Moreover, the municipality of Assen hired DWA to support in the development of the TVW. DWA provided a potential natural gas-free scenario for each neighbourhood in Assen.

Noordoostpolder: Hocosto, Innax
In Noordoostpolder Hocosto was hired to design the heating system, consisting of seasonal storage, a heat network and thermal collectors. Hocosto is an engineering firm that designs hot-cold storage. Moreover, an advisory committee consisting of experts from three themes, public support, resident participation and political processes was hired to support the pilot project. Based on the design of Hocosto, Innax provided a business case. Input for this business also came from the Irisk group, who provided financial validation of the plans.

Loppersum: Hanze Hogeschool, Energie Ploeg, WTC
In Loppersum the municipality collaborated with the Hanze Hogeschool (a Dutch college) to develop an optimization model that could be used for Loppersum. This model was supposed to utilize as much of the existing knowledge base/existing models as possible. The region was also setting up a heating transition centre (WTC) that would serve as an advisory institute for all municipalities in the region of Groningen. Moreover, in Loppersum the municipality hired a local company called the Energie Ploeg to conduct 'Energy Scans', which were house inspections to assess the potential for different heating and thermal insulation options for residents.

Tytsjerksteradiel: reluctance to use third party expertise, Energie inspectie (energy inspection)
The interviewee of Tytsjerksteradiel stated that the municipality was reluctant to use third parties such as consultancy firms because people of the village of Garyp were not fond of "people from outside the village that show up in expensive suits and cars that use up a lot of money". Another reason that limited use of third party expertise in Loppersum was that there were no energy models used in this pilot project, meaning the municipality did not require expertise on modelling or result interpretation. The municipality of Tytsjerksteradiel did hire the 'Energie Inspectie', to conduct house inspections and to advise residents on quotations.

Conclusion:
This overview showed that all the municipalities from this sample have used third party expertise at some point while planning for the heating transition. Third-party expertise was used at all scope levels, RES development, TVW development and for pilot projects. Municipalities of this sample hired third parties to provide modelling calculations, house inspections, modelling result interpretation or to provide studies, for example into available heat sources. Parties that were specifically hired to conduct or assist in modelling processes where CE Delft, Over Morgen, DWA, Innoforte, KAW and EnTra Management.

4.4.3 Collaboration

All thirteen interviews provided information about collaboration between different parties in the Dutch heating transition. A total of 42 quotes was collected, An overview of quotes can be found in figure 19 in Appendix F. The results are discussed below.

Energy Cooperatives
Five out of thirteen interviews mentioned collaborations with energy cooperatives. Both in Noordoostpolder and Tytsjerksteradiel, the pilot project application was organised by the local energy cooperative and the project leader and interviewee is part of this energy cooperative. In Loppersum the municipality collaborated with the local energy cooperation (LOPEC). The interviewee of Loppersum

claimed this was beneficial for the project. In the pilot project in Utrecht, the municipality established a 'managing group' which was a collaboration between the municipality, the housing corporations and the local energy cooperative. In Eindhoven, the municipality considered involving a spokesperson of an energy cooperative to represent residents during the planned interactive stakeholder sessions for the development of the TVW.

Network operators

Seven out of thirteen interviews mentioned that collaboration with network operators was important in their heating transition projects. In Tytsjerksteradiel the network operator wanted to be involved in the pilot project because they were eventually responsible if any network reinforcements would be needed. Similarly, the network operator was involved in Noordoostpolder to discuss the options for the underground infrastructure. In the pilot project of Eindhoven, the network operator was represented in the project team. A similar construction was set up for the pilot project in Utrecht, however, here it was called a managing group. For the TVW in Eindhoven, it was foreseen that the network operator would be present at interactive stakeholder sessions to design the TVW. Such stakeholder sessions with, among others, network operators, had already been organised for the TVW design in Brunssum.

Housing corporations

Seven out of thirteen interviews mentioned the importance of collaboration with housing corporations. The interviewee of the pilot project in Eindhoven stated that housing corporations were the start engine of the energy transition and that the municipality collaborated with the housing corporation in the pilot project to develop a business case for 500 houses. The interviewee of Eindhoven did state that it took over one and a half year to develop a common 'language' with the housing corporation to make this possible. The housing corporations were also represented in the earlier mentioned project team that Eindhoven set up for the pilot project. In Utrecht, the housing corporations were also represented in the 'managing group' of the pilot project. For the TVW in Eindhoven, the housing corporations would likely also be involved in the earlier mentioned planned interactive stakeholder sessions. The interviewee of Katwijk also stated that housing corporations played an important role in the current heating transition. In Katwijk this meant that the municipality would likely start with the heating transition in districts where housing corporations own much property. In Katwijk the municipality collaborated with housing corporations both in and outside of the pilot project to identify coupling opportunities with renovation plans and to incentivize residents to change to a new system. In Brunssum, the idea for the pilot project application came from housing corporations, because housing corporations wanted to become natural gas-free. Several housing corporations in Brunssum had already started the design process for new heating systems for their buildings and they were involving residents in this process. The municipality of Brunssum was hoping to gain insights from this. In the pilot project of Noordoostpolder, the housing corporation was involved in the process surrounding the contest for a new heating concept. In Assen, the municipality had "Mijnbuurt Assen" which was a collaboration between housing corporations, the municipality and a party for wellbeing work together to combine the social and physical side of heating transition projects.

Model developers

In Utrecht, the municipality collaborated with PBL to better understand the Vesta MAIS model. Feedback from the modelling and data team from the municipality was occasionally incorporated in new versions of the model as well. Other municipalities of this sample, if they had contact with model developers, this was in the form of a consultancy agreement, this was detailed in the chapter about third party expertise.

Regional collaboration

In Loppersum the municipality collaborated with other municipalities in Groningen to develop the TVW. In Zeeland (the province in which Middelburg is located) almost all municipalities worked together for the RES, together they have hired Over Morgen to help in this process. A similar collaboration existed in Brunssum where the municipality collaborated with six other municipalities in a regional collaboration to make heat plans such as the RES and the TVW.

Conclusion

The results suggest that collaboration with housing corporations and network operators was important during heating transition projects to prepare implementation plans and to find coupling opportunities. Housing corporations were important as they have property within the pilot projects and because they have renovation plans that may or may not align with the heating transition plans of the municipality. Network operators were important because they are responsible for underground infrastructure and network reinforcements. Therefore they have to be made aware of the municipal heating transition plans and they have to provide input about the current limitations of the infrastructure for specific heating options. Moreover, energy cooperatives played an important role within heating transition pilot projects, especially in smaller villages, where they even occasionally provided applications and project leaders for heating transition projects. For TVW projects at larger municipalities energy cooperatives seem to have less influence. Collaboration with model developers happened mostly in municipalities that had established modelling teams that model independently. Most municipalities, however, hired model developers such as consultancy agencies to conduct the modelling process for them, as discussed in chapter 4.4.2.

4.4.4 Motivation residents

Twelve out of thirteen interviews provided information about the perception and motivation of residents regarding the heating transition, a total of 51 quotes was collected, an overview of quotes can be found in figure 20 in Appendix F. Information about the perception and motivation of residents was thought to be relevant because, at present, building owners (either citizens or associations) have the right and responsibility to make investment decisions about the heating supply of their buildings (TNO & Gemeente Zoetermeer, 2020; Warmtenetwerk, 2020). This section discusses the motivation of residents to assess the need for the integration of social and socio-economic factors in modelling approaches.

Costs & Subsidies

Ten interviewees mentioned the importance of costs and financial arrangements such as subsidies for the motivation of residents. All interviewees seemed to agree that costs were the most determining factor for residents. There were many concerns regarding affordability among residents of pilot projects and it was expected that there would be low to no commitment if costs for natural gas alternatives were higher than they are now. The interviewee of Tytsjerksteradiel stated a share of residents could be incentivized by showing them the potential financial savings in the long term and which subsidies they could use to lower their initial investment costs. However, this interviewee also stated that there were still people who would not be able to afford the needed investments and that better financial arrangements were needed. Moreover, multiple pilot project interviewees mentioned that the pilot project would not have been possible without the PAW subsidy and that even with this subsidy it was financially challenging or unfeasible.

Sustainable mindset

Nine interviewees offered insight into the sustainable mindset of residents. The interviewee of Utrecht stated that there was little discussion about the need for a heating transition and that residents of Utrecht agreed that climate change was a problem and that something should be done about it. The majority of people in Loppersum and Noordoostpolder agreed with this as well, according to the project leaders of the pilot projects. The interviewee of Rotterdam claimed that costs were not the determining factor for every resident and that a few wanted to change due to the earthquake problems of Groningen or for the future of their children. In Utrecht, during a resident meeting, residents rated sustainability as the second determining factor, after costs. However, in Katwijk the interviewee stated that costs and the degree of hassle and nuisance were more important for residents in Katwijk than sustainability.

No urgency or Incentive

One challenging aspect was that there was no real urgency or incentive for residents, this was mentioned by three interviewees. According to these interviewees, the energy transition is less tangible than other issues for residents, such as having to buy a new laundry machine. As the interviewee of the pilot project of Eindhoven stated, people think that you have to choose between heat pumps and heat networks, but there is a third choice, to do nothing and to wait and see. This point was also made by the interviewee of Assen. According to this interviewee, there were roughly three groups of people in Assen, a small group of pioneers who were already making their house more sustainable, a slightly bigger group of opponents and a really big group who was just waiting and who would probably only take action If there was some pressure and a concrete offer. In the pilot project of Assen, this was strengthened by the fact that many residents were not convinced of the added value of natural gas free heating.

Unburden and limit hassle & nuisance

One aspect, mentioned by six interviewees, that helped in motivating residents was to unburden them and to limit the amount of hassle and nuisance they experienced by changing from heat supply. According to the interviewee of Utrecht, costs were the determining factor followed by the degree of sustainability and then the amount of hassle. The interviewee of Katwijk stated that is the second most important factor after costs and sustainability comes after that. The interviewees of Eindhoven and Brunssum simply stated that limiting nuisance and hassle was an important factor in motivating residents to participate.

Uncertainty

Five interviewees mentioned the effect of uncertainty on the motivation of residents. The interviewee of the pilot project in Eindhoven stated that there was a lot of uncertainty about the future and that residents were afraid to make the wrong choice. This was complex because the municipality also could not guarantee that it was making the best or the cheapest choice for the future. Moreover, the interviewee of Eindhoven stated that there was still a lot of uncertainty regarding future laws and regulations. The pilot project leader was also struggling with uncertainty about the earthquake reinforcement programme in Loppersum. Residents in Loppersum were uncertain whether their houses (and when) would be reinforced by the Earthquake Reinforcement Programme. They were waiting until they knew this before they would decide on their heat supply. Interviewees of Utrecht and Brunssum also mentioned the effect of the uncertainty over financial arrangements. This made it difficult to calculate or predict potential end-user costs. Plus the interviewee of Brunssum stated that there was uncertainty over the cost division, what should the municipality pay and what should the residents pay for?

Conclusion

All interviewees seemed to agree that costs were the most determining factor for residents. There were many concerns regarding affordability among residents of pilot projects and it was expected that there would be low to no commitment if costs for natural gas alternatives were higher than they are now. This suggests that including social and socioeconomic factors would be less relevant than analysing the costs of different heating alternatives and to assess the possibilities of financial arrangements. This was considered challenging because there was still a lot of uncertainty regarding future laws, regulations and arrangements. Such uncertainties also seem to decrease the motivation of residents. Other factors that were important for the motivation of residents, according to interviewees, were the amount of hassle and nuisance that the transition brings and how much it helps to make the neighbourhood more sustainable. Decreasing hassle and nuisance for participants could therefore increase the participation of residents, especially if shown in combination with the sustainable advantages of changing the heat supply.

4.4.5 Coupling Opportunities

All thirteen interviews provided information about the importance and use of coupling opportunities while developing heating transition plans and projects, a total of 70 quotes was collected. An overview of quotes can be found in figure 21 in Appendix F. Researching coupling opportunities was thought to be relevant as it could act as an incentive for building owners and because it could prevent an unnecessary doubling of activities. The results of the interviews are described below.

Infrastructure coupling

Interviewees of Rotterdam and Middelburg stated that there might be potential in coupling heating transition activities with infrastructure projects, such as sewer and gas pipe renovations. In Rotterdam, these had already been taken into account for the prioritization of neighbourhoods. In the pilot project in Middelburg, the municipality had put all renovation projects for the infrastructure and the public space near the pilot neighbourhood on hold so that when the heating transition pilot happened they could 'make work with work'. The interviewee stated that such coupling opportunities were also assessed for the prioritization of neighbourhoods for the TVW. The Interviewee of Tytsjerksteradiel and Noordoostpolder stated there were limited infrastructure coupling opportunities for the pilot projects, due to the individual approach in Tytsjerksteradiel and due to the recent infrastructure renovations in Noordoostpolder. The interviewee of Tytsjerksteradiel did state that for the future, if a heat network would be placed, it would be logical to for example repave the streets or renovate some gardens as well since it is not logical to open up a street twice in a short period. The interviewee of Eindhoven mentioned that it was difficult to organize infrastructure coupling because current projects, such as sewage system or gas pipe updates, had a very different temporal planning.

Moving and renovations

Interviewees from Tytsjerksteradiel and Eindhoven stated that moving and residential renovations offered logical coupling opportunities for heating transition projects. According to the interviewee of Eindhoven, moving and renovations offered a suitable moment to intervene and to make sure that all investments that are being made work towards the heating transition. The interviewee of Rotterdam was less sure of the value of this coupling, he claimed that if a neighbourhood or a residence needed much renovation, for example, due to deferred maintenance, that it might be better to wait until those issues are resolved instead of making them more complex by coupling them to the heating transition. The interviewee of Katwijk stated the municipality was assessing how they could couple the renovations of a local shopping centre to their heating transition project.

Housing corporation plans

Interviewees from Rotterdam, Noordoostpolder, Utrecht and Rotterdam mentioned that they were taking into account the renovation and investment plans of housing corporations and that they used or were planning to use these plans to find coupling opportunities.

Climate adaptation

Interviewees from Eindhoven and Brunssum saw potential in coupling heating transition projects with climate adaptation activities. In Eindhoven, the municipality considered new street layouts that were better adapted for our changing climate when implementing a heat network. In Brunssum, the municipality was planning to execute measures for climate adaptation, for example, to prevent flooding, while executing the PAW pilot project.

Earthquake Renovation Programme

The interviewee of Loppersum stated that the renovations from the Earthquake Renovation Programme were identified as a coupling opportunity at the start of the pilot project. However, in contrary to the the expectations, residents were more hesitant to participate in heating transition activities due to the uncertainty of Earthquake Reinforcement Programme and the Programme itself was not able or willing to alter its planning to align with the heating transition pilot project activities.

Conclusion

Municipalities find it important to identify coupling opportunities, the reason for this seems to be more to prevent redundant activities than to motivate residents. No coupling opportunities had been realized within the pilot projects from this sample yet. Coupling opportunities that were currently mostly assessed were infrastructure projects, such as sewer and gas pipe renovations. These could, however, be difficult to organize because infrastructure projects have very different temporal planning than heating transition projects. Renovation and investment plans of housing corporations were also seen as a coupling opportunity.

4.5 Summary Interviews practitioners

Which energy models are used while planning for the heating transition and how?

Over half of the sample used models or modelling studies at some point during the pilot project. The municipalities that did not utilize models or modelling studies for their pilot projects belonged to the four smallest municipalities of this sample, indicating a relation between municipality size and model usage. All cases in this sample that provided information about their TVW stated that they used or were planning to use models or modelling studies during development. Added-value of using energy models mentioned by interviewees was that the modelling process and its results provided perspective for action, financial insight and socio-economic insights. Moreover, interviewees stated that modelling processes and results created transparency and legitimacy towards residents, made it possible to offer concrete propositions to residents and that it modelling offered means to start useful discussions with residents and other stakeholders.

How can the energy models be improved to better support decision making for the heating transition?

Limitations of energy models that were mentioned by at least two interviewees were the following. Modelling results were too abstract, too general or too simplified for local analysis and models were not user-friendly and complex. Modelling results provided no insight into available heat sources, limited insight into the impact of nearby heat networks and no insight into end-user costs. Moreover, Statistics Netherlands (CBS) neighbourhood definitions did not always provide a logical division of the city and one always had to conduct a reality check after modelling to filter out odd results, especially for the utility sector. Besides, there was a lot of disagreement regarding the different assumptions of green gas availability in different models and modelling studies. Modelling results were often presented with GIS-maps. To overcome the limitations of energy models and to move from abstract visions towards concrete implementation plans municipalities use tools such as energy scans, business cases, heat source studies, resident meetings, resident questionnaires, stakeholder workshops and non-energy models.

Data seemed to play an important role for municipalities in making heating transition plans. If municipalities chose to use a model, this model proved to be more useful if it was fed with local data. Five interviewees stated that there was no lack of data but that it was not always clear how to use available data and that data was occasionally unavailable due to privacy restrictions. Unavailable data that could be useful according to interviewees is data about energy use per connection, data about the willingness to pay of residents and data about the potential impacts on the electrical network. Building typology data, such as BAG data, seemed to be crucial for the functioning of energy models but this data did not always provide enough insight into building specifics, especially regarding current thermal insulation levels. House visits to conduct 'Energy scans' provided a solution to this in some municipalities.

What is needed, besides energy model improvements, to facilitate effective use of energy models for decision making in the heating transition?

All municipalities from this project used third parties at some point during their heating transition projects. CE Delft, Over Morgen, DWA, Innoforte and EnTra Management are consultancy agencies that were hired by municipalities to support, interpret or conduct modelling studies. Other parties were hired to support communication and participation processes with stakeholders and residents to conduct specific studies, to make detailed financial calculations or to conduct energy scans. Municipalities also collaborated on a regional level with other municipalities when designing heat visions and they collaborated with network operators, housing corporations and local energy cooperatives

Social and socio-economic data, such as resident composition, income and motivation, was also seen as important in this transition by interviewees. However, the impact that social or socio-economic data should have on the prioritization of neighbourhoods or the choice of heating alternatives was not always clear and data collection occasionally proved difficult due to the sensitive nature of this data. Municipalities also collected data about infrastructure and renovation plans, internally and from network operators and housing corporations, to assess coupling opportunities.

5 Results of the interviews with Dutch heating transition model developers

This chapter discusses the results of the interviews with model developers conducted within the embedded case studies. Chapter 5.1 introduces the cases and the interviewees. Chapter 5.2 discusses results relating to sub-question 1, which energy models are used while planning for the heating transition and how? Chapter 5.3 discusses results relating to sub-question 2, how can the energy models be improved to better support decision making for the heating transition? Chapter 5.4 discusses results relating to sub-question 3, what is needed, besides energy model improvements, to facilitate effective use of energy models for decision making in the heating transition? Chapter 4.5 concludes with a summary of the relevant findings.

5.1 Case description

Seven interviews were conducted, with a total of seven interviewees. An overview of the agencies that were interviewed is shown in Table 23. The seven agencies shown in Table 23 were approached because they either developed a model or a modelling study that was mentioned by practitioners. All agencies that were approached agreed to participate. These interviews yielded 561 quotes divided over 53 thematic codes. An overview of quotes per thematic code is shown in Table 38, Appendix H. This chapter will shortly describe the agencies and interviewees interviewed, the next chapter will analyse the relevant findings of the interviews.

Table 23: An overview of the interviewed model developers

	Agency	Heating transition models developed/utilized	Interviewee
1	Quintel Intelligence	ETM	Partner & modeller at Quintel
2	Ecorys	Vesta MAIS	Consultant natural resources
3	DWA	IKM WWM	Senior Consultant
4	CE Delft	CEGOIA	Consultant & technical expert CEGOIA model
5	PBL	Vesta MAIS	Researcher climate, air and energy
6	Over Morgen	WTM ETM	Consultant heating transition Previously part of the expert group on models Previously GIS-specialist
7	Innoforte	Caldomus	Director & modeller Board member of the foundation of heat networks Advisory board ECW

PBL

PBL, or Planning agency for the living environment, is a national institute for strategic policy advice in the area of environment, nature and spatial planning. PBL supports policymaking processes by conducting research, analyses and evaluations with an integral approach. PBL was the only non-commercial agency of this sample and it conducts its research independently and with academic funding (PBL, 2020a). PBL developed the Vesta MAIS model and collaborated with ECW for the development of the SA.

Quintel Intelligence

Quintel is a Dutch firm that aims to accelerate the energy transition, to do this the firm combines expertise on energy research, modelling and software development to create energy transition tools and to support others in using such tools. Quintel developed the Energy Transition Model (ETM). This model is constantly improved by Quintel and its partners. Next to the model, Quintel facilitated fact-based discussions, workshops and they contributed to various educative projects. Quintel made the ETM available for free and open-source and they collaborated with their partners, experts, the modelling community, energy consultants and their clients to improve the model. The Team of Quintel consists of ten people (Quintel Intelligence, 2020).

Ecorys

Ecorys is an international research and consultancy agency, who also offers management and communication services. Ecorys supported PBL and ECW in the development of the Vesta MAIS model and Ecorys utilized the Vesta MAIS model for the development of the OB (Ecorys, 2020). At the time of the interviews, Ecorys was analysing the impact of the differences between the last and the new SA.

DWA

DWA is a Dutch engineering and consultancy firm that focuses on the sustainability of the built environment. DWA developed multiple models and tools (such as a heating transition monitor) to support Dutch heating transition projects. Two models DWA uses to support municipalities in heating transition projects are the Integral Costs Model (IKM) and the Neighbourhood Heat Model (WWM) (DWA, 2020).

CE Delft

CE Delft is a Dutch research and consultancy firm that focuses on a sustainable society. They have economic, technical and policy expertise and use this to advise public and non-public organisation to realize change (CE Delft, 2020). CE Delft developed the CEGOIA model. The CEGOIA model calculates the costs of different natural gas alternatives. CE Delft utilized this model to advise parties on their heating transition plans (CE Delft, 2019).

Over Morgen

Over Morgen is a Dutch consultancy firm that aims for a more sustainable world by utilizing an integrated approach that combines area development with the energy transition. They support clients with process, project and program management by helping them with data-analysis, financial advice, co-creation and participation (Over Morgen, 2020). Over Morgen utilized the ETM to support RES projects and the firm developed the WTM for smaller-scale heating transition projects, such as TVW design.

Innoforte

Innoforte is a small Dutch consultancy firm that supports the development and exploitation of heating and cooling systems, the company offers consultancy and auditing to, among others, public organisations and heat suppliers (Innoforte, 2020b). Innoforte develops and manages the Caldomus model, a calculation model focused on the heating transition of existing residential neighbourhoods. Innoforte used the Caldomus model, together with BDO accountants & advisors, to support municipalities and housing corporations in heating transition projects (Innoforte, 2020a).

5.2 Which energy models are used while planning for the heating transition and how?

5.2.1 Model users & uses

All seven interviewees provided information about the current uses and users of their respective energy models. A total of 52 quotes was collected, divided over 8 codes. An overview of quotes can be found in figure 22 in Appendix G. The results are discussed below.

WTM

The WTM was developed by Over Morgen and was mostly used for TVW and WUP projects. It was too detailed for RES projects. Over Morgen has used the WTM to support over sixty municipalities in the design of their TVW.

Vesta MAIS

PBL had no exact insight into who was using the Vesta MAIS model because it is an open-source model. In general, the biggest user groups of the Vesta MAIS model were consultancy agencies, municipalities (direct or with the help of a consultancy agency) and universities. These parties used the model themselves and were responsible for how they applied the model. The interviewee of PBL mentioned three consultancy agencies that used the Vesta MAIS model: Ecorys, Greenvis and Ekwadraat. Moreover, the interviewee stated that some consultancy agencies had fully emerged in the model and model scenarios while other agencies only offered, for example, interpretation of the SA. Well known modelling studies conducted with the Vesta Mais model are the OB (here Ecorys applied the Vesta MAIS model) and the SA. The interviewee of Ecorys stated that Ecorys used the Vesta MAIS model for heating transition projects of Ecorys but that they also have a unique relationship with PBL in which they occasionally support PBL or ECW in Vesta MAIS studies, model developments or training sessions. The interviewee stated that Ecorys was, in ICT-terms, a 'superuser' of the Vesta MAIS model. At the time of the interviews, Ecorys was providing training about the Vesta MAIS model and the 'SA', commissioned and organised by ECW. Training sessions were meant as a helping hand for the use of the SA for consultants, practitioners and housing corporations. The goal was to provide more knowledge about the underlying model and rationale of the study. These training sessions were visited by consultancy agencies (such as RHDHV, Ekwadraat and Overmorgen) and practitioners. Practitioners did come to training sessions, but often they did not have the right background to master such a complex model. Practitioners visited the sessions to gain some basic knowledge about modelling and the Vesta MAIS model, but according to the interviewee of Ecorys, one can already see that these practitioners will not be the ones that will be working with the model. Most parties that visited the training sessions around the time of the interview wanted to develop a TVW and/or a WUP. Ecorys also provided training to data teams in Apeldoorn, because the municipality of Apeldoorn wanted to utilize the Vesta MAIS model themselves to model scenarios. This is very rare, the only other case that is known by the interviewee, that models in Vesta MAIS as a municipality, is the municipality of Utrecht.

CEGOIA

According to the interviewee of CE Delft, the CEGOIA model was mostly used for municipalities, provinces and network operators. It was used to develop certain visions and to test the effect of certain policy measures. Some users thought the CEGOIA model would offer a blueprint, but that is not true. According to the interviewee, the model calculations are the first step in a process and CE Delft tries to communicate this clearly.

DWA models (IKM, WWM)

The main clients that DWA used their heating transition models for are public organisations (such as municipalities), housing corporations and real estate owners. The main goal of DWA when utilizing a model for one of these clients was to make the heating transition easier, instead of more complex.

ETM

According to the interviewee of Quintel, the ETM has been used in the broadest scope of the energy transition. Gas companies, network operators and government agencies used the model to design large strategic scenarios. Municipalities used the ETM to design their RES or TVW. Consultancy agencies used the ETM to help municipalities. Consultancy agencies that used the ETM were Over Morgen, Witteveen & Bos, Bereschot, E&E Advies, Ecofys and DNV GL. Over Morgen has used the ETM to support fifteen Dutch regions (of the thirty present) with the design of their RES. The ETM was designed so that everyone could get insight and understanding in the model so that if you have used the model, and something changes, practitioners can adjust it themself. In this way, practitioners do not need a new consultancy agency at every little change or new question. However, according to the interviewee of Quintel, practice learns that the ETM and the heating transition are still too complex for some end-users. In some municipalities (Groningen, Gelderland) practitioners were able to use the ETM themselves, other municipalities needed more support and some just wanted someone else to calculate entire scenarios.

Innoforte

Innoforte used the Caldomus model to support municipalities in the development of their TVW. Examples of municipalities that Innoforte has supported are Nijmegen, Rotterdam, Maastricht and Heerlen.

Conclusion

The energy models found in this study were used mostly by consultancy agencies to support municipalities or other pubic organisations in designing heating transition plans. These plans include Regional Energy Strategies (RES), TVW, and Neighbourhood Implementation plans (WUP). Moreover, these models were used for visions of Gas companies and Network operators and as a start for more detailed business cases of heating alternatives by municipalities, housing corporations and heat companies. Energy models seem to have impacted the design of the TVW the most. This was expected, since the climate agreement in which municipalities agree to use modelling studies such as the SA, stated the following on the TVW: "… municipal authorities will provide insight into the social costs and benefits and the integral costs for the end-users. In the transition visions for heat, municipalities will be programming as much as possible based on the lowest social costs and costs for the end-user" (Government of the Netherlands, 2019). Such specific demands were not found in this agreement for the RES or WUP.

5.2.2 Modelling & Consultancy approach

All seven interviews provided information about the modelling and/or consultancy approach that is used to support municipalities during heating transition projects. A total of 187 quotes was collected, divided over 4 codes, an overview of quotes can be found in figure 23, figure 24, and figure 25 and figure 26 in Appendix G. The results are discussed below.

Result interpretation & client support

All (consultancy) agencies spoken to directly or indirectly helped their clients (e.g. municipalities) with the interpretation of modelling results. When Over Morgen used the WTM to support a client with heating transition projects, the result interpretation was conducted by Over Morgen and results were then validated together with stakeholders. The interviewee of Over Morgen stated that municipalities generally were not able to interpret the results correctly on their own, due to the technical difficulty of the model.

According to the interviewee of CE Delft, The CEGOIA model was always used in collaboration with the client. At the start of the project, CE Delft explained what the model does and how it works, which usually led to a discussion of assumptions. CE Delft then tried to uncover how the client feels about certain assumptions and which parameters they would like to be able to alter in the interactive tool that is provided. Based on these discussions and the provided data, CE Delft modelled scenarios in the CEGOIA model. CE Delft then provided a presentation of the results (mostly shown in GIS-maps) and they provided an interactive tool in which the client can alter certain parameters.

The interviewee of DWA mentioned the 10-step plan, a plan that was used for many heating transition projects. According to the interviewee, this 10-step plan was useful for practitioners because it provided an easy to follow setup. Practitioners had a central role in heating transition projects, but according to the interviewee, they often did not have in-depth knowledge on the topic. The interviewee stated that their 10-step plan approach made it easier to communicate about what needs to happen, why and how? Within the 10-step plan, the IKM was used to analyse which heating options are possible in which neighbourhood and in which neighbourhood you want to start. The WWM was usually applied after to the starting neighbourhoods. The interviewee of DWA stated that compared to approaches of some other agencies the 10-step plan of DWA provided a look into the future. It showed that after the 'start neighbourhoods' municipalities needed implementation plans, business cases and letters of intent. The 10-step plan showed which factors municipalities have to take into account to develop an approach, according to the interviewee this occasionally caused municipalities to gather more resources and capacity, because the municipalities realised the challenge ahead.

According to the interviewee of Ecorys, providing support to the client took up the most time during most heating transition projects. Support such as helping with result interpretation and answering questions. According to this interviewee, if you cannot communicate and defend the results of your study in an adequate manner, the whole modelling study might be deemed useless by a client. The interviewee of Ecorys stated that within heating transition projects the results of the Vesta Mais model were always just a small part of a study, it could be an important part but was still only a share of the process. According to the interviewee, presenting these numerical results to municipalities could lead to a false sense of accuracy. The interviewee, therefore, urged that the most important part of the process was to explain the meaning of results.

The interviewee of Quintel stated that the manner of client support differed per project. Either Quintel or a consultancy agency helped end-users to adjust the parameters in the ETM and to interpret its results. For larger projects, at a national level, Quintel offered support, for smaller more regional projects it was often consulting agencies such as Over Morgen. The interviewee stated that most end-users and consultants used a hybrid form of the ETM where they could only change a selection of parameters and for the remaining parameters they used the national standards as set in the ETM.

The interviewee of PBL stated that they have tried to make the results of the SA as easy as possible to interpret and that ECW offered support to municipalities to interpret these results as well. In general, PBL did not offer help in result interpretation of the Vesta MAIS model or the SA directly, this was usually executed by ECW or by consultancy agencies.

Innoforte tried to capture the complexity of the heating transition and to communicate this as easy and transparently as possible to different parties. The interviewee of Innoforte stated that they did not just 'hand over the results'. Results were achieved and discussed in workshops where the client asked questions and offered suggestions. This was a time-intensive process according to the interviewee, but he stated that it was very important to create results that are widely supported.

Interactive tools & Visualization

Interviewees of CE Delft and DWA mentioned the importance of interactive tools and visualization of modelling results in heating transition projects. Previously CE Delft only provided GIS-maps, however, these looked quite absolute. The interviewee stated that even though they were always presented with the notion that it was not a blueprint, these maps frequently were seen as 'the answer'. For this reason, CE Delft added the interactive tool, this helped with the interpretation of results for the client and provided them with more insight into what's behind the model and its sensitivities. The interactive tool was an interface to the full model. There was both a demand from clients for such a tool and It helped CE Delft to show clients that there was no right answer. According to the interviewee, the interactive tool was very educational/ for clients. Together with the rest of the support process of CE Delft, clients learned which factors were determining in the heating transition. This support process was mentioned as the biggest advantage of the modelling approach of CE Delft by the interviewee. The interviewee of DWA also recognized the importance of offering support and stated that the most important thing during this process is that stakeholders and clients can understand the results and that they trust the results presented. The interviewee mentioned that visualization was important for this. Because different people learn in different manners, DWA tried to use different presentation and visualization approaches for different people.

Comparative analysis

Usually municipalities or other clients have already conducted some analysis before they hire an agency to support them in heating transition projects. All Dutch municipalities had for example access to the SA since October 2019. Interviewees of Over Morgen, DWA and CE Delft offered statements about what they did with such existing analysis. The interviewee of Over Morgen stated that results of the WTM were always presented in a comparative analysis. Different models and maps can provide different results, this created confusion and uncertainty, Over Morgen tried to create clarity by providing comparative analysis. All the different modelling results that the municipality owned were compared to each other and against the results of the WTM and differences in methodology, assumptions and data were explained by Over Morgen. According to the interviewee of Over Morgen, the WTM usually had more similar results with the CEGOIA model results than with the SA. This is most likely due to a similar approach to thermal insulation level optimization. (CEGOIA and WTM both calculate the costs of multiple thermal insulation levels and then optimize, while the SA assumes all houses will become label B). The WTM has never been compared to the model(s) of DWA or the Caldomus model of Innoforte. DWA only conducted a comparative analysis if the client requested this and if there was enough time and money available within the project. The same goes for Innoforte. Innofore had had clients ask to compare the results of the Caldomus model to the SA. The interviewee of Innoforte stated that they have always been able to explain possible differences between the two because they were familiar with the SA. Innoforte was involved in the benchmark conducted by Brouwer (2019). This document was discussed in the literature section of this thesis and compared the Vesta MAIS model, the CEGOIA model, the model from DWA, the Caldomus model and the WTM/WTA. The interviewee of Innoforte claims there is never an easy answer as to why results differ but that you usually have an idea about the differences between models and based off of that you could assume where the differences originated from.

Social, socio-economic and political factors & participation processes

The interviewee of CE Delft mentioned that within heating transition projects techno-economic analysis was only a small piece of the puzzle and that there were all sorts of political, social and psychological aspects which were harder to take into account. The interviewee of Over Morgen agreed to this and stated that the technical and comparative analysis was usually the simplest step in the process. The interviewee of Over Morgen stated that, when helping a municipality in their TVW design, the most difficult part was the prioritization of neighbourhoods, due to the need of the inclusion of more "soft" factors. These soft factors did not come from a technical-economic analysis but were more a political game. The interviewee of DWA also mentioned that understanding the political factors was important, this interviewee stated that some consultants at DWA found it difficult to understand the political factors that influenced the decision-making processes at municipalities. Moreover, the interviewee of DWA stated that understanding the participation process was important for heating transition projects because residents eventually decided whether anything happened in their neighbourhood. Therefore, if a municipality required a large participation process then DWA collaborated with another party that is specialized in this. Innoforte was never involved in participation processes but the interviewee of Innoforte also mentioned the importance of participation activities such as organising discussion groups and identifying coupling opportunitie. However, they always left this to other consultancy agencies.

