ENERGY JUSTICE IN THE HEATING TRANSITION

Exploring justice considerations in Energy Model Use Cases in the Netherlands

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EXECUTIVE SUMMARY

The energy transition is a fundamental shift in the world's energy landscape, aimed at reducing carbon emissions and transitioning to a more sustainable, low-carbon energy system. This transition is closely aligned with the goals of the Paris Agreement, the landmark international treaty adopted in 2015, which seeks to limit global warming, with an aspirational target of limiting it to 1.5 degrees celsius. The European Union has been a key player in both the development of the Paris Agreement and its implementation, demonstrating its commitment to combating climate change. To achieve this target, the European Union is pursuing various strategies, including the decarbonization of its energy sector. In order to stay in line with the goals, drastic actions are being carried out without entirely assessing the long term outcomes. Energy transitions are often accompanied by changes in the distribution of benefits and harms, and if these changes are not managed equitably, they may increase existing inequalities and create new forms of injustice.

The government of the Netherlands has taken several measures to achieve climate neutrality, one crucial task being the replacement of natural gas in its heating network. The heating sector so far has been reliant on shale gas for the past few decades, and the government now wants to implement new alternatives that are more sustainable. To anticipate the most favorable options, governmental bodies and local authorities are utilizing tools to assist them in their decision-making processes, especially energy system models.

Energy system modelling is a process of developing and analyzing models that represent the components and processes of energy systems. These models help to simulate the operation and behavior of energy systems under different scenarios and conditions, and to evaluate the impacts of policy decisions and technology choices. However, energy system models often neglect the social dimensions which are essential components of energy justice. This study aims to present a critical analysis of the representation of energy justice in energy system models through a case study and identifies the challenges of integrating energy justice considerations into energy system modelling. Thus the following main research question was formulated:

To what extent have energy justice principles been represented in Energy modelling employed in the Dutch Heating Transition?

To set up the study, it was essential to establish the concept of energy justice and explore what kind of modelling approaches were being deployed. A literature review on this topic helped to understand the concepts, and select an energy justice framework that would serve as the base for this study (Sovacool & Dworkin, 2015). The framework provided a set of justice principles that were selected to assess the modelling use cases. This thesis explores the integration of energy justice principles within energy system modelling through an analysis of two distinct use case approaches in the municipality level, in the districts of Amersfoort and Drechtsteden in the Netherlands. These two use cases were chosen since they both had a large, diverse population, they had implemented a Heat Transition Vision and they made use of an energy model in their decision making process. The study aims to understand how energy justice considerations are manifested in the models and transition visions that were drafted, the challenges and opportunities they present, and their implications for equitable and sustainable energy transitions.

The study then included a document analysis to collect information, where a total of eleven reports were scrutinized to find how justice principles were defined in the models and heat visions. This was followed by semi structured interviews with eight participants from varied backgrounds, to gather their perspectives on how justice principles were interpreted and the challenges they faced. The data collected was categorically grouped in themes, focusing on affordability, transparency, resistance

and sustainability. The results of this study reveal that both use cases incorporate elements of energy justice in an indirect manner. Affordability is addressed through mechanisms like tax credits and investment allowances. Transparency is facilitated through engagement platforms and collaborative sessions, promoting stakeholder involvement. While resistance in the form of economic barriers is recognized, social aspects of resistance receive less attention. Sustainability is evident through considerations of energy-saving potential and monitoring carbon emissions.

While energy justice principles are not explicitly defined in the models, various attributes and mechanisms correspond to these principles. However, challenges and limitations include diverse interpretations of energy justice, tensions between prioritizing technical and social dimensions, and the quantification of ethical concepts. The difficulty in selecting the right modelling approach and the right source of information also leads to uncertainty and complexity.

This study contributes to the understanding of energy justice by providing empirical insights into its integration within energy system modeling. The findings highlight the complexities and possibilities of this integration, offering lessons for policymakers, researchers, and model developers. Recommendations for future research include exploring the impacts of energy justice measures in other sectors of the transition and also utilizing other frameworks to assess energy justice.

Contents

Nomenclature

CGE	Computable General Equilibrium
ECN	Energy Centre Netherlands
EIA	Energy Investment Allowance
ETM	Energy Transition Model
GDP	Gross Domestic Product
HDI	Human Development Index
$HREC$	Human Research Ethics Committee
$MAIS$	Multi Actor Impact Simulation
$MARKAL$	Market Allocation
NPV	Net Present Value
PBL	Planbureau voor de Leefomgeving
$PRIMES$	Policy Response Integrated Model
RES	Regional Energy Strategy
SDE	Sustainable Energy Transition Incentive Scheme
$SMART$	Simple Multi-Attribute Rating Technique
$UNDP$	United Nations Development Programme
VNG	Vereniging van Nederlandse Gemeenten

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1 INTRODUCTION

This chapter provides the reader with background information and context for the topics of energy modelling and energy justice, outlining what is currently known about these topics, gaps in knowledge, and why the research in this field is necessary.

The energy transition refers to the global shift from reliance on fossil fuels to more sustainable and renewable energy sources. It is an essential and urgent process aimed at addressing the challenges posed by climate change and achieving a more sustainable and resilient energy future. In recent years, there has been notable advancement in transitioning the energy system away from fossil fuels. In the Paris Agreement of 2015, nations committed under the United Nations Climate Change Convention to strive for containing the global temperature increase to less than 2°C above pre-industrial levels, with an additional target of aiming to restrict the rise to 1.5°C by 2050 (IEA, 2020). This has primarily been achieved by significantly increasing the capacity of electricity generation from renewable sources, which has more than doubled in the past ten years (IEA, 2020). Despite these positive developments, the level of progress achieved so far falls short of the level of ambition required to effectively steer the world towards the 1.5°C target. Many countries still heavily rely on fossil fuels for areas like domestic and industrial heating, industrial processes, and transportation. This reliance not only contributes substantially to emissions but also maintains susceptibility to price fluctuations in fossil fuel markets.

Implementing this energy transition is challenging due to complex decision-making and policy formulation, as it involves numerous actors with varying level of authority. The energy transition is a complex process that goes beyond technological advancements in renewable energy. It involves significant societal and institutional changes, requiring new practices, rules, and regulations. It can be seen as a societal transformation, encompassing various aspects of society. The energy transition is considered a ”wicked issue” due to its high uncertainties and differing opinions on how it should be approached in terms of methods and pace. Conflict is inherent in this process, as different stakeholders hold diverse interests and perspectives. For example, conflicts may arise when residents oppose the location of new energy projects, or when policymakers face pressure from climate activists demanding swift action. These conflicts should not be avoided or underestimated; instead, they can serve as valuable learning opportunities. While some may perceive conflict as an obstacle to effective policy making, it is actually a crucial element for steering the energy transition in a democratic and equitable manner.

The energy transition goes beyond achieving carbon neutrality; it also focuses on promoting equity and avoiding disproportionate impacts on specific groups. It is crucial to address justice concerns and prioritize the interests of marginalized communities within the transition. The concept of energy justice has gained significant attention among policymakers and communities worldwide, highlighting the need for fair and inclusive approaches to energy transition. Energy justice is important because it seeks to address environmental and social impact on the human population by promoting sustainable and equitable energy systems that minimize harm to people and the planet. Energy systems are shaped by complex social, economic, and political factors, including power relations, cultural norms, and institutional structures. Energy justice recognizes that these factors can influence who benefits and who bears the costs of energy production and consumption, and seeks to promote democratic participation and accountability in energy decision-making.

To assess the consequences and outcomes of potential policy measures or decisions, such as adopting a specific technology for natural gas-free heating in urban areas, evidence-based policy making involves utilizing factual knowledge to inform decision-making processes. One approach to achieve evidence-based policy making is through the use of data-driven policies. Energy modelling is playing a critical role in the energy transition in Europe. It is a method used to simulate and analyse the behaviour of energy systems under different scenarios and assumptions. Energy models use mathematical equations and algorithms to represent the physical, economic, and environmental factors that influence energy production, consumption, and distribution. They help to evaluate different energy scenarios, assess the impacts of energy policies, and support decision-making in the energy sector. These models are a valuable tool for understanding the complex relationships and interactions between various stakeholders, and can help inform the transition to a more sustainable energy future. Understanding the outcomes of these models is also vital because the decisions made based on the outcomes have a long term effect on the society and could lead to economic and social disparities.

The integration of energy justice aspects within energy models remains a relatively uncharted territory. While energy models have been valuable tools for assessing various aspects of energy transitions, their consideration of energy justice, which emphasizes equitable access to sustainable and affordable energy, remains limited. Incorporating such energy justice principles into modeling frameworks could provide valuable insights into how different policy choices and technological pathways might impact diverse communities, ensuring that the benefits and burdens of the transition are more equitably shared, and consequently addressing some of the conflicts in the process of energy transition.

The government of the Netherlands has taken major steps in the recent past to accelerate this Energy Transition, and support the European region's ambition (IEA, 2020). Taking a strong stance against shale gas extraction, designating the closure of coal-fired power plants, and investing in projects such as offshore wind and electric charging stations are some of the positive actions taken by the government. Apart from the industrial shift, policies such as the Dutch Climate Agreement in 2019 have been drafted to push for a carbon-neutral economy and support strong economic growth and energy security.

One major segment of this transformation is in the heating sector. The heating and cooling sector accounted for half of the European Union's energy consumption in 2016, and in the Netherlands, more than half of the national heat supply came from natural gas (Henrich, Hoppe, Diran, & Lukszo, 2021). However, the Dutch government made a decision in March 2018 to end natural gas extraction from the Groningen gas field as part of the heating transition to meet climate goals and reduce the negative impacts of gas extraction. The transition involves replacing natural gas with sustainable heating alternatives in various sectors. The Climate Agreement sets a target to reduce carbon emissions by three megatons in the built environment by providing sustainable heating to 1.5 million residential homes by 2030. In the Netherlands, all regions were assigned the responsibility of creating a Regional Energy Strategy (RES) and were encouraged to employ energy system models for this purpose. At the local level, municipalities are increasingly utilizing energy system models to support their decision-making processes (Henrich et al., 2021). Much is yet to be understood about how they deploy these models and how they aid in local policy making.

1.1 PROBLEM STATEMENT

The Energy industry, and in particular the heating sector accounts for the major chunk of greenhouse gas emissions, and this sector is now pressurized to tackle the situation with urgent action. The transition to renewable systems is taking place rapidly, and this shift requires extensive planning and decision making that presents a significant challenge. Technical, political and economic considerations are the primary focus points, but justice and equity must also be prioritized in this transition. The shift towards renewable energy must consider the impact on society and nature, and sustainable practices must be prioritized to achieve the final goal.
Energy justice and energy modelling are distinct concepts, but they are increasingly seen as complementary, with energy modelling being seen as an important tool for informing efforts to promote equitable and just energy systems. While energy system models can provide important information and insights for promoting energy justice, the ultimate outcome depends on how the results of the models are used and the policies that are implemented based on their findings. It is crucial that energy models are designed and used in a way that considers the principles of energy justice and takes into account the needs and perspectives of all communities and individuals.

1.2 KNOWLEDGE GAP AND RELEVANCE

This section will explain why the research topic is important, highlighting the potential of studying modelling and energy justice, and its impact on decision making.

Energy system modeling is being widely implemented and crucial for making energy policy, but there has been limited research on its actual use in practice. There are a few studies that have explored the realm of modelling approaches and how they are evolving along with the energy transition. The work of Susser et al seeks to find the difference in perspectives between modellers and users on modelling improvements (Süsser et al., 2022). It highlights that models and modelling approaches are becoming more sophisticated and better aligned with user needs. However, there is also a divergence between the desires of modelers and users. While both groups want to improve existing models, users also seek new modeling approaches that incorporate societal and political factors. In another piece of work by Susser, the authors conducted empirical research involving modelling and policy documents, and found that models influence policy making by assessing impacts, aiding in target setting (Süsser et al., 2021). The study also highlights that policymakers can use modeling results both to inform evidence-based policy making and to support pre-existing policies.

Other studies focus on the social and justice aspects of energy modelling in the transition. The work by Vagero aims to map and analyze existing research that includes justice aspects at various stages of energy system modeling (Vågerö & Zeyringer, 2023). The study suggests a need for more exploration of alternative constructions of justice beyond the equality principle, considering concepts such as capabilities, responsibilities, and opportunities in energy modeling. This can lead to a more comprehensive understanding of justice and avoid overly simplified assumptions. Van Berkel explores how the heat transition and energy poverty are related and provides practical guidelines for addressing energy poverty in the context of the heat transition, with a focus on the social housing sector in the Netherlands (van Berkel, 2019).

The inclusion of energy justice in these studies regarding models and modelling approaches still remains unclear and is even less studied, despite its significance in ensuring a fair energy transition. This area of research is new and critical, and this study explores the overlap of modelling and justice. This research aims to fill the gap between energy justice and energy system modelling by conducting a qualitative case study using content analysis through semi-structured interviews and document analysis to understand how justice principles and social aspects are integrated with modelling to aid decision making in the heating and built environment sector of the Netherlands.

The study will explore the impact of including or excluding forms of justice on the fairness of energy model's outputs and the distribution of burdens and benefits among the general population with the help of models. The research will also investigate how principles like availability, affordability, transparency, and accountability could affect the relationship between modelling and decision making. The study aims to contribute to the existing literature on energy justice and modelling techniques in the energy industry and provide insights for policy makers, researchers and organizations seeking to implement energy models in simulating and optimizing energy systems. Thus on understanding the problem and knowledge gap, the main objective is:

To investigate the ways in which the principles of energy justice are integrated in Energy modelling

With this objective in mind, this study aims to reach out to experts in the energy transition and officials from the industry, and collect information on whether and how they observe energy justice being delivered with using models to aid their decision making process.

1.3 RESEARCH QUESTION

To what extent have energy justice principles been represented in Energy modelling employed in the Dutch Heating Transition?

The sub questions to support the main research are:

- What are the principles of energy justice?
- What types of energy models are currently used in policy making in the Dutch heating transition?
- How are energy justice principles defined and executed in the context of energy system modeling in the heating sector?
- What are the challenges, limitations and best practices in incorporating energy justice principles into energy system models?

1.4 THESIS STRUCTURE

The report is organized into eight chapters, each serving a specific purpose in providing a detailed analysis of the research topic.

The introductory chapter sets the context for the study, presenting information about the energy transition, the concept of energy justice and the role of energy system modeling in informing energy transitions. The chapter is then used to define the scope of the research and state the main research questions.

Chapter 2 focuses on the literature review, beginning with the concept of energy justice. It is used to examine existing literature related to energy justice, and define what are the various tenets and principles under this field. This chapter synthesises all the current knowledge and helps to provide a theoretical framework for the study.

Chapter 3 describes how energy models are used in the energy transition and discusses in detail the various modelling approaches that are implemented. The chapter also describes how the energy models are classified based on criteria such as spatial and temporal resolution.

In Chapter 4, the current state of the Dutch heating transition is presented. This chapter describes how the developments in the sector have evolved, and what are the new changes in policy and models that are coming into the picture.

Chapter 5 presents the research methodology employed to investigate the representation of energy justice principles in energy system models within the Dutch heat transition context. The research design, data collection process, and analytical framework are discussed. The selection of relevant models, data sets and indicators for evaluating justice dimensions is explained.

Chapter 6 presents the findings derived from the analysis conducted in the previous chapter. The representation of energy justice principles in the selected energy system models is discussed in detail. The chapter highlights commonalities, differences, and challenges encountered in integrating justice considerations into the modeling process. The results matrix compares the modelling approaches and highlights variations in their treatment of justice themes.

The Discussions Chapter 7 interprets and evaluates the documented results in the context of existing literature. The connection between the findings and the theory of energy justice is explored. The arguments in support of the conclusions are presented, focusing on the challenges and opportunities associated with incorporating energy justice principles into energy system modeling.

The concluding chapter summarizes the main findings of the study and offers conclusive remarks on the research questions. The contribution of the study to the fields of energy transitions, energy justice, and energy system modeling is outlined. The limitations of the research are acknowledged, and future recommendations for enhancing the integration of energy justice within energy system models are provided. The chapter concludes by reflecting on the broader implications of the study for policy-making and decision support in the context of sustainable energy transitions.

2 ENERGY JUSTICE

In this chapter, the concept of energy justice, its tenets and principles are described. This chapter helps the reader to understand how energy justice is categorized and interpreted, the different justice frameworks used and helps to answer the sub question regarding the existing principles of energy justice.

2.1 DEFINITION OF ENERGY JUSTICE

Justice is a multifaceted concept that can be defined in different ways depending on the research focus and context. Justice in the fields of ethics and philosophy is about creating a society that is fair and equitable for all individuals, where everyone is treated with respect and dignity and has the opportunity to live a fulfilling and meaningful life. And energy is one critical resource that can enhance such opportunities and capabilities for individuals to have a better future. Thus, Energy justice is concerned with ensuring that energy policies and practices are designed and implemented in such a way as to ensure a fair distribution of both benefits and costs, taking into account issues of social equity, environmental justice, and human rights (Sovacool, 2016). Energy justice is also defined as a framework that aims to address issues of distributional equity, participation, and recognition across energy systems and policies. It recognizes that the social and environmental consequences of energy production, distribution, and use are not distributed equally and that some groups may be systematically excluded from participating in decision-making processes (Heffron & McCauley, 2017).

Every day we are witnessing innovations in all fields of science and technology. There is a rapid overhaul of existing systems and understandably, it is hard for people to understand and keep pace with the new inventions and utilize them to the maximum potential. The process of low carbon energy transition has many cases of injustice that are not yet obvious to policymakers (Sovacool & Dworkin, 2015). Practical situations in the last few decades have demonstrated that implementing new energy policies or carrying out new energy projects can be a challenging and often controversial process due to conflicts that can arise among different stakeholders. Large firms are often in a higher position of power and have a network that helps them execute their vision without being contested. Examples of these conflicts include disagreements over the extraction of fossil fuels, opposition to large-scale hydroelectric power and nuclear power. Due to these conflicts and sustainability issues, energy-related questions are often filled with complexity and difficulty. That is where energy justice is important because it introduces an approach to combine social sciences with natural sciences that is backed by scientific data, and answer the main predicament of who is affected, for what reason and at what cost (Sari, Voyvoda, Lacey-Barnacle, & Karababa, 2017).

The recent literature on Energy Justice mainly categorizes the concept in the form of tenets, and amongst them the most commonly defined are distributive, procedural and recognition justice (McCauley et al., 2019) (Jenkins, McCauley, Heffron, Stephan, & Rehner, 2016). Distributional justice is the idea that the benefits and negative impacts of the social environment are not equally distributed among individuals and communities. It takes into account both the physical inequality in the distribution of social benefits and harms, as well as the unequal distribution of responsibility for them. Recognition justice involves acknowledging the unique experiences and perspectives of marginalized groups, and recognizing the ways in which their identities and experiences have been oppressed. While distributive justice focuses on economic and material equality, recognition justice is concerned with cultural and symbolic equality. Procedural justice is concerned with ensuring that the rules, procedures, and decision-making processes used by institutions are fair and transparent, and that they protect the rights of individuals and groups. In addition to these three tenets, recent studies have also categorized justice in the form of cosmopolitan and restorative justice. Cosmopolitan justice emphasizes the need for global justice and moral responsibility towards all human beings, regardless of their nationality, ethnicity, or cultural background (McCauley et al., 2019). It recognizes the inter-connectedness of the world and the global challenges that require a collective action. Restorative justice is a theory of justice that emphasizes the need to repair the harm caused by criminal behaviour, rather than simply punishing the offender. It is based on the principles of healing and reconciliation, and aims to promote accountability, community involvement, and restoration for both the victim and the offender (Heffron & McCauley, 2017).

Beside these existing tenets, there are a few theories in the field of energy justice that are considered as guidelines for decision making. The ”all affected principle” is a concept that holds that all people who may be affected by a decision or policy should have a say in the decision-making process (Näsström, 2011). Other principles that promote fairness and impartiality in decision making are the representative democracy principle, the lottery principle, the coin-tossing principle (Miller, 2017). To promote distributive form of justice, the Capability approach and Rawls' maximin rule are principles that provide a framework for a just and fair society (Rawls, 2001).

The Capabilities approach is an alternative to traditional approaches that focus solely on income, wealth, or utility as measures of well-being (Nussbaum, 2011). It emphasizes that individuals should have the capabilities necessary to live a life that they have reason to value, which goes beyond mere material resources and includes a wide range of valuable functioning, such as nutrition, health care, and shelter, as well as opportunities for education, political participation, and social engagement (Nussbaum, 2011). It is often used in debates about social justice, poverty alleviation, and human development, and has influenced a range of policies and initiatives aimed at improving people's lives around the world. For example, The United Nations Development Programme (UNDP) developed the Human Development Index (HDI) as a composite measure of human development that goes beyond GDP per capita (UNDP, 1990). The HDI incorporates indicators related to health, education, and income to assess the overall well-being and capabilities of individuals in a country.

According to the Rawlsian maximum rule, social and economic inequalities should be arranged so that they are both to the greatest benefit of the least advantaged members of society, and attached to positions and offices open to all under conditions of fair equality of opportunity. This means that while some degree of inequality may be acceptable in a just society, such inequality should only be tolerated to the extent that it benefits the least advantaged members of society (Mandle & Reidy, 2015). The principle of the Rawlsian maximum rule has been used to argue for progressive tax systems, where individuals with higher incomes are taxed at higher rates. Proponents argue that progressive taxation helps redistribute wealth and resources from the affluent to the less advantaged, aligning with the principle of benefiting the least advantaged members of society.

A clear bifurcation of the types of justice helps to analyse a real life setting more specifically and engage in that particular form of justice. Even with the concept of energy justice being established, the processes for making decisions that have significant local impacts often fail to meet the requirements of justice, which include access, recognition, and the potential for influence (Ottinger, Hargrave, & Hopson, 2014). A classification of the types of energy justice is illustrated in Figure 1 below.