Heat source data

Over Morgen did not reason from the availability of heat sources when analysing natural gas alternatives. According to the interviewee of Over Morgen, many see heat sources and heat networks as a 'chicken-and-egg' problem. According to the interviewee, there is no such dilemma, one should first develop the heat demand and then the sustainable heat source. Until the heat source becomes available, one can feed the demand with a temporary source such as biomass. The Vesta MAIS model, the CEGOIA model and the DWA models did reason from the heat source data when assessing the potential of natural gas alternatives.

Posing correct research questions

The interviewee of Over Morgen argued that municipalities did not always have a suitable research question or research aim. Practitioners from municipalities, for example, made the scope too broad which made it unnecessarily complex. According to the interviewee this was caused by a lack of knowledge at the municipality. The interviewee stated that he would prefer it if municipalities would first approach multiple agencies to propose their research question, to see whether this would be an appropriate question or whether it should be adjusted. Because as soon as municipalities put the research question in the market, it cannot be changed anymore, agencies than just have to choose whether to make an offer or not.

Conclusion

All (consultancy) agencies spoken to directly or indirectly helped their clients (e.g. municipalities) with the interpretation of modelling results. There seems to be agreement that the techno-economic analysis that is conducted with the energy models that these agencies offer were only part of the analysis needed in heating transition projects and that political, social, economic and behavioural factors were important as well. Such factors were often assessed alongside modelling results, as explained in 5.3.4. The modelling process was described by interviewees as a collaborative process where model developers discuss different assumptions and parameters that could be used within the model with municipalities and where model developers requested additional (local) data. The results suggest that there was a lack of knowledge, skills and expertise at municipalities regarding energy models. Municipalities occasionally provided unsuitable research questions and they were generally not able to interpret the results correctly on their own, due to the technical difficulty of the model. Hence, model developers (consultancy agencies) invested a lot of time into explaining and interpreting results together with municipalities. The collaborative process and the result interpretation support were both intended to increase the trust and support for modelling results. Another challenge was that the myriad of models available frequently provided different results, which created confusion and uncertainty at municipalities. At times model developers conducted comparative analysis to decrease this uncertainty by explaining which assumptions, parameters or datasets caused different results in different models. One striking difference in modelling approaches between different agencies was the approach towards heat sources.

5.2.3 Connection RES, TVW, WUP

Three out of seven interviews provided information about how different abstraction levels come forward within the modelling process. A total of 12 quotes was collected, an overview of quotes can be found in figure 28 in Appendix G. The results are discussed below.

The interviewee of Quintel stated that there were many visions and plans being made on different abstractions levels (e.g. climate agreement, RES, TVW and WUP) but that it was not always clear if and how these plans and visions would fit together. To overcome this difficulty Quintel tried to position the ETM in such a manner that it could assess how plans fit together. The interviewee stated that if you made a TVW that you should still take the systems perspective into account to check whether your vision still fits the bigger picture of the energy system. This approach of including the system integration was not integrated within local analysis yet, people had a feeling that it would make the process too complex according to the interviewee. Although the interviewee of Quintel agreed to the fact that it initially might become more complex, he also thought it would be very useful. It could be useful if a party had a scenario made with a different model, for example, the Vesta MAIS model, that the output of this model could be fed back into the ETM to see how this scenario fits the broader energy system. Quintel was trying to make this possible with the Geo-map editor from the Mondaine project of TNO (see appendix J). The interviewee stated that the ultimate test was to see whether such a systematic approach is valuable in heating transition projects compared to using just one model such as Vesta MAIS or CEGOIA.

According to the interviewee of Quintel, the Vesta MAIS model was able to provide more detail than the ETM and some other parties, such as Greenvis, could provide more knowledge about heat networks and the Warmetransitiemakers were good at making business cases. The interviewee stated that he saw value in a 'train of models' where scenario's made with the ETM could be fed into the Vesta MAIS model followed by some iterations. After that, these scenarios would be used by engineers or a consultancy agency, who would provide even more detail, for example in business cases. Finally, the scenario's would be fed back into the ETM, to see whether all scenarios still fit together. Iterating through this 'train of models' going from abstract to detailed and vice versa could be useful according to the interviewee of Quintel. An interpretation of this proposed approach is shown in figure 7.

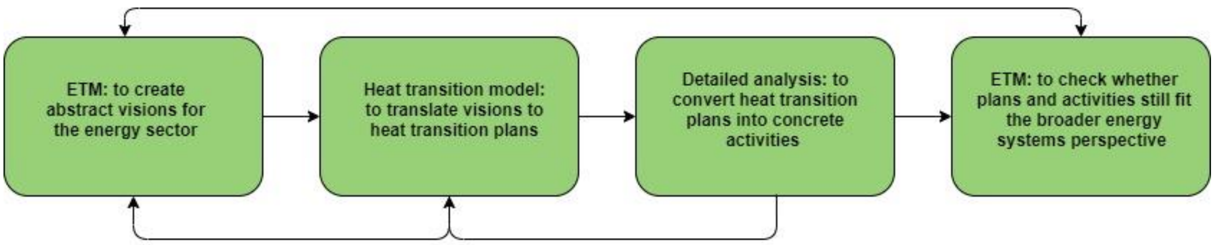

Figure 7: An interpretation of a future modelling approach as proposed by the interviewee from Quintel.

The interviewee of Over Morgen stated that the agency is active on multiple abstraction levels, which helped the consultants to understand the relationship between visions and plans on different abstraction levels (e.g. RES, TVW and WUP). The interviewee mentioned that stakeholders were often waiting on choices to be made in the RES before they were willing to make choices on a more detailed level. The interviewee stated that this was not necessary because municipalities could start with more detailed projects without having all the details of the RES, as long as practitioners at municipalities realize that all different scale levels influence each other.

Where Quintel and Over Morgen tried to be active on all levels to ensure plans fit together, Innoforte was planning to focus more on the execution level of plans. The interviewee of innoforte stated that there was a demand for a company that could make the more abstract visions and plans that were already there (e.g. RES and TVW) into more concrete implementation plans (e.g. WUP or smaller) and business cases. The interviewee stated that they were planning to position the Caldomus model towards this goal as well. According to the interviewee of Innoforte, this would allow Innoforte to do 'what we are good at and what we like'.

Conclusion

Multiple practitioners mentioned the difficulty of fitting together plans on different abstraction levels, such as the RES, TVW and WUP. These levels influence each other yet are all three still in the planning phase, which raises questions about the sequence. E.g. should one wait with the execution of the pilot project until the TVW is finished? The interviewee of Over Morgen suggested that municipalities should not wait but that it is important for practitioners to realize how different abstraction levels influence each other. Quintel was trying to make this influence and its effects more concrete by positioning the ETM in such a manner that it could test the compatibility of plans on different levels, made with different energy models. Innoforte was trying to bridge the gap between the TVW, the WUP and concrete business plans by repositioning their energy model.

5.3 How can current energy models be improved to better support decision making for the heating transition?

5.3.1 Added value and limitations of energy models

All seven interviews provided information about the advantages of using (specific) energy models within heating transition projects A total of 28 quotes was collected, divided over 6 codes. An overview of quotes can be found in figure 29 in Appendix G. All seven interviews provided information about the limitations of using (specific) energy models within heating transition projects and planned model changes to improve these limitations. A total of 61 quotes was collected, divided over 9 codes. An overview of quotes can be found in figure 30 in Appendix G. The results are discussed below, Table 24 provides an overview of the advantages and limitations of specific energy models.

Vesta MAIS

Two interviewees mentioned advantages of using the Vesta MAIS model and six interviewees mentioned limitations of the Vesta MAIS model. When asked about the advantages of the Vesta MAIS model, one of the interviewees mentioned that it was hard to identify such advantages because they were highly dependent on the research question. There were models which could provide more detail on a building level and there were models which provide broader insights into the whole energy system. This interviewee emphasized that the most important thing was to choose the right model for a research question. However, some general advantages were mentioned. First of all, the model is open source and adjustable to a specific case. Everyone could download the model and all input data, modelling codes and assumptions were publicly available and can be adjusted. One of the interviewees, therefore, stated that critique about assumptions of the Vesta MAIS model was unjust because users could change these assumptions. Moreover, interviewees mentioned that the datasets and key figures used in the Vesta MAIS model were updated regularly and that validation was done well. According to the interviewee of Ecorys, a lot of validation has been conducted for the Vesta MAIS model. According to this interviewee, this was done less for other models, because validation takes time, and commercial companies do not always have the money to spend much time on validation.

Table 24: An overview of the advantages and limitations of specific energy models mentioned by model developers.

Model	Advantage	Limitations
Vesta MAIS	● Can assess financial interactions ● Adjustable to a specific case ● Open-source ● A non-commercial party that invested in the validation ● Calculated on building level ● Well adapted to look at multiple scale levels ● Data and key-figures were up to date ● Optimization from different perspectives possible ● Forced practitioners to explicitly formulate goals	● Not user-friendly/complex model ● Did not take into account the impact of existing waterways on costs ● Energy use was always shown as an average ● Need to insert heat source data ● The utility sector was difficult to model ● How to translate abstract scenarios to practical matters?
CEGOIA	● Interactive tool ● Flexible ● Extensive support process ● Took into account the costs of the entire supply chain	● Calculations of end-users costs were difficult due to the large degree of uncertainty regarding regulations and financial arrangements ● Occasionally concluded renewable gas for relatively new neighbourhoods ● Practitioners found the interactive tool hard to use ● Techno-economic analysis was just part of the analysis, you also have social, political and psychological aspects. ● Data about affordability was only available on averages and data about energy use is not available due to privacy restrictions ● Not opensource
WTM	● Pragmatic approach ● Not limited by heat source data	● The techno-economic analysis was only a small part of the entire process
ETM	● Interactive model ● Forced practitioners to explicitly formulate goals ● Able to compare plans at different scope levels	● How to translate abstract scenarios to practical matters? ● How specific do your calculations have to be? ● End-users needed to add assumptions about the future ● ETM was complex due to the number of parameters that need to be set
Caldomus	● Integral approach ● Calculates at building level (more detailed than SA)	● Did not look at heat sources (chicken-egg problem heat network and heat sources) ● Green gas and hydrogen were not included in the model as alternatives ● Not possible to use other neighbourhood definitions than Statistics Netherlands (CBS) definitions
DWA models	● Heat network pipe layout could be plotted	

According to one of the interviewees, the Vesta Model was particularly good at assessing different impacts and different scale levels and the model provides the opportunity to optimize from different perspectives. (For example a national perspective, an individual resident perspective or a heat supplier perspective). The Vesta MAIS model is based on a spatial model, which means it is positioned well to assess infrastructures and heat networks on different scale levels. Since the addition of MAIS, which stands for Multi-actor Impact Simulation, the Vesta model is focused on the different perspectives of different actors. The Vesta MAIS model is able to model the impact of certain (policy)choices on different actors. Finally, the Vesta MAIS model calculates on building level, something not all models do. The interviewee of Ecorys stated the Vesta MAIS model was unique in its level of detail by calculating everything on building level.

Interviewees also provided statements about the limitations of the Vesta MAIS model. An often mentioned limitation of the Vesta MAIS model is that it's not user friendly. The Vesta MAIS model is complex and it can be difficult for end-users to interpret the results. One interviewee stated that it takes about 20 to 30 workdays to learn how the model works and to realize what kind of factors/assumptions are in there. The model forces its users to explicitly formulate goals, which is a useful but very time-consuming process. The future scenarios that end-users can create with the Vesta MAIS model have a lot of inherent uncertainties. The utility sector was harder to model than residential buildings because there is a bigger diversity in factors that could influence the outcomes of the model (such as energy use). PBL was trying to improve the modelling approach for the utility sector, but for a while, data and methods for residential buildings will improve more than the utility according to the interviewee of PBL. A specific limitation mentioned by one of the interviewees is that the model offered no insight into the impact of large waterways on the costs of infrastructure changes. Large waterways could drastically increase costs if you have to put the infrastructure under the waterway, but the model did not take these into account. Some limitations of datasets used by the Vesta MAIS model were also mentioned. Two interviewees stated that it was inconvenient that energy usage can only be shown as an average. PBL was trying to improve the heat source data set that is available in the Vesta MAIS model at the time of the interview by collecting data from municipalities about possible heat sources. (This was realised in collaboration with ECW).

WTM

The interviewee of Over morgen offered information on the advantages and limitations of the WTM. One of the advantages mentioned by this interviewee is that no data was needed from municipalities to run the WTM, it only used public data such as the BAG dataset. Another advantage mentioned was that the WTM did not include heat source data and was therefore not limited by heat source data. The model assumed infinite sources. The model was therefore based purely on costs and after the model has run a study was conducted to assess the actual heat source potential. Vesta and CEGOIA did include heat source data, the interviewee of Over Morgen mentioned this as a limitation because the data about heat sources was uncertain. According to the interviewee of Over Morgen, Vesta MAIS and CEGOIA used the ETS register to see which buildings produce CO_2 and all these buildings were then seen as potential heat sources. The WTM had a more pragmatic approach with renewable gas than Vesta MAIS and CEGOIA. The WTM dictated that in the most complex neighbourhoods you should leave the gas network there. According to the interviewee of Over Morgen, these were usually neighbourhoods from before 1920 or neighbourhoods with an extremely low density. After the model has run, Over Morgen conducted a test of renewable gas perspective. Based on the assumptions from the national climate agreement they assumed in this test that 15% of the municipality could use renewable gas in the future. According to the interviewee of Over Morgen, Vesta MAIS and CEGOIA occasionally concluded renewable gas for neighbourhoods with houses from 2005, according to the interviewee, this is not logical. The interviewee stated that in general, the WTM is more pragmatic where Vesta MAIS and CEGOIA are more technocratic. Some practitioners like the pragmatic approach, which does required a bit more common sense and interpretation. Others require more 'certainty' (according to the interviewee of Over Morgen, a false sense of certainty) and therefore want a model purely based on data, this was especially the case in municipalities where there was already much discussion and disagreement about the future heat supply.

ETM

The interviewee of Quintel offered some comments about the advantages and limitations of using the ETM. One advantage mentioned by this interviewee is that the ETM was very interactive. The interviewee stated that the ETM was more interactive than other existing models. According to the interviewee, this was an advantage because it shows that the calculations are not precise. Practitioners needed this interactivity to get an understanding of the model. Another advantage mentioned by this interviewee was that the model forces practitioners to explicitly formulate goals and that the model allowed practitioners to compare different plans at different scope levels to see whether visions at different levels (for example RES, TVW and WUP) still fit together. The interviewee of Quintel also stated some limitations and challenges of using the ETM. The ETM had approximately 400 input parameters. Nothing was pre-set, to make a prognosis/scenario, the end-user has to make assumptions about the future and then adjust the parameters accordingly. This could be quite difficult for end-users. Moreover, the interviewee also mentioned that it was always difficult to translate abstract scenarios made with the ETM, or with other models such as Vesta MAIS, to practical implementation plans. According to the interviewee, this was partly due to a trade-off between detail and perspective. According to this interviewee, the biggest challenge with modelling is often how specific can you make your calculations, while still providing perspective for a region or a country. This trade-off was clearly visible in the ETM because it had a quite abstract approach. Translating abstract choices made while designing national or regional scenarios, which are useful to make, into practical measures remained difficult.

CEGOIA

One interviewee stated advantages of the CEGOIA model and four interviewees provided information about the limitations. One advantage mentioned by the interviewee of CE Delft was that the model was more complete than other models because it also took the supply side into account and all other costs along the supply chain. Another advantage mentioned by this interviewee was that CEGOIA model was flexible, if a client wanted to include new technology, for example, this was possible as long as CE Delft could find the right parameters. Moreover, the interviewee of CE Delft stated that the biggest advantage of using the CEGOIA model was the extensive support process from CE Delft that comes with the model.

The interviewee of CE Delft mentioned the following limitations of the CEGOIA model: practitioners frequently found the model or the interactive webtool hard to use or to interpret, the calculations of end-user costs are uncertain and it only parts part of the analysis, namely the techno-economic part, and does not include social or political factors. One other interviewee stated that the fact that the CEGOIA model is not open source is a limitation. Yet another interviewee mentioned that in the past some clients had not agreed with the green gas assumptions used in the CEGOIA model. In addition to this, another interviewee mentioned that the CEGOIA model occasionally concludes renewable gas as the optimum solution for relatively new neighbourhoods, which he deemed illogical. Finally, one interviewee stated that the fact that one has to insert uncertain heat source data sets into the CEGOIA model in order to get results poses a limitation.

The interviewee of CE Delft also offered some aspects of the CEGOIA model that CE Delft was trying to improve. First of all, CE Delft was working on a module to provide insight into end-user costs. This module had been developed and tested at a project in Overvecht Noord (Pilot project Utrecht). The interviewee mentioned that it was still quite difficult to calculate end-user costs for the future due to the large degree of uncertainty regarding regulations and financial arrangements. As mentioned with other models, CE Delft also encountered issues with energy use data. Therefore, they changed the average energy use data from Statistics Netherlands (CBS) to key figures that were analysed by Merosch (a different consultancy agency). This was done because energy use data is privacy sensitive, so CE Delft only had access to less useful averages. Merosh made estimates based on building types, age etc.

Merosh also provided estimates for the costs of different thermal insulation options. A final aspect CE Delft wanted to change to their model were the energy labels. Dutch energy labels will be replaced with the BENG[3] and CE Delft is planning to adjust the CEGOIA model to this.

DWA models

The interviewee of DWA offered some advantages and limitations of the models DWA offers. One advantage, compared to other models on the market, that the interviewee stated is that with the DWA WWM (in combination with GIS-maps) one can plot the layout of heat pipes. One challenge mentioned by the interviewee was the required transparency of other parties such as heat distributors. To have useful calculations, data and information was needed from third parties, if these parties were reluctant to give this it would become hard to make realistic calculations.

Conclusion

The results showed that each model had its own advantages and limitations. One advantage for all of them is that they forced practitioners at municipalities to explicitly formulate goals. Using an energy model sparked discussions and forced both practitioners and model developers to think about the validity of assumptions and the impact of data. The most explicit advantages per model were as followed. The Vesta MAIS model had up to date key figures, allowed for optimization from different perspectives and calculated on building level. The Caldomus model was also able to calculate on the building level, at least as detailed as the Vesta MAIS model. The CEGOIA model was flexible and had an interactive tool, which came with an extensive support process. The WTM was not limited by uncertain heat source data. The ETM was highly interactive and could compare plans at different scope levels. Finally, DWA was able to use their model to plot the heat network layout. Almost all model developers mentioned the complexity of their model as a limitation. This made it difficult for practitioners to use the model or to understand the modelling results. Moreover, within modelling studies, there were difficulties with accessing or using heat source data and energy use data, which could affect the quality of the modelling results. Other specific limitations per model mentioned were as followed. The Vesta MAIS model did not take the impact of existing waterways into account and the utility sector was difficult to model. The CEGOIA model concluded renewable gas for relatively new neighbourhoods. The ETM needed end-users to add assumptions about the future, which could be time-consuming and complex. Finally, the Caldomus model did not include green gas and hydrogen in the model calculations.

5.3.2 Modelling studies: Advantages & Limitations

Six out of seven interviews provided information about the limitations of using (specific) modelling studies within heating transition projects and planned model changes to improve these limitations. A total of 31 quotes was collected, divided over 5 codes. An overview of quotes can be found in figure 31 in Appendix G. Results are discussed below, Table 25 shows an overview of the mentioned advantages and limitations of the SA and the OB.

Two interviewees provided advantages of the SA and five interviewees provided comments about limitations. One advantage mentioned by the interviewee of Ecorys was that even small municipalities with fewer resources, often too little for a complete modelling study, had access to the results. This could then help them to conduct a decent analysis, even with little resources. The fact that there was one study done on a national level, that was openly available for everyone, was an advantage according to this interviewee.

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[3] In the Netherlands, permit requests for new buildings (residential and utility), have to meet the BENG requirements from the first of January 2021. BENG stands for “Bijna Energieneutrale Gebouwen” which translates to nearly energy neutral buildings. The BENG indicator is based on energy demand, fossil energy use and the use of renewable sources.

Table 25: Advantages and limitations of using modelling studies in heating transition projects mentioned by model developers.

Modelling study	Advantage	Limitations
SA	● All practitioners have access to the results ● Causes people to 'talk in the same language' ● Validated assumptions (validated for the TVW by PBL) ● Comes with guidelines for result interpretation and local data enrichment	● Critique on assumption energy label B ● Critique on the assumption of 15% green gas ● Uncertain dataset about heat sources ● Municipalities occasionally do not conduct local enrichment
OB	● All practitioners (in the Stedin area) have access to the results ● Assesses robustness of modelling results	● Practitioners tend to look at the maps but forget the rationale behind them

Another advantage, mentioned by the interviewee of PBL was that the SA caused people to talk more "in the same language". According to this interviewee, many models were being used in the heating transition, which were based on different assumptions, which could cause 'confusion of tongues'. The SA was based on assumptions that PBL thought to be suitable for the design of a TVW. Moreover, the interviewee of PLB thought it was an advantage that the SA came with a guideline, offered by ECW, that informed municipalities on how to use the SA, how to enrich the analysis with local data and how to interpret the results.

According to the interviewee of Ecorys, the biggest critique was towards some assumptions used in the SA. In the SA it was assumed that all residential buildings would have energy label B and it assumed that 15% of residential houses could be supplied with green gas, both assumptions were often criticized. Both of these assumptions were based on the Dutch climate agreement (Government of the Netherlands, 2019). Another limitation mentioned by the interviewees was the input data about heat sources. There was a lot of discussion about uncertain and incorrect data sets and about the impact of the availability of heat sources. In the guidelines for the SA ECW, 2019) ECW mentioned that municipalities should alter the input about heat sources for the local situation. However, especially in the beginning, parties often did not conduct local enrichment of the study. End-users (municipalities) strictly looked at the national results and If they did not agree with these, they would not use the SA results all together. This was getting better, but it was a challenge that was felt by PBL and ECW. More and more end-users understood at the time of the interview that the SA is just a starting point and that you need to enrich this study with data and information about the local situation.

At the time of the interviews, a new version of the SA was being developed. Interviewees could not share too many details about how this new version would look like, but they shared a few things that would be changed. First of all, the assumption of minimum energy label B will be changed and hydrogen will be added as a heating option. Moreover, the assumption regarding the green gas limit of 15% will be changed, partly because the hydrogen option will influence this. Key figures and calculator process will be adjusted as well, and special attention goes to the reassessment of the energy use key figures. The new 'SA' will not include end-user costs, because it is a national study that reasons from the national perspective of societal costs..

The interviewee of Ecorys and CE Delft offered some advantages and limitations of the OB. First of all, the interviewee of Ecorys mentioned that the OB was the only modelling study that looked at the robustness of modelling results, which was useful according to him. This, in turn, helped municipalities to determine in which neighbourhoods they should start with their heating transition. Another advantage of the OB was that even small municipalities with fewer resources, too little to personally conduct a model study, had access to the results. This could then help them to conduct a decent analysis, even with little resources. (Only municipalities within the Stedin area have access to the OB). One challenge of the OB mentioned by the interviewee of Ecorys was that practitioners tended to only look at the maps/results and forgot the rationale behind those results. Ecorys made an interactive viewer in an attempt to solve this. Collaboration with the area managers from Stedin helped with this as well, because these area managers had to explain the study/tool and its use to municipalities before municipalities were allowed to use it.

Conclusion
The biggest advantage of national modelling studies mentioned was that they offer every municipality the chance to use a modelling study, even if there are limited resources. Moreover, both national studies offer guidance for result interpretation. The SA via ECW and the OB via the area managers of Stedin. However, it was still challenging to get practitioners to use the studies correctly. E.g. to conduct local enrichment for the SA and to look at the rationale behind the coloured maps of the OB. Lastly, not all practitioners agreed with the assumptions used in the SA. There was especially disagreement about assumptions regarding energy labels and the availability of green gas, which could limit its usability for those practitioners.

5.3.3 Data use & availability
All seven interviews provided information about the use and availability of data when modelling for the heating transition. A total of 44 quotes was collected, an overview of quotes can be found in figure 32 in Appendix G. The results are discussed below.

Requests for non-public (local) data
The interviewee of Quintel stated that all the data used in the ETM had to be public. Most of the data used for the model was aggregated to national averages and end-users could change these numbers based on their local data or assumptions. When conducting a project, for example, to design a TVW for a municipality, CE Delft had a standard list of data that they requested from practitioners to provide local analysis. This list included data on potential coupling opportunities, e.g. planning schedules of infrastructure renovations and renovation and construction plans of housing corporations and heat source data. The data requested by CE Delft was usually non-public, potential issues with privacy were usually solved with either an non-disclosure agreement or by aggregating the data. According to the interviewee of CE Delft, data collection is a time-consuming process. Municipalities were often able to provide all the data requested by CE Delft, but it took a long time to get all the data from different parties within and outside of the organisation. Moreover, data provided by municipalities and other clients did not always come in the correct format, changing the format was another time-consuming activity for CE Delft. The interviewee of DWA stated that within the modelling approach of DWA data was also gathered from the client. The interviewee also mentioned data from network operators on infrastructure projects and data from housing corporations on renovation plans. Usually, this data was accessible, however, occasionally stakeholders were hesitant in sharing the data. DWA then conducted the calculations with key figures, and frequently these stakeholders changed their mind later in the process because they realized that they would be affected by the calculations and plans as well. The interviewee of Over Morgen stated that the WTM only used public data sets. However, during projects data was usually gathered about new construction and demolition plans (big projects), for the prioritizing of neighbourhoods in the TVW.

Heat source data
Heat source data in the CEGOIA model came from the Warmte Atlas, which was quite an uncertain data set according to the interviewee of CE Delft. Therefore the first question at municipalities was always whether they had local data about heat sources. Municipalities knew which heat sources exist in their

region, but they often did not know how much heat was available and at what temperature. The interviewee of Over Morgen stated that he felt that the WTM was currently not missing any data. However, the interviewee stated that he looked forward to the updated results of the SCAN research (SCAN Aardwarmte, 2019), which would provide more up to date data on the potential of geothermal heat sources in the Netherlands. The WTM did not include heat source data and was therefore not limited by heat source data. The model assumed infinite sources. The model was therefore based purely on costs and after the model had run a study had to be conducted to assess the actual heat source potential.

Infrastructure data & Housing corporation plans

One challenge regarding infrastructure and housing corporation planning data was that this was short term data, more long term data would be nice according to the interviewee of CE Delft.

Energy Label Data

When asked about missing or uncertain data in the Vesta MAIS model, the interviewee of Ecorys stated that the BAG data that was used was not complete, especially regarding data on energy labels. For the heating transition, data on thermal insulation levels is relevant. Energy labels from the BAG data set were used to estimate this, however other factors than thermal insulation affected this label, such as the presence of PV panels. According to the interviewee of Ecorys, this “caused the most noise” in Vesta MAIS modelling studies. The interviewee of Innoforte stated that they used ‘more’ than just the BAG data to identify building characteristics.

Conclusion

Data forms the foundation of energy models, together with calculation rules and assumptions. According to the garbage-in = garbage-out principle from Nikolic et al. (2019a), as proposed in the literature review, incorrect input data or assumptions cause incorrect modelling result. This chapter showed that model developers tried to make the datasets as accurate as possible for local situations by requesting data at municipalities. However, this was a time-consuming process and occasionally data was not available due to privacy restrictions. If there was no time or data was not available due to privacy sensitivity, then national key figures or aggregated data was used. Which frequently did not reflect the local situation as good as one would like. The most difficult data sets were heat source, energy use and thermal insulation data. National heat source data was highly uncertain, but municipalities had limited insight into how much heat was available and at what temperature. Energy use and insulation data were both from the BAG data set and were both deemed too aggregated or inaccurate to use for heating transition projects. This was especially the case on lower abstraction levels, such as pilot projects.

5.3.4 Inclusion of social and socio-economic factors

All seven interviews provided information about the potential of integrating social or socio-economic factors into the decision-making process of choosing an alternative heat supply. A total of 43 quotes was collected, an overview of quotes can be found in figure 33 in Appendix G. The results are discussed below.

Present Social or socio-economic data alongside modelling results

None of the models discussed with model developers integrated social or socio-economic factors within the model. The interviewee of Ecorys stated that it would be very complex to integrate social and or socioeconomic factors into models because these kinds of factors are very hard to compare to factors such as technology costs. The interviewee of Ecorys, therefore, thought it was not wise to incorporate such factors in techno-economic models. However, this interviewee stated that social and socio-economic factors could be incorporated in modelling studies such as the OB. The interviewee of Quintel shared this opinion, he also stated that he did not think that it was a good idea to include social and socio-economic. The interviewee from Quintel recommended to ‘keep struggling with those social factors for another while so we can learn more about their influence'. The interviewee of Over Morgen also agreed to this, stating that Over Morgen did discuss socio-economic factors with practitioners when prioritizing neighbourhoods but that to do this socio-economic factors did not have to be included in the model. According to the interviewee of Over Morgen, 'Everyone knows which neighbourhoods are well off and which are not'. Instead of integrating social or socio-economic factors into the techno-economic models, all model developers from this sample presented relevant social or socio-economic data next to the modelling results.

The interviewee of PBL stated that in the Vesta MAIS model Socio-economic data, from Statistics Netherlands (CBS) on an aggregated level, was shown in the model but that it did not influence the choice of a heating alternative. However, there was the option to show this data next to the modelling results. PBL did not focus on socioeconomic or social factors because these factors were not part of the techno-economic analysis, however, these sorts of factors were taken into account in reports that were made by PBL for heating transition projects. CE Delft also did not include social and or socioeconomic factors into their model but rather presented socioeconomic data on so-called opportunity maps. These maps showed factors such as income, housing corporations present and energy cooperatives present. (This was presented next to the modelling results or as an extra layer in the GIS-maps, it is not included in the model to determine heating options). This helps in determining which neighbourhoods would be good to start. CE Delft also tried to show the affordability of the heating transition in different neighbourhoods with the opportunity maps, but quickly ran into issues with sensitive information. DWA used a Multi-criteria analysis when they supported municipalities with their TVW design. Within this Multi-criteria analysis, they tried to incorporate social and socio-economic components such as data of Statistics Netherlands (CBS) on the 'transition readiness' of homeowners or the degree of resident organisation around certain themes. The weight of different factors in the multi-criteria analysis was dependent on the wishes of practitioners. Again, this multicriteria analysis was not part of the model calculation but rather offered a separate process that was conducted next to the modelling calculations.

Inclusion of studies regarding resident typology and motivation

The interviewee of Quintel stated that the Participatory Value Assessment (PWE)(see appendix G) from the TU Delft was an interesting tool to include more social factors while conducting heating transition projects and they were involved in the development of the PWE as well. Moreover, the interviewee stated that qualitative research into resident motivation might provide some insight into the future, showing where the energy transition might be easier and where it might be harder. Over Morgen, when the client required more detailed participation research, conducted data analysis in collaboration with a different organisation to identify the location of certain target groups. However, the interviewee of Over Morgen had doubts about the added value of doing this. The interviewee stated that he thought that costs were the most important factor in the heating transition and that this should be the determining factor when choosing a natural gas alternative.

Conclusion

Interviewees agreed that social and socioeconomic factors were important as the success of heating transition projects was dependent on how financially feasible it is for residents and whether there is an interest to participate from residents. However, contrary to the theoretical proposition, model developers did not recommend to include such factors in current energy models. This had multiple reasons. First of all, it was not clear how such factors should influence the choice of a heating alternative, as these models were focused on finding the lowest-cost options. Second of all, it was easier and currently more useful to present social and socioeconomic alongside modelling results and finally, it was not always clear how social and socio-economic factors influence heating transition projects. Studies into resident typology and resident motivation occasionally provided useful insights for heating transition projects.

5.3.5 Coupling Opportunities

Six out of seven interviews provided information about the potential of integrating coupling opportunities within energy models. A total of 22 quotes was collected, an overview of quotes can be found in figure 34 in Appendix G. The results are discussed below.

The interviewee of Over Morgen stated that they did identify coupling opportunities if municipalities wanted this by requesting data about future investments plans from different stakeholders. However, Over Morgen always tried to nuance the added value of coupling opportunities. The interviewee stated that the costs of the heating transition were so high that coupling opportunities would not make a significant difference. Moreover, this interviewee stated that coupling opportunities such as plans from housing corporations were very uncertain and therefore not very useful for long term plans.

PBL stated that they used a cost bandwidth to incorporate coupling opportunities into their modelling approach. The upper boundary of this bandwidth was if you would individually approach the measure, the lower boundary showed the costs if you would combine the measure with a 'natural moment' (such as sewer renovations or building renovation plans). The interviewee of PBL stated that the actual potential of coupling opportunities should always be assessed at a local level.

The interviewee of CE Delft stated that it would be possible to include coupling opportunities into models if you would know their costs, which was extremely difficult to determine. Therefore, CE Delft did not include coupling opportunities in their model but they did provide 'opportunity maps' alongside their model calculations, as discussed in chapter 5.3.4. This helped in determining in which neighbourhoods it would be convenient to start. CE Delft also stated that there were other agencies which could profile people, which might be useful in the future to see in which neighbourhoods people might be most open for a heating transition

The interviewee of DWA stated that they used a multi-criteria analysis while designing a TVW to assess different coupling opportunities. However, the interviewee of DWA also stated that finding coupling opportunities was not useful if the residents had no motivation to change heat supply in the first place.

The interviewee of Quintel stated that they hoped to uncover some coupling opportunities within the Mondaine project (see appendix J). Within the Mondaine project, ages of different underground infrastructures and when they have to be replaced were being mapped, which could provide insight into possible technical coupling opportunities. The interviewee does not think Quintel will ever 'model' such opportunities.

Conclusion

Two interviewees tried to nuance the importance of coupling opportunities, suggesting that coupling opportunities will have a limited impact on the costs of heating systems and/or motivation of residents. Moreover, interviewees stated that coupling opportunities are uncertain for long term plans and that it was difficult to identify the costs or benefits of coupling opportunities. To solve the latter issue partly, PBL used a bandwidth of costs in the Vesta MAIS model. The other model developers used a different approach where they tried to identify coupling opportunities, if the municipality requested this, by conducting studies next to the modelling process.

5.4 What is needed, besides energy model improvements, to facilitate effective use of energy models for decision making in the heating transition?

5.4.1 Collaboration & Competition

All seven interviews provided information about how they collaborated or competed with other model developers or agencies. A total of 75 quotes was collected, divided over two codes. An overview of quotes can be found in figure 35 in Appendix G. The results are discussed below. Figure 8 shows an overview of the identified consultancy firms, institutes and network operators that use or develop energy models within the Dutch heating transition.