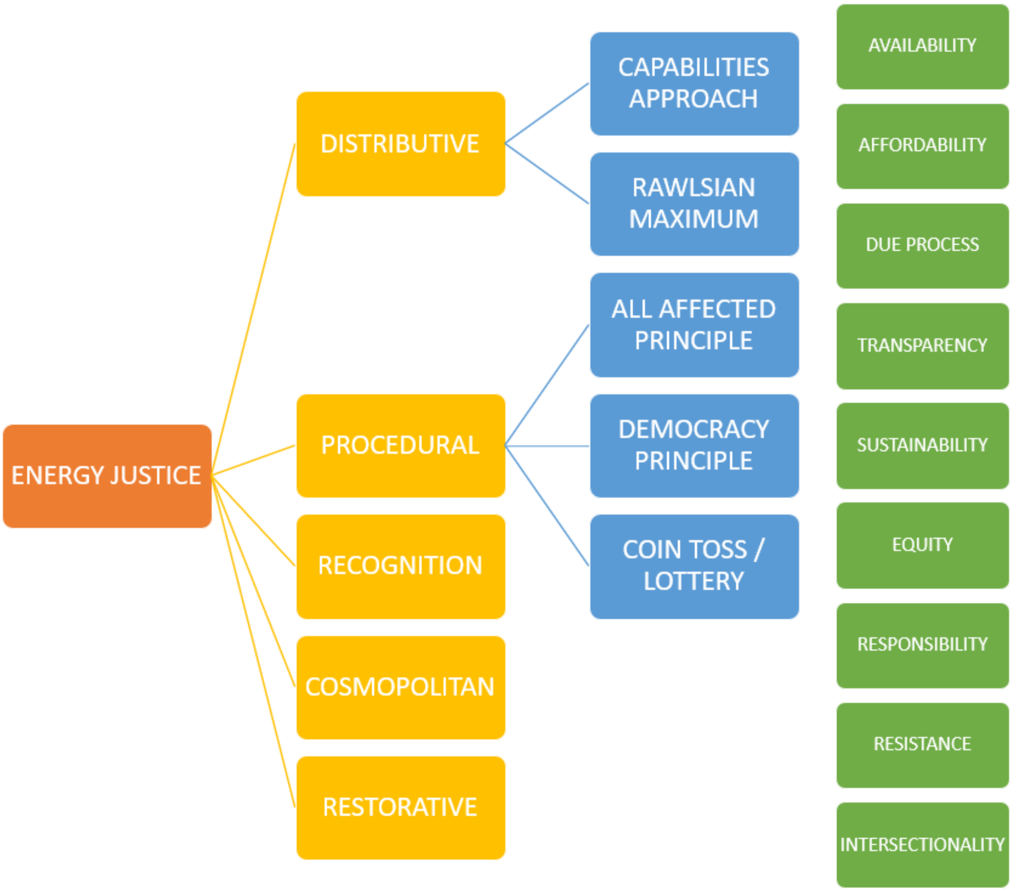

Figure 1: Own Illustration of Classification of Energy Justice

2.2 ENERGY JUSTICE PRINCIPLES

The tenets of energy justice can be related to broad categories or concepts, that provide for a label or classification to a set of statements or events. These tenets can be further defined by characteristics or attributes that can be known as "principles". Principles can be abstract statements or rules that contain information that is worth knowing, and thus is worth exploring. A principle of energy justice can then be defined as a fundamental rule or value that guides the decision making on handling energy resources. In general, there are eight principles that have been defined under these tenets of energy justice (Sovacool & Dworkin, 2015). They are availability, affordability, due process, good governance, sustainability, intergenerational equity, intragenerational equity and responsibility. These principles can relate to any one, or encompass a few tenets of justice. A brief summary of these principles can be referred to in Table 1.

Energy justice framework	
Principle	Description
Availability	People deserve sufficient energy resources of high quality
Affordability	The provision of energy services should not become a financial burden for consumers, especially the poor
Due process	Countries should respect due process and human rights in their production and use of energy
Transparency and accountability	All people should have access to high-quality information about energy and the environment, and fair, transparent and accountable forms of energy decision-making
Sustainability	Energy resources should not be depleted too quickly
Intragenerational equity	All people have a right to fairly access energy services
Intergenerational equity	All people have a right to fairly access energy services
Responsibility	All nations have a responsibility to protect the natural environment and reduce energy-related environmental threats
Resistance	Energy injustices must be actively, deliberately opposed
Intersectionality	Expanding the idea of recognitional justice to encapsulate new and evolving identities in modern societies, as well as acknowledging how the realization of energy justice is linked to other forms of justice e.g. socio-economic, political and environmental

Table 1: Energy Justice Framework
(Sovacool & Dworkin, 2015)

As an example, to address the affordability justice for a low income family in a particular region, governments or energy authorities can implement certain measures, providing targeted subsidies or financial assistance, establish tariff structures that consider income levels or offer tiered pricing et cetera. The principle of availability justice in energy refers to ensuring that all individuals and communities have access to reliable and sufficient energy services to meet their basic needs and enable a decent standard of living. Consider a rural community located in a developing country that lacks access to reliable electricity. To address availability justice in this situation, several measures such as investing in the electrical grid extension, deploying decentralized renewable energy systems can be taken. Intergenerational equity is a principle of justice ensuring that the actions and decisions of the present generation do not compromise the well-being and opportunities of future generations. A country that heavily relies on fossil fuels for its energy needs can address intergenerational equity by prioritzing the transition to renewable energy sources and investing in resilience measures against climate change. Due process aims to ensure that the level of stakeholder participation in energy policymaking aligns with the significance of the issues involved and the irreversible nature of the decisions that may be made (Sovacool & Dworkin, 2015). The construction of a large-scale energy infrastructure project, such as a hydroelectric dam has significant implications for the environment and local communities. Due process in this context would involve the government initiating a series of public consultations to engage stakeholders, an environmental impact assessment conducted to evaluate the potential environmental and social consequences of the project, and so on.

The framework developed by Sovacool and Dworkin provides an excellent foundation for studying justice within energy system models. It offers a multidimensional approach that encompasses key principles of justice, including equity, procedural fairness, recognition of rights, and sustainability. By integrating these dimensions, the framework enables a refined understanding of the social, economic, and environmental impacts of energy systems, facilitating an in-depth analysis of justice considerations.

One of the strengths of this framework is its practical applicability. The framework emphasizes the translation of theoretical concepts into practical applications, making it well-suited for studying justice in the context of energy system models. Moreover, the interdisciplinary perspective of the framework is particularly valuable for studying justice within energy system models. Energy systems are complex and interconnected, requiring a comprehensive understanding that goes beyond a single disciplinary lens. This framework draws on multiple disciplines, such as economics, sociology, and political science, enabling a holistic analysis of justice issues. This interdisciplinary approach enhances the accuracy and depth of the modeling efforts.

Furthermore, the influence and recognition of the Sovacool and Dworkin framework within the field of energy justice make it a compelling choice for studying justice with energy system models. The framework has been widely cited and referenced in subsequent studies, indicating its impact and acceptance within the research community. Choosing a well-established framework enhances the credibility of the research and allows for meaningful engagement with existing literature and methodologies.

3 ENERGY MODELS

In this section we will discuss the various modelling approaches in general, how they are created and how they are different from each other. The objective of this section is to help the reader familiarize themselves with the various models used and the situations in which these models can help in decision making.

Energy models are computational tools used to analyze, optimize and simulate energy systems, and are simplified representations of the real-world energy system and economy. Energy system models typically incorporate various components, including energy sources, infrastructure, technologies, and economic factors. They aim to capture the relationships and dependencies between these elements to provide insights into the behavior of energy systems under different scenarios and conditions. The earliest energy models emerged in the 1960s as computers became more accessible, and these models focused on analyzing energy supply and demand, primarily in the context of oil and gas markets. With technological advancements in computers, these models began incorporating multiple energy sources and considered the interactions between energy systems and environmental factors. In recent years, the availability of larger datasets, improved computational algorithms, and the integration of data analytics have enhanced the accuracy and capabilities of energy models.

While energy models can offer a useful approximation of current conditions, they inevitably involve some degree of approximation and uncertainty when answering specific questions about energy technologies or economic implications. Despite their limitations, energy models provide an important tool for researchers and decision-makers to explore and analyze different scenarios and policies. A classification scheme can support the identification of differences and similarities of the energy system models, hence assisting the process of selection of the proper one (van Beeck, 1999). Various modeling approaches have been developed over time, depending on factors such as the intended use, target audience, regional scope, and available information.

Van Beeck in 1999 introduced a classification based on the identification of different features such as general and specific purpose, analytical approach, model structure, mathematical approach, underlying methodology, geographical coverage, sectoral coverage and time horizon (van Beeck, 1999). Horschig and Thran have also identified and classified a few modelling techniques to begin with (Horschig & Thran, 2017). The techniques have been categorized based on parameters such as spatial coverage, sectoral coverage, time horizon, ex-post vs. ex-ante, quality of data sources, assumptions about actor behavior, assumptions about markets and systems, and the possibility to implement the approach in a computer-aided framework. Prina et al further make a re-elaboration of the previous classifications, and along with them introduce certain challenges that arise in segregating modelling approaches (Prina, Manzolini, Moser, Nastasi, & Sparber, 2020). They consider that models differ in terms of a resolution theme, specifically in time, space, sector and techno economic detail. An additional indicator that is used to separate the models is in terms of transparency of input output data, documentation and software used.

Classifying energy models can be challenging because there are numerous ways to characterize them, but very few models fit neatly into a single category. The complexity and diversity of energy systems often lead to models that incorporate elements from multiple approaches, making it difficult to assign them to specific classifications with clear boundaries. From understanding the sources of literature mentioned above, it can be said that models can be roughly classified into Top Down, Bottom Up, and the Hybrid Models based on their approach. These approaches can been further categorized as Optimization or Simulation models based on what purpose they are being used for. An illustration of the classification is generated with the help of the above literature and is shown in Figure 2

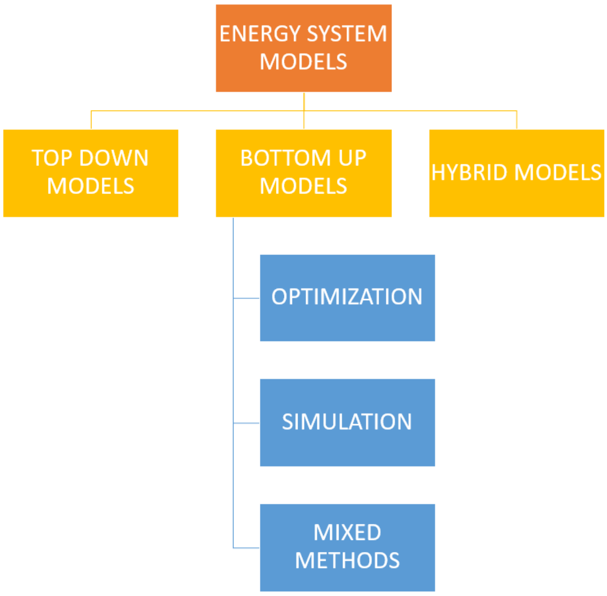

Figure 2: Own Illustration of Modelling Approaches

3.1 TOP DOWN vs BOTTOM UP

The top-down approach is associated with but not exclusively restricted to– the “pessimistic” economic paradigm, while the bottom-up approach is associated with the “optimistic” engineering paradigm van Beeck (1999). Therefore, the latter is also referred to as the engineering approach.

In a top-down approach, the analysis begins with a broad view or overview of the system being studied. It starts with aggregated or macro-level data and focuses on the system as a whole. The modeling process typically involves using simplified assumptions and high-level parameters to capture the behavior and characteristics of the system. Top-down models often rely on aggregated data, statistical analysis, and mathematical equations to understand the overall trends, patterns, and relationships within the system. This approach is useful for studying large-scale systems, policy analysis, and scenario planning. It provides a high-level perspective and can identify key drivers and trends that shape the system’s behavior.