Collaboration for model development or modelling studies

Over Morgen had a partnership with Quintel. Over Morgen utilized the model developed by Quintel, the ETM, in projects focused on developing RES. In return, Over Morgen had supported Quintel in the development of heat-related parts of the ETM. The interviewee from PBL mentioned that there had been a synergetic collaboration with CE Delft while developing both models. PBL also had a unique collaboration with Ecorys, according to the interviewee of Ecorys. Ecorys had helped with the development of the Vesta MAIS model and at times got specific projects from PBL or ECW regarding the Vesta MAIS model or the SA. At the time of the interviews, Ecorys provided workshops to use the Vesta MAIS model and the SA and was conducting a comparative analysis for the current and new version of the SA. CE Delft, Quintel and Ecorys collaborated on the development of the OB, a modelling study. The interviewee of CE Delft stated that this study was a “nice way to embrace all the different methods available and to strengthen each other”.

Agencies utilize each other’s models

Over Morgen had a partnership with Quintel. Over Morgen utilized the model developed by Quintel, the ETM, in projects focused on developing RES. Some parties, such as Over Morgen and Witteveen & Bos became so adept in using the ETM that they provide ETM workshops as well.

Agencies assess each other’s modelling results

Over Morgen occasionally got hired to check model calculations made by other agencies. One time they had to do this for the municipality of Amsterdam, they contacted CE Delft to talk about the assumptions and source data that was used in the original study used by CE Delft. The interviewee of CE Delft mentioned that they had carried out some projects with Innoforte where the CEGOIA model was already used and where Innoforte offered a more detailed analysis after that (up until building level). Moreover, as described in the section on the modelling & consultation approach, model developers frequently conduct comparative analysis within their modelling process.

Agencies collaborate with other agencies in heating transition projects

In some projects, CE Delft collaborated with ABPM. ABPM was focused on the process side of the project, for example organising resident meetings and leading discussions at the municipality. CE Delft offered the material to discuss and ABPM led the discussions. If the municipality required a large participation process, then DWA collaborated with another party that was specialized in this, such as Buurkracht. Quintel occasionally collaborated with MSG, an agency specialized in participation processes and political and decision-making processes.

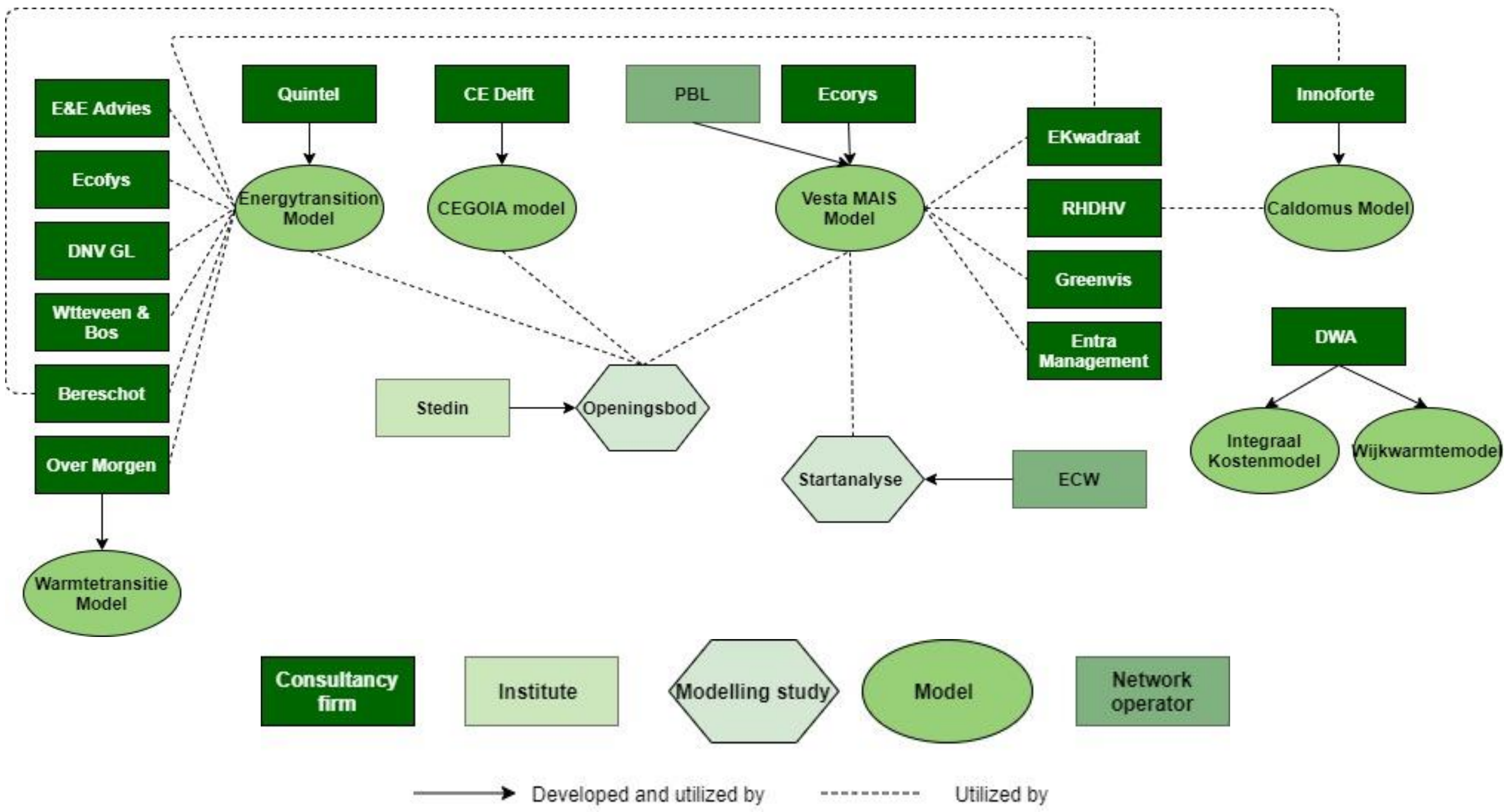

Figure 8: An overview of the consultancy firms, institutes and network operators that use or develop energy models within the Dutch heat transition.

Collaboration with knowledge institutes
Ecorys had a close collaboration with PBL and ECW. Ecorys also had a collaboration with TNO to use components of the Mondaine project (ESDL and GEO-map editor)(see appendix J). Quintel also collaborated with TNO, both for specific system studies on a provincial level and within the Mondaine project (see appendix J). Within the Mondaine project, Quintel provided a system integration/energy accountancy role. Quintel had many collaborations, with national and international parties, to see what can be learned and used from other parties. Quintel also collaborated with the TU Delft on the development of the PWE (participative value assessment)(see appendix I).

Future suggestions
The interviewee from DWA urged agencies to collaborate more. He found it a waste that all these consultancy agencies performed the same trick after each other and that all this money and time was wasted. He wanted more collaboration and everyone to do what they are good at (specialisation).

Conclusion
Model developers/consultancy agencies frequently collaborate to improve current models, to develop new models or to set up comparative modelling studies (OB). As the Vesta MAIS model and the ETM are open-source and open access, other agencies than PBL and Quintel, utilized these models within heating transition projects as well. All the other models were privately owned and were not utilized by other parties than by those who developed them. Agencies occasionally assessed each other's modelling results when conducting comparative analyses, this required collaboration and transparency between agencies. Within heating transition projects, model developers/consultancy agencies frequently collaborated with parties that are specialized in participation and communication processes, such as ABPM, Buurkracht and MSG. Quintel and Ecorys both have close collaborations with knowledge institutes to improve the use of the ETM and the Vesta MAIS in heating transition projects. Both are for example active within the Mondaine project, which is developing, among others, ESDL and a GEO-map editor (see appendix J).

5.4.2 Transparency

All seven interviews provided information about the transparency of their modelling approach A total of 44 quotes was collected. An overview of quotes can be found in figure 36 in Appendix G. The results are discussed below.

PBL & Ecorys: Vesta MAIS
The interviewees of PBL and Ecorys stated that the Vesta MAIS is an open-source and open-access model, with good documentation on assumptions made and input data used. PBL ensures that every update of the Vesta MAIS model was accompanied with documentation on what the model can do and what not. Moreover, the model and all affiliated studies conducted by PBL came with documentation about the inherent uncertainties, or at least, those uncertainties that should be taken into account when using the Vesta MAIS model or affiliated modelling studies for decision or policymaking. However, the interviewee of Ecorys did state that most studies with the Vesta MAIS models were conducted by consultancy agencies, how much these parties share on the assumptions and input data they used is highly dependent on the wishes of their client.

Over Morgen: WTM
The interviewee of Over Morgen stated that Over Morgen shares "almost everything" of their model. The Over Morgen modelling reports included all key figures used and tables with key cost figures and financial parameters in the appendix. These were not publicly shared, but people involved in the heating transition projects had access to them.

Ecorys: Statanalyse

The interviewee stated that documentation about input data, assumptions and how to use the model was good and quite complete for the Vesta MAIS model, but that it was even better for the SA. ECW, a knowledge institute, has provided much background information, including a manual on how to interpret the results of the SA and how to enrich these results for local analysis. Within this manual, ECW also provided a matrix that indicated which data was required to enrich, which was optional, and when one could use national validated data. A translated version of this matrix is shown in Table 26. Moreover, the interviewee mentioned that ECW visited municipalities on the use and limitations of the SA. One motivation for doing this was that both ECW and PBL noticed that many users of the SA would not conduct local analysis, but that they would just use or not use the results of the SA as is.

Table 26: A matrix developed by ECW to guide local analysis for the Startanalyse at municipalities.

	Mediocre connection of the generic data with the local situation	Reasonable connection of the generic data with the local situation
Large impact of analysis	Enrich local data: ● Heat sources ● Investment costs infrastructure ● Type of connections & heat demand of the utility sector	Optional to enrich local data: ● Heat demand residential houses ● Investment costs for residential houses ● Conversion techniques
Small Impact of analysis	Optional to enrich local data: ● Vacant houses and demolition and new construction plans ● Types of connections at residential houses	Use national validated data: ● Key figures conversion techniques ● Key figures heat sources

CE Delft: CEGOIA

The interviewee of CE Delft stated that clients had access to input data, assumptions and key figures used. The actual Excel model did not get shared with practitioners, however, practitioners did get access to an interactive tool where they could change certain parameters to test the effects. Within the online tool, based on the CEGOIA model, users could find data about the supply side and data on factors such as the number of houses or (assumed) energy use. Not all input data could be found in the interactive tool, but the most essential input data was accessible here. CE Delft had documentation available where clients could find all the parameters that were used in the model. CEGOIA modelling study were only made publicly available if the client of CE Delft requested this, such reports also included tables with the parameters that were used in the study.

DWA: Integraal kostenmodel & Wijkwarmtemodel

The interviewee of DWA stated that clients received input data, assumptions and key figures, but the Excel model that made the calculations, was never shared. The interviewee of DWA stated that they shared all assumptions they used with practitioners and that these were open for discussion. The reports delivered by DWA usually contained an appendix of about four pages with input data and assumptions used regarding the types of houses, thermal insulation options and costs. The interviewee of DWA did mention that when a client asked to assess analysis carried out by other agencies, it was often not possible to gain access to the assumptions and input data of other agencies.

Conclusion

Two models of this sample are open source and open access (Vesta MAIS and the ETM). All model developers stated that they shared and discussed input data and assumptions with the end-users (practitioners) and that they answered questions about the model. However, getting access to underlying assumptions, data or sensitivities from other models, for example, to conduct a comparative analysis, occasionally proved difficult for model developers. This indicates that the commercial agencies cannot or will not always be fully transparent regarding their models towards other agencies. The SA, according to interviewees of Ecorys and PBL, was highly transparent due to the efforts of ECW.

5.4.3 Feedback channels

Six out of seven interviews provided information about how they receive feedback from end-users. A total of 30 quotes was collected. An overview of quotes can be found in figure 37 in Appendix G. The results are discussed below.

CE Delft: CEGOIA

CE Delft received most feedback during the modelling process with clients, the interviewee stated that they also explicitly asked for feedback during the process. Moreover, CE Delft offered two years of support for the interactive web tool and they received questions through this channel. Some questions were practical (how does it work again?), but most questions were about the assumptions used. Occasionally questions were asked about the sensitivity of parameters, this usually happened during the process. The interviewee of CE Delft stated that these questions were difficult to answer but that the interactive web tool helped with this because it allowed clients to get a 'feeling' for the sensitivity of certain parameters. One often asked question by clients was what the difference is between the CEGOIA calculations and the SA. CE Delft then provided a list with some differences between the model calculations (such as presented in Table 27) and used this to answer the question. Usually, the differences in results originated from differences in assumptions. Clients occasionally requested to compare the CEGOIA results to other modelling studies as well, CE Delft did this as well and the interviewee stated that again differences usually originated from different assumptions.

Table 27: An overview of differences between the CEGOIA model and the Startanalyse (SA) as provided by the interviewee of CE Delft.

Theme	CEGOIA	SA
Presentation yearly costs	Total yearly costs including gas infrastructure, investments and maintenance	Yearly costs in comparison to the gas reference scenario of 2018, e.g. excluding gas infrastructure
Thermal insulation levels	Optimized thermal insulation levels or a set minimum thermal insulation level	Minimum thermal insulation label B
Allocation heat sources	Optimization based on the extra costs of the alternative per house	Allocation based on the profitability of the heat network and the potential to connect neighbourhoods to lower transport costs
Length heat network	Length is based on the length of the natural gas network (if not available, then a mathematical formula is used)	Length is based on the length of a nearby road network (MT-network) or the surface area of the demand area (LT-network)
Pellet stoves	Included	Not included
Hydrogen	Included	Not included
Heat demand	Calculated based on actual energy use	Calculated based on key-figures
Neighbourhoods with a low resident density	Not included	Included

DWA: Integraal kostenmodel & Wijkwarmtemodel

The interviewee of DWA also mentioned that they were asked to explain differences in results or assumptions with other modelling studies such as the SA. The interviewee from DWA stated that they had never encountered differences that they could not explain and that differences were often based on different assumptions. One example of such a request; one municipality first received calculations from Over Morgen and then from CE Delft. These two provided different results and then DWA was asked to conclude what to do with these different results.

Quintel: ETM

Quintel received questions about the ETM and they answered them all. They also received requests for model changes/improvements. They conducted these model improvements, however, because the ETM is an open-source and open-access model a financing party was needed to fund large improvement projects. Therefore, Quintel waited for more parties to have the same request, this request could then be bundled and a financing party could be found. This meant that even though Quintel had a list of improvements they would like to address for the ETM, they chose from this list based on feedback from the market. Smaller improvement suggestions, such as incorrect data point, were always checked and then adjusted as soon as possible. Network operators were parties that often have specific improvement requests for the ETM that they were willing to pay for. Every change that was made in the model is available for everyone, not just for the paying partner.

Over Morgen: WTM

Over Morgen only rarely receives questions about assumptions or data used in the WTM.

Innoforte: Caldomus

Innoforte discusses criteria and assumptions used for the analysis with the Caldomus model with end-users before they start modelling in the Caldomus model and during the modelling process. The interviewee of Innoforte stated that this is important because there is a constant stream of new questions and insights that develop during the process and because it is simply impossible to discuss everything in advance. Besides, Innoforte also answers questions after the modelling process. One example of this mentioned by the interviewee was the Council of Nijmegen, modelling results were presented to the council, who then provided questions for Innoforte to answer. Questions that heard at Innoforte are focused on how the model works, on the needed thermal insulation label of houses, on the location of housing corporation property, on the alternatives of heat networks. Next to answering these questions, Innoforte also offers a publicly available manual (Mans et al., 2017) of the Caldomus model.

Ecorys & PBL: Vesta MAIS, OB & the SA

Ecorys receives questions about the OB via Stedin. Stedin hired area managers who facilitate the contact between Stedin, Ecorys and municipalities. Answering these questions is important according to the interviewee because the whole modelling study can be deemed useless by end-users if they do not receive a logical answer on the question 'where do these results come from?'. In general, Ecorys is not responsible for questions about the SA, these go to PBL. However, PBL at times directs specific questions toward Ecorys. Moreover, indirectly Ecorys receives questions about the SA if they use the Vesta MAIS model in projects. The interviewee stated that many end-users do not understand the difference between the Vesta MAIS model and the SA.

For the Vesta MAIS model, PBL has an email address where they receive questions about the model. Depending on the time available at PBL these questions are answered and people are invited to PBL so they can offer support. However, most questions about the Vesta MAIS model and the SA go to ECW and they provide training to use the model and the SA. Also, PBL offers an online wiki page and publicly available reports where people can find out how the model works.

Conclusion
Six out of seven model developers state that they receive questions about the model or the modelling process. Such questions are often about differences between modelling results from different modelling studies or about assumptions used in the model. Model developers receive these questions before, during and after the modelling process in person or via email. Most model developers also engage in discussions with the client about assumptions and criteria that will be used during the modelling process. Multiple model developers state that they are usually able to explain different results from different modelling studies and that they are usually caused by different underlying assumptions. Next to verbal feedback, some models also have written publicly available guidelines such as the manual of the Caldomus model (Mans et al., 2017), the guidelines for the SA (ECW, 2019) and the online wiki for the Vesta MAIS model (van den Wijngaart, 2020).

5.4.4 Municipality size & modelling knowledge
Four out of seven interviews provided information about the influence of municipality size on the use of energy models for heating transition projects. A total of 12 quotes was collected, an overview of quotes can be found in figure 38 in Appendix G. The results are discussed below.

All four interviewees agreed that larger municipalities usually have more knowledge about and experience in modelling. Quintel stated that in general, larger municipalities have more human resources and that they are more focused on developing internal knowledge and expertise regarding models. The interviewee from Caldomus stated that bigger municipalities often have more knowledge about modelling in the heating transition and that they also simply have more people focusing on the transition.

Over Morgen stated that the modelling approach they use for small and big municipalities is, in essence, the same, but that small municipalities need to be more unburdened. Moreover, since small municipalities often have less expertise with modelling studies, they are less critical about modelling results. Finally, the general process at small municipalities is a bit less complex because there are fewer stakeholders and due to the fact that communication is more direct. However, the technical analysis at small municipalities is often more complex because smaller municipalities often have fewer heat sources. Ecorys stated that one of the advantages of the SA is that even smaller municipalities, with smaller budgets, have the opportunity to conduct modelling studies.

Conclusion
Larger municipalities usually have more knowledge about and experience in modelling. This allows them to occasionally model themselves, or to more critically reflect on modelling studies conducted by third parties.

5.4 Summary Interviews model developers

Which energy models are used while planning for the heating transition and how?
The energy models found in this study were used mostly by consultancy agencies to support municipalities or other public organisations in designing heating transition plans. These plans included Regional Energy Strategies (RES), TVWs, and Neighbourhood Implementation plans (WUP). Moreover, these models were used for visions of Gas companies and Network operators and as a start for more detailed business cases of heating alternatives by municipalities, housing corporations and heat companies.

How can the energy models be improved to better support decision making for the heating transition?

The energy models were complex in their use and the results were difficult to interpret for non-experts. Practitioners did not have the right background or the time to master these complex tools, which meant that they were often dependent on third parties such as consultancy agencies to conduct the modelling process and/or to help them with the interpretation of results. Larger municipalities had more time and resources to learn how to use a model than smaller municipalities. This meant that if a third party conducted the modelling process, larger municipalities were better able to critically reflect on the results. Interactive models seemed to help end-users with a better understanding of the model. Models or tools where end-users could alter certain parameters helped end-users to see the connection between different variables, helped them to understand that the model calculations do not provide one precise answer and helped with getting a feeling for parameter sensitivity.

There was disagreement among model developers on the impact of heat source data. All model developers agreed that the datasets used for heat source data were uncertain and that extra research was always needed to assess the local situation. However, whereas some models used the availability of heat sources as a determining factor for the choice of a natural gas alternative, other models did not use heat source availability as a determining factor. The latter group required a heat source study after the modelling process to assess the potential of the heat networks suggested by the modelling process. At the time of the interviews, PBL, in collaboration with ECW, was trying to improve the heat source data set that was available in the Vesta MAIS model by collecting data from municipalities about possible heat sources. Moreover, different models used different assumptions regarding renewable gas which led to discussions because there was a lot of uncertainty regarding the future availability of renewable gas.

Model developers ran into issues with the energy use data available from Statistics Netherlands (CBS). This data was aggregated and deemed too inaccurate to use for heating transition projects. CE Delft had tried to solve this issue in the CEGOIA model by swapping the Statistics Netherlands (CBS) key figures for key figures that were found in research from Merosch. Similarly, modellers stated that the dataset from the BAG regarding energy labels provided too little insight into the levels of thermal insulation present.

Another challenging aspect of modelling heating transition plans was to make sure all heating transition plans ‘fit’ together and to take abstract plans to concrete projects. Some agencies were active on multiple levels of abstraction (RES, TVW, WUP, business cases) and emphasized to municipalities that plans on one level will have an impact on another level. However, this was challenging formunicipalities because there was no standard sequence, all plans were made simultaneously. Quintel was trying to address this challenge by positioning the ETM in such a manner that they could assess whether plans at different scope levels (climate agreement, RES, TVW, WUP) would fit together. To achieve this they collaborated with the Mondaine Project, which will potentially enable the possibility to feed scenario’s made with other models back into the ETM and to make an interactive process where one can go from abstract to detailed plans and vice versa. Innoforte was trying to address the present gap between abstract plans and concrete projects.

What is needed, besides energy model improvements, to facilitate effective use of energy models for decision making in the heating transition?

The case studies provided models which could provide detail on building level models which could provide broader insights into the whole energy system. The most important thing, according to model developers, is to choose the right model for a research question. Incorrect research questions were caused by a lack of knowledge and experience with modelling at municipalities. Over Morgen suggested that municipalities should approach multiple agencies to propose their research question, to see whether this is an appropriate research question for a modelling study.

All model developers spoken to directly or indirectly helped their clients (e.g. municipalities) with the interpretation of modelling results. Model developers all emphasized that supporting end-users, such as municipalities, during the modelling process and with result interpretation was an important and time-consuming activity during heating transition projects. Municipalities and practitioners had a central role in heating transition project but they often did not have in-depth knowledge on the topic and they were generally not able to interpret modelling results correctly on their own. In general, larger municipalities had more knowledge about and experience in modelling than smaller municipalities, which could simply be due to the available (human) resources. Larger municipalities were also often more focused on developing internal knowledge and expertise regarding models.

Often, different models/modelling studies provided different results, this created confusion and uncertainty at municipalities. Over Morgen conducted comparative analysis to decrease this uncertainty and other agencies did this when the client requested this. In this sample, there was only one openly available modelling study that looked at the robustness of different modelling results, the OB. However, this study was only available for municipalities within the Stedin Area

Model developers of this sample engaged in many collaborations during heating transition projects. They collaborated with other model developers to develop modelling studies such as the OB, they utilized each other's models, they collaborated with agencies with different expertise and they collaborated with knowledge institutes such as TNO. However, the interviewee of DWA still urged that consultancy agencies should collaborate more. Often multiple agencies performed very similar projects in a row for one municipality. This interviewee urged for more specialization and 'fewer agencies who perform the same trick'.

Two models of this sample were open source and open access (Vesta MAIS and the ETM). Getting access to underlying assumptions, data or sensitivities from other models, for example, to conduct a comparative analysis, occasionally proved difficult for model developers. This indicates that commercial agencies cannot or would not always be fully transparent regarding their models. All model developers stated that they shared and discussed input data with the end-users and answered questions about their respective models. These questions were about used assumptions or differences with the results of other modelling studies. Model developers also at times experienced difficulties with the transparency of stakeholders such as housing corporations or heating companies. These stakeholders were frequently reluctant to share needed data or would not be transparent about needed profit margins

One challenge felt by PBL and ECW, which was mentioned by Ecorys, was that local analysis is not always carried out for the SA. The SA is just a starting point and municipalities are supposed to enrich this study with local data. ECW provided guidance for this in the form of guidelines and workshops. However, especially in the beginning, parties did not conduct local enrichment of the study. End-users (municipalities) strictly looked at the national results and If they did not agree with those, they would not use the SA all together. This was getting better at the time of the interviews. Most model developers requested data from their client to provide a more local analysis. The data collection process at municipalities was time-consuming. Municipalities were able to provide all the data requested, but it took a long time to get all the data from different parties within and outside of the organisation. This was strengthened by the fact that some stakeholders were hesitant in sharing data and by the fact that data did not always come in the right format.

According to model developers, techno-economic analysis is only a small piece of the puzzle and there were all sorts of political, social and psychological aspects which influenced the success of heating transition projects. The technical analysis was usually the simplest step of heating transition projects. None of the models discussed with model developers integrated social or socio-economic factors within the model. Model developers thought it was complex and unnecessary to integrate social and socio-economic factors in energy models. However, they stated that such factors could and should be incorporated in modelling studies and modelling reports. This was usually carried out by model developers by collecting social or socio-economic data and by presenting this data next to the modelling results to provide context for the discussion or by conducting social studies (e.g. PWE). PBL was the only developer from this sample who included coupling opportunities in their model, the Vesta MAIS model, by using a cost bandwidth. CE Delft tried to identify coupling opportunities with opportunity maps. Interviewees of Over Morgen and DWA saw less value in the identification of coupling opportunities and tried to nuance their value to municipalities. According to the interviewee of Over Morgen, the costs of the heating transition are so high that coupling opportunities would not make a significant difference.

6 Results in light of the theoretical propositions

This chapter discusses the empirical findings in light of the theoretical propositions and literature. Table 28 shows an overview of the theoretical propositions and a short explanation on why they were confirmed or rejected. The sections underneath provides a more detailed description.

Table 28: An overview of the findings that confirm or reject the theoretical propositions made.

Theoretical proposition	Confirmed/rejected	Explanation
Different municipalities use different energy models (if any) with different aims.	confirmed	Six different models were found to be used in heating transition projects. The target users, geographical scopes and formats of the six models differed slightly. All models from this sample, except for the ETM, were optimization models.
If energy models are complex to use, then practitioners will make limited use of them while planning for the heating transition.	confirmed	The use of energy models was not necessarily limited, but there were issues regarding the complexity of energy models that hindered effective usage in heating transition projects.
If energy models are not user friendly, then practitioners will make limited use of them while planning for the heating transition.	confirmed	The use of energy models was not necessarily limited, but there were issues regarding the user-friendliness of energy models that hinder effective usage in heating transition projects.
If energy models do no integrate social or socio-economic factors, then practitioners will make limited use of them while planning for the heating transition.	rejected	Social and socio-economic factors played a large role in heating transition projects to prioritize neighbourhoods and to identify coupling opportunities but that they did not influence the choice of heating alternatives, which was the focus of the energy models of this sample. Model developer argued that it might be better to consider these factors alongside the techno-economic modelling results.
If assumptions within energy models are uncertain, than this will decrease the trust within energy models for practitioners.	unclear	Practitioners offered critique on assumptions of models or modelling studies, mostly about assumptions regarding energy labels and the use of renewable gas. However, the effect this had on the trust in models did not become clear.
If data is uncertain or unavailable, then this will decrease the trust within energy models for heating transition decision making of practitioners.	unclear	Data played an important role for municipalities and model developers in developing heating transition plans and even though data was occasionally unavailable, this study offered no proof that this decreased the trust of practitioners in energy models. Currently unavailable data included energy use per connection, data on thermal insulation levels, data about the willingness to pay of residents and data about the potential impacts on the electrical network. Heat source data sets had a high degree of uncertainty.
Practitioners seek the help of external parties to use and interpret energy models.	confirmed	Seven municipalities from this sample used third parties at some point during their heating transition projects to conduct modelling studies. CE Delft, Over Morgen, DWA, Innoforte and EnTra Management were consultancy agencies that were hired by municipalities to support, interpret or conduct modelling studies.

External parties have commercial reasons to not be transparent about their energy model design.	unclear	Model developers stated that it could be difficult to gain access to underlying assumptions, data and parameters of models from other commercial agencies. Transparency, especially at commercial model developers, could be improved, but it did not seem to be a limiting factor for practitioners to use energy models.
Practitioners need new (in-house) expertise to effectively use energy models	confirmed	Only one municipality in this sample was able to model independently. Even when outsourcing, a minimum knowledge level was required to be able to design a suitable research question and to correctly interpret and critically reflect on modelling results. Model developers stated that the knowledge level at (smaller) municipalities was insufficient for this.

The literature review showed that different models have different target users (ranging from modelling experts to practitioners), different geographical scopes, different formats and different calculation methods. Based on this, the following theoretical proposition was proposed: 'Different municipalities use different energy models (if any) with different aims'. The results of the interviews validated this statement. Six different energy models were used by municipalities in the sample of this study to support heating transition projects: the Vesta MAIS model, the CEGOIA model, the Caldomus model, DWA models (IKM & WWM), the ETM and the WTM. This is in line with the report of Brouwer (2019) which mentioned these six models as the most used models for the Dutch heating transition. Moreover, two national modelling studies based on one or more of these energy models were used, the SA and the OB. The target users, geographical scopes and formats of the six models differed slightly. Target users of the Vesta MAIS model, and especially from the SA, and the ETM included practitioners, which is partly since these models are open source. However, in the case studies, these models were seldom used by practitioners, the only exception in this sample was the municipality of Utrecht, who has a modelling team was able to use the Vesta MAIS model to develop heat scenarios. The other models in this sample were not open source and the target users were consultants and modellers of the developing firm. All models from this sample, except for the ETM, were simulation and optimization models. The ETM did not offer an automated optimization function. All models, except for the ETM, aimed to find the heating alternative with the lowest societal costs. The ETM had a more broad aim where users could test the effect of changes across the entire energy sector. Municipalities used models and modelling studies to support the decision-making process, to provide legitimacy towards residents or as a basis for more detailed heating transition business cases. No STET modelling methodologies or ABM methodologies were found in this sample, indicating that these do not play a large role in the planning and execution of the Dutch heating transition at municipalities yet.

One of the most pressing issues that came forward in the literature review was that current energy models were not usable for non-experts such as practitioners (Erker et al., 2019; Sakellaris et al., 2018). Based on this the following propositions were proposed: 'If energy models are complex to use, then practitioners will make limited use of them while planning for the heating transition' and 'If energy models are not user friendly, then practitioners will make limited use of them while planning for the heating transition'. Although this results proved that the use of energy models was not necessarily limited, the interviews indicated were issues regarding the complexity and user-friendliness of energy models that hinder effective usage in heating transition projects. For this reason, both of these propositions could be confirmed. Practitioners stated that modelling results were too abstract and too general or too simplified for local analysis and that energy models were not user-friendly and complex. Model developers agreed that energy models are complex and stated that practitioners often did not have the right background or the time to master these complex tools, which meant that they were often dependent on third parties such as consultancy agencies to conduct the modelling process and/or to help them with the interpretation of results. Larger municipalities usually had more time and resources to learn how to use a model than smaller municipalities. This also meant that if a third party conducted the modelling process, larger municipalities were better able to critically reflect on the results. All seven municipalities from this sample that used energy models in their heating transition projects used third parties at some point during their heating transition projects to conduct modelling studies. CE Delft, Over Morgen, DWA, Innoforte and EnTra Management were consultancy agencies that were hired by municipalities to support, interpret or conduct modelling studies. This confirmed the following theoretical proposition, 'Practitioners seek the help of external parties to use and interpret energy models'.

Furthermore, the literature review suggested that the complexity of heating transition projects is partly due to the dependency on social factors such as human behaviour and that models which consider not only-objective but also social and socio-economic factors could increase the value of modelling approaches in heating transition projects (Androutsopoulou & Charalabidis, 2018; Busch et al., 2017; Li & Strachan, 2019; Li et al., 2015; Nakata et al., 2005; Qadrdan et al., 2019; Nässén & Holmberg, 2013; Åberg & Henning, 2011; Zvingilaite & Klinge Jacobsen, 2015). Hence, the theoretical proposition 'If energy models do no integrate social or socio-economic factors, then practitioners will make limited use of them while planning for the heating transition' was proposed. The interviews provided evidence to reject this proposition. Practitioners agreed that social and socio-economic factors were important in heating transition projects, especially to prioritize neighbourhoods in TVW projects and to identify coupling opportunities. However, they did not influence the choice of heating alternatives, which is the focus of the energy models of this sample. In addition, practitioners mentioned that it was very difficult to determine the impact of social and socioeconomic factors. Do you, for example, start in neighbourhoods with higher incomes or in neighbourhoods with lower incomes. Both have pros and cons. Model developers agreed on the fact that techno-economic analysis is only a small piece of the puzzle and that there all sorts of social, political and psychological aspects that influence heating transition projects. However, model developers stated that these factors should not and/or could not be included in their respective models and that it would be better to consider these factors alongside the techno-economic modelling results.

The literature review also suggested that the correctness and sensitivity of assumptions has an impact on the trust and willingness of practitioners to use energy models (Brouwer et al. 2019) in their heating transition projects. Hence, the theoretical proposition 'If assumptions within energy models are uncertain, than this will decrease the trust within energy models for practitioners' was proposed. This proposition could not be confirmed or rejected based on the empirical results. Practitioners offered critique on assumptions of models or modelling studies, in particular about assumptions regarding energy labels and the use of renewable gas. However, the effect this had on the trust in models did not become clear in the interviews. The interviews showed that if practitioners did not agree with assumptions used in models or modelling studies that they requested model developers to change said assumptions or that they opted for a different model that used different assumptions. It was not possible for practitioners to change (some) assumptions in national modelling studies such as the SA. All model developers stated that they tried to be transparent about the assumptions they used and that, in collaboration with the end-users (practitioners), assumptions could be altered during the modelling process.

Next to assumptions, the literature review suggested that there is more data needed in the themes of buildings, infrastructure and energy production to utilize current energy models for the heating transition (Diran, van Veenstra et al., 2020). Hence, the following theoretical proposition was proposed If data is uncertain or unavailable, then this will decrease the trust within energy models for heating transition decision making of practitioners'. Based on the interviews this proposition could not be confirmed or rejected. Data played an important role for municipalities and model developers in developing heating transition plans and even though data was occasionally unavailable, this study offered no proof that this decreased the trust of practitioners in energy models. If municipalities chose to use a model, this model proved to be more useful if it was fed with local data. Model developers mentioned that the data collection process at public organisations was time-consuming. Unavailable data that could be useful according to practitioners and model developers is data about energy use per connection, data about the willingness to pay of residents and data about the potential impacts on the electrical network. Model developers ran into issues with the energy use data available from Statistics Netherlands (CBS). This data was aggregated and was often deemed too inaccurate to use for heating transition projects. Similarly, modellers stated that the data from the BAG regarding energy labels provided too little insight into the level of thermal insulation present at residential houses. One of the most uncertain data sets used for heating transition projects was data about available heat sources. All model developers agreed that the datasets for heat source data were uncertain and that extra research was always needed to assess the local situation. However, whereas some models used the availability of heat sources as a determining factor for the choice of a natural gas alternative, other models did not use heat source availability as a determining factor.