In a bottom-up approach, the analysis starts with detailed and specific data at a granular level. It focuses on individual components, entities, or agents within the system. The modeling process involves capturing the behavior, interactions, and characteristics of individual components and then

aggregating the results to understand the system's overall behavior. Bottom-up models often rely on individual-level data, agent-based modeling, simulation techniques, or detailed process modeling to analyze the system. This approach is useful for understanding the behavior of complex systems, such as supply chains, energy networks, or social systems, by considering the interactions and dynamics of individual components. A summation of the differences is mentioned in Table 2.
Top-down models are the clear winner in supply considerations as they are heavily weighted by historical energy consumption which places their estimates of supply within reason. Bottom-up statistical models can account for occupant behaviour and use of major appliances, which leads to the identification of behaviours and end-uses which cause consumption of unwarranted quantities of energy (Swan & Ugursal, 2009). As the effects and limitations of conventional energy sources are widely acknowledged, alternative energy sources and technologies are continuously being investigated and developed. To determine the impacts of such new developments requires a bottom-up model. This is further exemplified by the focus being placed on efficiency and on-site energy collection and generation at individual houses. During this period of rapid technological development and implementation, the bottom-up techniques will provide much utility as policy and strategy development tools. (Swan & Ugursal, 2009)

Top-Down Models	Bottom-Up Models
use an "economic approach"	use an "engineering approach"
give pessimistic estimates on "best" performance	give optimistic estimates on "best" performance
can not explicitly represent technologies	allow for detailed description of technologies
reflect available technologies adopted by the market	reflect technical potential
the "most efficient" technologies are given by the production frontier (which is set by market behavior)	efficient technologies can lie beyond the economic production frontier suggested by market behavior
use aggregated data for predicting purposes	use disaggregated data for exploring purposes
are based on observed market behavior	are independent of observed market behavior
disregard the technically most efficient technologies available, thus underestimate potential for efficiency improvements	disregard market thresholds (hidden costs and other constraints), thus overestimate the potential for efficiency improvements
determine energy demand through aggregate economic indices (GNP, price elasticities), but vary in addressing energy supply	represent supply technologies in detail using disaggregated data, but vary in addressing energy consumption
endogenize behavioral relationships	assess costs of technological options directly
assumes there are no discontinuities in historical trends	assumes interactions between energy sector and other sectors is negligible

Table 2: Top Down vs Bottom Up Models
(van Beeck, 1999)

3.2 OPTIMIZATION

Optimization models are used to find the best possible solution to a problem within a set of constraints. These models involve formulating an objective function to maximize or minimize, along with a set of constraints that must be satisfied. The objective function represents the goal to be achieved, while the constraints represent the limitations or conditions that must be met. Optimization models use mathematical techniques, such as linear programming, nonlinear programming, or

stochastic programming, to find the optimal values for decision variables that optimize the objective function while satisfying the constraints.
The MARKAL (MARKet ALlocation) model is an energy system modeling framework that is widely used for analyzing technology choices, energy policies, and greenhouse gas mitigation strategies. It is designed to optimize the allocation of energy resources and technologies to meet energy demands and policy objectives efficiently (Loulou, Goldstein, & Noble, 2004). In the case of the MARKAL model, the objective function and constraints are typically defined based on energy-related criteria, such as minimizing the total system cost, minimizing greenhouse gas emissions, or maximizing the use of renewable energy sources. The model takes into account factors such as energy supply and demand, conversion efficiencies, investment costs, energy prices, environmental policies, and technological constraints.

3.3 SIMULATION

Simulation models are used to mimic real-world systems or processes by building a computer-based model that represents the behavior of the system over time. These models involve creating a simplified representation of the real system and defining the relationships and rules that govern its behavior. Simulation models allow researchers to observe how the system behaves under different scenarios and conditions. They are particularly useful for studying complex and dynamic systems where it may be difficult or impractical to conduct real-world experiments. Simulation models can be used to analyze and optimize processes, evaluate the impact of policy changes, or study the behavior of social systems.
PRIMES (Policy Response Integrated Model) is a simulation model that is widely used for energy system analysis and policy assessments. It captures the interactions between different sectors of the energy system and simulates their behavior under various scenarios and policy measures (MIDAS & EU, 2023). PRIMES relies on a comprehensive set of input data, including historical energy consumption, production, and prices, as well as socio-economic indicators, policy frameworks, and technology characteristics. These data inputs are used to initialize the model and provide a basis for simulating the energy system behavior. PRIMES generates outputs that provide insights into energy supply, demand, prices, emissions, investment needs, and other relevant indicators.

3.4 HYBRID MODELS

Hybrid models combine multiple modelling approaches to take advantage of their respective strengths and address complex problems that cannot be fully captured by a single approach. These models integrate different techniques or methodologies to capture various aspects of the system being modeled. A hybrid model might combine optimization techniques with simulation modeling to optimize decisions while considering the dynamic behavior of the system. Hybrid models can also combine statistical analysis with machine learning algorithms to make accurate predictions based on historical data. The goal of hybrid models is to leverage the strengths of different approaches to provide more accurate insights into the system being studied.
GEMINI-E3 is a CGE (Computable General Equilibrium) Model and represents a family of models of

different specifications and with several successive versions (Bernard & Vielle, 2008). It retains many specifications that are common to CGE models but also some specific features, mainly concerning the measurement and analysis of the welfare cost of policies and the great detail in the representation of taxation and social security contributions.

3.5 ADDITIONAL CRITERIA TO CLASSIFY MODELS

Now that these approaches are fairly understood, it is necessary to establish a few more general criteria to differentiate the models based on their specifications. This is done in order to look at models that vary to some degree from each other, and then identify if they have any similarities or differences in the way they are being formulated and implemented.

Transparency is one aspect that segregates models. Transparent models provide detailed information about the sources of data, the methods used to collect or derive the data. Transparent models make their output data easily accessible and understandable to stakeholders. Documentation transparency relates to the availability of detailed information about the model itself. This includes describing the model structure, equations, algorithms, and methodologies used. Models developed with transparency in mind often provide access to the software or code used to implement the model. Open-source models, for example, make their source code freely available for inspection and modification. These attributes of models can clearly translate to a form of achieving procedural justice because transparency promotes accountability, reproducibility and the advancement of knowledge. Energy system models and data should be open to improve quality of science, to create more effective collaboration between science and policy-makers, to increase productivity and to establish relevant knowledge as a basis of societal debates(Pfenninger, DeCarolis, Hirth, Quoilin, & Staffell, 2017). Thus transparency in models can be identified as low, medium or high depending on how many of the above attributes they posses.

Resolution is another aspect that can be used to evaluate models. It refers to the level of detail or granularity at which the model represents the energy system. Choosing the appropriate resolution for an energy model depends on the decision-making objectives and the availability of data. Higher resolution models tend to provide more detailed and accurate insights but require more data and computational resources. They are often used for analyzing specific locations or assessing the impacts of policy interventions at a local or regional level. Lower resolution models are useful for long-term planning, national-level energy policy analysis, or evaluating broad trends and system-wide implications. Resolution is generally defined in terms of the scale of spatial and temporal resolution. Spatial resolution pertains to how finely the model divides geographic areas or regions, and Temporal resolution relates to the time intervals at which the model captures changes in the energy system. Distributional justice is the fair and equitable distribution of resources, benefits, or burdens among different individuals or groups in society. High resolution models can help identify regions or communities that may face energy access challenges, environmental impacts, or higher energy costs.

By understanding these disparities, policymakers and stakeholders can develop targeted interventions, policies, or investments to address the distributional imbalances and promote more equitable outcomes. Thus Resolution can contribute to understanding principles of distributional justice like affordability, equity and sustainability. Bouw et al (Bouw, Noorman, Wiekens, & Faaij, 2021) analyse the characteristics of a few available models from the scientific community and professional practice, which will provide a valuable reference for this study. The list of characteristics can be found in the table below.

Evaluation criteria for the classification of energy models.

CRITERIA	Purpose of the model	Methodology	Spatial resolution	Sectoral coverage	Time horizon	Temporal resolution	Data availability	Model availability
CATEGORIES INCLUDED	Description of specific purpose	Simulation Scenario Operation optimization Investment optimization	Global National Regional Local/ community Single-project/ building	Electricity Gas Heat Transport Industry	Years	Yearly Monthly Weekly Hourly Minutely	Internal database External database External data required	Commercial Proprietary Open source

Table 3: Evaluation Criteria
Bouw et al. (2021)

4 THE DUTCH HEATING TRANSITION

This section help us answer the sub question regarding types of energy models used, along with explaining to the reader the evolution of the Dutch heating transition and energy justice issues that have been recognised in this field.

4.1 EVOLUTION OF THE HEATING TRANSITION

The heating sector in the Netherlands has undergone significant changes over the years. Historically, the country has relied heavily on natural gas for heating purposes and until the mid twentieth century, the primary heating method in the Netherlands was coal-fired central heating. However, following the discovery of vast natural gas reserves in the Groningen field in the 1950s, natural gas quickly became the dominant energy source for heating. Natural gas was considered cheap, readily available, and efficient, leading to the widespread adoption of natural gas boilers and central heating systems in residential, commercial, and industrial buildings. However, concerns over the environmental impact of fossil fuel use and the safety factor of extracting shale gas have led to a shift in the heating sector.

One of the key developments in the Netherlands' heating sector is the adoption of district heating systems. District heating involves supplying heat to multiple buildings from a centralized source, which can be a combined heat and power plant, waste heat from industrial processes, or renewable energy sources such as geothermal energy or biomass. Another important aspect of the evolving heating sector in the Netherlands is the increasing use of renewable energy sources. The country has been investing in sustainable heating technologies such as heat pumps, solar thermal systems, and biomass boilers. Over fifty percent of the annual energy consumption in the Netherlands is still dedicated to heating purposes (Segers, Niessink, van den Oever, & Menkveld, 2020). This heating energy is distributed among the built environment, industrial sector, and agricultural sector as shown in Figure 3. Specifically, one-quarter of the country's total energy demand is attributed to heating residential and commercial buildings. The Dutch government has positioned itself as a leader in Europe's efforts to decarbonize heating systems. The government's commitment to the decarbonization of heating reflects a broader goal of reducing greenhouse gas emissions and promoting sustainable energy sources.

In a context of an international commitment to a carbon-neutral transition, resulting in agreements such as the Paris Agreement in 2015 (UNCC, 2015) or the European Green New Deal in 2019 (European Commision, 2022), the Netherlands is aiming for a rapid transition to a carbon-neutral economy that supports strong economic growth and energy security. To drive this transition, the government's energy and climate policy focuses on bringing down greenhouse gas emissions, with targets to reduce them by forty nine percent by 2030 and by ninety five percent by 2050, compared with 1990 levels (Netherlands Enterprise Agency, 2022). Also as part of the transition process, each municipality in the Netherlands is required to develop a Transition Vision Heat, and an implementation plan within their local government plans (Netherlands Enterprise Agency, 2022).

These documents should outline how the municipality intends to establish a heat supply that is both

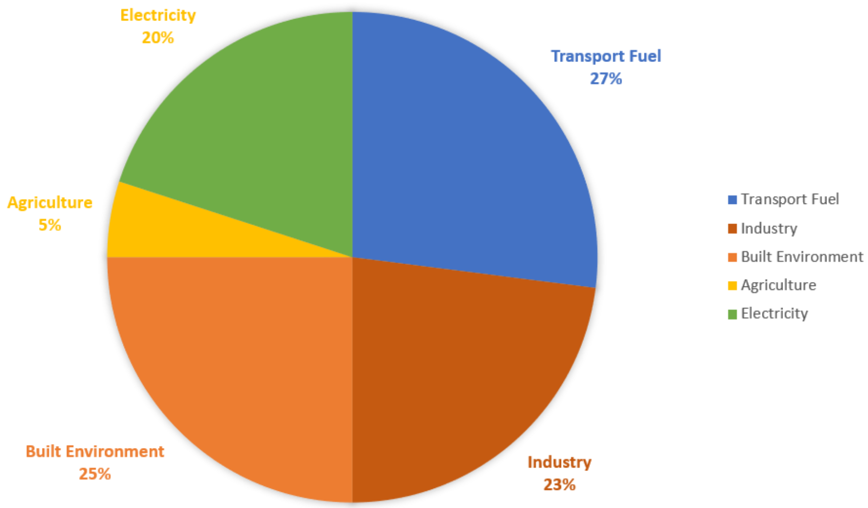

Figure 3: Total Final Energy
(Segers et al., 2020)

free from natural gas and affordable, in accordance with the Environment and Planning Act. This places the responsibility on municipalities to play a prominent role in driving the transition towards sustainable heating. The Netherlands has made notable progress on its transition to a carbon-neutral economy. Thanks to increasing energy efficiency, energy demand shows signs of decoupling from economic growth. In addition, the share of energy from renewable sources doubled between 2008 and 2019 (European Environment Agency, 2022). However, the Netherlands remains heavily reliant on fossil fuels and has a concentration of energy and emission-intensive industries that will be difficult to de-carbonise.

4.2 JUSTICE ISSUES IN THE ENERGY TRANSITION

The process of low carbon energy transition has many cases of injustice that are not yet obvious to policymakers (Sovacool & Dworkin, 2015). For instance, while the transition to clean energy is expected to result in cost reductions in the long term, it is important to note that energy prices may rise in the short term. Injustices in the transition have been brought to light through some cases studies in the recent past.

To begin with, the region of Noordoostpolder has seen a lot of activity with respect to shale gas extraction and the establishment of wind parks. In their work, Rasch and Kohne (Rasch & Köhne, 2017) looked into the situation at Noordoostpolder, and have highlighted that participants in their study considered shale gas exploitation as unjust, and renewable energy was seen as the just alternative. This they mentioned could be due to the perception of shale gas extraction burdening the local citizens over time, which is similar to the concept of inter-generational concerns explained in other energy studies (Sovacool & Dworkin, 2015). But in another instance, the "just" alternative of renewable energy was also not entirely accepted. Noordoostpolder inhabitants saw wind power as energy justice because they were recognized as partners in the project and stood to benefit from it, whereas residents of a nearby village of Urk considered it "unjust" because their view and surrounding would be disturbed and have no economic interest in the wind parks (Rasch & Köhne, 2017). This example portrays that justice is experienced depending on the time, specific setting, type of energy and the actors involved.

Another study was carried out by Milchram et al (Milchram, Hillerbrand, van de Kaa, Doorn, & Künneke, 2018), which involved the use of the energy justice framework to broaden the concept of justice with respect to smart grid systems in the Netherlands and the United Kingdom. Smart grids are new and evolving technologies within a larger shift towards different energy sources, and this shift is marked by a significant level of unpredictability regarding what technologies and regulations will emerge in the future, and how they will affect different groups involved in the system. The study involved collecting data from public debates, articles and arguments to understand the values identified with this system and conduct a qualitative analysis. The findings show that since smart grids represent a merging of the energy and information and communication technologies sectors,there exists a negative perception beyond those related to energy supply and use; issues related to digitally connected systems, automation, and increased collection and sharing of real-time data. The use of ICT systems can result in inequalities particularly in terms of discrimination against those who are elderly, disabled, or have limited experience with technology (Balta-Ozkan, Amerighi, & Boteler, 2014). There were certain values such as transparency and comfort that were perceived as positive because they also aligned with the energy policy triad of cost, security and sustainability.

Pesch et al (Pesch, Correljé, Cuppen, & Taebi, 2017) have an interesting take on two situations in the Netherlands describing how perceptions of justice or injustice play a role in controversies about new energy projects. The main idea presented in this paper is that the adoption of certain energy policies or projects is driven in part by the injustices that are perceived by different actors in society. This can lead to the formation of groups that resist or oppose these initiatives. One case was about a carbon capture storage in Barendrecht, where the oil company Shell was awarded a tender for the project by the Ministry of Economic affairs. The local municipality voted against the plan but the ministry managed to overrule the decision, leading to opposition and media attention, which ultimately resulted in abandoning the project. This highlights the fact that controversies about justice with such projects have strong recoil effects, and assessment of policies are done only after they are executed.

Van Berkel has also highlighted a number of injustices while studying the impact of expanding the heating grid in the region of Holendrecht, which is a densely populated area in Amsterdam. Net congestion causing an inability to decouple from the existing gas grid, followed by the limited space underground causing long waiting times to implement heating infrastructure were observed to be major problems in the region. Financial differences between tenants and homeowners, exclusion of tenants surrounding apartment complexes and limited involvement of those directly affected are mentioned as critical aspects to be aware of when decoupling existing buildings from the gas grid in Holendrecht as identified by the respondents.

The above examples of research studies confirm that energy justice has gained importance, but the link between decisions taken and the use of models to aid in the formation of just conclusions is yet to be explored. While there have been studies exploring the concept of energy justice in the Netherlands through case studies, there seems to be a lack of research on how energy modelling could be utilized to incorporate energy justice principles in decision-making. Thus, the research gap lies in exploring the potential of energy modelling in incorporating energy justice principles and addressing the perceived injustices associated with energy policies and projects.

4.3 USE OF ENERGY MODELS

The energy transition is faced with significant uncertainties, encompassing technological advancements, energy and raw material markets, energy regulations, and financial investments. Multiple scenarios exist for the transition, resulting in diverse energy systems by 2030 and 2050. The presence of these uncertainties highlights the importance of independent and trustworthy knowledge and expertise for local policymakers.

Numerous energy models have been used and created in the Netherlands with the aim of simplifying complexity and offering a better understanding of the inter- dependencies within the local energy system. These models serve as valuable tools for making informed decisions regarding the transition to sustainable energy. To assist municipalities, housing corporations, and energy cooperatives in finding suitable models, an expert group on energy transition models, Netbeheer Nederland, comprised of leading stakeholders in energy modeling and simulation, initiated the development of a toolkit called "Energy Transition Models" (Diran, Henrich, & Geerdink, 2020). This toolkit provides support and guidance in selecting appropriate models that align with the specific requirements and objectives of these organizations. These models are mainly used in the heating and electricity sector. An overview of these models is shown in Figure 4.

In addition to these models, other commercial models focused on the heat transition with the poten-

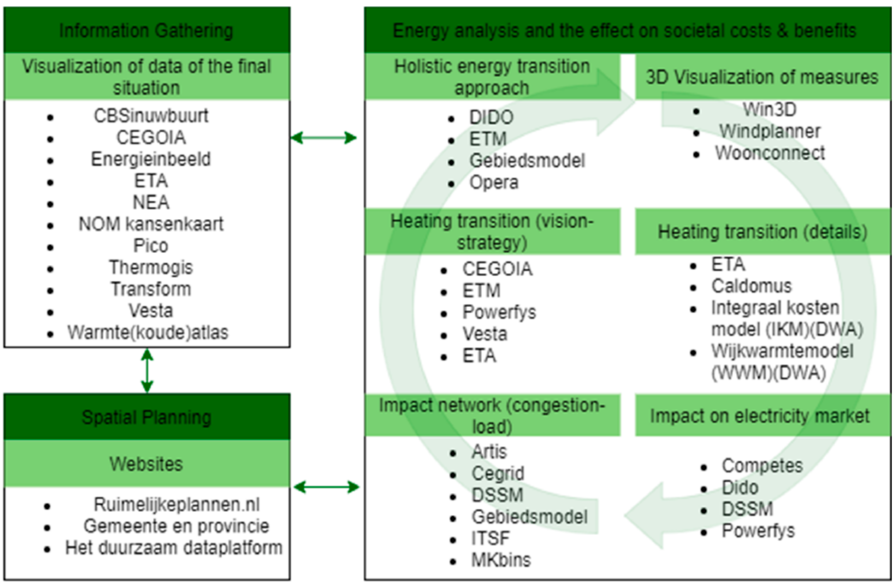

Figure 4: Dutch Energy Models
(Henrich et al., 2021)

tial of being used in the Netherlands have been listed by Diran et al (Diran et al., 2020). The detailed list can be referred to in the appendix. Amongst all these models there are six models that are most frequently used by the municipalities and for professional practice, namely the Heating Transition model by OverMorgen, the Vesta MAIS (Multi Actor Impact Simulation) model, the CEGOIA model, the Energy Transition Model (ETM), an Integral cost model by DWA and the Caldomus model. (Henrich et al., 2021) (Brouwer, 2019) (Bouw et al., 2021).

There have been a few recent studies on potential decarbonization pathways for the Dutch built environment towards 2050, that display the utilization of energy models. Ecofys conducted a study that presents four scenarios outlining potential developments that could drive social and economic changes in the built environment and facilitate the transition to energy neutrality by 2050 (Slingerland, Terlouw, & Lohuis, 2016). The primary focus of the study is to compare the overall costs of the energy system under these different scenarios. To analyze these scenarios, Ecofys utilized a system integration model developed in collaboration with ECN, Alliander, Gasunie, and TenneT. This model enables an assessment of the costs and impacts associated with heating homes, considering the entire energy supply chain, including energy consumption, transport, distribution, and generation.

Quintel, on behalf of the Dutch Raad voor de Leefomgeving en Infrastructuur (RLI), has created and examined two sample scenarios representing emission reductions of eighty percent and ninety five percent using the Energy Transition Model (ETM) (Kerkhoven, Wirtz, & Kruip, 2015). The ETM, developed by Quintel, is a simulation model for the energy system that allows users to design future energy scenarios by selecting their own input parameters.
The organization CE Delft conducted two studies in which they analyzed the availability of green gas and developed scenarios based on different societal and political pathways for the Netherlands (Schepers, Rooyers, & Meyer, 2016) (Afman & Rooijers, 2017). In these studies, they utilized the CEGOIA model, a bottom-up scenario simulation model specifically designed for the heat transition in the built environment. The CEGOIA model was used to calculate the most cost-effective technology options in 2050 for each neighborhood type.

5 RESEARCH METHODOLOGY

This chapter describes the research methods that are utilized in this study which includes a literature research and interviews with experts and policymakers.

5.1 APPROACH and CASE SELECTION

The general research approach was qualitative and exploratory, as the focus was on gaining an in-depth understanding of the concept of justice in modelling, rather than testing a specific hypothesis or theory. Qualitative methods allow for adaptation and modification of research questions and objectives as new insights emerge throughout the research process. Researching justice involves a wide range of methodological considerations, approaches and reflections over appropriate research designs (McCauley et al., 2019). Qualitative research designs cover a range of techniques for collecting and analyzing data about the opinions, attitudes, perceptions and understandings of people and groups in different contexts. In energy social science, the most popular approaches to qualitative data collection tend to be semi-structured interviews, focus groups, direct observation, participant observation and document analysis (Sovacool, Axsen, & Sorrell, 2018).

To carry out this study, first it is required to identify suitable use cases. For that purpose the regions of Drechtsteden and Amersfoort were selected for this study. Both these regions have a fairly decent size, meaning they have a diverse population consisting of people from different levels of society. This demographic diversity can contribute to disparities among different social sections within the society. The presence of a varied demographic in these regions highlights the importance of addressing social inequalities and promoting inclusive policies that benefit all members of society. Both regions have implemented a Heat Transition Vision, indicating that they are actively working towards transitioning their energy systems to more sustainable and climate-friendly alternatives. This implies that they are committed to reducing greenhouse gas emissions and aligning with the goals of the National Climate Agreement of the Netherlands. Both cases have also utilized an energy model in their decision-making processes, which is the primary reason for selecting them. Moreover, the involvement of various stakeholders in the decision-making process suggests a collaborative and participatory approach. The models utilized also satisfy the selection criteria that will be useful for this study. They are as follows:

- Sectoral Coverage: Models utilized in the built environment and heating sector have been selected for this study. There are many stakeholders involved in this transition who want to make the most of the business opportunities such as changes in the infrastructure and switch of energy sources. This creates room for social aspects that need to be addressed.
- Data and Model Transparency : The models selected have information that is openly available on the company websites and municipality portal such as PBL, Netbeheer Netherlands and the Association of Netherlands Municipalities (VNG), so that they can be easily accessed for the purpose of the study. More transparency also provides the possibility of identifying instances of procedural justice.

- Spatial Resolution: The models selected have to be of a regional scale. Models that offer higher spatial resolution can highlight more details about the interventions and outcomes at a localized scale and address the aspect of distributional justice.
- Modeling Approach : The models used are utilized for the purpose of simulating scenarios. This criteria has been considered since more number of simulating models are being adopted because the heat transition is still in an explorative phase where multiple options are still being considered. Optimisation models will be significant at a later period when the systems are already in place.