The literature review also mentioned that municipalities need to develop more internal knowledge to understand and make use of models (Janssen & Helbig, 2018; Koussouris et al., 2015; Poel et al., 2015; Nikolic et al., 2019a; De Ridder et al., 2019), Based on this claim the following theoretical proposition was proposed 'Practitioners need new (in-house) expertise to effectively use energy models'. Based on the empirical results, this proposition could be confirmed. Only one municipality in this sample was able to model scenarios individually, others relied on the modelling expertise of third parties. Even if a municipality outsourced the modelling process, a minimum knowledge level was required to correctly interpret and critically reflect on results. Moreover, more modelling expertise at municipalities and other governmental agencies would help these organizations to provide third parties with the correct modelling research question, something that was problematic according to model developers. Next to developing more expertise at governmental agencies the literature review also suggested that interactive visualization can help in making models and their results more understandable for non-experts. This led to the following theoretical proposition 'interactive visualization and different interfaces for different stakeholders could improve the usability of energy models'. This proposition can be confirmed based on the interviews. Multiple model developers had developed interactive models, maps or tools that, according to them, helped clients such as practitioners to better understand and interpret the modelling results.

Furthermore, according to the data-driven approach and good modelling practices discussed in the literature review, models and modelling studies require a high degree of transparency (Argyrous, 2012; Nikolic et al. 2019a). The following theoretical proposition was proposed about the transparency of the modelling approach External parties have commercial reasons to not be transparent about their energy model design'. This proposition could not be confirmed or rejected based on the interviews. Model developers stated that it was not always possible to gain access to underlying assumptions, data and parameters of models from other commercial agencies. However, all six models found in this case study were compared to each other in the benchmark study of Brouwer et al. (2019), indicating that agencies were at least willing to be transparent towards independent researchers. Moreover, the OB also compared the results and underlying assumptions, datasets and parameter sensitivities of multiple models (of which two were commercial). Besides, transparency was only mentioned as a limiting factor by one practitioners. Hence, one could state that even though transparency, especially at commercial model developers, could be improved, it did not seem to be a limiting factor for municipalities to use energy models.

7 Recommendations based on the present study

Based on this study, which entailed a literature review and embedded case studies of heating transition projects at ten Dutch municipalities, seven recommendations for more effective use of energy models were designed. These recommendations are shown in Table 30. Validation of these interviews was realised with two interviews with independent experts, an overview of the interviewees is shown in Table 29. This chapter discusses how the recommendations were formed based on this study, how they will help the current situation and the outcomes of the validation interviews.

Table 29: A descriptive overview of the independent experts that offered feedback on the proposed recommendations

Interviewee	Current function/activities	(Relevant) Previous experience
Interviewee A	Director program system integration at Topsector Energy Member innovation council ENERGIIQ Member supervisory board Green village from the Delft University of Technology	Managing Director Energy at TNO (Dutch Knowledge Institute) Advisory council member zero-emission platform European Commission Board member Netherlands Energy Research Alliance Advisory board member TenneT TSO GmbH
Interviewee B	Project manager data-driven plan-making at the Knowledge and Learning Programme (KLP) of the PAW Senior policymaker at the Association of Netherlands Municipalities (VNG)	Consultant CE Delft Innovation analyst TKI Urban Energy Consultant MWH Consultant NEN

Table 30: Seven recommendations for more effective use of energy models in the Dutch heating transition.

Practitioners	Model developers	Practitioners & model developers
1.Develop and preserve knowledge, competences and skills for energy modelling	2.Provide more user-friendly models and/or model interfaces	5.Demand and/or offer a transparent model and modelling processes
3.Improve heat source, energy use and thermal insulation level data sets	7.Collaborate and specialize where possible	6.Improve robustness of modelling results by offering and/or demanding comparative analysis
4. Develop more efficient data collection processes		

7.1 Develop and preserve knowledge, competences and skills for energy modelling

The Dutch national climate agreement stated that the new responsibilities that municipalities have received regarding the Dutch heating transition require new knowledge expertise and competences.

This also came forward within the literature review, where multiple studies expressed their concern about the current knowledge and competences regarding energy modelling and data management at municipalities (Janssen & Helbig, 2018; Poel et al, 2015; Koussouris et al., 2015). Model developers interviewed in this study agreed to this and stated that supporting municipalities during the modelling process, for example with result interpretation, is a very time-consuming task. Based on this study it is therefore expected that developing knowledge about available energy models and modelling processes will enable practitioners from municipalities to either model scenarios themselves or to correctly and critically interpret and reflect on modelling studies conducted by third parties. The latter because it enables practitioners to ask more targeted questions, which improves both the speed and the transparency of the modelling process. Moreover, more knowledge about models and the modelling process will likely make it easier for municipalities to explain the results and their impacts to other stakeholders, such as network operators and residents, which could increase the legitimacy of the (policy)choices that follow from the modelling results.

To develop more knowledge at municipalities, this study agrees with the recommendation of Nikolic et al. (2019a) who suggest that providing training material, for example as an online course, to critically evaluate the problem definition, the modelling process, the use of models and how to prevent some common pitfalls would be useful for both model developers and practitioners. Since most practitioners do not have time to read lengthy and theoretical guideline descriptions, such training materials are recommended to be practical and interactive (Nikolic et al., 2019a). ECW already tries to offer such training materials for the SA and might be able to provide more training about other models, modelling processes and common pitfalls. In addition to knowledge about energy models and modelling processes, municipalities should ensure they have sufficient knowledge about available heating technologies and societal transitions. The first provides input for the heating alternative analysis carried out with energy models and the latter provides insight about the impact of modelling results and the social factors that should be considered next to the techno-economic factors from the energy model.

Next to developing knowledge, municipalities should also ensure to secure knowledge regarding modelling in the heating transition. Practitioners or project leaders are only working in a specific role for a set amount of years, it is important to ensure the gathered knowledge about energy models and modelling processes does not dissipate when these employees transfer to different roles, projects or companies. Securing knowledge can, for example, be realised by having multiple employees schooled in this area and by making sure this knowledge is transferred from these employees to new employees. Moreover, municipalities should regularly update their knowledge by having employees visit training opportunities or by researching available models and modelling processes. The latter could, for example, be realised, as Nikolic et al. (2019a) suggest, by providing more interaction between academia and practitioners. Practitioners could provide realistic problems and case materials and academia could provide more sophisticated modelling methods and practices.

Interviewee A recognized the recommendation and agreed to its message, stating that there is 'a great need for more knowledge'. The interviewee stated that especially smaller municipalities do not have the needed experience and knowledge, which is something model developers from the present study and interviewee B also mentioned. According to interviewee A, this causes third parties to gain large power and responsibility, which can be problematic as not all third parties are knowledgeable and capable either. Interviewee A agreed to the fact that training facilities would decrease this issue and that currently, concrete options for such are still missing. Interviewee A mentioned that Topsector Energie had tried to decrease this gap by giving CE Delft the assignment to launch a website to share knowledge about energy modelling. For future training options, interviewee A agreed that ECW would be a logical and suitable option. Interviewee B also stated that more knowledge and skill development in the theme of energy modelling would be beneficial. Moreover, B agreed that small municipalities are usually more reliant on third parties. Interviewee B adds it would be more feasible and desirable for small municipalities to develop knowledge and skills on a regional level in collaboration with other municipalities.

7.2 Provide more user-friendly models and/or model interfaces

The literature review showed that energy models are too complex in their use and the results are difficult to interpret for non-experts (Erker et al., 2019; Sakellaris et al., 2018). This was also mentioned by both practitioners and model developers in this study. Next to developing more knowledge at municipalities to improve the understanding of these models, it is recommended to model developers to make energy models more user friendly and accessible for non-experts by offering interactive models or model interfaces. According to interviewees of this study, interactivity helps end-users, such as municipalities, with understanding the dependencies of variables and the sensitivities of parameters within energy models. It shows that modelling results do not provide absolute answers and that they are dependent on the underlying assumptions. This is in line with the claim of Koussouris et al. (2015) as described in the literature review, who found that interactive visualization is crucial for explaining in an understandable and digestible way the operation and the results of complex models.

Interviewee A agreed that models were not user friendly and that interactivity could help to decrease this issue. However, this interviewee stated facilitating interactivity, not only in the model but also in modelling sessions together with relevant stakeholders, was more important than user-friendliness of models. According to A, having an interactive model, model interface and/or modelling process allows to immediately see the effect of changing certain variables, which is helpful for practitioners. This is in line with Itten et al., (2019) and van Veenstra & Kotterink (2017) who state that co-creation with local stakeholders can create more legitimacy for policy choices. However, interviewee A also mentioned that some energy models will always remain too complex to use for non-experts, but this does not have to be problematic if results are achieved during a collaborative and interactive process. Interviewee B agreed that some energy models were too complex for end-users and that a more user-friendly model would be beneficial. Interviewee B also agreed with interviewee A that some models will always stay complex as they reflect a complex transition. Interviewee B nuanced that you cannot always simplify a model without it losing its value. There is always a trade-off and If one simplifies a model too much it might provide unrealistic results that seem to reflect reality. Moreover, interviewee B argued that there is nothing wrong with using third parties since municipalities cannot have expertise in everything.

7.3 Improve heat source, energy use and thermal insulation level data

The literature review suggested that the most important shortcomings of data for techno-economic energy models in the themes of energy use, thermal insulation and installations of the utility sector (Diran, van Veenstra et al., 2020). The interviews with practitioners and model developers showed that data for the utility sector is indeed underdeveloped but also showed that data sets regarding energy use and thermal insulation levels for residential areas are insufficient for energy modelling. Besides, this study found that heat source data was insufficient. This study, therefore, urges that there is a need for improved heat source data, energy use data and thermal insulation level data for energy models to be more useful for heating transition projects, both for the residential and utility sector. Current heat source data sets are uncertain and incomplete, energy use data is only available in averages and insulation data is inaccurate. Although there is a discussion on how to use heat source data, inside the model as a determinant for the choice of a heating alternative or after model calculations to conduct a heat source potential study, there is agreement that more accurate data in this theme would be beneficial for heating transition projects. It is recommended to municipalities to invest in heat source studies and to involve potential heat suppliers, such as industrial facilities, in this study to get more certainty about the availability, temperature and price of potential heat sources. New legislation might be needed to incentivize or force parties to share this information. In addition, it is recommended for municipalities to stay updated on national studies that are being conducted, such as the SCAN study (SCAN Aardwarmte, 2019). Interviews with practitioners showed that within pilot projects municipalities at times try to improve thermal insulation level data by conducting 'energy scans' inside people's homes, voluntarily. Doing this across the municipality could offer a solution for the current thermal insulation data issue, however, such a solution is expensive and far from efficient.

Interviewee A recognized the issues regarding these three datasets and agreed that improvements are needed. However, the interviewee urged that municipalities should not try to improve these datasets individually. Interviewee A suggested that it would be more efficient and feasible to collect such data at a national or regional level. Interviewee A mentioned 'VIVET' as a useful research project that was improving national datasets, among others by setting up collaborations between public organisations. Interviewee B had very similar comments, stating that data sets should not be improved by individual municipalities but by national efforts, where municipalities, for example, provide local data for a national database. Otherwise, there is the risk of getting hundreds of different databases that cannot be combined. Interviewee B also mentioned the 'VIVET' project as a useful party for this. Besides, interviewee A agreed that there will be new legislation needed to motivate potential heat suppliers to share data about the availability of heat. Because currently there is no incentive for commercial parties to supply their residual heat. Interviewee A proposed legislation where companies that provide residual heat are rewarded in terms of CO_2 emissions.

7.4 Develop more efficient data collection processes

This study showed that data collection at municipalities is important to ensure that the modelling study provides enough local detail and to define potential social or infrastructural coupling opportunities. However, both model developers and model users stated that the data collection process can be time-consuming. Occasionally there simply is not enough time in a project to gather the needed data, which leads to model calculations that are carried out with national key figures. This study, therefore, proposes that a more efficient data collection process at municipalities enlarges the potential benefits of using an energy model. This study has not focused on the data collection process itself but a few general recommendations are proposed. First of all, set up covenants with stakeholders in the municipality to share data relevant for heating transition plans. Such stakeholders could include housing corporations, network operators, heat suppliers and potential suppliers of residential heat and relevant data could include investment plans, maintenance plans and desired profit margins. Second, it is recommended to improve the data collection process within municipalities by having clear guidelines on how to store, access and share data. Some municipalities are for example working on a data-warehouse that should make it easier for practitioners within the municipality to find and gain access to specific data sets. Third, if a heating transition project has already been conducted, then make sure to provide documentation on which data has been collected by the municipality, from where, with what goal and under which conditions. People involved in other heating transition projects, for example, project leaders, should then be able to access this documentation. This would prevent duplication of analysis activities.

Both interviewee A and B agreed that it would be useful to develop more efficient data collection processes but again urged the importance of doing this collectively, especially for smaller municipalities. One reason for this, according to A, is that data collection requires knowledge, expertise and the correct facilities. Developing and maintaining this collectively would be easier, plus it would allow data to be exchangeable and of the same quality. Interviewee A stated that it is at times wise to hire third parties with experience to do this. Setting up something like a data-warehouse is, according to A, is only useful if there are sufficient resources to maintain such a database. Interviewee B added that offering data warehouses might offer a temporary solution for large municipalities but that it would be beneficial if data collection happens in a standardized manner at a national level. Finally, interviewee B agreed that setting up agreements with stakeholders about data sharing can be helpful and mentioned that the VNG was developing standardized agreements that municipalities can use to set up covenants with stakeholders, such as housing cooperatives.

7.5 Demand and/or offer a transparent model and modelling process

In this study, transparency was not mentioned as a limiting factor by practitioners. However, the literature showed that transparency is an important requirement for modelling processes (Argyous, 2012; Nikolic et al. 2019a). Moreover, model developers did mention issues with transparency regarding underlying assumptions, parameters and parameter sensitivities of other developers. This study, therefore, urges model developers and model users to be transparent about the input data, mathematical principles, assumptions, parameters and parameter sensitivities used within heating transition projects. It is recommended for both model developers (third parties or municipalities and model users (municipalities) to follow the seven standards of transparent evidence-based policy design as proposed by Argyous (2012) when conducting modelling studies for heating transition projects. These standards are shown in Table 31. An exception might be needed for privacy-sensitive data used in modelling studies. If such data cannot be publicly presented, then it is recommended to at least explicitly state which privacy-sensitive data is used, with what goal and how this data affects the modelling results. If a municipality chooses to use a third party to conduct the modelling process, it is recommended to demand transparency in these seven themes. Besides, it is recommended to keep the red flags as presented by Nikolic et al. (2019a) (see table 32) in mind when hiring a third party to conduct the modelling process and to take action to improve the modelling process if one of these red flags is present.

Interviewee A agreed with this recommendation and stated that this is an extremely important point. A stated that the two lists of standards and red flags were clear and would be truly useful for municipalities. A mentioned that this topic deserves more attention in the field than that it currently receives. Interviewee B urged that more transparency in this theme is always beneficial and thought the standards and red flags would be useful for municipalities. Interviewee B did nuance that transparency should be adjusted to the level of the end-user. As transparency is not useful when the end-user does not understand the materials offered, for example, coding documents.

Table 31: Seven standards for transparent evidence-based policy design, as proposed by Argyous (2012).

#	The standard for transparent evidence-based policy design
1	Make raw data available
2	Make the data collection instrument available
3	Make metadata available
4	Make analytical assumptions explicit
5	Make analytical choices and their testing explicit
6	Make the relationship with past research explicit
7	Declare financial and other interests

Table 32: Seven red flags that indicate an inadequate modelling approach, as proposed by Nikolic et al. (2019a)

#	Red flags
1	Lack of a clear modelling question that was mutually agreed on.
2	Incapacity or reluctance to clarify the choice for a modelling formalism.
3	Not explicitly discussing or demonstrating input data uncertainties.
4	Not explicitly discussing or demonstrating the parameter sensitivities.
5	Not consciously varying parameters within plausible ranges when testing the effect of a policy/decision.
6	If (some) outcomes cannot be satisfactorily explained in terms of (1) the assumptions used, (2) the properties of the model/model type (3) and the experiment conducted.
7	Incapacity to answer the 'Why is this happening' inquiry.

7.6 Improve robustness of modelling results by offering a comparative analysis

Comparative studies such as the OB provide robustness of modelling results by comparing the underlying assumptions, data and sensitivities and modelling results of different models/modelling studies. The myriad of models, that occasionally provide different results for the same research question, create confusion and uncertainty at municipalities. Offering comparative analysis ensures the myriad of models and modelling studies is used to create more certainty by showing for which neighbourhoods models provide the same results, where results differ and why? It is recommended to perform more national studies such as the OB and to conduct comparative analysis during heat projects. For example, when hiring a third party to conduct a modelling study with a model, municipalities should request a comparison of the results and approach with the SA or with previous modelling studies conducted at the municipality. This will provide municipalities with more insight into the trustworthiness and robustness of results, which will most likely enable them to make policy and project choices more quickly.

Interviewee A was a proponent of conducting a comparative analysis. With the lack of standardisation regarding assumptions and data, comparative analysis offered a pragmatic method to show the robustness of heating transition plans, according to A. Interviewee B agreed to this and stated that comparative analysis shows end-users that model results do not offer absolute truths and that it provides more robustness of results. Interviewee A stated that municipalities should always conduct comparative analysis during the modelling process, as this can also create trust and support among residents. A does mention that comparative analysis will cause more work for municipalities, which means that there should be a clear incentive to do this. The potential trust and support that it could create for residents could be a good motivating factor according to interviewee A. Next to comparative analysis, interviewee A stated that the current lack of standardisation of assumptions and data should be solved, as this would increase the trust of practitioners in models. According to A, this was realised thirty years ago in the Dutch water sector, in this sector there used to be much discussion about models and data, but little about solutions. After the Dutch Ministry of Infrastructure and Water Management standardised data and assumptions, discussions became much more solution-oriented according to A.

7.7 Collaborate and specialize

Within this study, it became clear that practitioners experience the myriad of models and modelling studies available as confusing, especially when models provide different answers for the same research question. Occasionally, multiple consultancy agencies are hired after one another to address the same questions and to "perform the same trick" as one model developer put it. This can make the modelling results more robust, but only if a decent comparative analysis is conducted, as proposed in recommendation 6. However, one model developer did state that it is a "waste of time and resources" to repeat the same research over and over again in different projects. More collaboration between different model developers, where multiple models are used within one project, could save municipalities or other practitioners time. As they only have to conduct the data-collection process and the workshops with the model developers once. Also, model developers can learn from each other and modelling results can immediately be compared to one another. However, it is not feasible that all energy models are used next to each other in one project. Two or three is most likely the maximum of modelling studies that can be carried out simultaneously before the number of stakeholders involved becomes too much. One of these will most likely be the SA as this modelling study is available for all municipalities and its use is recommended by the national government (Government of the Netherlands, 2019). In addition, it is recommended that a large share of models and model developers, as not all models are needed to facilitate comparative analysis, should specialize in other abstraction levels or on the connection with other industries. First, this is recommended because due to a large number of comparable models and modelling studies available, there is a chance that a share of models will become obsolete, as one of the model developers within this study mentioned as well. Second, this is recommended because both model developers and practitioners of this study indicated that there is a clear gap between abstract visions created with heating transition models and implementation plans and a lack of models that show the impact of heating transition choices on other industries and networks. It is recommended that model developers position and improve current models or develop new models in such a manner that they offer specialized expertise in one of these areas, for example by showing the impact of heating choice on the electrical network. To make the most use of a range of specialized models it is recommended to keep investing in multi-modal ecologies, as further explained in chapter 9.2. A multi-model ecology is an interacting group of models and data sets that co-evolve together within the context of a social-technical environments. Every model that is able to exchange messages with at least one other model is part of the multi-model ecology (Nikolic et al., 2019b). A combination of collaboration and specialization as proposed would alter the current and future modelling landscape. An example of how this landscape could look like is shown in figure 39.

Interviewee B did not have a strong opinion about this recommendation. B stated that some models might indeed become redundant, but that this is not problematic. Moreover, B stated that collaboration between model developers would be beneficial, but that municipalities might have limited influence on this. Interviewee A stated had been working on multi-modal ecologies for several years and agreed to the fact that we should move towards a multi-modal situation. One of the reasons for this is, according to A, is that the current heating transition is analysed too much in isolation. The effects and connections with other aspects in the energy system are usually not taken into account. Interviewee A urged for a more integral approach, which multi-modal ecologies could facilitate. Interviewee A mentioned that in September 2020 there will become a subsidy available for the development of multi-modal ecologies and for the development of an energy modelling platform, where model developers and model users can come together to design an infrastructure for model coupling. A agreed that the Mondaine project, and especially the ESDL (see appendix H), would be a useful development for multi-modal ecologies and also referred to the whitepaper of Nikolic et al. (2019b) on multi-modal ecologies. A expected that multi-model ecologies would be available for municipalities in the heating transition soon, partly because the water and environmental sector had been working with similar frameworks for years. Interviewee B wondered whether multi-modal ecologies would not make heating transition projects even more complex.

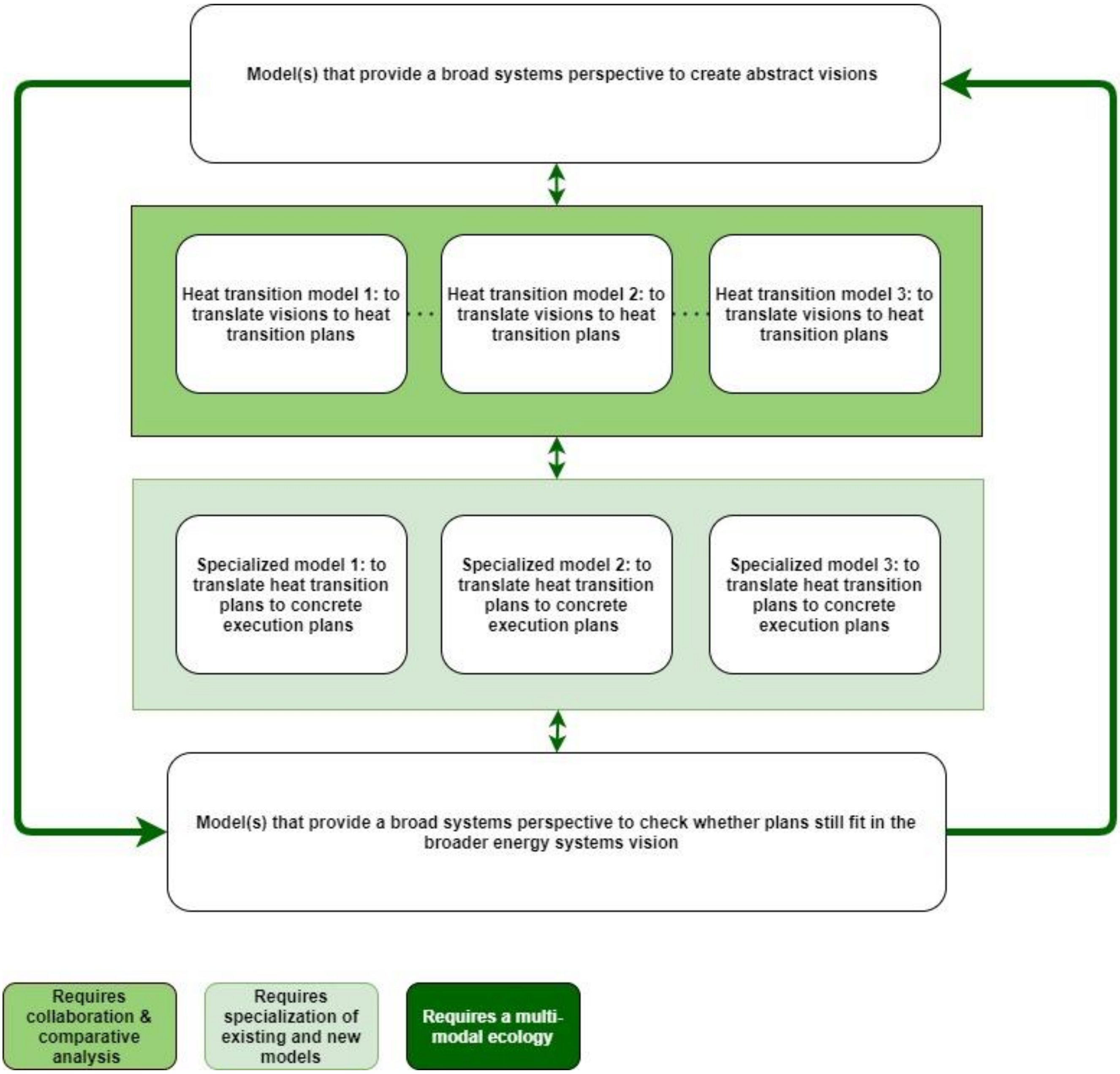

Figure 9: An example of how the Dutch modelling landscape could look like with more collaboration and specialization that would facilitate comparative analysis and a multi-modal ecology.

8 Discussion

8.1 Reflection on academic and grey literature

The present study has provided a more concrete image of the role of energy models in data-driven policymaking and decision-making in the Dutch heating transition. The literature discussed showed that modelling methodologies have the potential to reduce the uncertainty and complexity of heating transition projects. The present study provided a concrete overview of advantages of using energy models in heating transition decision making as experienced by practitioners and model developers. Advantages of using models in heating transition projects mentioned in the interviews were that the modelling process and its results provided perspective for action, financial and socio-economic insights, transparency and legitimacy towards residents, concrete propositions for residents and means to start useful discussions. These advantages seem to indicate that although energy models do not necessarily make a heating transition project less complex, they at least offer means to make legitimate choices. The advantages found are in line with the advantages of data-driven policy design mentioned by Koussouris et al. (2015) who stated that ICTs, such as energy models, will simplify decision-making processes, even under the most complicated conditions, by facilitating the opportunity to model complex processes and the opportunity to collaborate with different actors involved and those mentioned by Adam et al. (2018) who stated that providing evidence for the effectiveness of policy choices is one of the cornerstones of legitimate policymaking. In addition, the present study offered recommendations targeted at Dutch practitioners and model developers to facilitate more effective usage of energy models in heating transition decision-making. Such targeted recommendations were not found in literature before and could help towards designing a systematic approach for integrating energy models and other ICTs in data-driven policy making, which is needed and currently missing according to Androutsopoulou & Charalabidis (2018) and van Veenstra & Kotterink, (2017). Reflecting on the integration of energy models in decision-making in the case studies, the biggest challenges were regarding: the knowledge and skills of practitioners, which was at times insufficient to critically reflect on modelling studies or modelling result interpretations conducted by third parties; the lack of transparent comparative analysis between energy models and; the uncertainty of data-sets and assumptions.

Although this study confirmed certain advantages of using energy models and provided recommendations on how to use such ICTs in decision-making, using energy models for decision-making also has its limitations. Designing modelling scenarios is a time-consuming and costly task, modelling results are not absolute truths but rather results subject to calculation rules and assumptions and if a model or its results are incorrect, one might be worse off than when not using a model to start with (Nikolic et al., 2019a). According to model developers of this sample, not all practitioners understood these limitations and interpreted modelling results as absolute truths. All municipalities of this sample that provided information about their TVW design used or were planning to use models/modelling studies. This was not unexpected as it was agreed in the national climate agreement of 2019 (Government of the Netherlands, 2019) (PBL, 2020b) that municipalities would use the SA and its guidelines (ECW, 2019) to design their TVW. According to the climate agreement, this would provide all stakeholders with a “uniform frame of reference regarding the impact of the various natural gas alternatives in a district” (Government of the Netherlands, 2019). This agreement might have incentivized municipalities to use a data-driven approach using energy models when designing their TVW. However, three pilot projects did not use energy models to choose a natural gas alternative. The pilot projects of this sample all started before this statement was made in the climate agreement and before the SA and its guidelines (ECW, 2019) were published. Therefore, practitioners in pilot projects might have been less familiar with available models and modelling studies, might have had less access to models and modelling studies and/or might have been less incentivized to use available models or modelling studies. Furthermore, pilot projects in this sample that did not use an energy model to choose a natural gas alternative had a few things in common. All three pilot projects were located in villages with less than 2000 residents. All three pilot projects had active energy cooperatives and two pilots were organized by the local energy cooperative, two pilot project leaders were not familiar with energy models and two pilot projects entailed only or mostly detached houses, from before 1940, with poor thermal insulation levels. These similarities are shown in figure 10. Practitioners from pilot project 1 and 3 from figure 10 stated that they did not feel that they needed an energy model because the choice for a heating alternative could be made with common sense and information about the house characteristics. This indicates that an energy model might not always be needed or desirable for heating transition decision-making and that it is important to consider when the use of an energy model would be beneficial and when other sources of evidence or data might be sufficient to support decision-making.

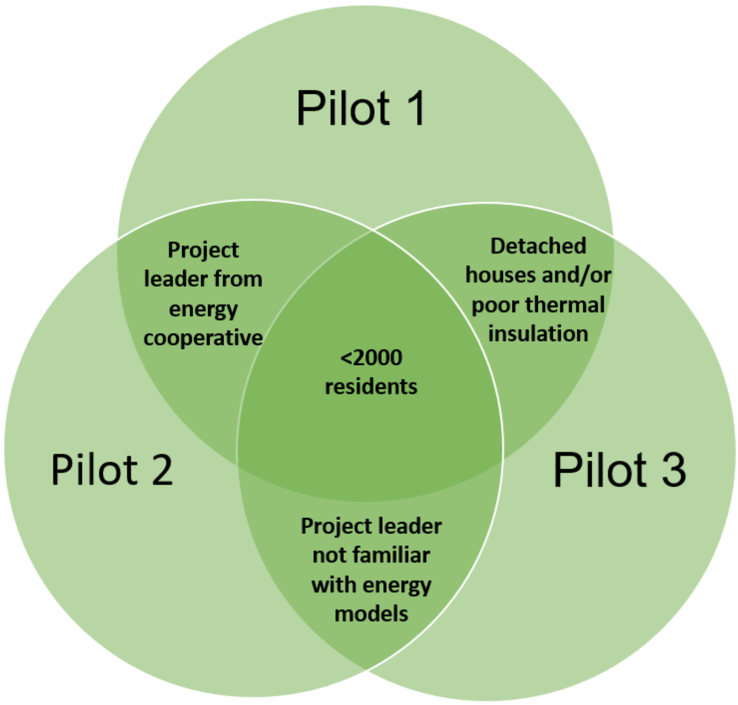

Figure 10: An overview of the similarities between the pilot projects that did not utilize an energy model to analyse different heating alternatives.

Finally, the literature suggested that it is problematic that current heating transition models do not include social and/or socioeconomic factors, as the transition is highly dependent on humans and their behaviour (Androutsopoulou & Charalabidis, 2018). However, the present study showed that practitioners were not always sure how social or socioeconomic data should influence the choice of a heating alternative or the prioritization of neighbourhoods. Moreover, accessing this data was occasionally difficult due to privacy restrictions. In addition, model developers did not see value in including social or socioeconomic factors within their heating transition models, which all had a techno-economic focus. It is not illogical that these models were focused on finding the lowest societal and/or individual costs for different heating alternatives and did not include social factors, as affordability for residents is seen as one of the main challenge of the Dutch heating transition (Schellekens et al., 2019). The costs of a heating alternative are, as far as known, do not dependent on social or socioeconomic factors. Something that could be dependent on such factors is, for example, the degree of participation and technology adoption rates. In this sample, not one case was using model methodologies focused on assessing social interactions, such as Agent-Based Models, System Dynamic Models or STET models.

Instead, municipalities used models with a techno-economic focus and assessed social and socio-economic data alongside the results of these modelling efforts to identify coupling opportunities and/or to determine a prioritization of neighbourhoods. The present study nuanced the importance of social and socio-economic factors, suggesting that it might be less important for selecting a heating alternative because policymakers thus far always seem to aim to offer the natural gas alternative with the lowest societal costs.

8.2 Reflection on the theoretical propositions

The ten theoretical propositions proposed in chapter two helped in guiding the research activities, especially in setting up the interview questionnaires. The propositions offered a good starting point for this study, but did not cover the full range of findings. However, combined with the use of semi-structured in-depth interviews and with the inclusion of emerging themes unrelated to the propositions in the questionnaires the findings were sufficient to answer the research questions and to provide recommendations on more effective use of energy models. Seven out of ten propositions could be confirmed or rejected based on the case studies. Information was gathered about the remaining three propositions, but it was deemed insufficient to confirm or reject them based on the data gathered. Two of these propositions could have been confirmed or rejected if interview questions would have been added about the 'trust in energy models' by practitioners. Time constraints and the inherent subjectivity of the concept of trust led to the decision to not do this. One could therefore argue that using trust as a concept in two theoretical propositions did not offer clearly measurable propositions. Five out of seven recommendations were related to the theoretical propositions of this study, the recommendations regarding comparative analysis, collaboration and specialization were not related to any theoretical propositions. This indicates that the present study has either introduced new topics that were not previously mentioned as influencing effective use of energy models or that theoretical propositions in these themes were missing.

8.3 Limitations of the present study

As with the majority of academic studies, the design of the current study is subject to limitations and the findings, therefore, have to be seen in light of these limitations. This section discusses limitations regarding generalizability of the results, limitations regarding access to data and limitations regarding the chosen research data collection tools.

The external validity of the empirical results and the recommendations is limited by the context in which the case studies were conducted, the Dutch heating transition. The selected cases were all municipalities that took part in the PAW-programme, which means they all received subsidies to set-up a heating transition project. Therefore, these municipalities might have more financial room to hire or develop expertise regarding energy modelling compared to other municipalities. This means that the results of this study might not reflect the situation at municipalities that are not taking part in the PAW programme. The literature review reflects on energy model usage in other cultural and geographical contexts but the empirical part of this study focuses on the use of energy models in the Dutch municipal heating transition. This was a scope choice motivated by the case study design and time constraints of the present study. The recommendations of this study are targeted at Dutch practitioners and model developers and were validated by Dutch heating transition experts. The generalizability of these results to other geographical, political and cultural contexts might therefore be limited. It is expected that generalizability will especially be limited for countries where the heating transition is not organized in a decentral manner or where there are not multiple (national) energy models available to analyse the costs of this transition. In the present study the challenge of external validity was decreased by designing the majority of theoretical propositions based on academic literature of the international context. Of the seven recommendations proposed in this study, three are directly related to challenges of energy modelling mentioned in international academic studies: 1) Practitioners should develop and preserve knowledge, competences and skills in energy modelling; 2) Model developers should offer more user friendly models and/or model interfaces; 3) Practitioners and model developers should demand and offer transparent models and modelling processes. This increases the likeliness that at least these three recommendations are generalizable to other contexts outside of the Netherlands.