Based on the list of models mentioned in the section 4.3 and the criteria mentioned above, the Energy Transition Model by Quintel and the Vesta Mais model by PBL were mainly utilized in the use cases and they will be assessed further during this study.

5.2 CASE STUDY

Case studies enable us to zoom in on a specific instance or example to obtain a comprehensive understanding of various aspects, ranging from individual life cycles and group behavior to organizational rules, managerial processes, international relations, or the growth trajectory of a country. These studies provide a detailed account within the real-world context, offering valuable insights and analysis into the subject under investigation (Yin, 2009).
In this case study, the primary methods of data collection were interviews and document analysis. The documents utilized include government publications, organizational records, and technical papers related to the models being studied. The interview data was analyzed using a qualitative approach known as content analysis, which involves systematically examining and interpreting the information obtained from the interviews.

Case 1: Heat Transition Amersfoort

The municipality of Amersfoort, with a population of approximately 160,000 people, consists of 31 districts (Gemeente-Amersfoort, 2023). The majority of the buildings in this area rely on natural gas for heating. On average, space heating accounts for about 80 percent of the natural gas consumption in these households. On July 9, 2019, the Council adopted a Heat Transition Vision with key principles in mind (Gemeente-Amersfoort, 2023). These include ensuring that sustainable heat is clean and efficient, minimizing negative climate impacts, keeping housing costs stable, making the transition to alternative heat supplies affordable for all, and promoting local energy generation whenever possible within the district, city, or region. To estimate the impact of these developments on the built environment and the overall energy system, the Quintel Energy Transition Model (ETM) was utilized. The ETM provided insights into carbon dioxide emissions across all sectors in Amersfoort. Different scenarios were considered, ranging from a maximum effort scenario where all building are natural gas free by 2030, to a minimum effort scenario were one third of all buildings were transformed. These scenarios were used to compare against a baseline path, which was derived from Quintel's interpretation of the PBL's calculation of nationally determined and proposed policies, projected specifically for Amersfoort.

Case 2: Heat Transition Drechtsteden

In 2016, as part of the Regional Energy Strategies Program, five pilot regions were selected to develop regional energy strategies (PBL, 2023). The aim was to gain experience in achieving carbon dioxide reduction at the regional level. The PBL (Netherlands Environmental Assessment Agency) has committed to providing support in this process. One such project was conducted for the Drechtsteden region in South Holland. The Drechtsteden region consists of municipalities with around 270,000 inhabitants residing and working in approximately 140,000 buildings (Geldhof, van 't Hek, Iossifidis, & Oudejans, 2021). These buildings are predominantly heated by individual natural gas-fired boilers, consuming about seven Petajoules (PJ) of natural gas in 2015. The region's goal, as stated in the Regional Energy Strategy, is to become energy neutral by 2050, with all energy used in buildings coming from sustainable sources by 2035 (Geldhof et al., 2021).

To achieve these goals, working groups, including the Heat Transition Plan working group, have been established. This group, comprising representatives from municipalities, heat suppliers, grid operators, and the province of South Holland, aims to develop a Heat Transition Vision and a process plan for the municipalities in the Drechtsteden region to arrive at their heat transition plans by 2021. The Vesta MAIS model has been used in this particular case for exploring the potential of energy-saving measures and alternative heating methods, such as high-temperature or low-temperature heat networks, as well as individual electric heat pumps. By utilizing the Vesta MAIS source data, which is specifically tailored to the region, the profitability of different energy-saving measures and alternative heating techniques was determined at both the building and district levels.

5.3 DATA COLLECTION

The data collection for this study employed a combination of two primary methods: semi-structured interviews and documents related to the models and transition visions. Semi-structured interviews were conducted with individuals who have extensive experience as modellers, policy advisors, and municipality officials participating in the heat transition. The interviews were tailored for targeted individuals who have been involved in the projects implementing the selected energy models to explore their first-hand experiences, perspectives, and insights regarding the impact of models and integration of energy justice. In addition to the interviews, document analysis plays a crucial role in the research. This analysis involved a thorough examination of documentation related to heat transition in Drechtsteden and Amersfoort, as well as any company-specific model documents. By analysing these documents, the study aimed to gain a detailed understanding of the model assumptions, practical implementation, and policy implementation at a regional level.

5.3.1 INTERVIEW PROCEDURE

Interviews are the most commonly used data collection method and the semi-structured format is the most frequently used interview technique in qualitative research (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). The semi-structured interview is widely used as a data collection method due to

its proven versatility and flexibility. It allows for the exploration of new paths and the discussion of new topics that may arise during the conversation, which were not previously considered (Saunders, Lewis, & Thornhill, 2007).
A systematic approach will be followed in conducting the interviews to ensure reliable data collection. Participants will be selected based on their roles, experience, and knowledge with respect to the case studies. Prior to the interviews, the interviewees are contacted and provided with an invitation that explains the purpose of the interview and request their input in scheduling a suitable time. The interviewees were fully informed about the study's objectives and their role, and ethical procedures are strictly followed to protect data privacy and confidentiality according to the rules of the Human Research Ethics Committee. The interviews were conducted online using Microsoft Teams, with explicit consent obtained for recording. The interviews begin with general questions about the interviewee's background and then proceed to specific questions tailored to their roles and the case study. The questions are designed based on the literature review and document analysis. After the interviews, the transcripts will be shared with the interviewees for accuracy verification and the opportunity to provide additional insights. The transcripts serve as the basis for data analysis to extract valuable insights relevant to the research objectives. A total of thirty people were reached out to give an interview of out whom eight responded positively. An external policy advisor was also interviewed in the process, to have a more objective and unbiased view of the subject matter. It serves as a form of validation and credibility for the findings, if their views align with or complement those of the case study participants. The list of interview questions are mentioned in the appendix.

Participant	Role within Heat transition	Municipality	Participant Code
Participant 1	Modeller	Drechtsteden	P1
Participant 2	Policy Advisor	Drechtsteden	P2
Participant 3	Policy Advisor	Amersfoort	P3
Participant 4	Modeller	Amersfoort	P4
Participant 5	Policy Advisor	Amersfoort	P5
Participant 6	Municipality Project Manager	Amersfoort	P6
Participant 7	Policy Researcher & Advisor	Drechtsteden	P7
Participant 8	Policy Advisor	Den Haag	P8

Table 4: List of Interviewed Participants

5.3.2 DOCUMENT ANALYSIS

The second data collection method utilized in the research involves reviewing documents. Documents offer valuable insights into the context of research participants and can guide interviews and observations (Bowen, 2009). Additionally, documents provide stable information that is not influenced by the researcher or the data collection process. They can cover a wide time span of multiple events. However, retrieving documents can be challenging, and they may lack sufficient details as they are primarily created for purposes other than research (Bowen, 2009). For this study, the main documents collected were technical reports that describe the inputs and assumptions for the models, and reports about the heat transition projects from the specific municipalities. The main sources for such documents are

- Website of the Planning Office for Living Environment, that grant public access to energy model documentation.
- Website of Netbeheer Nederland, that grant public access to energy model input and assumptions.
- Municipality portals, containing reports of the specific transition visions of Amersfoort and Drechtsteden
- Academic database of Scopus and Google Scholar, to gain access to literature and any studies previously carried out on the selected models and cases.

The main keywords used to find the selected documents were ”Heat Transition Vision”, ”Gemeente Amersfoort”, ”Gemeente Drechtsteden”, ”VESTA Mais”, ”Energy Transition Model”, ”Energy Justice” and ”Energy Poverty”. The search results provided documents mainly in Dutch which were then translated to English. In total there were 11 documents that were analysed for this study.

Keywords	Municipality
Heat Transition Vision	Both
Energy Justice	Both
Energy Poverty	Both
Gemeente Amersfoort	Amersfoort
Gemeente Drechtsteden	Drechtsteden
Vesta MAIS	Drechtsteden
Energy Transition Model	Amersfoort

Table 5: List of Keywords

5.4 DATA ANALYSIS

The data analysis for this study involves analyzing and organizing qualitative textual data gathered from semi-structured interviews and documents. The interview questions were categorized based on the research objectives, and different sets of questions were tailored for each interviewee group to capture their specific roles and perspectives. To manage and structure the data, the software tool Atlas.ti was utilized. This software facilitated systematic organization of the data by evaluating and coding the information, identifying its significance, and establishing connections between different pieces of data. Before proceeding with the coding process, it is crucial to clarify the definition of ”code” in the context of this study. In this study, codes refer to specific words or phrases that succinctly capture the emerging topics and themes found in the interview transcripts. These codes are used to transform the raw data into meaningful and analyzable information. After conducting and transcribing the interviews, the data analysis process begins by inputting the interview transcripts into the Atlas.ti software. The data is then organized by assigning relevant codes to the text using both deductive and inductive coding approaches. Deductive coding involves applying pre-existing concepts or theories from the literature to create codes, while inductive coding involves an iterative process of reading through the data and allowing new codes to emerge from the information itself. This combination of deductive and inductive coding facilitates a nuanced analysis of the data, capturing both expected themes and unexpected insights that emerge from the interviews.

Deductive Codes	Description	Source
Affordability	All people, including the poor, should pay no more that 10 percent of their income for energy services	Sovacool & Dworkin, 2015
Sustainability	Energy resources should not be depleted too quickly	Sovacool & Dworkin, 2015
Resistance	Energy Injustices must be actively and deliberately opposed	Sovacool & Dworkin, 2015
Transparency	All people should have access to high quality information about energy, and accountable forms of energy decision making	Sovacool & Dworkin, 2015
Equity	All people have a right to fairly access energy services	Sovacool & Dworkin, 2015
Availability	People deserve sufficient energy resources of high quality	Sovacool & Dworkin, 2015
Freedom of choice	Individuals have the right to have the freedom of choice regarding energy services	Jenkins et al, 2016
Misrecognition	Failure to recognize legitimate concerns due to prejudice	Jenkins et al, 2016
Non-recognition	Failure to recognize the needs of specific affected groups	Jenkins et al, 2016
Mobilizing local knowledge	Seeking inclusion and engagement of those affected	Jenkins et. al. 2016
Disrespect	Not taking voiced concerns seriously	McCauley et al, 2019
Access to formal involvement	Right to a fair process both in free share of knowledge as in costs	McCauley et al, 2019
Temporal variations	Benefits and ills shift overtime	McCauley et. al. 2019

Table 6: List of Deductive codes from Energy Justice Literature

The initial deductive codes selected were mainly those described in the Energy Justice literature, as in the framework by Sovacool, and defined in the works of McCauley and Jenkins. (McCauley et al., 2019) (Jenkins et al., 2016). Some of the codes are shown in table 6 above. These codes were used to as a starting set of words to which the inductive codes would be matched with. The next step was inductive coding, and this was carried out by coding the transcripts line-by-line from the interviews. The initial rounds provided numerous codes but they were merged or omitted in case of duplication. These codes were then placed in code groups that were the main themes for the analysis. The Figure 5 below displays the codes and groups that were formulated.

Following the coding process, the thematic analysis of identifying patterns and connections among the codes was carried out. Figure 6 illustrates the process of coding quotes from the interview tran-

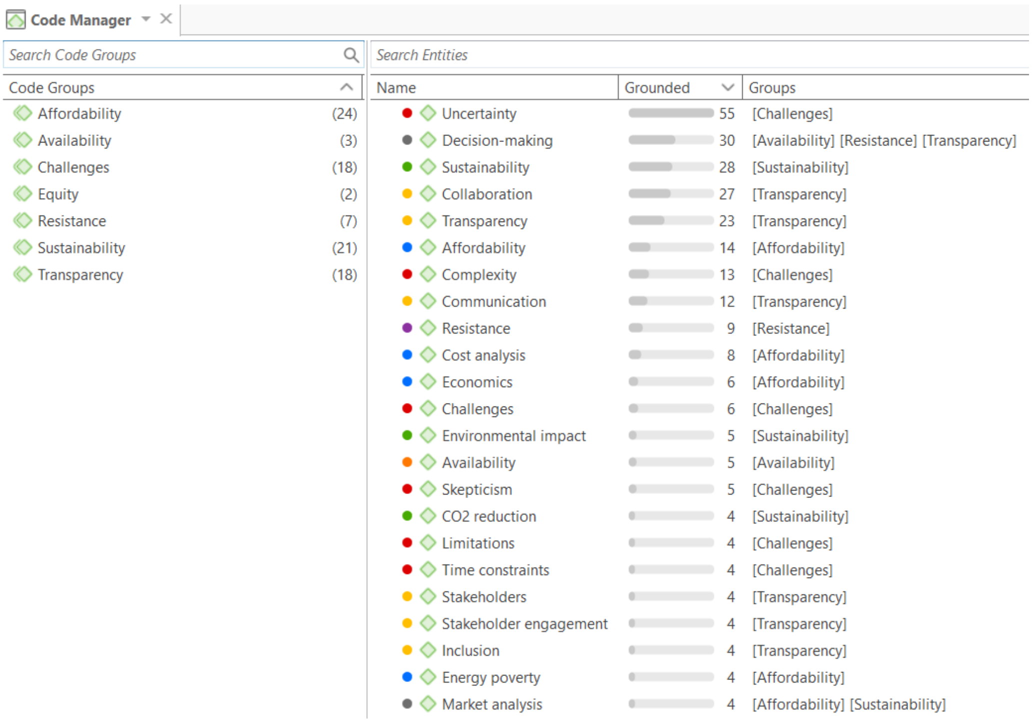

Figure 5: Snapshot of Codes and groups formulated with Atlas.ti

scripts. The highlighted text was given two codes and the interviewee talked about Collaboration and Transparency. The same codes were given to other quotes from different interviewees. This helped in identifying different themes and factors which were needed to answer the sub-questions.

Justice Indicators: It is important to identify instances and mentions of energy justice or social indicators in the documents and interviews collected. There are a few studies that examine the energy transitions from the perspective of socio-technological systems allowing for greater recognition of the influence of society on the transition process and its results (Krumm, Süsser, & Blechinger, 2022) (Hanke, Guyet, & Feenstra, 2021). They explain the use of certain indicators that can be related to the principles of the justice framework. The mentioned studies emphasize on social and behavioural factors that scholars identified as relevant to socio-technical transitions and, therefore, where energy models need to be improved. In the scope of this study, the focus was centered on the foundational principles delineated by Sovacool and Dworkin, as outlined in the table 1 on page 9. Operationalizing the comprehensive Energy Justice Framework necessitates a nuanced array of indicators, which can at times be intricate and multifaceted. Attention was directed towards the principles of affordability, transparency, sustainability, and resistance, which will serve as overarching themes under which the collected quotes will be systematically coded. Focusing on these four overarching themes provides a structured and targeted approach to analyzing the data. Analyzing all nine energy justice principles simultaneously can be overwhelming and make the analysis too broad. By narrowing the focus to four key principles, the analysis becomes more manageable and allows for more in-depth examination of each principle.

Additionally, any instances where allusions can be drawn to the principles of availability and equity will be segregated into distinct categories. Instances of synonymous or equivalent meanings will

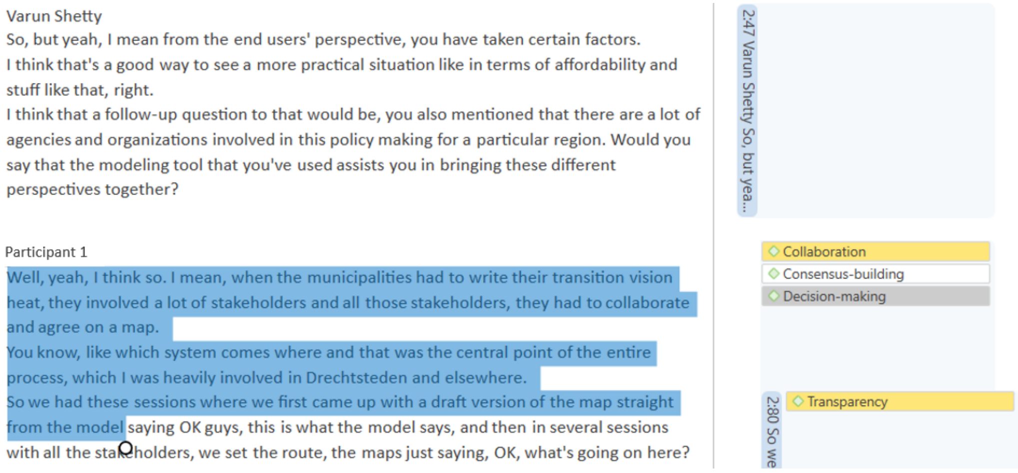

Figure 6: Example of quote labelling from the interview transcript

also be appropriately grouped within their respective thematic categories for the sake of cohesive analysis. To provide a practical illustration, consider the quote: ”The municipality has introduced a series of targeted programs aimed at providing financial assistance to low-income households, such as subsidized energy bills, energy efficiency upgrades, and grants for renewable energy installations.” In this context, this quote aligns seamlessly with the theme of affordability, given its emphasis on supporting low-income households through measures that alleviate their energy-related financial burden. Likewise, the quote: ”Regulatory agencies have mandated utilities to provide detailed breakdowns of energy billing, outlining the components that contribute to the final cost. Additionally, online portals have been established to allow consumers to track their energy usage in real time” is readily categorized under the theme of transparency. The passage highlights regulatory efforts to enhance information dissemination to consumers, bringing about a higher level of transparency in energy billing processes and fostering informed consumer decision-making.

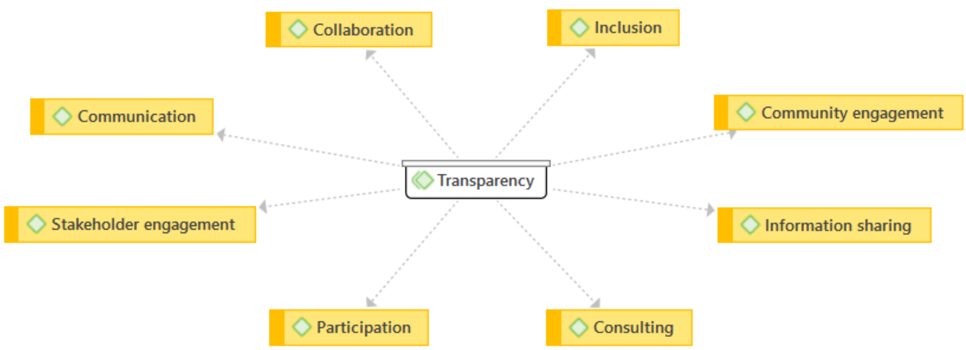

Figure 7: Inductive codes merged into a single group

5.5 DATA COMPARISON

The data collected from both the documents and interviews were collated into a results matrix in order to compare the two case studies across the different principles of justice. In order to make a quantifiable comparison, a simple weighting criteria and priority setting was followed. The Simple Multi-Attribute Rating Technique was used for this purpose, which is widely applied because of the simplicity of both the responses required of the decision maker and the manner in which these responses are analyzed (Wright & Goodwin, 2009). The assignment of weights is a subjective process, and it can vary depending on the context. For this comparison, affordability is assigned the highest priority, followed by transparency, sustainability and resistance in that order. Next the relative weights based on the pairwise comparisons was calculated using the weighted average method. These calculations provide the following relative weights:

Affordability : 0.46;
Transparency : 0.23;
Sustainability : 0.31;
Resistance : 0.00

5.6 ETHICS

The research strictly adhered to ethical guidelines throughout the entire process. Prior to beginning data collection, ethical approval was obtained from TU Delft's Human Research Ethics Committee (HREC). This approval ensures that all necessary precautions were taken to minimize potential risks during the research. The study also established a data management strategy to ensure participant confidentiality and anonymity.

Participants were fully informed about the study and their rights. The research diligently followed ethical principles to prioritize participant well-being. Obtaining informed consent was a key consideration. Participants received a consent form outlining the study's purpose, their involvement, and potential risks. They had the right to withdraw without consequences. Participants were informed that Microsoft Teams would record interviews solely for transcription. Privacy was emphasized, assuring secure storage and deletion after the thesis was completed. To protect data confidentiality, all collected participant information was treated as highly private. Before analysis, personal details were carefully removed to ensure participant anonymity. These rigorous ethical measures were implemented to maintain study integrity and protect participant well-being and privacy.

6 RESULTS

This chapter presents the outcomes and insights gathered through the analysis of data collected from interviews and document analysis. Through this chapter the research sub question "How are energy justice principles defined and executed in the context of energy system modeling?" will be answered in section 6.1, followed by the findings that will answer the next question of "What are the challenges, limitations and best practices in incorporating energy justice principles into energy system models?" in section 6.2.

6.1 ARE ENERGY JUSTICE PRINCIPLES DEFINED?

Social and demographic factors play a crucial role in energy models by capturing the human dimension of energy consumption and behavior. These factors encompass aspects like population growth, societal preferences, and lifestyle patterns that influence energy demand. To take an example, the Smart Energy Cities model considers social inputs in equal measure with other factors. It works with an input called "Social District Data", which helps to obtain an initial understanding of the neighborhood's makeup using data provided by the municipality (Waser, 2023). Information concerning income levels, educational attainment, household ages and structures, property values, as well as the distribution between rented and owned properties, and the ratio of apartments to houses are gathered. The Meetlat tool and Gebiedsmodel exhibit some considerations such as municipality's sustainability ambitions, residents' voting behaviour and the presence of local sustainability initiatives and trends of regional employment (van Berkel, 2019). Such factors can be considered as justice principles and portray energy justice, as they help to address affordability, transparency and sustainability principles of energy justice.

Case of Amersfoort:

From the documentation studied on the Energy Transition model, it is designed as an interactive tool for energy modelling and allows the user to explore the possibilities and limits of their energy system. The inputs for this model are taken in the form of energy demand and supply, costs for the technology installed and fuel, and the emissions associated with the system. There are no factors that could possibly address social or political issues. This has been captured through the interviews as well. Interviewee P4 stated that, *"Actually, a lot of models do focus on the costs and other factors, especially optimization models I think, but we focus more on all the energy key performance indicators. So that would be factors like whether the demand and supply are balanced, or if you need any peak capacity system like a gas boiler to cover the peaks and the demands, whether you need to import energy from across the borders, things like that. We do sometimes show the effect of changing the fuel prices, and it is a huge factor, but it wasn't really taken into account for the heat transition.*

The Transition visions though have addressed energy justice and energy poverty. The documents state that *"The current conversations are often about sustainable sources, infrastructure, installations and heating systems, about affordability and feasibility. But the heat transition mainly requires practical measures and investments from residents and entrepreneurs. This transition requires a change in thinking, acting,* *communicating and organizing. Also for us as a municipality, we learn to work better with residents and neighborhoods every day."* (Sparenburg, van Keimpema, & Maas, 2021)

Case of Drechtsteden:

The same goes for the VESTA MAIS model, where it has been described that the model focuses on technical-economic factors that are important for decision-making in addition to social and other economic factors such as natural investment opportunities (PBL, 2023). The model is primarily designed to explore the technical-economic potential of measures regarding energy conservation, renewable energy and collective energy systems in the built environment and the impact of related policy measures (van der Molen, van Polen, van den Wijngaart, & Tavares, 2021). It is good to realize that, like any other model, VESTA MAIS mimics reality, but cannot fully grasp it. Limitations of the model are, for example, that it only simulates the technical-economic dimension of the heat transition and for other dimensions, only preconceived assumptions and future scenarios can be drawn up. Examples of this are, behavior and choices that do not have a technical-economic rational basis, but arise from socio-economic, political or, for example, emotional drivers. This could include issues such as the willingness of homeowners to invest, political policy choices with regard to facilitating or stimulating sustainable heat technologies, or behavioral effects of homeowners when they insulate their homes. Such drivers have not been defined in the characteristics of the model.