Limited access to background information on some commercial energy models limited the reflection on technical aspects of the models reviewed in the case studies. As most commercial models do not share their actual model and do not always share documents outlining their model, its capabilities, limitations, underlying assumptions etcetera this study only compared the models on a surface level, based on publicly available reports and the challenges and advantages mentioned by interviewees. This limited access is understandable, as sharing these models has the risk of negatively impacting the business models of commercial developers. However, it did limit the potential for an in-depth model comparison, which could have been relevant for designing a recommendation targeted at model improvement. On the other hand, the time restraints of this research and the focus on user experiences and the modelling process rather than the actual energy models also limited this potential. This choice was made because the limited access to commercial models was foreseen and because there are already other Dutch studies, such as Brouwer et al. (2019), who focus on this in depth model comparison.

The chosen data collection tools, interviews and thematic coding also have their respective limitations. Interviews and thematic coding are research methods that require a high degree of interpretation from the researcher. The verbatim transcripts, the coding process and the coding reports ensured quotes were methodologically analysed and that it was possible to review the original quotes. However, the meaning of these quotes in light of the research questions remain interpretation of the researcher and might not fully reflect the original views of the interviewees. Another limitation of interviews as a data collection method is that the interview questions can bias interviewees. Statements of interviewees will always be shaped, to some extent, by the questions asked (Alshenqeeti, 2014). For example, by specifically asking interviewees about the importance of coupling opportunities or socio-economic factors in heating transition decision making they might have overstated their importance. In addition, perceptions of interviewees are subjective and may change over time due to circumstances. Statements given for this research, therefore, might not be in line with the views of the interviewees at a different point in time (Alshenqeeti, 2014). The present study used multiple sources of evidence in a triangulating fashion to decrease the subjectivity of the answers and to check their consistency over time. Striking was that for the pilot projects of this sample, the views and plans of interviewees did not always align with the views as exhibited in the implementation plans of the pilot projects due to advancing insights. Finally, using theoretical thematic coding to sort and analyse the interviews this method is that the scope is being limited causing ignorance towards critical aspects or causing too much focus on specific parts of the data (Javadi & Zarea, 2016). This risk was lowered by including research themes in the interview questionnaires unrelated to the theoretical propositions, by using open-ended questions and by allowing open-coding during the coding process (as opposed to only using pre-defined codes).

Despite the limitations mentioned, the results of the present study are still considered valid for answering the research questions. First of all, the results are generalizable enough to provide Dutch practitioners and model developers with useful insights. Second, the limited access to background information of energy models did not hinder the reflection on their user experience, limitations and benefits. Third, the interview and coding methods chosen, although subjective, provided a useful tool to gather, structure and present the empirical data and to analyse this data as objectively possible.

9 Conclusion

9.1 Answer to the research questions

The goal of this study was to answer the question "How can Dutch municipalities effectively use energy models within their data-driven decision-making processes regarding heating transition towards a gas-free heat supply?" by conducting a literature review and embedded case studies at Dutch municipalities. To do this, three sub-questions were proposed. 1) Which energy models are used while planning the heating transition and how?; 2) How can current energy models be improved to better support decision making in the heating transition?; 3) What is needed, besides energy model improvements to facilitate effective use of energy models for decision making in the heating transition? The following sections answer these questions.

Which energy models are used while planning the heating transition and how?

The energy models found in this study were used mostly by consultancy agencies to support municipalities or other governmental agencies in designing heating transition plans. These plans include Regional Energy Strategies (RES), TVW, and Neighbourhood Implementation plans (WUP). Over half of the sample of municipalities used models or modelling studies at some point during their respective heating transition pilot projects and all cases that provided information about TVW development were using of planning to use models or modelling studies for the design of the TVW. Models that were used were the CEGOIA model, the Vesta MAIS model, DWA models, the ETM and the WTM. Modelling studies that were used were the OB and the SA. The municipalities that did not utilize models or modelling studies for their pilot projects belonged to the four smallest municipalities of this sample, indicating a relation between municipality size and model usage.

How can current energy models be improved to better support decision making in the heating transition?

Energy models can be improved by becoming less abstract, more user friendly and interactive. In the present study modelling results were found too abstract, too general or too simplified for local analysis and models were not user-friendly and complex. Model developers mentioned that results are difficult to interpret for non-experts such as practitioners and claimed that Interactive models help end-users to gain a better understanding of the answer and to get a feeling for parameter sensitivity. Improved data sets regarding energy use and thermal insulation levels could also improve the discussed energy models, as well as including parameters that provide insight into the impact of nearby heat networks and end-user costs. Model developers agreed that the current datasets for heat source data are uncertain and that extra research is always needed to assess the local situation. Model developers and practitioners ran into issues with data from Statistics Netherlands (CBS): energy use data was aggregated and was deemed too inaccurate to use for heating transition projects and Statistics Netherlands (CBS) neighbourhood definitions did not always provide a logical division of the city. Therefore, practitioners or model developers always had to conduct a reality check after modelling to filter out odd results, especially for the utility sector. Similarly, model developers and practitioners stated that the current data from the BAG regarding energy labels provided too little insight into the current levels of thermal insulation present. Lastly, more consensus on assumptions regarding the availability of green gas could improve the discussed energy models. The different assumptions of green gas availability used in different models and modelling studies created confusion for practitioners.

What is needed, besides energy model improvements to facilitate effective use of energy models for decision making in the heating transition?

This study has shown that all practitioners needed third party expertise at some point during their heating transition projects. CE Delft, Over Morgen, DWA, Innoforte and EnTra Management were consultancy agencies that were hired by municipalities to support, interpret or conduct modelling studies. Other parties were hired to support communication and participation processes with stakeholders and residents to conduct specific studies, to make detailed financial calculations or to conduct energy scans. All (consultancy) agencies spoken to directly or indirectly help their clients (e.g. municipalities) with the interpretation of modelling results. Model developers all emphasize that supporting practitioners during the modelling process and with result interpretation is an important and time-consuming activity. Practitioners from municipalities have a central role in heating transition project but they are generally not able to interpret modelling results correctly on their own. Next to the need of third party expertise, this study also showed that practitioners from municipalities need internal knowledge and skills to pose the correct research questions and to choose energy models that fit these research questions. Moreover, the results showed that municipalities need efficient data collection processes to facilitate local analysis. The data collection process at governmental agencies in the case studies was considered time-consuming. Municipalities were able to provide all the data requested, but it took a long time to get all the data from different parties within and outside of the organisation. This was strengthened by the fact that some stakeholders were hesitant in sharing data and by the fact that a large share of the data was not provided in the correct format.

This study has also shown a need for social & socio-economic data, such as resident composition, resident incomes and resident motivation. Model developers claimed that the technical analysis was usually the simplest step of heating transition projects and that there are all sorts of political, social and psychological aspects which influence the success of heating transition projects. An unexpected finding of this study was that both model developers and practitioners had little desire to include social and/or socioeconomic factors within the techno-economic energy models used since these models were focused on finding the lowest societal costs of different heating alternatives. Model developers and practitioners considered social and socio-economic factors to be useful to prioritize neighbourhoods for the heating transition, to get a sense of how residents could be motivated and to identify coupling opportunities. Therefore, social and socio-economic data was gathered and presented alongside of modelling results as a means to start useful discussions.

Lastly, this study has shown a need for transparency and collaboration to access data and to provide comparative analysis. The results suggested that offering comparative analysis helped practitioners to deal with the myriad of occasionally contrasting models, modelling studies and modelling results available. Comparative analysis offered robustness and made it easier for practitioners to prioritize neighbourhoods to start the heating transition activities. Model developers engaged in many collaborations during heating transition projects. They collaborated with other model developers to develop comparative modelling studies such as the OB, they utilized each other's models, they collaborated with agencies with different expertise and they collaborated with knowledge institutes. Two models of this sample were open source and open access (Vesta MAIS and the ETM) but getting access to underlying assumptions, data or sensitivities from other models, for example, to conduct a comparative analysis, at times proved to be difficult. Moreover, stakeholders such as housing corporations or heating companies were frequently reluctant to share needed data or would not be transparent about needed profit margins

How can Dutch municipalities effectively use energy models within their data-driven decision-making processes regarding heating transition towards a gas-free heat supply?

Based on the results it can be concluded that the use of energy models for decision making in heating transition projects can become more effective by developing and preserving knowledge regarding energy modelling at municipalities, by providing more user-friendly models and/or model interfaces, by developing more efficient data collection processes at municipalities, by improving heat source, energy use and thermal insulation level data sets, by offering comparative modelling studies and by ensuring model developers collaborate and specialize more. Validation with independent experts offered the following additions. Both knowledge and skill development and data collection should be carried out collectively where possible and models should not only be made interactive to increase usability, but the entire modelling process should be an interactive process with a multitude of stakeholders involved. The latter could also improve the legitimacy and support of modelling results among residents and stakeholders. However, some models will remain too complex for end-users and this is partly because they reflect a complex socio-technical transition. Simplifying models too much to increase user-friendliness has the risk of decreasing the value of the modelling results.

9.2 Academic and societal relevance

This study is useful for both academics and practitioners and therefore has both societal and academic relevance. The study bridged several knowledge gaps that were identified in the literature review by studying the relationship between the use of energy models and the complexity of the heating transition decision-making process. Variables of influence on this relationship were presented in a conceptual model and explored in order to test the theoretical propositions and to provide substantiated recommendations on how to effectively use energy models to improve the heating transition.

The literature review showed that there was a lack of literature that considered how energy models affect practitioners and a lack of clear guidelines for the use of energy models in decision-making processes. The present study showed the needs and wants of energy models for municipal practitioners in real-life heating transition projects decision-making processes. The results confirmed challenges and advantages of using models for decision-making processes as mentioned in international and grey literature focused on energy models, data-driven policymaking and good modelling practice. The interviews with practitioners provided insights into how practitioners use energy models and how such models affect their decision-making processes. The recommendations of the present study provided a starting point for a structural guidelines and offered clear measures that can be taken to improve the effectiveness of using energy models in heating transition decision-making processes. A second research gap that was identified was that among energy models that are currently used for decision-making processes, there are challenges regarding the correctness and sensitivity of assumptions, regarding the transparency and usability for practitioners and regarding the need to integrate more social factors. The present study provided detailed descriptions about how these challenges are experienced and overcome by both model developers and practitioners and which other factors are needed to facilitate effective use of energy models, such as a developed and shared knowledge base and a transparent modelling processes. The recommendations offer suggestions to decrease a share of these challenges. A third research gap identified was the clear lack of academic research about Dutch energy models. This knowledge gap was bridged by conducting a study focused on Dutch energy models used by practitioners in the Dutch heating transition.

Finally, the present study urged both academics and practitioners to think about when the use of energy models adds value to the decision-making process and when it unnecessarily increases the complexity of the decision-making process. The present study presented heating transition projects in which energy models played a significant role in deciding a heating transition alternative, but also shed light on the characteristics of heating transition projects were no energy models were used to choose a suitable alternative.

9.3 Recommendations for future research

This study could not provide a definitive answer as to when heating transition projects should and when they should not use energy models to guide their heating transition decision-making process. The discussion offered some criteria that might indicate projects that do not need energy models such as municipality size, residential housing characteristics and the presence of an energy cooperative. It is recommended to conduct more research into which criteria could indicate that projects would have an advantage of using an energy model. Exploring this topic could be done by conducting more case studies, at different types of heating transition projects.

Furthermore, it is recommended to further study the impact of social and socioeconomic factors. The literature review suggested that social and socioeconomic factors are highly important for heating transition decision-making processes, but currently, the impact of social and socioeconomic data within heating transition projects is limited and at best influences the prioritization of neighbourhoods. One of the reasons for this is that it is not clear what the impact of certain social and socio-economic factors is on the heating transition and vice versa. More research into certain factors, for example, income or the presence of energy cooperatives, could provide insight into the correlation of these factors with heating transition project progress and into the potential value of models that include such factors. On the one hand, this research should entail desk research about socio-technical transitions and models (such as STET, System Dynamics or Agent-Based models). On the other hand, it should entail practical case studies that test socio-technical transition theories and models in the Dutch heating transition setting. The second generation of PAW pilot projects might offer options for this.

Finally, it is recommended to conduct more research into the field of multi-modal ecologies (e.g. systems of interacting models). This study has shown the need for comparative analysis, for modelling at different abstraction levels and for assessing the impact of choices regarding the heating transition in other disciplines, such as electrical infrastructure and social welfare. This study, therefore, agrees with Bollinger et al. (2018) that modelling efforts that span multiple scales, disciplines and perspectives could be beneficial, but that improved methods are needed to guide the development of multi-model ecologies. One such research project, that is already being conducted, is the Mondaine project (Zwamborn, 2020b), which tries to offer a coupling mechanism for different Dutch energy models. However, this study does not couple with STET, System Dynamics or Agent-Based models yet, which might offer an interesting opportunity for future research to include more social and behavioural components into multi-modal ecologies.

9.4 Link with the COSEM-programme

This thesis was written as part of the MSc Complex Systems Engineering and Management (COSEM), the Energy and Industries tracks. This research has a clear technology component, energy models, and the design of recommendations required addressing the technical specifics of energy models but also wider aspects relating to socio-technical system design. Clear links from the materials and theories taught within this programme are present. First of all, the courses 'MSc thesis preparation' and 'COSEM research challenges' have provided the necessary skills to conduct academic research. Courses such as 'Design of Integrated Energy Systems' have provided knowledge about and experience in good modelling practice, model result interpretation and multi-model ecologies. This knowledge was crucial for this study to understand the topic and the potential advantages and challenges that model developers and practitioners encounter. Moreover, courses such as 'Engineering Optimization and Integrating Renewables in Electricity Markets' provided knowledge about optimization principles, which helped in understanding the underlying mathematical principles of the models researched. Also, courses such as 'Electricity and Gas: Market Design and Policy Issues', 'Sociotechnology of Future Energy Systems' and 'Institutional Economics for Designing in Socio-technical Systems' have helped to grasp the complexity of the energy and heating transition and the value of theories about socio-technical transitions. Something that was crucial to understand the effect that energy models might have in this transition and to design effective recommendations. Finally, the content of the course 'Research Methods' helped in designing the embedded case studies that were used for this study. This course is not part of the COSEM programme but from the Management of Technology programme. In hindsight, it would also have been useful to follow the course 'Agent-based Modelling' as this could have provided more insight into why Agent-Based Modelling methodologies are currently not used by practitioners in the heating transition.

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Appendix

Appendix A: Literature overview data-driven policy

The total sample included eight articles. Three relevant articles were found with the title search term "evidence based polic?" on Scopus (limited to energy/engineering/policy related journals from 2011-2020). Two relevant articles were found with the title search term "data-driven polic?" (limited to energy/engineering/policy related journals from 2011-2020). One relevant article was found by using the title search term "data-driven" AND "energy transition"(limited to energy/engineering/policy related journals from 2011-2020). Two relevant articles were found by snowballing the references of the first five articles.

Table 33: Overview of the reviewed literature including title, authors, year and findings.

Title	Authors & year	Relevant findings for this study
Neglected challenges to evidence-based policy-making: The problem of policy accumulation.	(Adam et al., 2018)	Providing evidence for the effectiveness of policy choices is one of the cornerstones of legitimate policymaking.
A framework for evidence based policy making combining big data, dynamic modelling and machine intelligence.	(Androutsopoulou & Charalabidis, 2018)	Dynamic modelling has the potential to reduce the uncertainty of complex social issues. There is a lack of systematic approaches that consider people's behaviour. The goal of their data-driven framework is to enable the combination of objective facts coming from statistical databases with subjective data revealing the public opinion and people's behaviour.
Evidence Based Policy: Principles of Transparency and Accountability: Evidence Based Policy.	(Argyrous, 2012)	Guidelines to ensure transparency and accountability for evidence-based policy design.
A Data Ecosystem for Data-Driven Thermal Energy Transition: Reflection on Current Practice and Suggestions for Re-Design.	(Diran et al. 2020)	Use of data for public decision making is underdeveloped in the energy sector.
Innovating and changing the policy-cycle: Policy-makers be prepared!	(Janssen & Helbig, 2018)	More participative approaches could help in understanding the needs from and perceptions of stakeholders. New expertise within governmental organisations is needed to deal with these new responsibilities caused by advances in ICTs
Accelerating Policy Making 2.0: Innovation directions and research perspectives as distilled from four standout cases.	(Koussouris et al., 2015)	Policymakers should adopt research teams within their own organisation to break down barriers of communication and context understanding when it comes to using new ICTs for policy development.
Data for policy: A study of big data and other innovative data-driven approaches for evidence-informed policymaking, report about the state of the art	(Poel et al. 2015)	Concerns about the availability of relevant skills in governmental organisations related to data collection, data analysis and interpretation of data The risk that a data-driven approach can reduce transparency for the policy process.
Data-driven policy making: the policy lab approach	(van Veenstra & Kotterink, 2017)	Integration of data and stakeholders creates legitimacy. ICTs can capture new data and support collaboration with different stakeholders. New methodologies are needed to effectively integrate new data sources and technologies in policy design.

Appendix B: Literature overview of energy models

Due to the large differences in vocabulary and definitions used to describe modelling tools for the energy transition, it was not possible to collect sufficient literature with one or two search queries. Instead, a multitude of search queries with a combination of keywords (see Table 34) was used to find articles. Studies outside of the scope of energy journals and environmental journals were excluded. Articles that did not focus on heat supply, but for example on the integration of electric photovoltaic systems, were also eliminated. These criteria provided a sample of 24 articles that were reviewed (see Table 35)

Table 34: Keywords used to find relevant literature regarding modelling within the heating transition

Keywords used			
Model? (model/models/modelling/modeling)	Agent-based	Emission? (emission, emissions)	Sustainab? (sustainable, sustainability)
Polic? (policy, policies, policy-planning)	Optimi?ation (optimization, optimisation)	Transition? (transition, transitions)	District heating
Heat? (heat, heating)	STET	Decarboni? (decarbonize, decarbonisation)	Residential

Table 35: Overview of the reviewed literature including title, authors, year, and country/region of focus.

Title	Authors & Year	Country
Investigating the energy transition to a coal-free residential sector in Kazakhstan using a regionally disaggregated energy systems model	(Kerimray et al., 2018)	KAZ
Low carbon scenarios for higher thermal comfort in the residential building sector of Southeastern Europe	(Novikova et al., 2018)	SE-Europe
Eco-sim: A parametric tool to evaluate the environmental and economic feasibility of Decentralized energy systems	(Siraganyan et al., 2019)	CH
A review and critique of UK housing stock energy models, modelling approaches and data sources	(Sousa et al., 2017)	UK
Design for renewable energy systems with application to rural areas in Japan	(Nakata et al., 2005)	JP
Gas and electricity supply implications of decarbonising heat sector in GB	(Qadrdan et al., 2019)	UK
How to maximise the value of residual biomass resources: The case of straw in Denmark	(Venturini et al., 2019)	DK
Electricity and heating system in Kazakhstan: Exploring energy efficiency improvement paths	(Sarbassov et al., 2013)	KA
Heat savings and heat generation technologies: Modelling of residential investment behaviour with local health costs	(Zvingilaite & Klinge Jacobsen, 2015)	DK
On the potential trade-offs between energy supply and end-use technologies for residential heating	(Nässén & Holmberg, 2013)	SW
Optimisation of a Swedish district heating system with reduced heat demand due to energy efficiency measures in residential buildings	(Åberg & Henning, 2011)	SW

Economic-Engineering modelling of the building sector to study the transition towards deep decarbonisation in the EU	(Fotiou et al., 2019)	EU
METIS- An energy modelling tool to support transparent policymaking	(Sakellaris et al., 2018)	EU
System dynamics model analysis of pathway to 4th generation district heating in Latvia	(Ziemele et al., 2016)	LV
Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system	(Connolly et al., 2014)	EU
Interdisciplinary decision support model for grid bound heat supply systems in urban areas	(Erker et al., 2019)	AUT
A review of socio-technical energy transition (STET) models	(Li et al., 2015)	UK
Take me to your leader: Using socio-technical energy transitions (STET) modelling to explore the role of actors in decarbonisation pathways	(Li & Strachan, 2019)	UK
German Energiewende and the heating market - Impact and limits op policy	(Bauermann, 2016)	GE
An area-based modelling approach for planning heating electrification	(Calderón et al., 2019)	UK
Residential solid fuel use: modelling the impacts and policy implications of natural resource access, temperature, income, gas infrastructure and government regulation	(Fu et al., 2014)	IE

Appendix C: Literature Overview Dutch context

Table 36: Overview of the reviewed literature including title, type of document and focus of the document.

Source	(Translated) Title	Type of document	Focus
(CE Delft, 2019).	CEGOIA: insight into heat costs	Website CE Delft	Introduction of the CEGOIA model
(Schepers et al., 2019)	Function design of the Vesta MAIS 4.0	Report PBL	Introduction of and explanation about the Vesta MAIS model
(Netbeheer Nederland, 2020)	Energy Transition model	Report Netbeheer NL	Introduction of the ETM
(Quintel Intelligence, 2020).	About Quintel	Website Quintel	Introduction of the ETM
(DWA, 2020).	Mission & Vision	Website DWA	Explanation of the role of DWA and their models in heating transition projects
(Mans et al., 2017)	How the Caldomus model works	Report Innoforte	Introduction of and explanation about the Caldomus model
(Stedin, 2020a)	Openingsbod Heating transition	Website Stedin	Introduction of the Openingsbod, a modelling study
(Stedin, 2020b).	Why do they call it the Openingsbod	Website Stedin	Answers to often asked questions about the Openingsbod
(ECW, 2019)	Guidelines for local analysis	Report ECW	Explanation of the Startanalyse and guidelines for local (data) analysis
(Expertgroep Energietransitie Rekenmodellen, 2019)	The use of calculation models in a process of regional energy strategy	Presentation Expert group	Comparison of available models and tools for the heating transition
(Brouwer, 2019)	One model is not the same as the other, a study of six calculation models for the built environment energy transition	Report Province of Zuid-Holland	Comparison of available models and tools for the heating transition
(Brand & Konijnenberg, 2019)	Overview of tools and models	Report VNG	An overview of the available models and tools for the energy transition
(Valk et al., 2018)	Exploration for a tool for natural gas free existing buildings	Report RVO	Comparison of available models and tools for the heating transition
(Nikolic et al., 2019a)	Guide for good modelling practice in policy support	White paper TU Delft	Guidelines for good modelling practice
(de Ridder et al., 2019)	Sustainability of the heat supply with heat networks, a policy report	Report of the Dutch General Audit Office	Eight recommendations for policy processes in the Dutch heating transition
(Diran, van Veenstra, et al., 2020)	Data for the TVW and WUP	Report TNO	Required data for heating transition projects and heating transition modelling

Appendix D: Consent forms

D.1 Consent form practitioners & model developers (Dutch)

Plaats alstublieft een X of een V bij de categorie die voor u van toepassing is (JA/NEE)

	JA	NEE
Ik doe vrijwillig mee aan dit onderzoek en ik begrijp dat ik niet verplicht ben om antwoord te geven op vragen en dat ik mij op elk moment terug kan trekken uit de studie zonder opgaaf van reden.		
Ik geef toestemming voor het opnemen en analyseren van dit interview.		
Ik geef toestemming dat de informatie die ik verstrek, gebruikt wordt voor de MSc scriptie van Birgit Henrich en voor rapporten en publicaties van TNO.		
Ik begrijp dat ik het recht heb om de samenvatting van het interview in te zien en om uitspraken terug te trekken of te laten wijzigen, ook zonder opgaaf van reden.		
Ik geef toestemming dat de uitspraken die tijdens het interview gemaakt worden geanonimiseerd geciteerd kunnen worden in de Msc Scriptie van Birgit Henrich en in TNO publicaties.		
Ik geef toestemming dat mijn naam gebruikt kan worden voor citaten in TNO publicaties.		
Ik geef toestemming dat de samenvatting van het interview geanonimiseerd mag worden opgeslagen in het online TU-Delft onderzoek archief, zodat het gebruikt kan worden voor toekomstig onderzoek en onderwijs.		

Participant	**Onderzoeker**
Naam:	Naam: Birgit Henrich
Datum:	Datum:
Handtekening (of naam bij online invullen):	Handtekening

Contact gegevens onderzoeker:
Tel nr: 06-47856294
Email: birgithenrich@gmail.com
Email: birgit.henrich@tno.nl

D.2 Consent form experts for validation (Dutch)

Plaats alstublieft een X of een V bij de categorie die voor u van toepassing is (JA/NEE)

	JA	NEE
Ik doe vrijwillig mee aan dit onderzoek en ik begrijp dat ik niet verplicht ben om antwoord te geven op vragen en dat ik mij op elk moment terug kan trekken uit de studie zonder opgaaf van reden.		
Ik geef toestemming voor het opnemen en analyseren van dit interview.		
Ik geef toestemming dat de informatie die ik verstrek, gebruikt wordt voor de MSc scriptie van Birgit Henrich en voor rapporten en publicaties van TNO.		
Ik begrijp dat ik het recht heb om de samenvatting van het interview in te zien en om uitspraken terug te trekken of te laten wijzigen, ook zonder opgaaf van reden.		
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Participant	**Onderzoeker**
Naam:	Naam: Birgit Henrich
Datum:	Datum:
Handtekening (of naam bij online invullen):	Handtekening:

Contact gegevens onderzoeker:
Tel nr: 06-47856294
Email: birgithenrich@gmail.com
Email: birgit.henrich@tno.nl

Appendix E: Interview questionnaires

E.1 Questionnaire practitioner interviews (Dutch)

1.Wat is uw functie (geweest) binnen dit proeftuin project?

2.In welk stadium is het proeftuin project nu m.b.t. het veranderen van de warmtetoevoer?

3.Hoe is voor de woningen in deze wijk de optimale warmte optie bepaald?

3.1Is dit intern bepaald of door een externe partij (bijv. Een adviesbureau)?

3.2Wat was/is de rol van data hierin?

3.3Wat was/is de rol van energie-modellen hierin? (Bijv. CEGOIA, VESTA MAIS. Energie transitiemodel, Infrastructurele Footprint model, Powerfys, Innovorte, Aardgasvrije wijken DWA etc.)

3.4 Geen modellen? Waarom niet? Wel modellen? Hoe is bepaald welk model geschikt was?

3.5 Zijn er nog andere analysetools gebruikt? Zoals, kostenbaten analyses, enquêtes onder bewoners etc.?

4. Wat was de toegevoegde waarde van deze analysetools en/of energie modellen binnen dit project?

5. Wat waren uitdagingen rondom het gebruik van analysetools en/of energie-modellen binnen dit project?

5.1 In hoeverre denkt u dat deze problemen opgelost kunnen worden door verbeteringen in de analysetools en/of energie modellen?

5.2 Zijn er dingen buiten deze tools die nodig zijn om het gebruik van dit soort tools te vergemakkelijken? (Bijv. organisatiestructuur gemeente, kennis & expertise, andere/meer data, AVG)

6. Hoe belangrijk denkt u dat de participatie en het perspectief van bewoners binnen dit project is?

6.1 Hoe wordt dit momenteel meegenomen in de analyse van aardgas alternatieven?

7. Welke factoren denkt u dat het belangrijkste zijn voor investeringskeuzes van gebouweigenaren m.b.t. de warmtetoevoer?

7.1 Hoe wordt dit meegenomen in de analyse van aardgas alternatieven?

7.2 Zijn er mogelijkheden om deze factoren meer te betrekken, bijvoorbeeld binnen analysetools en/of energiemodellen? Zo ja, wat is hiervoor nodig?

8. Zijn er koppelkansen geïdentificeerd en onderzocht in de proeftuin wijk en zo ja hoe?
(koppelkans = mogelijkheid om een activiteit die voor de warmtetransitie voltrokken wordt te combineren met een andere verbetermogelijkheid in de buurt (of vice versa) zoals renovaties, onderhoud en wensen van buurtbewoners.

8.1 Speelt data een belangrijke rol bij het identificeren van deze kansen? Ontbreekt hier data?

8.2 Ziet u mogelijkheden om dat met de huidige analyse tools/energie modellen te doen, nu of in de toekomst?

8.3 Welke koppelkansen worden binnen de warmtetransitie als kansrijk gezien en welke niet, om sociaal/technisch/ruimtelijk/economisch de energietransitie te versnellen?

9. Heeft de aanpak van de proeftuin wijk m.b.t. het bepalen van warmte alternatieven potentie voor andere wijken? Zo niet, wat zou u anders willen doen?

10. Is er gebruik gemaakt van de startanalyse & de handreiking voor de proeftuin? Zo niet, zit hier waarde in voor toekomstige projecten?

E.2 Questionnaire model developer interviews

Interviewvragen:

1. Wat is uw functie bij XX?

2. Welke partijen gebruiken model XX en met welk doel?

2.1 Hoe wordt naar deze partijen gecommuniceerd over wat deze modellen/tools wel en niet kunnen?

2.1 Hoe worden partijen ondersteund in het gebruik van deze modellen/tools? (Wordt er hulp geboden voor data verzameling, voor model simulaties of voor de interpretatie van resultaten?)

5. Ontvangt XX feedback van gemeenten/beleidsmakers/adviesbureaus over de modellen/tools die XX ontwikkeld?

5.1 Ontvangen jullie vragen/suggesties over bijvoorbeeld data, aannames of parameter gevoeligheid?

5.2 Hanteren jullie bepaalde richtlijnen over wat jullie wel en niet delen m.b.t. bijvoorbeeld data, aannames en parameter gevoeligheid?

6. Wat ziet u als grootste voordeel van het gebruik van de model XX voor besluitvorming in de warmtetransitie?

7. Wat ziet u als grootste uitdaging voor het gebruik van model XX voor besluitvorming in de warmtetransitie?

7.1 Zouden de modellen/tools aangepast kunnen worden om deze uitdagingen te overkomen?

7.2 Zou de aanpak van andere partijen of het proces van besluitvorming aangepast kunnen worden om deze uitdagingen te overkomen?

7.3 Welke modelverbeteringen binnen model XX denkt u dat de meeste potenties hebben?

7.4 Zijn er modelverbeteringen waar jullie nu bij XX mee aan het werk zijn?

8. In hoeverre wordt de potentie van model XX beïnvloed (beperkt) door de huidige data beschikbaarheid?

9. Hoe belangrijk denkt u dat sociale en sociaaleconomische factoren in de analyse van een nieuw warmtesysteem?

9.1 Wordt dit nu meegenomen in de analyse van warmteopties binnen model XX?

9.2 Zijn er mogelijkheden om deze factoren te betrekken binnen model XX?

9.3 Welke data denkt u dat hiervoor relevant is?

11. Is er binnen model XX aandacht voor meekoppelkansen?

(Mogelijkheid om een activiteit die voor de warmtetransitie voltrokken wordt te combineren met een andere verbetermogelijkheid in een buurt (of vice versa)).

11.1 Hoe worden meekoppelkansen geïdentificeerd?

11.1 Is het mogelijk en nuttig om meekoppelkansen te betrekken model XX?

11.1 Welke data denkt u dat hier relevant voor zou zijn?

E.3 Questionnaire validation interviews (Dutch)

Every recommendation is presented to the interviewee based on the findings of this research. This is done with the help of a PowerPoint presentation. The following four questions are then posed to the interviewees:

1. Herkent u zich in deze aanbeveling? (Ja/Nee + toelichting)

2. Denkt u dat deze aanbeveling bruikbaar is voor gemeenten? (Ja/Nee + toelichting)

3. Denkt u dat deze aanbeveling het gebruik van energie modellen in Nederlandse warmtetransitie projecten effectiever kan maken? (Ja/Nee + toelichting)

4. Zou u iets willen toevoegen aan deze aanbeveling? (Ja/Nee + toelichting)

Appendix F: Quotes interviews practitioners

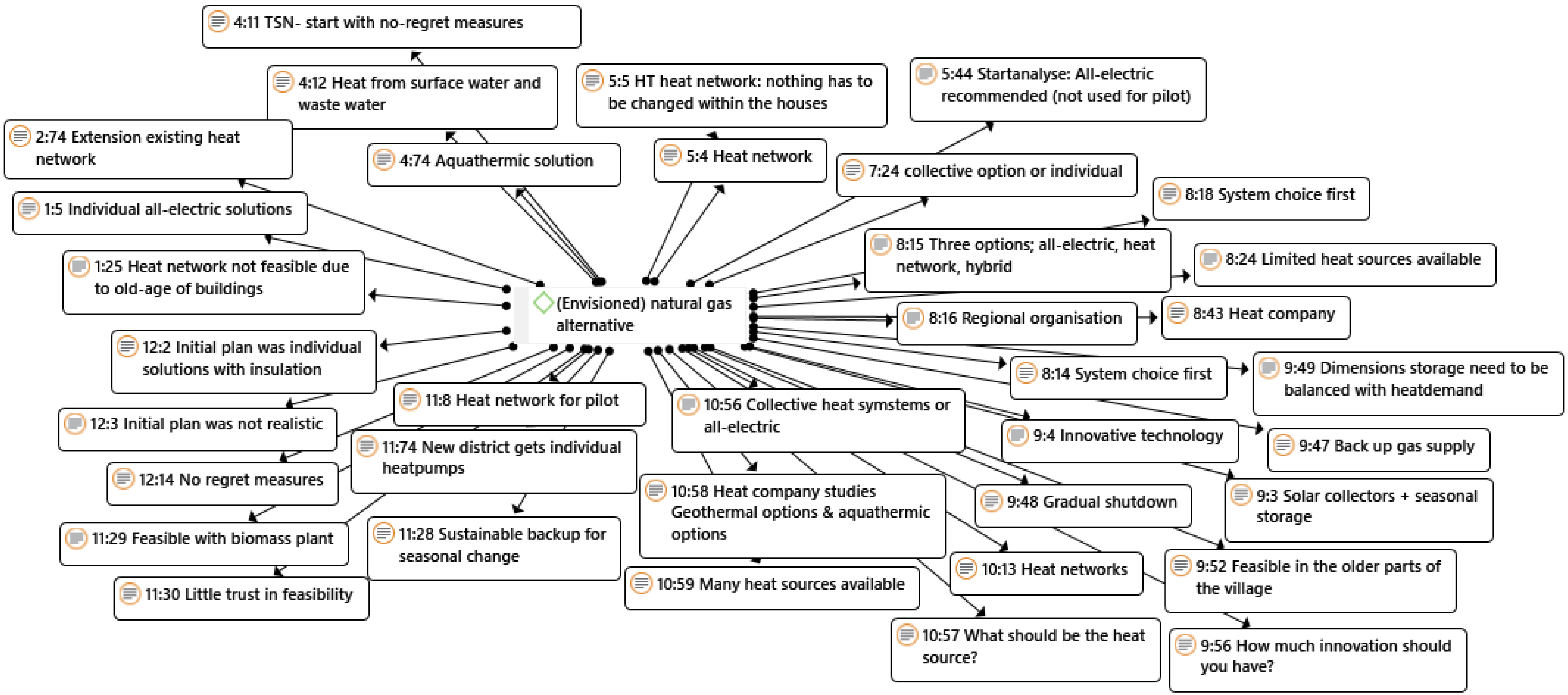

Figure 11: An overview of the quotes (with English titles) of the code '(envisioned) natural gas alternative'.

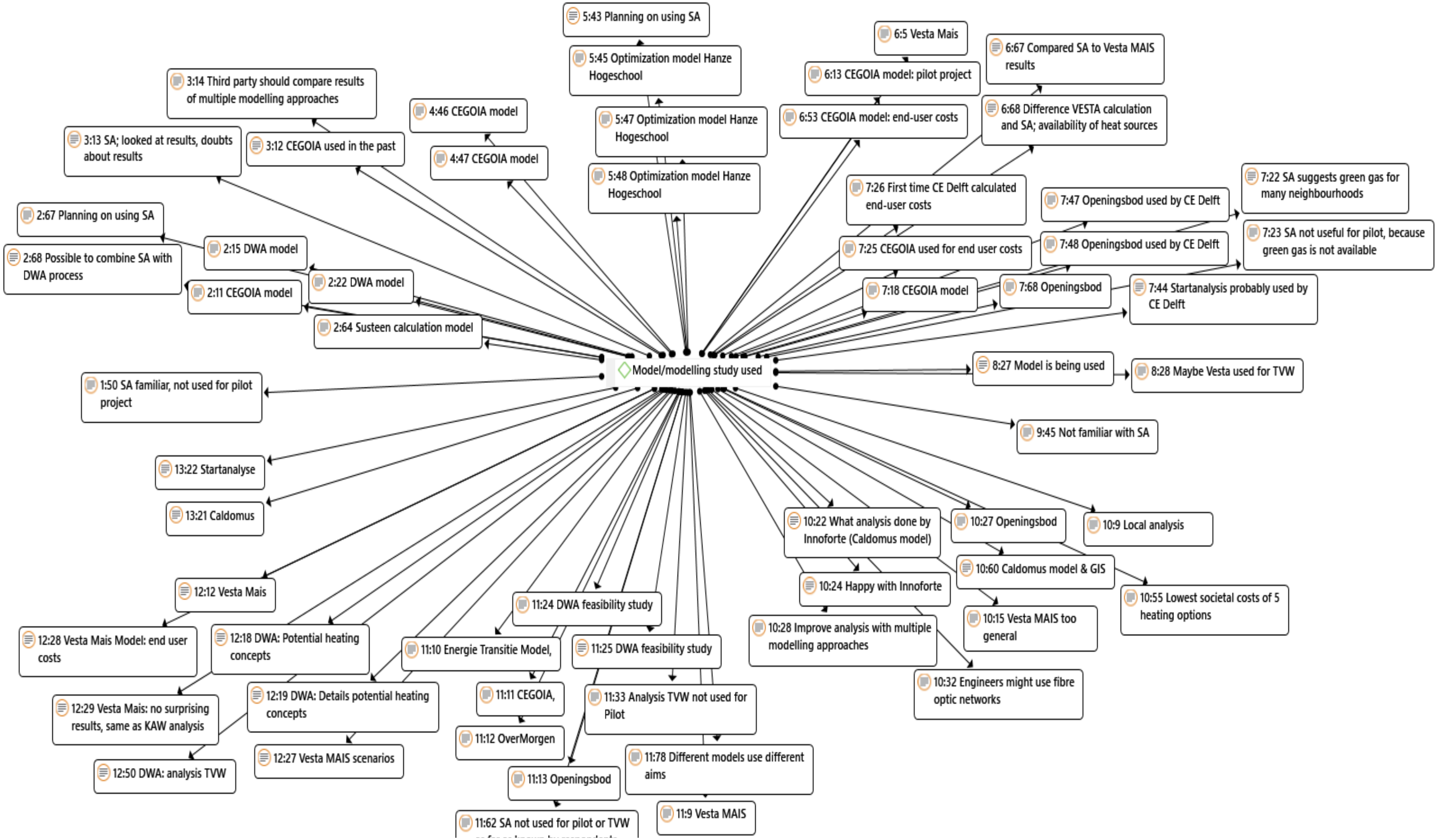

Figure 12: An overview of the quotes (with English titles) of the code 'model/modelling study used'.

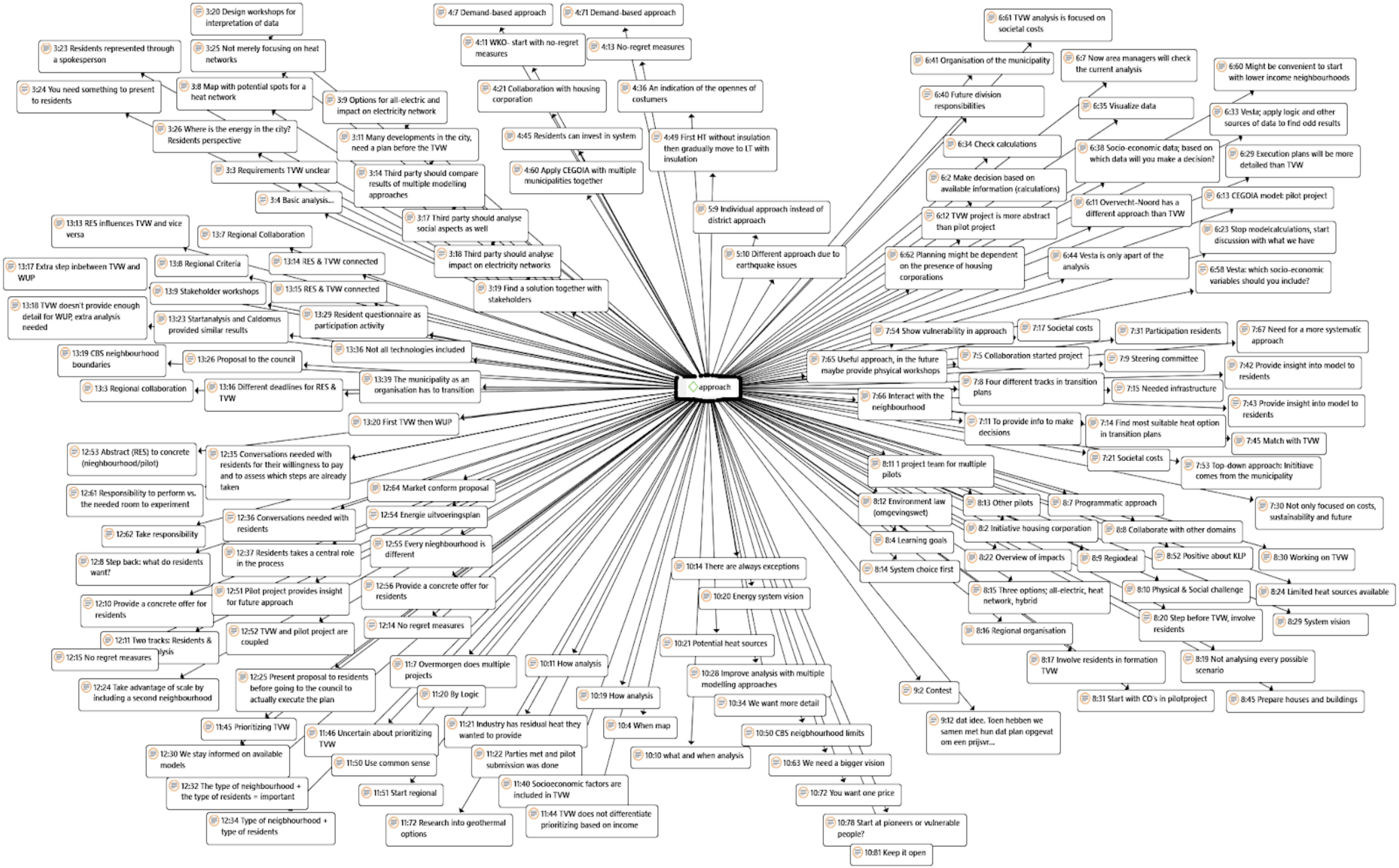

Figure 13: An overview of the quotes (with English titles) of the code 'approach'.

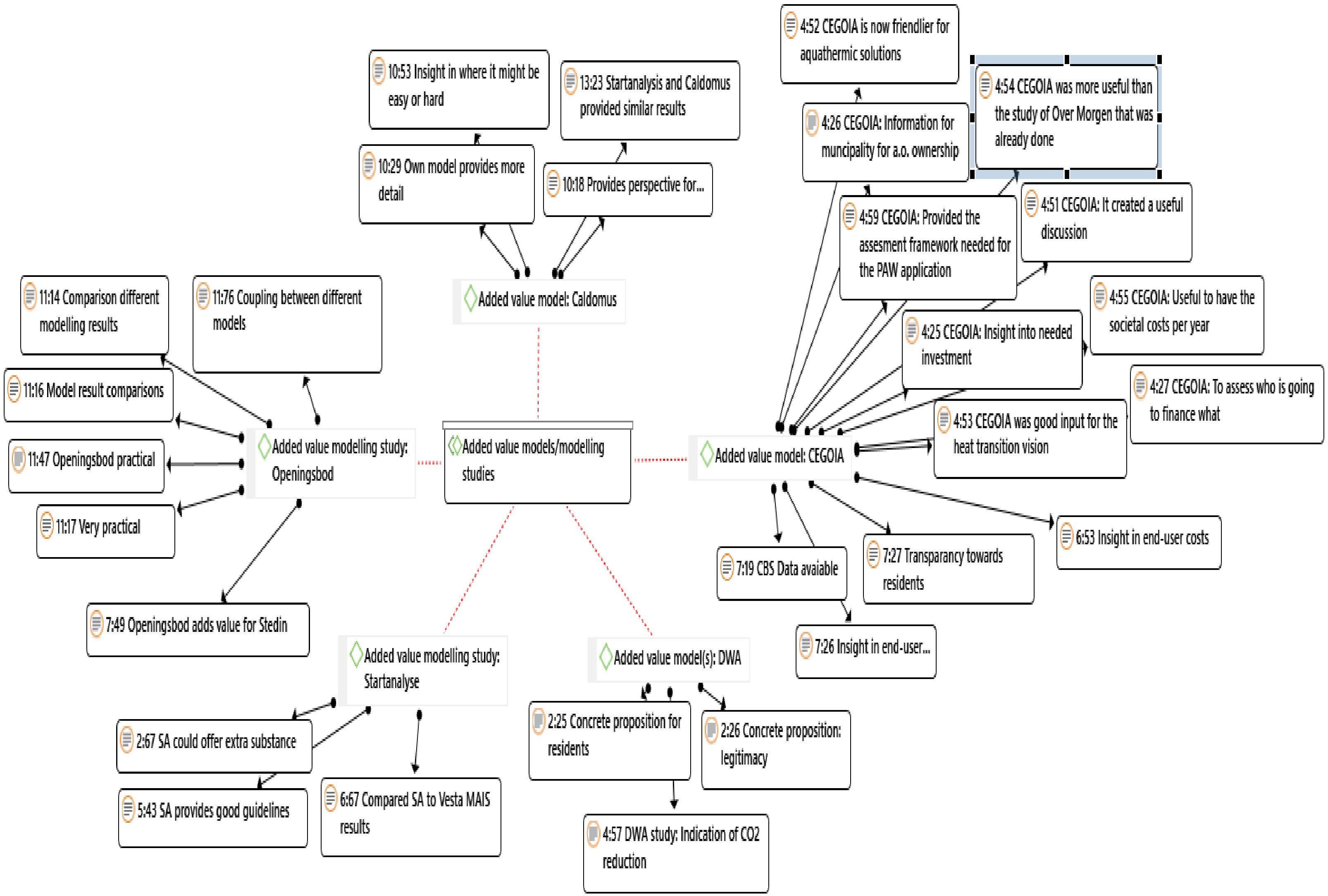

Figure 14: An overview of the quotes (with English titles) of the code group 'added value models/modelling studies'.

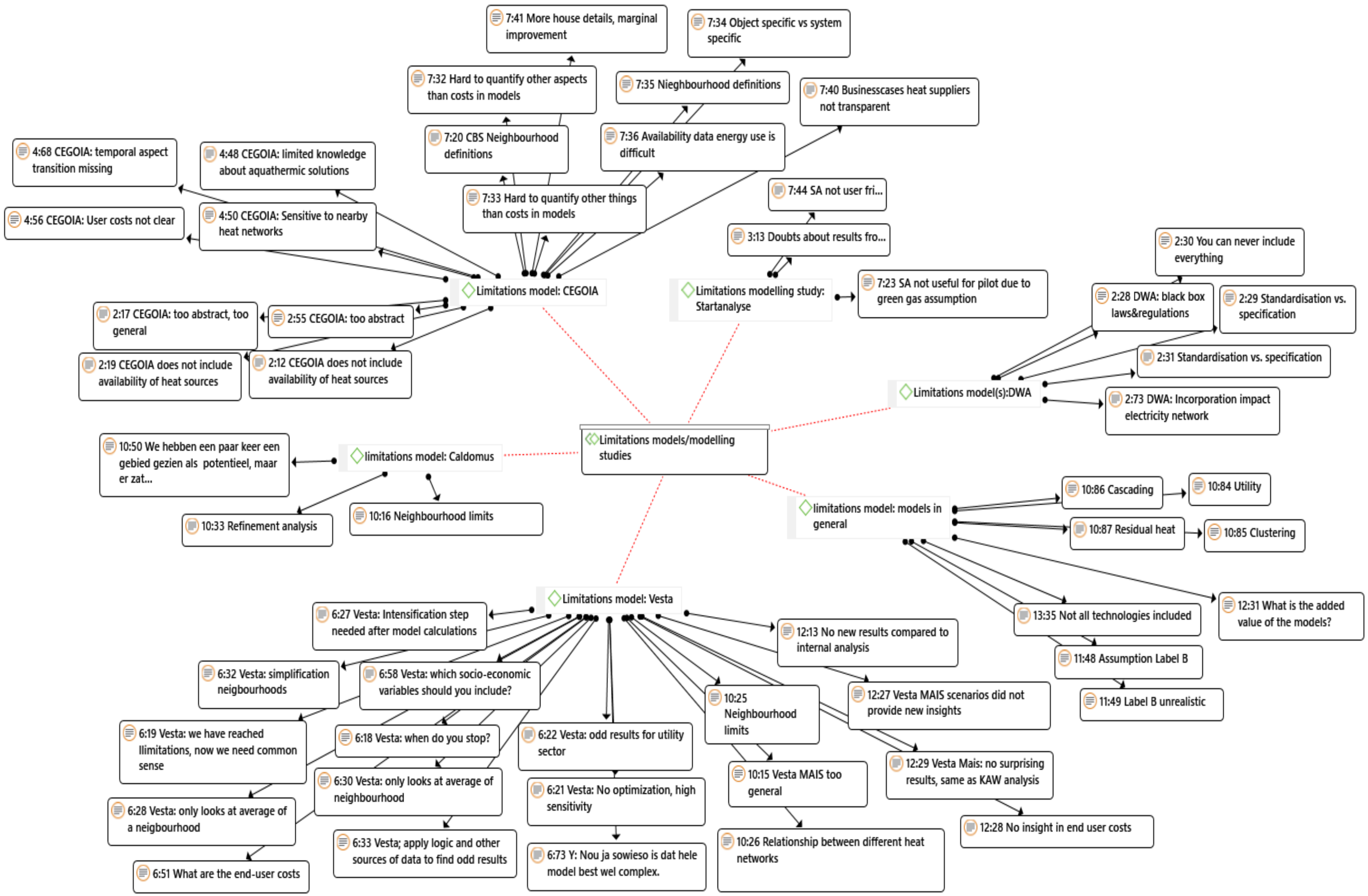

Figure 15:An overview of the quotes (with English titles) of the code group 'limitations models/modelling studies'.

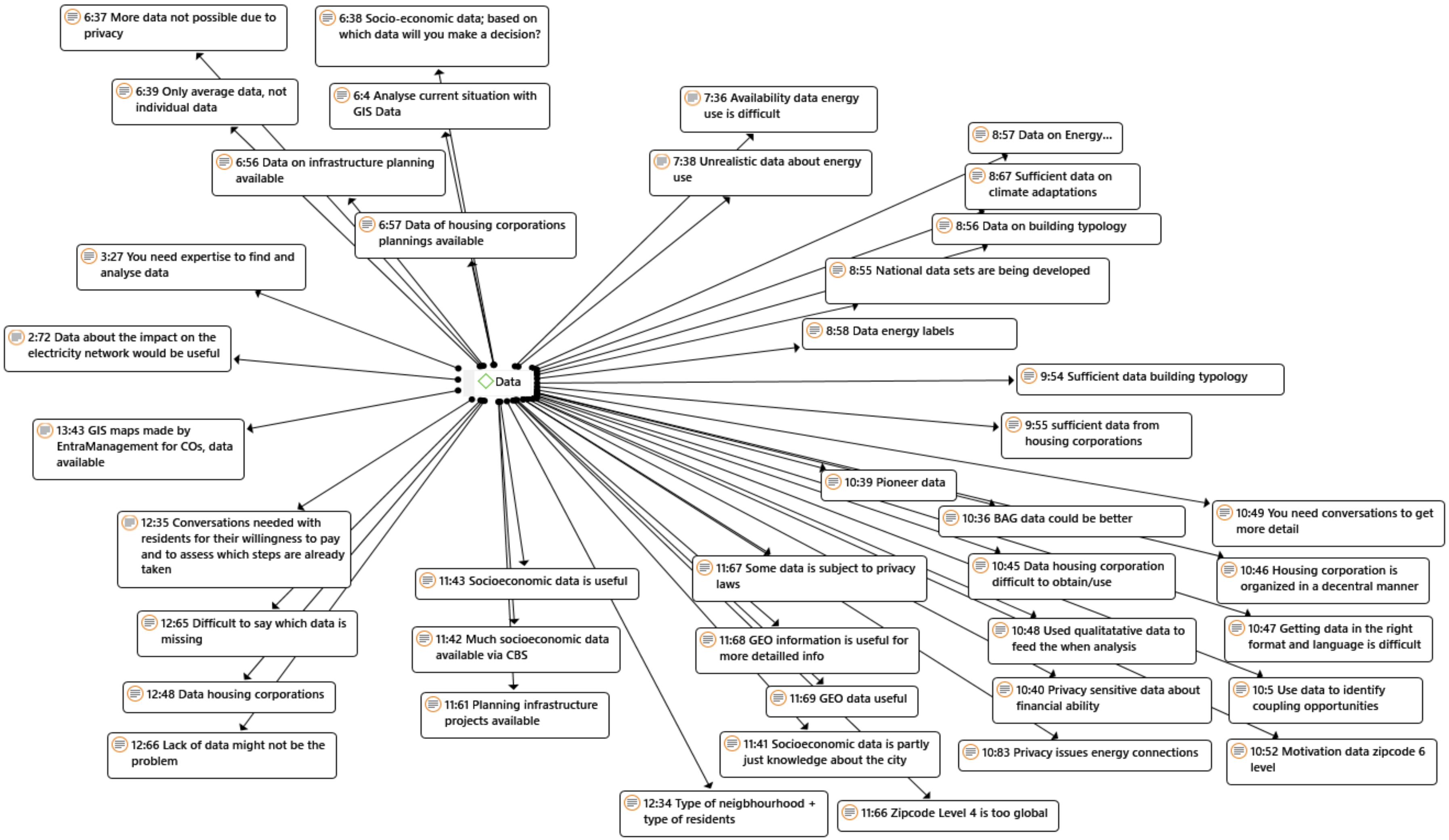

Figure 16: An overview of the quotes (with English titles) of the code 'data'.

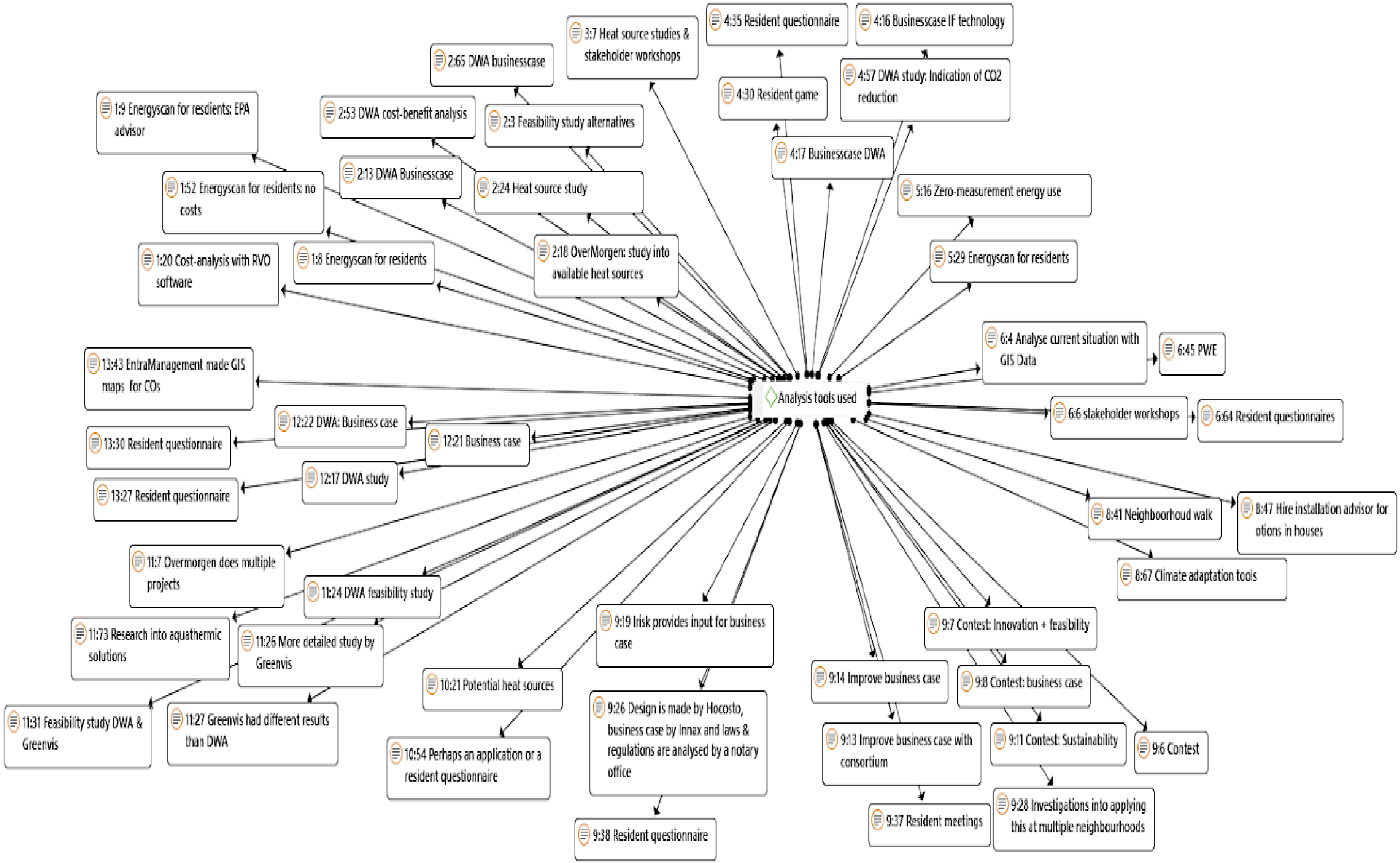

Figure 17: : An overview of the quotes (with English titles) of the code 'analysis tools used'

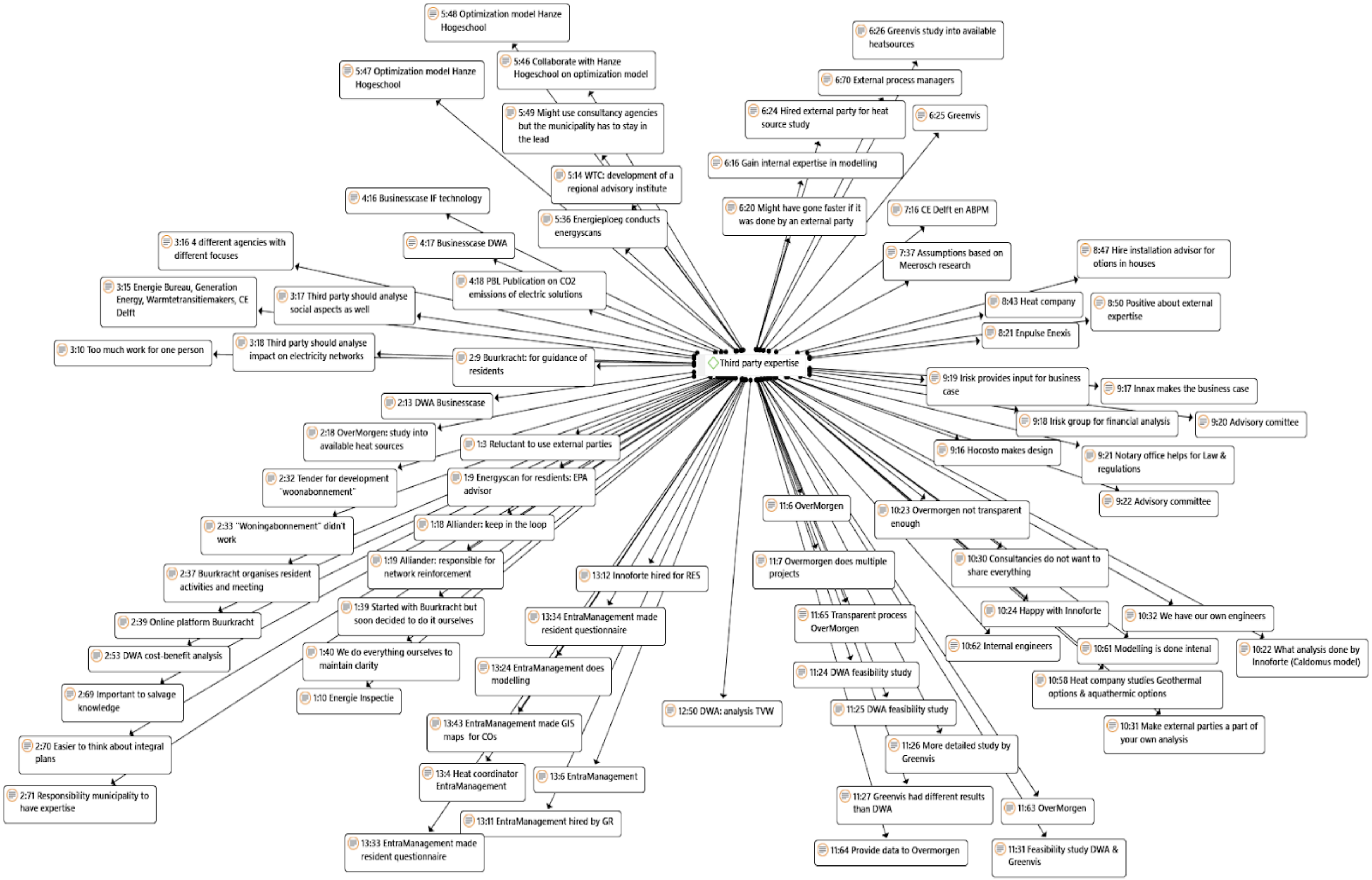

Figure 18: An overview of the quotes (with English titles) of the code 'third party expertise'.

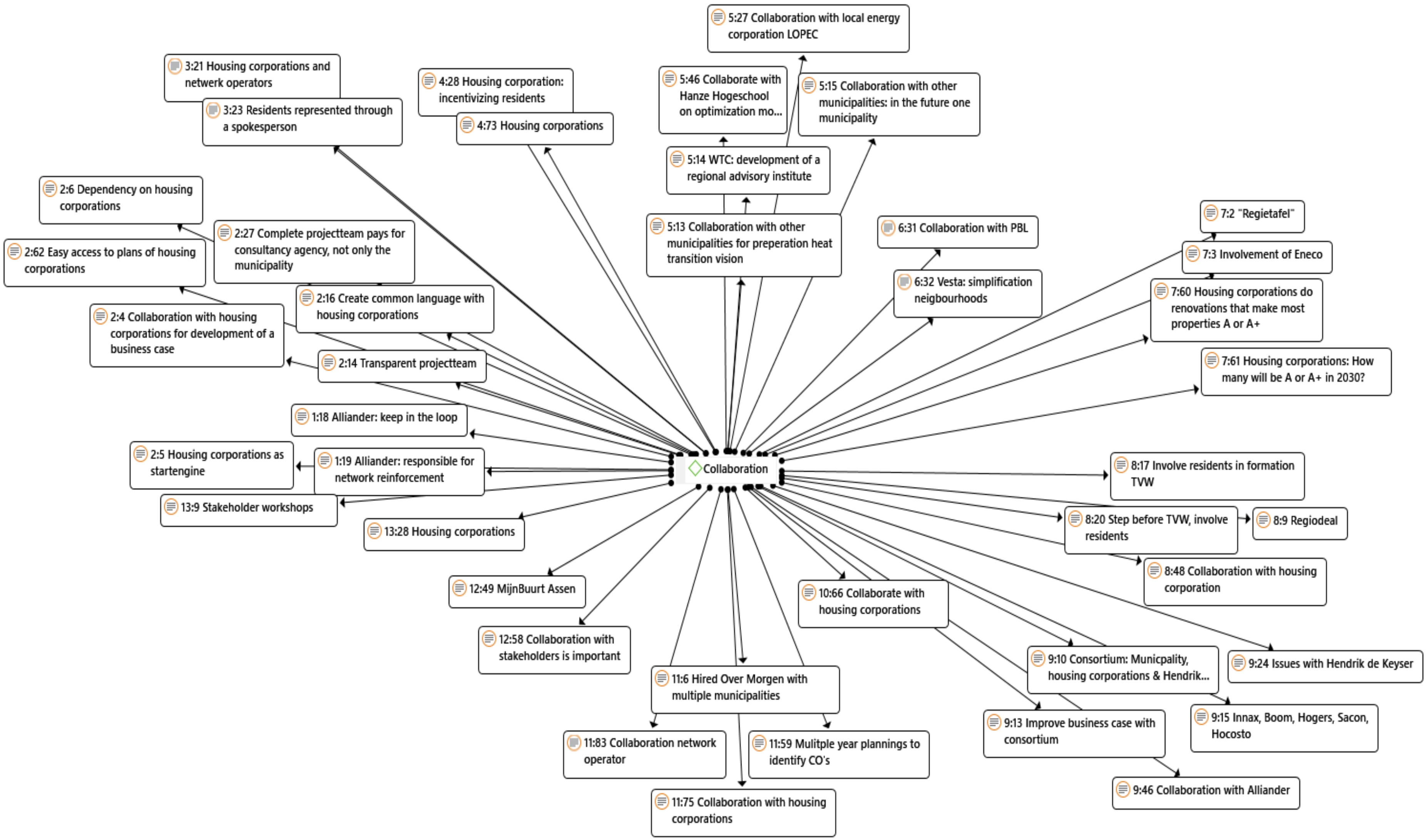

Figure 19: An overview of the quotes (with English titles) of the code 'collaboration'.

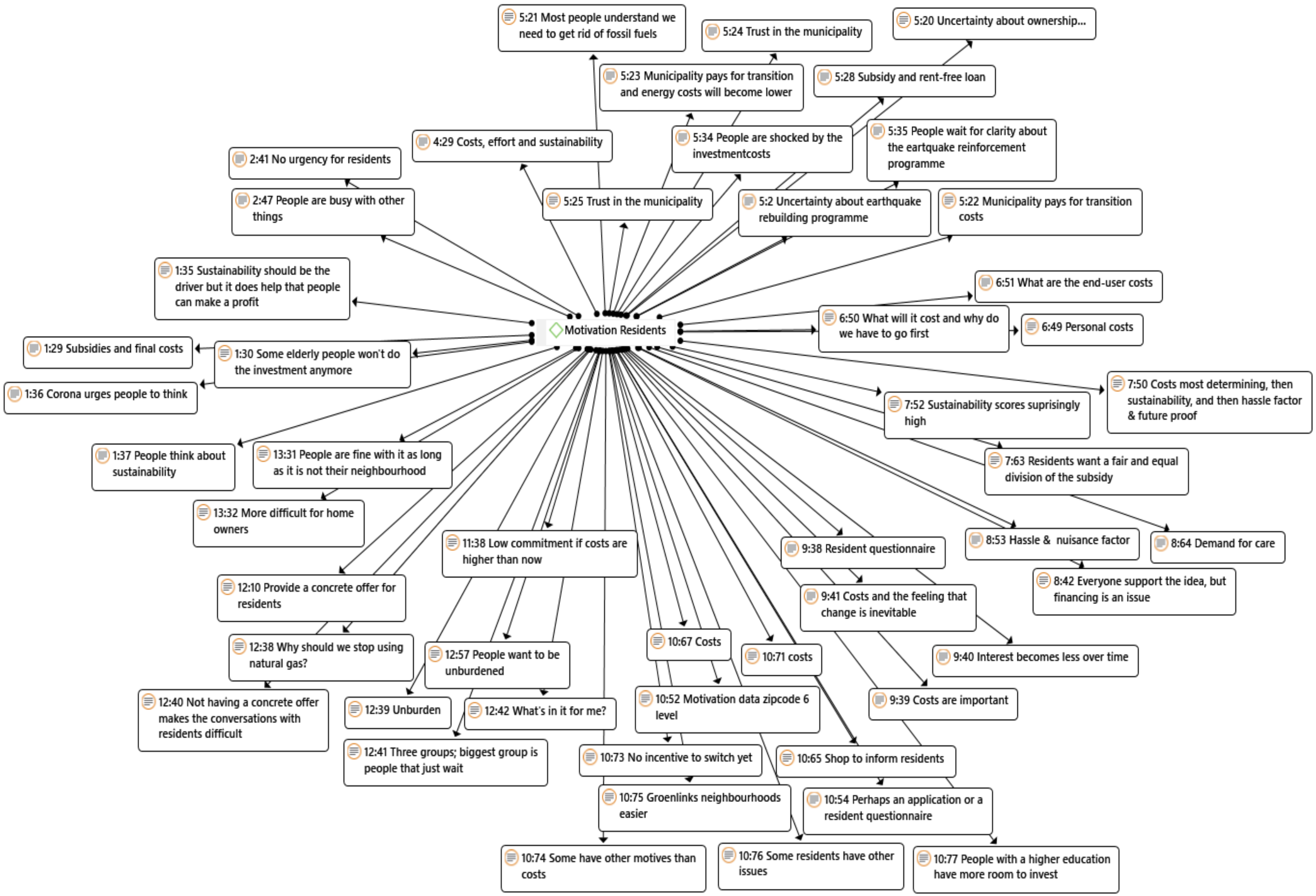

Figure 20: An overview of the quotes (with English titles) of the code 'motivation residents'.

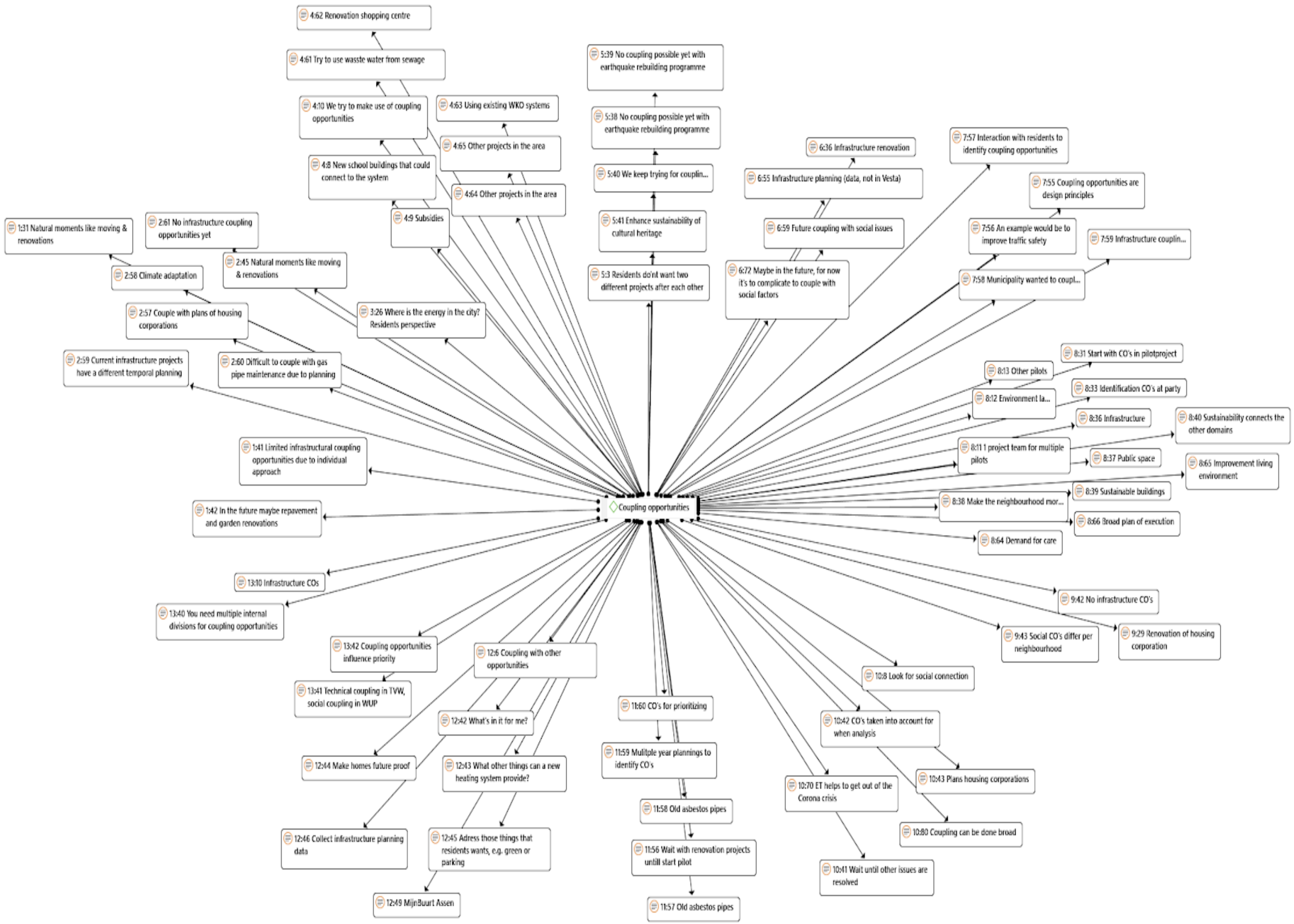

Figure 21: An overview of the quotes (with English titles) of the code 'coupling opportunities'.

Appendix G: Quotes results interviews model developers

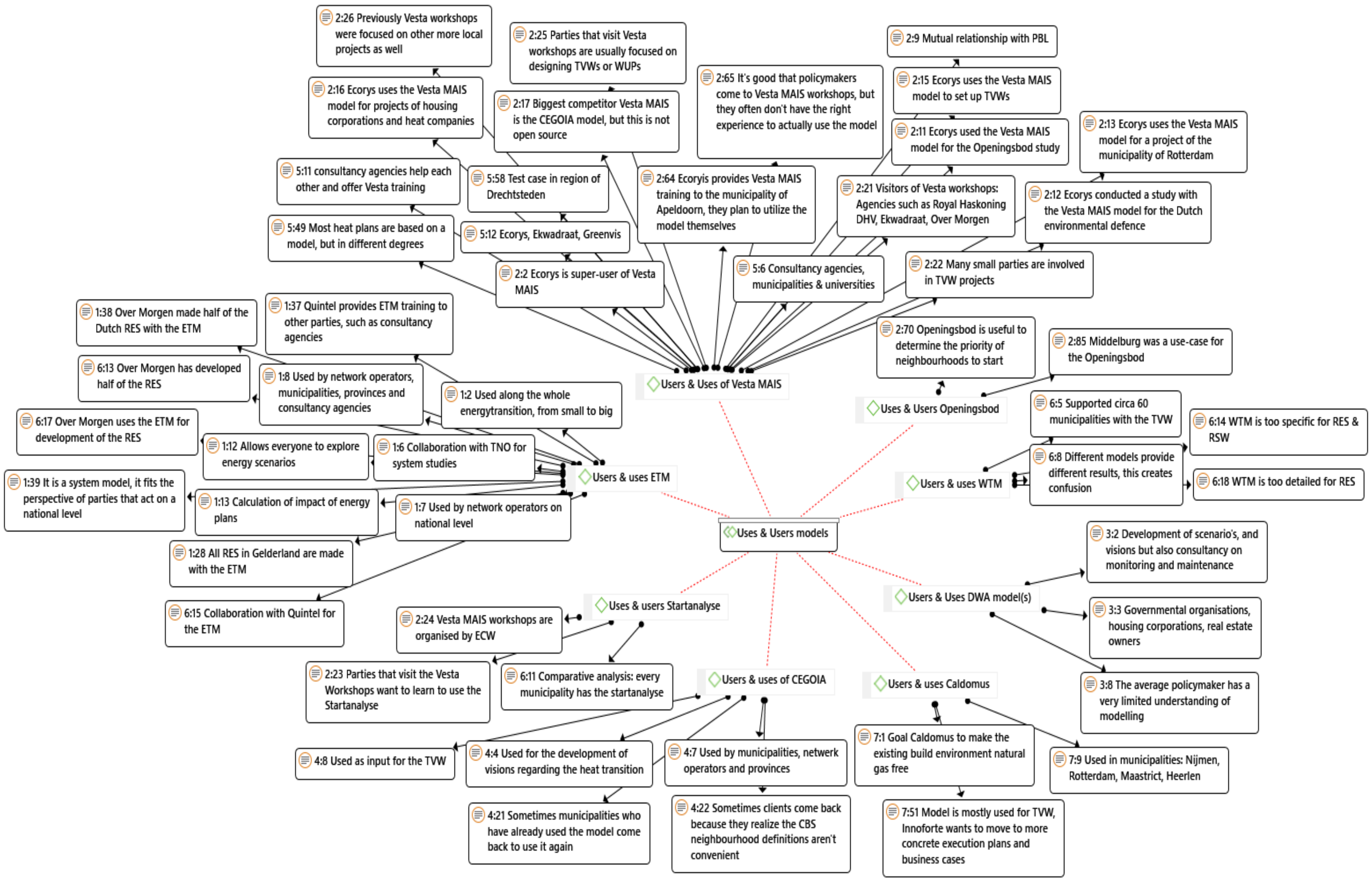

Figure 22: An overview of the quotes (with English titles) of the code group 'uses & users models'.

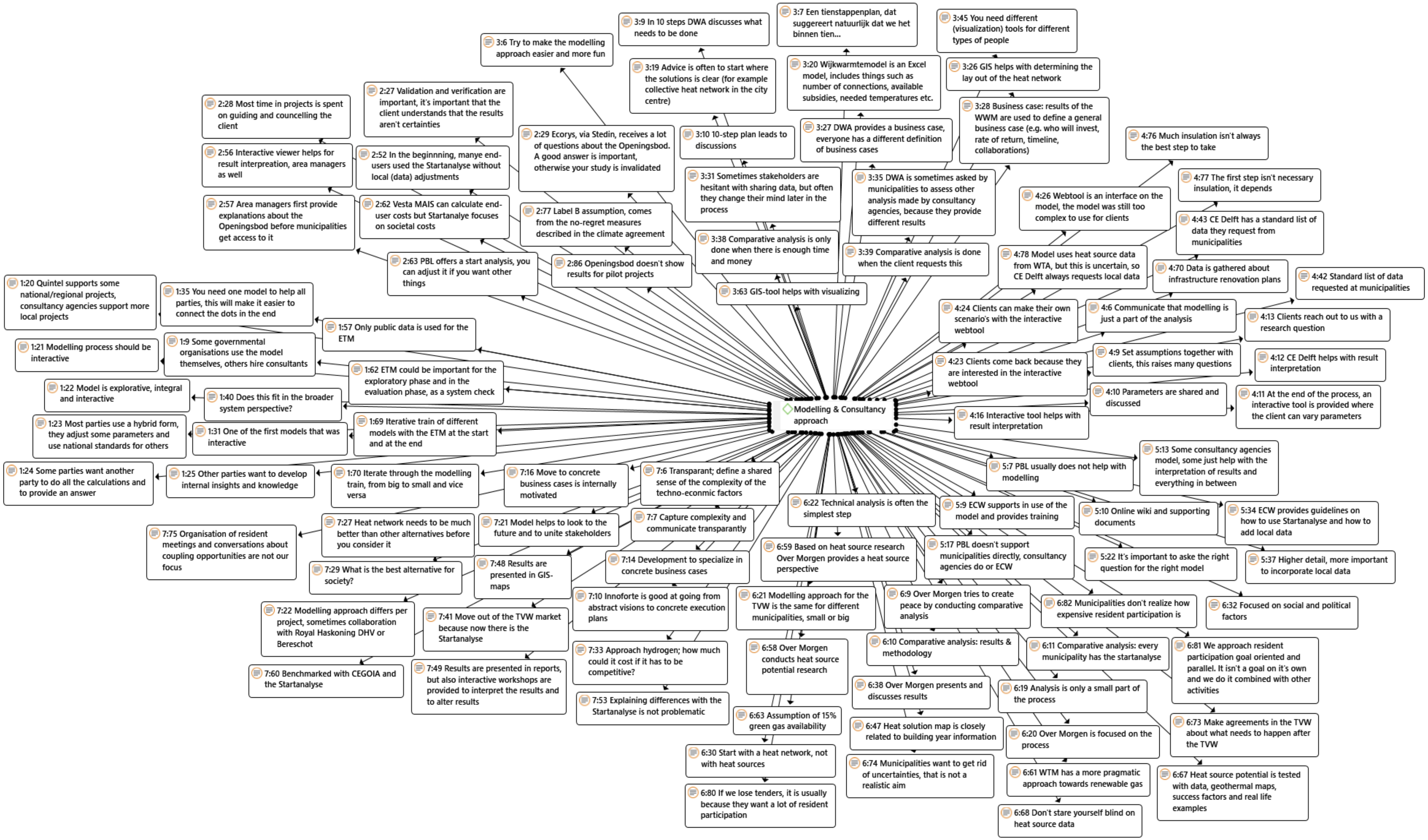

Figure 23: An overview of the quotes (with English titles) of the code 'modelling & consultancy approach'.

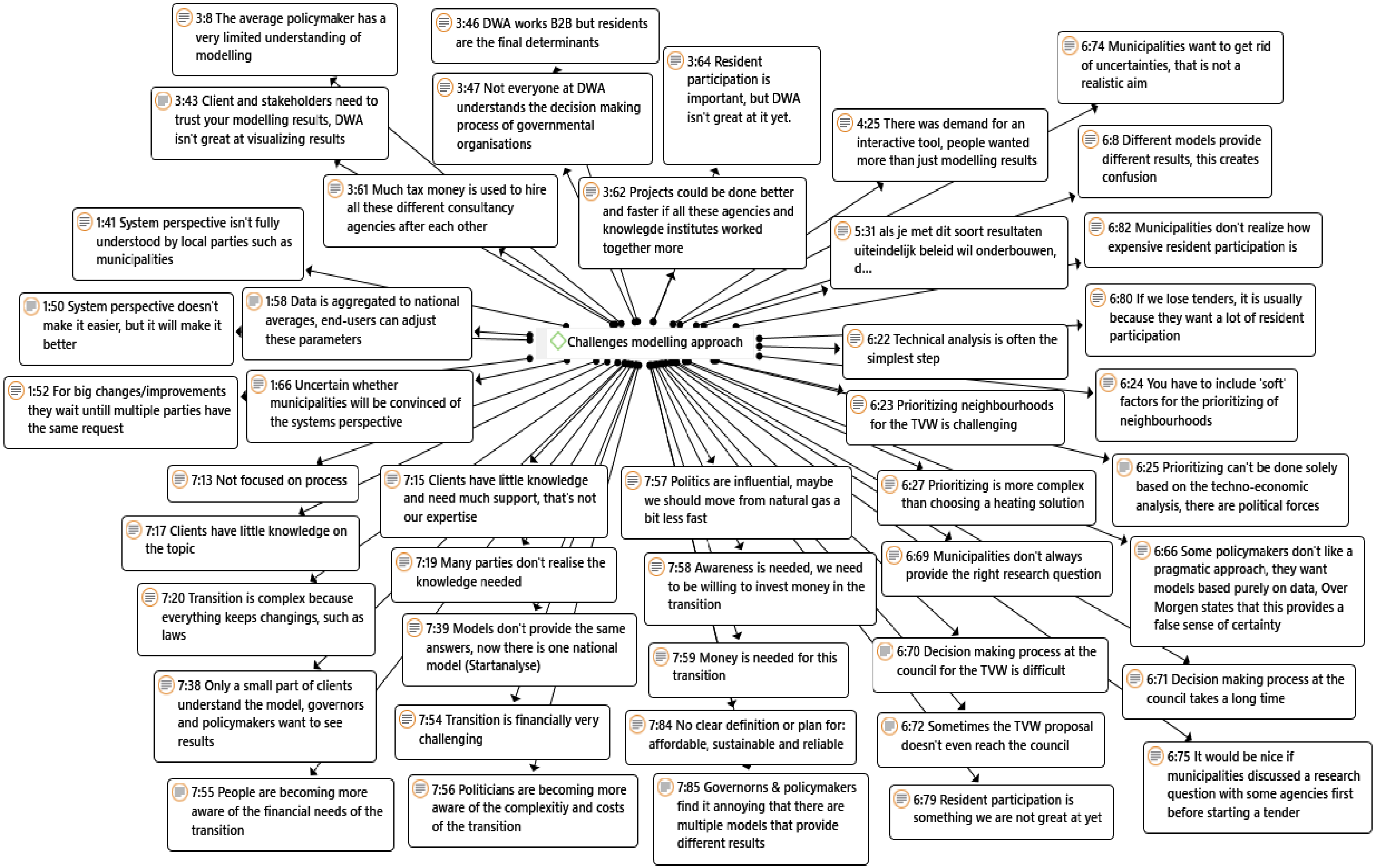

Figure 24: An overview of the quotes (with English titles) of the code 'challenges modelling approach'.

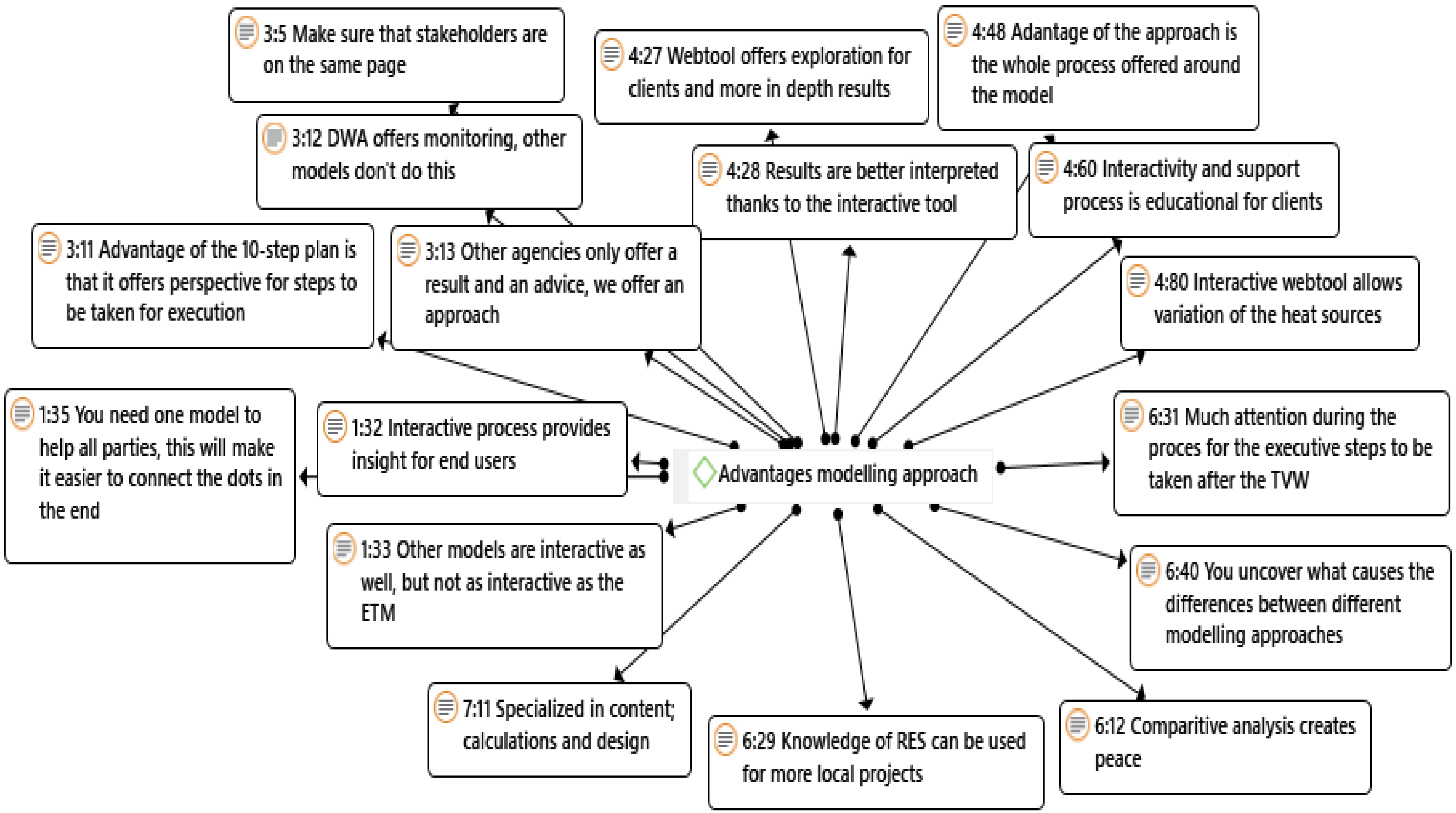

Figure 25: An overview of the quotes (with English titles) of the code 'advantages modelling approach'.

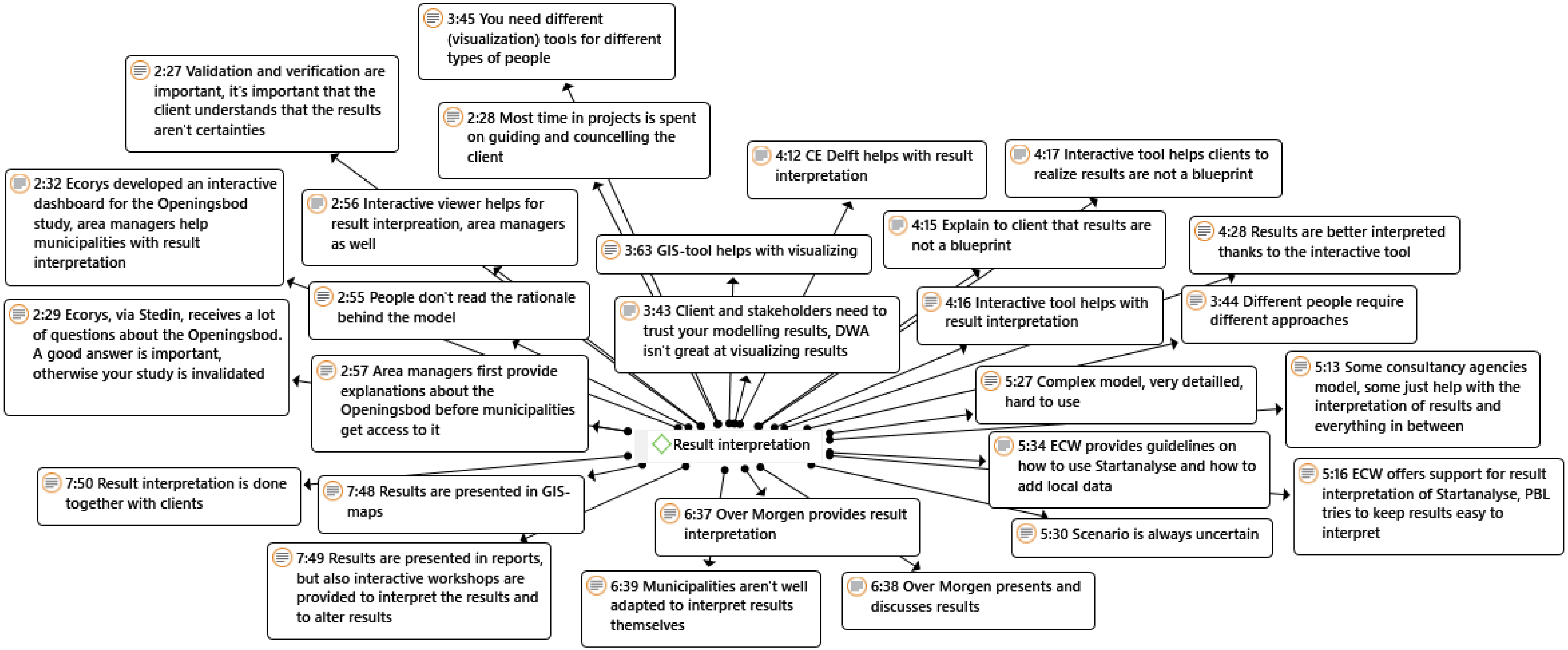

Figure 26: An overview of the quotes (with English titles) of the code 'result interpretation'.

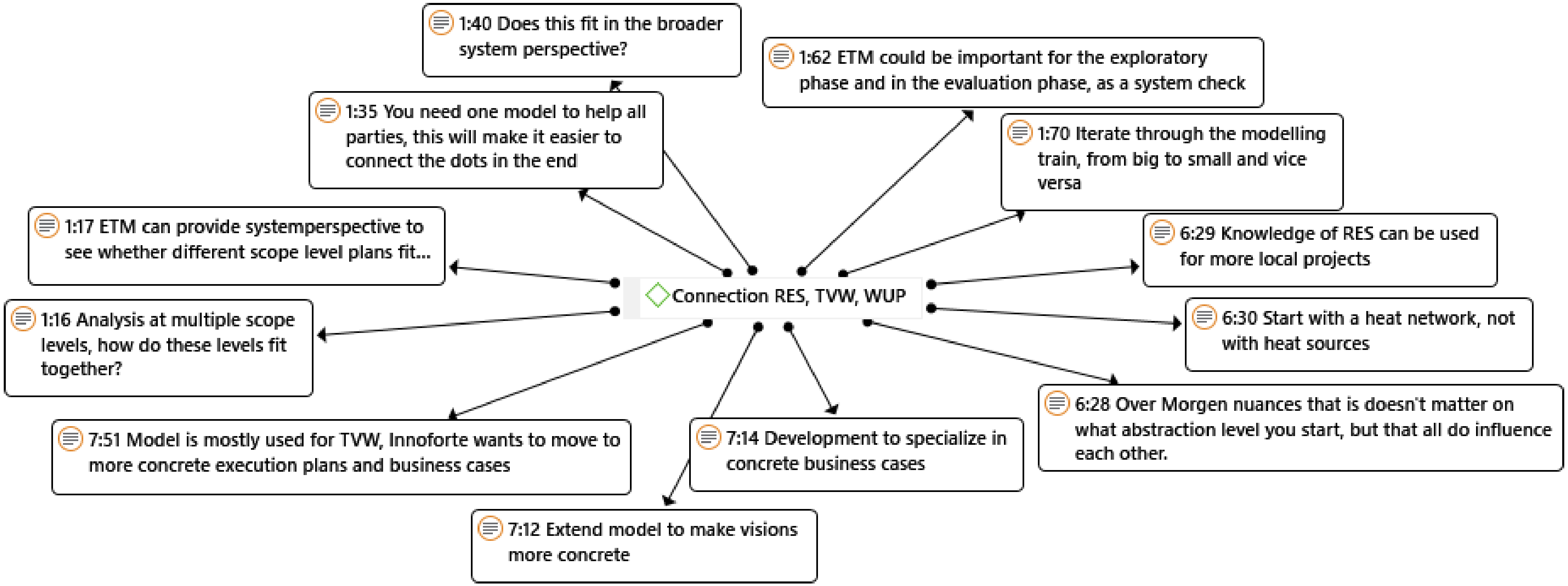

Figure 27: An overview of the quotes (with English titles) of the code 'connection RES, TVW, WUP'.

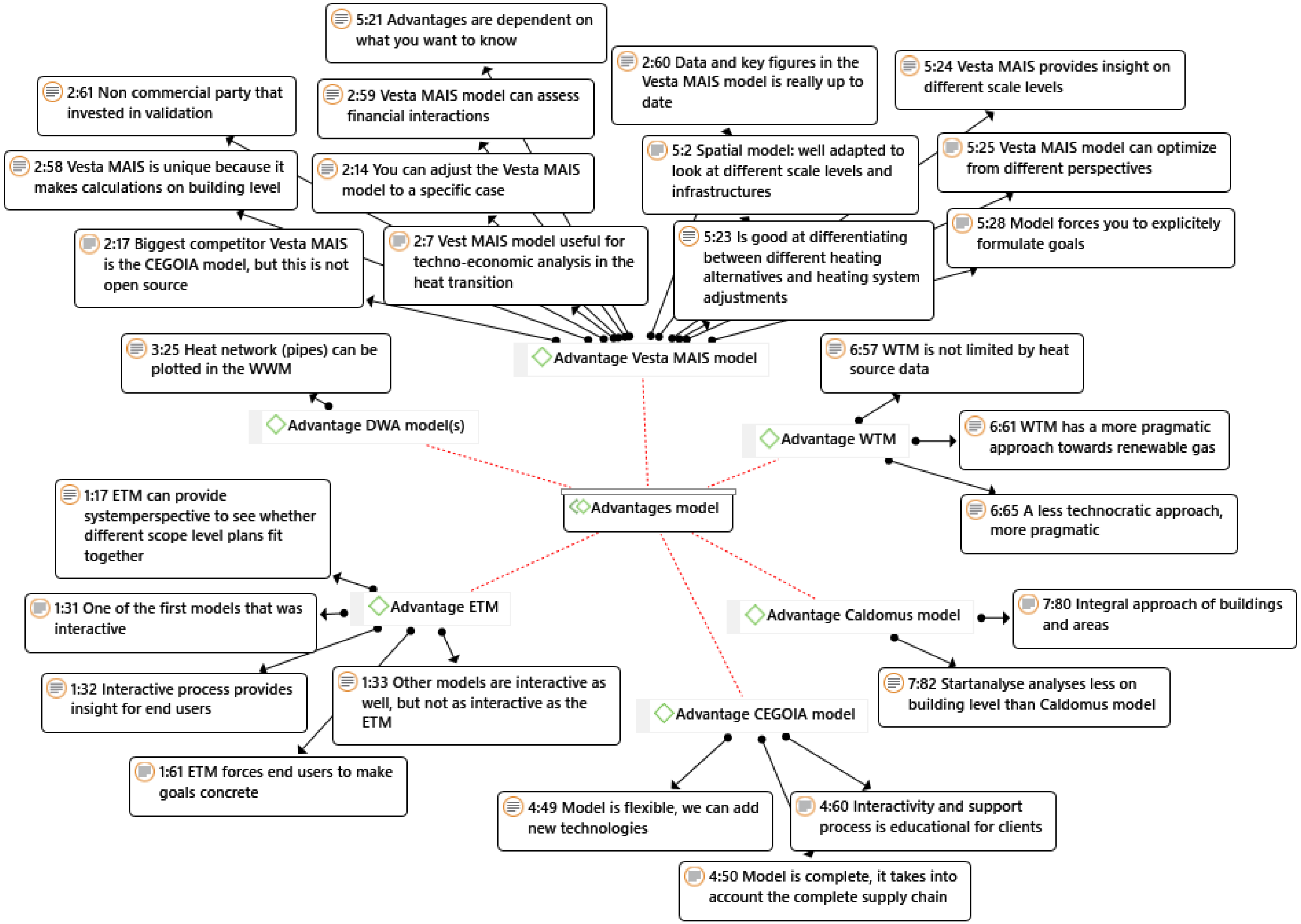

Figure 28: An overview of the quotes (with English titles) of the code group ‘advantages model’.

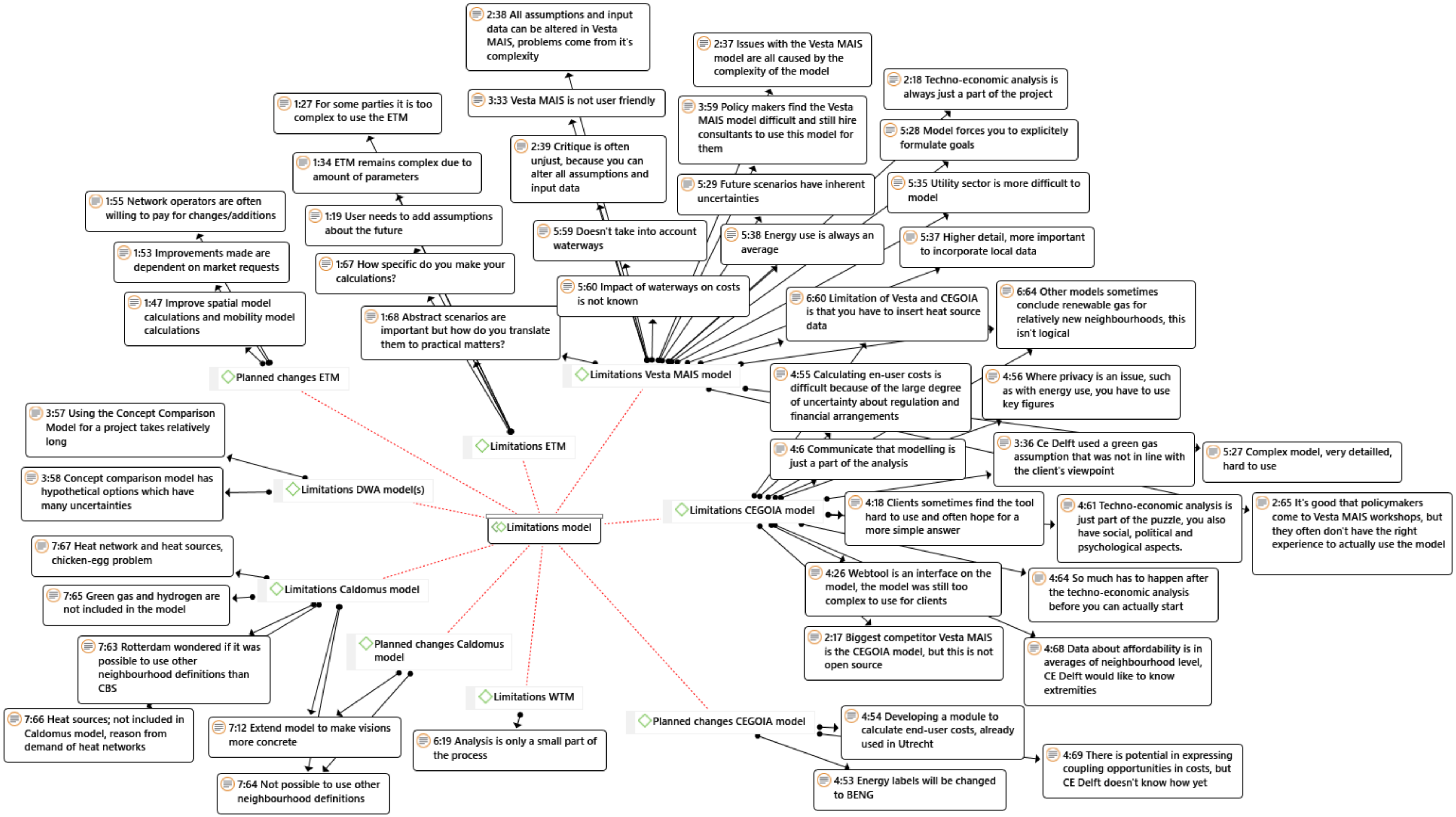

Figure 29: An overview of the quotes (with English titles) of the code group 'limitations model'.

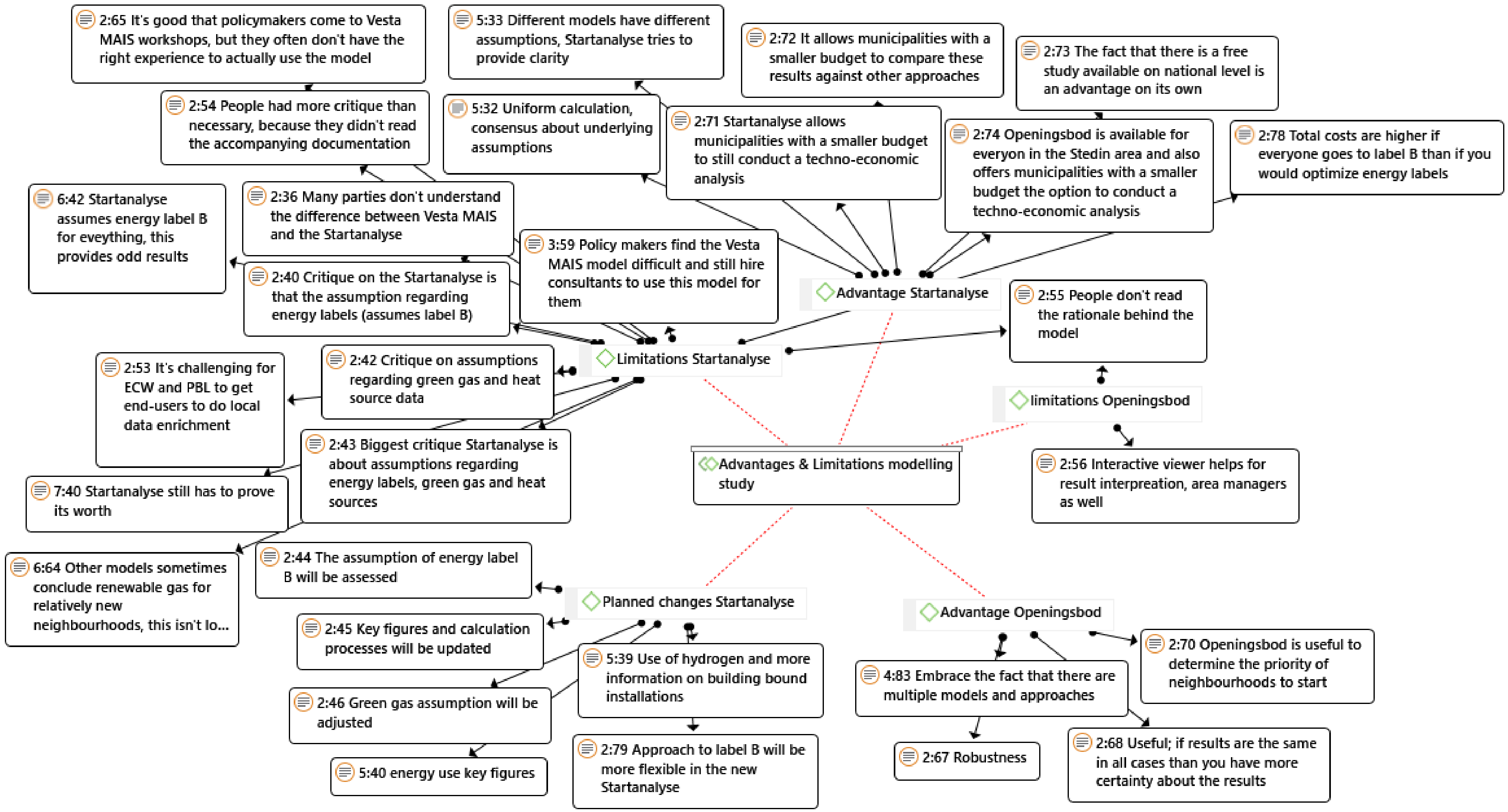

Figure 30: An overview of the quotes (with English titles) of the code group 'advantages & limitations modelling study'.

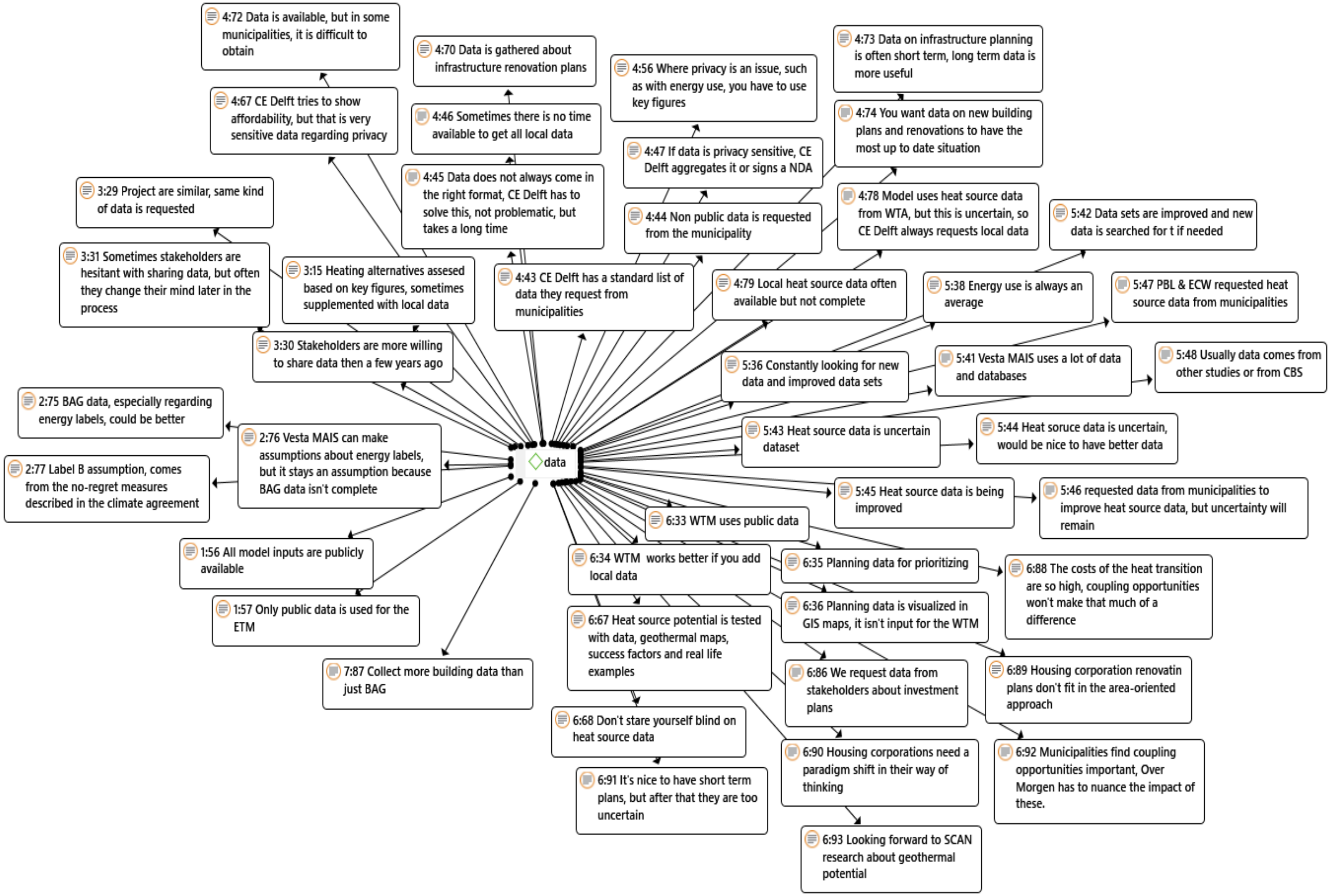

Figure 31: An overview of the quotes (with English titles) of the code 'data'.

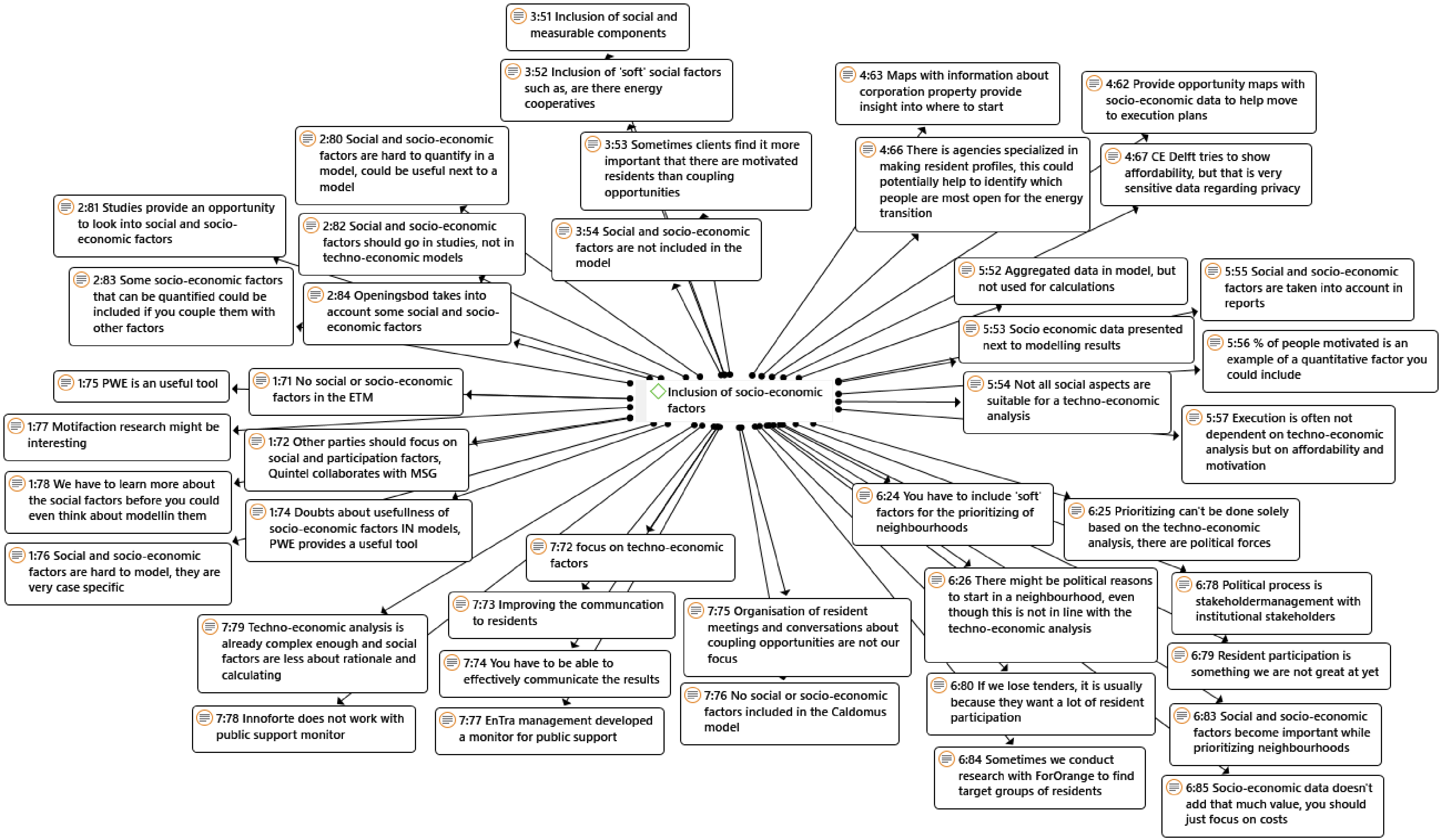

Figure 32: An overview of the quotes (with English titles) of the code 'Inclusion of socio-economic factors'.

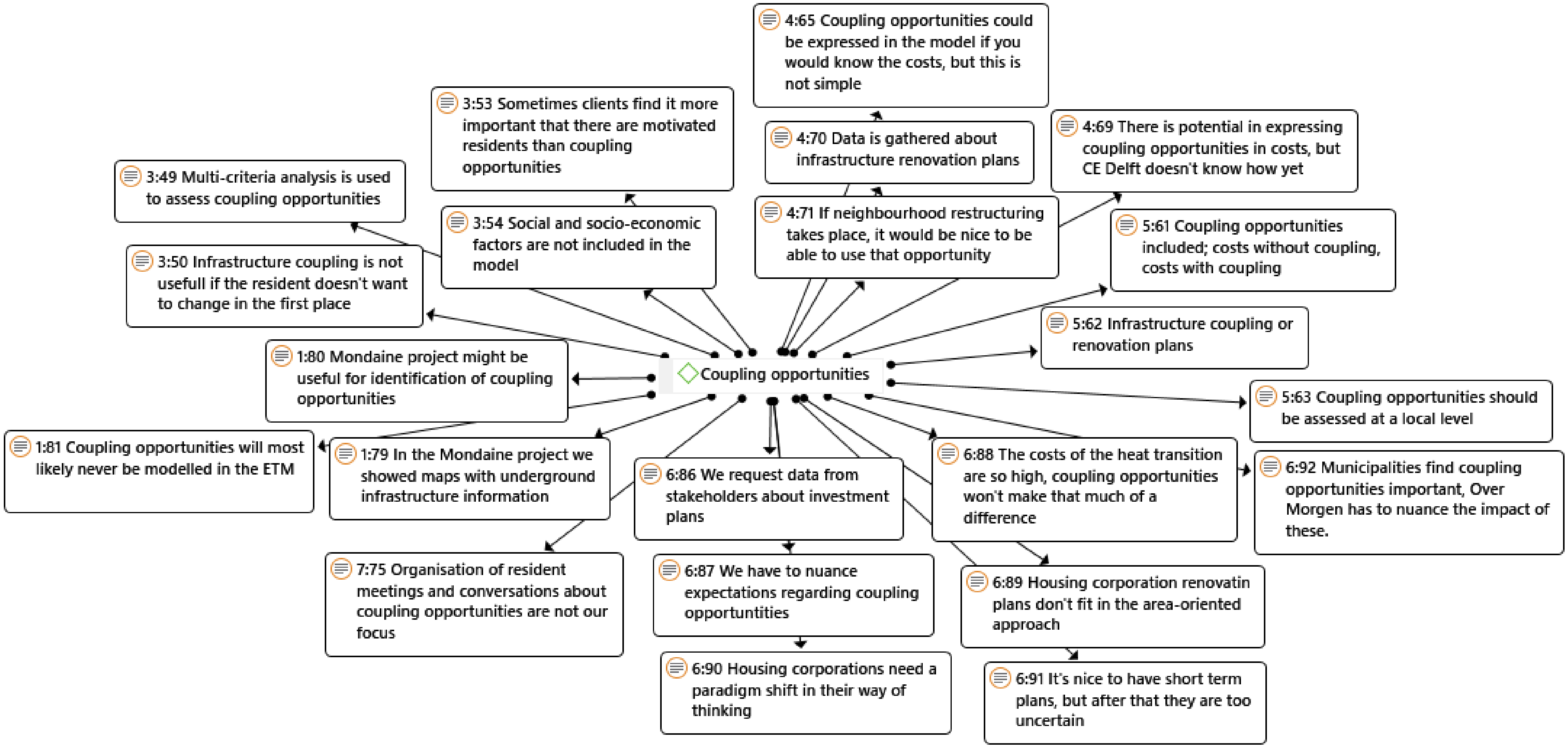

Figure 33: An overview of the quotes (with English titles) of the code 'coupling opportunities'.

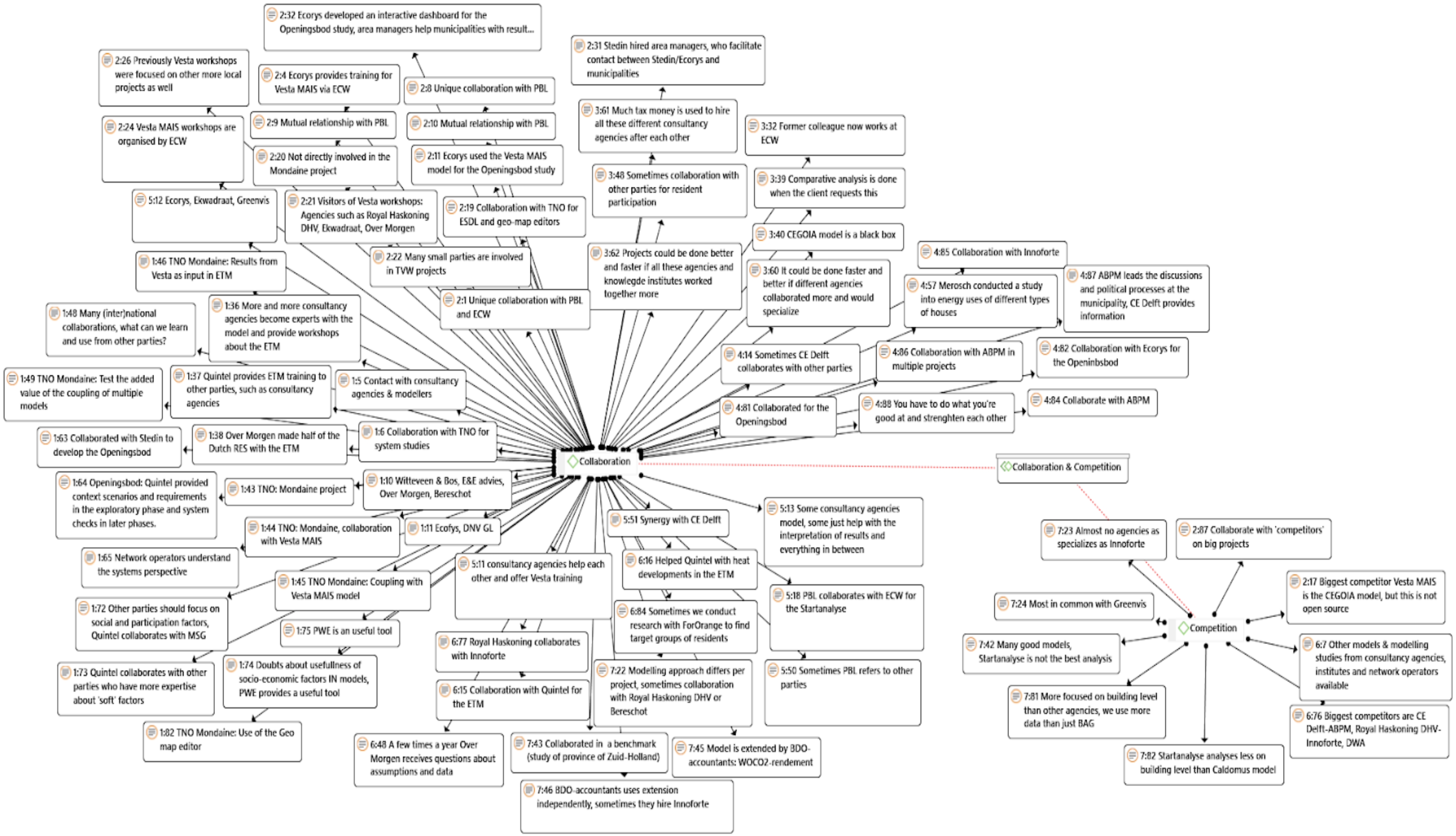

Figure 34: An overview of the quotes (with English titles) of the code group 'collaboration & competition'.

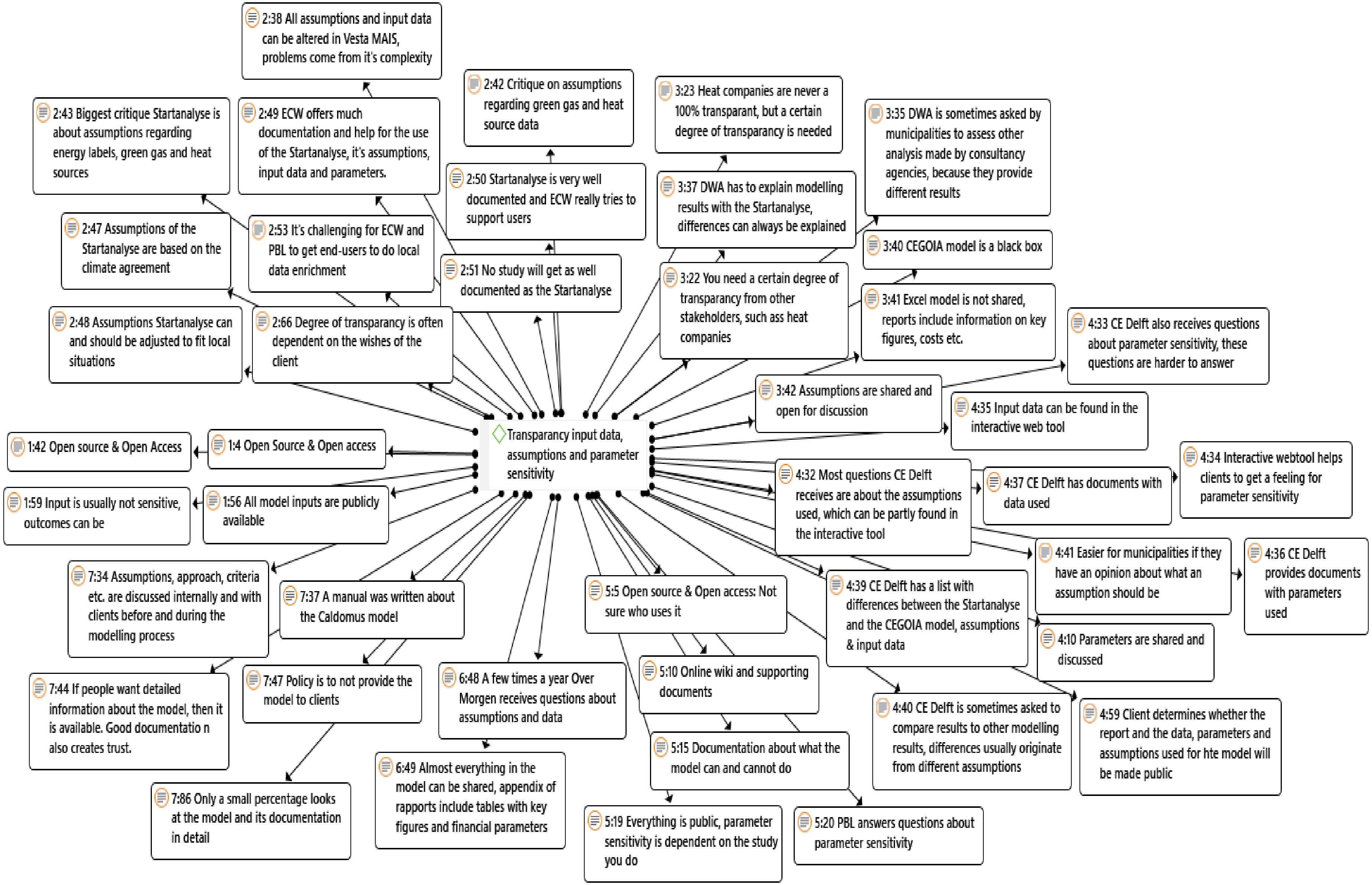

Figure 35: An overview of the quotes (with English titles) of the code 'transparency input data, assumptions and parameter sensitivity'.

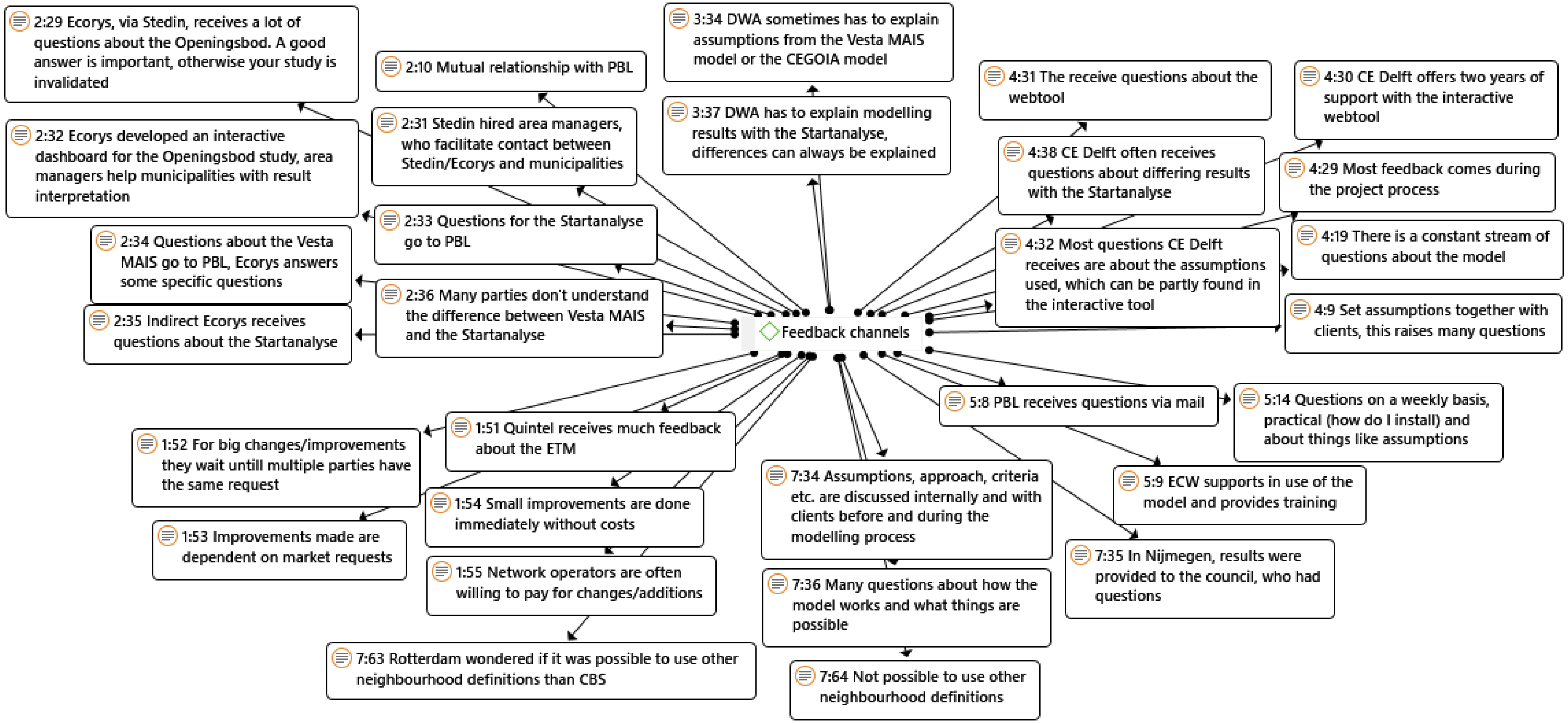

Figure 36: An overview of the quotes (with English titles) of the code 'Feedback channels'.

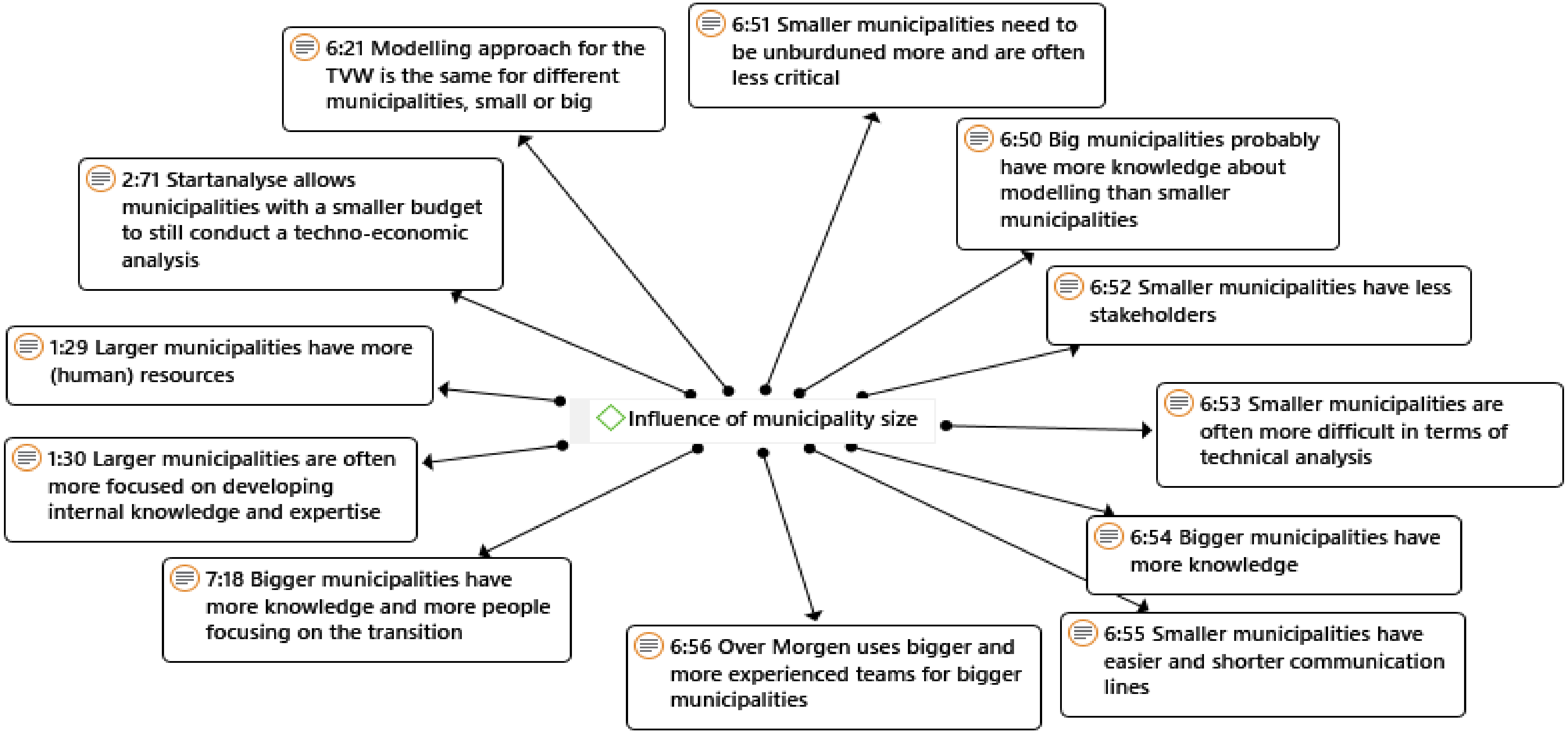

Figure 37: An overview of the quotes (with English titles) of the code 'influence of municipality size'.

Appendix H: coding tables

Table 37: An overview of the 37 thematic codes, code frequency (= number of quotes per code) and the number of transcripts that quotes were identified in.

Code	Code frequency	# Transcripts
Approach	149	11
Third-party expertise	79	13
Coupling opportunities	70	13
Model/modelling study used	65	13
Motivation residents	52	12
Analysis tools used	51	12
Project progress	51	13
Data	43	9
Collaboration	42	13
Participation activities	42	12
Information Interviewee	37	13
(Envisioned) natural gas alternative	35	10
Incentivizing Residents	30	5
Financial arrangement residents	27	9
Added value pilot project	25	1
Limitations approach:	22	9
Future approach	21	8
Limitations model: Vesta	19	5
Responsibility municipality	17	7
Added value model: CEGOIA	13	3
Limitations model: CEGOIA	11	4
Limitations models in general	11	5
Other reasons to opt for a heating alternative	8	3
Added value analysis tool: Resident questionnaire	7	1
Added value modelling study: Openingsbod	6	2
Limitations model: DWA	4	1

Added value model: Caldomus	4	2
Added value model: DWA	3	2
Added value modelling study: Startanalyse	3	3
Limitations model: Caldomus	3	1
Added value analysis tool: Greenvis	2	1
Not familiar with energy models	2	2
Added value analysis tool: Resident meetings	1	1
Limitations analysis tool: Resident game	1	1
Added value analysis tool: Susteen	1	1

Table 38: An overview of the 53 thematic codes, the groundedness of codes (= number of quotes per code), the number of transcripts that quotes were identified in and the code group.

Code	Code groundedness	# Transcripts	Code group
Modelling & Consultancy approach	100	7	Consultancy & modelling approach
Collaboration	68	7	Collaboration & Competition
data	46	7	
Challenges modelling approach	45	6	Consultancy & modelling approach
Inclusion of socio-economic factors	43	7	Consultancy & modelling approach
Information about assumptions	37	7	Consultancy & modelling approach
Information about parameter sensitivity	34	7	Consultancy & modelling approach
Information about input data	32	7	Consultancy & modelling approach
Feedback channels	30	6	Consultancy & modelling approach
Result interpretation	28	6	Consultancy & modelling approach
Coupling opportunities	22	5	Consultancy & modelling approach
Users & Uses of Vesta MAIS	19	2	Uses & Users models
Limitations Vesta MAIS model	18	5	Limitations model
Information interviewee	17	5	
Advantages modelling approach	17	6	Consultancy & modelling approach
Information Caldomus	15	2	General information model/modelling study
Users & uses ETM	13	2	Uses & Users models
Information model ETM	13	1	General information model/modelling study
Limitations Startanalyse	13	4	Limitations modelling stud

Advantage Vesta MAIS model	13	2	Advantages model
Influence of municipality size	12	4	
Limitations CEGOIA model	12	4	Limitations model
Information DWA Model(s)	11	1	General information model/modelling study
Planned changes Caldomus model	11	1	Limitations model
Connection RES, TVW, WUP	12	3	Consultancy & modelling approach
Competition	9	2	Collaboration & competition
Information model: CEGOIA	9	2	General information model/modelling study
Information Startanalyse	7	3	General information model/modelling study
Limitations Caldomus model	6	1	Limitations model
Planned changes Startanalyse	6	2	Limitations modelling stud
Advantage ETM	6	1	Advantages model
Information WTM	6	1	General information model/modelling study
Advantage Startanalyse	6	2	Advantages modelling study
Information Vesta Mais	5	2	General information model/modelling study
Limitations ETM	5	1	Limitations model
Users & uses of CEGOIA	5	1	Uses & Users models
Uses & users Startanalyse	5	2	Uses & users modelling studies
Advantage Openingsbod	4	2	Advantages modelling study
Users & uses WTM	4	1	Uses & Users models
Advantage CEGOIA model	3	1	Advantages model
Planned changes ETM	3	1	Limitations model
Planned changes CEGOIA model	3	1	Limitations model
Users & uses of the Caldomus model	3	1	Uses & Users models
Advantage WTM	3	1	Advantages model
Users & Uses DWA model(s)	3	1	Uses & Users models
Information Openingsbod	2	1	General information model/modelling study
Limitations DWA model(s)	2	1	Limitations model
Advantage Caldomus model	2	1	Advantages model
Uses & Users Openingsbod	2	1	Uses & users modelling studies

Limitations WTM	1	1	Limitations model
Information modelling study: Openingsbod	1	1	General information model/modelling study
Advantage DWA model(s)	1	1	Advantages model

Appendix I: Participatory Value Assessment (PWE)

PWE is a new economic evaluation tool that can assess the welfare effects of policy choices, based on the preferences of individuals about the allocation of public and private resources. Participants of a PWE see a restriction and a few possible policy options, including the effects of these options. Participants then have to choose within the restriction (Mouter et al., 2019)

Appendix J: Mondaine

The Mondaine suite is set-up by a collaboration between TNO, Quintel Intelligence, Geodan, Object Vision, Balance and Ekwadraat. This team combines knowledge about energy models and tools, GIS, software and ICT and knowledge about decision-making processes. The Mondaine suite is an innovative coupling mechanism for energy models. It can bundle the advantages of different energy calculation models, as it offers coupling of existing models. This creates an integral set of models and data. Because the energy models are coupled, data can be compared and combined more effectively and consistently (Zwamborn, 2020b).

The energy transition is a complex challenge. In order to make the complexity manageable, the energy transition is calculated using different calculation models. Each of these calculation models has its strengths and weaknesses. No model is strong in all aspects and in all levels of detail. To utilize the strengths of each model, it is necessary to make models work together. Within the Mondaine project, the VESTA MAIS model, the ETM and PICO models are linked. This was partly done via the ESDL MapEditor. ESDL, the Energy System Description Language provides a common language that, when models "speak" that language, allow them to work together The ESDL MapEditor is a map-based energy system editor. With this editor, you can define different scenarios for the energy transition, where all information is stored in the ESDL language (Zwamborn, 2020a).