As one of the first steps, four different sets of input data are read into the model: spatial data, building installations, key figures and energy prices (van der Molen et al., 2021). This is followed by the settings that a modeler gives to the model for calculating a future scenario. Two places are reserved for this in the model: the default settings and specific settings. Examples of spatial data are the Dutch building stock of the built environment, the size and placement of greenhouse horticulture objects in the Netherlands (relevant to heat demand), but also future scenarios for the demolition and new construction of buildings up to and including 2050. Input files are read for building installations information about devices, such as cost and performance. This also includes a list of possible building options that can be applied. The key figures include specific figures that are necessary for matching the demand for and supply of heat, or the associated costs and benefits, or the emissions of harmful substances. All these parameters that have been defined as the initial input resemble only technical factors. Thus there does not seem to be any such factors that have been explicitly defined that could address energy justice.

In another response from interviewee P1, we can observe that economic factors do take precedence over other aspects. The interviewee states that, *" As a policymaker, you can make better policies, so we have always taken that into account and acknowledge that it is important, but always from a financial perspective we want to predict which system is best for which area. We never took a justice argument into account, prioritizing poor neighborhoods or things like that, that was never in the scope."*

Thus we can observe that from the documentation of the energy models, there have not been clear cut mentions of addressing principles of energy justice, but there are certain factors that relate to the themes defined under energy justice. How these factors have been defined is explained in the following sections.

6.1.1 AFFORDABILITY

Affordability within energy modelling refers to ensuring that energy solutions and policies are economically accessible for all segments of society. It means considering the financial capabilities of individuals and communities when designing energy systems, so that energy services don't create undue financial burdens. With regards to the models used, there were a few input data that were identified that influence the costs regarding the new energy system being installed.

Case of Amersfoort:
There are incentives that have been identified in the Heat vision of the municipality that come under the theme of affordability. One of the documents state *"Affordability for all residents in the district must remain central. We ensure that financial instruments serve the entire city, all neighbourhoods, all residents. An important step in this is that we publicize subsidy schemes and other support."* (Sparenburg et al., 2021). Ensuring the feasibility of the heat transition was a pivotal initial consideration for the local government. To enhance the decision-making process regarding heat strategies tailored to specific neighborhoods, the Municipality of Amersfoort engaged MSG Sustainable Strategies and Quintel Intelligence. They conducted a study to assess the anticipated expenses for occupants (both tenants and property owners) when selecting various heating methods. This study projected the expenses associated with adopting different heating technologies for diverse types of housing. The resultant end-user costs were consolidated for each neighborhood, taking into account the prevalent building structures. This costing though was done outside of the models used, and the costs did not include income levels of the families which would have been more insightful, but only based on the kind of housing that was occupied.
"The Energy Saving Mortgage" is an initiative that has been operational since January 2021. This mortgage option is designed for homeowners with restricted borrowing capacity, who are not qualified for standard financing (Sparenburg et al., 2021). The Energy Saving Mortgage entails distinct terms and is acquired alongside the current mortgage or loans from other providers. The unique feature of this mortgage is that, for the initial three years, the borrower has no financial obligations whatsoever – neither interest nor repayment. The government covers the interest costs through the Heat Fund. Repayments commence only when the borrower's financial situation allows. The municipality is committed to preventing energy poverty. With the Scheme "Reduction Energy Consumption of Homes", homeowners and tenants are supported with subsidies to take small energy-saving measures and thus reduce their energy bills (Sparenburg et al., 2021). This scheme is particularly aimed at low-income people.

Case of Drechtsteden:
The municipality and housing corporations take affordability and the prevention of energy poverty into account in their transition approach. This is an important starting point in determining the planning and nature of the measures. Keeping residents' energy bills affordable is also an important starting point for the municipality in its approach towards natural gas-free neighbourhoods. In addi-

tion, private owners can use subsidies and financing options to take energy-saving measures at their home in order to reduce energy bills.
A number of parameters were identified in this case that come under the theme of affordability.

- Within Vesta MAIS it is currently possible to calculate the changes in the energy tax and the storage of sustainable energy for gas and electricity, and investment subsidies for building and area measures. The "Tax credit" is an allowance from the government to spare energy users in terms of taxes for the first part of the energy bill (van der Molen et al., 2021). This amount is entered in euros per connection per year. This amount is deducted in Vesta MAIS per electricity connection from the energy tax that the user pays.
- Another benefit that is used as input is "Energy Investment Allowance". EIA is government grant for investment, and through this scheme, a fixed percentage of a specific type of investment is returned to the actor making the investment (van der Molen et al., 2021). Various actors and components can be set and a different height can be specified for each type of EIA. For building-related investments, the model user can set different subsidy levels for each type of building.
- Sustainable Energy Transition Incentive Scheme (SDE++) is a production subsidy for heat networks based on the amount of heat supplied by the primary source. This subsidy is expressed in euros per gigajoule and is settled on the volume of heat that goes out from the primary source. This subsidy can be set in the parameter for Light temperature heat sources.

Such inputs or parameters can address affordability because they provide relief financially and lower the value of energy bills. These parameters have been taken into account in the modelling process, however the allowances and subsidies generally benefit the energy service providers and organizations in charge of installations, and not the end consumer in all cases. It only affects the end user when the energy providers disclose the costs and share the savings with the end users.

- Another input identified is the "Split Incentive Factor" (van der Molen et al., 2021). Split Incentive arises because the building owner is responsible for investments in building measures and the building user then benefits from this through a lower energy bill. If the owner is not the user himself, this means that there is no incentive for the owner to invest unless the owner can share in the savings. Through this parameter, the model user can enter a percentage that represents what part of the energy savings from building measures will be returned to the building owner via the building user.
- Rent Reduction at Area Option is another slider input. The import figures include an amount for rent reduction as a result of connection to a collective heat option. This is a consequence of the points system for rented homes, where private heating is valued higher than collective heat supply. Using this slider, the user can adjust the amount by scaling up or lowering the amount in percentage terms, possibly to zero. This rent reduction is calculated as a cost item for building owners and as a benefit for building users.
- And finally there is the Discount Rate. In order to be able to make profitability calculations, the model uses different discount rates for different stakeholders such as owners of new homes or

existing homes, district distributors et cetera. The stakeholders are separately included in the calculation and the discount rate used can be adjusted individually for each.

These parameters do qualify as affordability factors because if implemented they will directly affect the people who need such benefits. The models assumptions also define that such factors come into play only when the calculation perspective is done in terms of the end user charges. There are two viewpoints for evaluating costs: national costs, also known as social costs, and end-user costs. Determining costs is pivotal in analysis. When users are interested in outcomes without considering cost distribution, national costs are suitable. These costs allow comparing various scenarios and their overall impact on the entire country. Distribution effects matter in end-user cost calculations, as they reveal how policies financially affect all parties in the heat transition. This clarifies the influence of policy tools like taxes or subsidies on each entity's financial position. The primary distinctions between these approaches are related to government policy effects and discount rates used. National cost calculations don't account for internal fund shifts within a country due to taxes and subsidies since the overall balance remains unaffected. Additionally, they utilize a social discount rate that doesn't accommodate actors' individual considerations. In contrast, end-user cost approaches consider these distribution effects and accommodate different discount rates based on individual circumstances.

Interviewee P1 stated that in their modelling process, end-user costs were taken into account. He states, *"Within this national cost definition, it excludes taxes, it excludes transfers, it excludes subsidies. We have never done that because you get a very theoretical model, and it will not reflect the actual cost that the housing society or the owners of the houses must pay. These individuals are taxed and they can receive subsidies. So, we feel that taking into account taxes and subsidies does give you a more workable model."*

6.1.2 TRANSPARENCY

Transparency refers to the open and clear communication of information, decisions, and actions related to the energy transition. In a just energy transition, transparency implies making information about energy policies, plans, and decisions easily accessible to all stakeholders, engaging stakeholders in the decision-making process, and clearly communicating the potential social, economic, and environmental impacts of different transition choices.

When it comes to access to information, both the municipalities have shown evidence of sharing most of the data that they have used to come up with their decisions. The process of sharing this information was also carried out through different channels. In both cases, the Start Analysis was used as the starting point for taking inputs and creating heat strategies, and that has been mentioned in the heat vision of both the municipalities. The outcomes of the initial analysis by PBL are derived from public data. Local information accessible to stakeholders, such as housing associations or market parties, is not known to PBL and thus has not been incorporated into the analysis. Therefore, the results of the analysis were augmented with local data during a collaborative session with stakeholders, adhering to the Guide for Local Analysis of PBL.

Case of Amersfoort:

The municipalities approached the decision making process in a participatory manner. A lot of stakeholders were involved and their opinions were taken into consideration. In Amersfoort, throughout the preparation of the Heat Transition Vision, a total of six sessions were conducted, involving residents, collaborators, and other invested parties (Sparenburg et al., 2021). These entities were categorized into two distinct groups: the Partner Working Group and the Sounding Board Group. This was done in order to first draw up a plan and set the inital targets. The Partner Working Group comprised proficient stakeholders possessing substantial expertise in the field of heat transition, along with significant insights pertinent to the municipality. Notable members encompassed entities like Stedin, the primary grid operator, the three prominent housing associations that came under the "Woning Corporatie" for the municipality, and the Amersfoort Warmtebedrijf, which was the local heating organization. Meanwhile, the Sounding Board Group encompassed a more extensive representation of stakeholders within Amersfoort. Profiles for each district were prepared by the municipality, and communication and participation activities were modified accordingly. The coordination of these activities with other entities engaged in a neighborhood, such as corporations and residents' initiatives, was carried out by the municipality.

The municipalities also brought in consulting companies to help with the process. Interviewee P6 states that *"We were in the picture then with the municipality. But we wanted to specifically make a vision for the heat transition, and that was before the Dutch Government applied the municipalities to make such a thing, so they were a little bit ahead of the regulations. And we helped them with that and we did it in a participatory fashion. We organized a work sessions. We spoke with all the stakeholders. We organized meetings with, with the municipality and the different organizations, and we wrote a heat vision document and we knew already that that there was an obligation to make such a documentation. I think the communication with the stakeholders was our job. Before we organized the meeting, we would interview them individually to know their concerns, to know what their plans were. So these could be aligned and then we use that to set up an agenda on what to discuss. And the larger public was involved, but more at the moment when it was already kind of clear what kind of direction the plans would go, because we believe that if you want to make a vision and that is too abstract for most citizens, and there's some people that like to be involved, we involve them."*

In one of the documents it has been stated that *"Where the assumptions in the calculation of the Plan-*

Criterion	Elaboration	Sources)
Low social costs	The national costs of a heat strategy per neighbourhood	Start Analysis (PBL)
Local information	The local availability of heat sources Plan heat companies Plan business areas Choices for heat technology in new construction plans	Feasibility studies (see table appendix 2) Heat companies Business parks Developers' new construction plans
Low end-user costs	The costs of a heating strategy for building owners and tenants	Own global cost calculations based on cost estimates from Milieucentraal

Figure 8: Elaboration of criteria for choice of Heat strategy (Sparenburg et al., 2021)

ning Bureau deviated from locally known situations, the choices have been brought into line with the insights submitted by the partners. Appendix 2 provides insight per neighborhood into where and for what reasons the initial analysis has been deviated from." (Sparenburg et al., 2021)
Information regarding which neighbourhood was cleared for the transition, what technology is suited for that region and a reasoning if solutions were not feasible were all shared via the documents, that were made publicly available through the municipality portals.

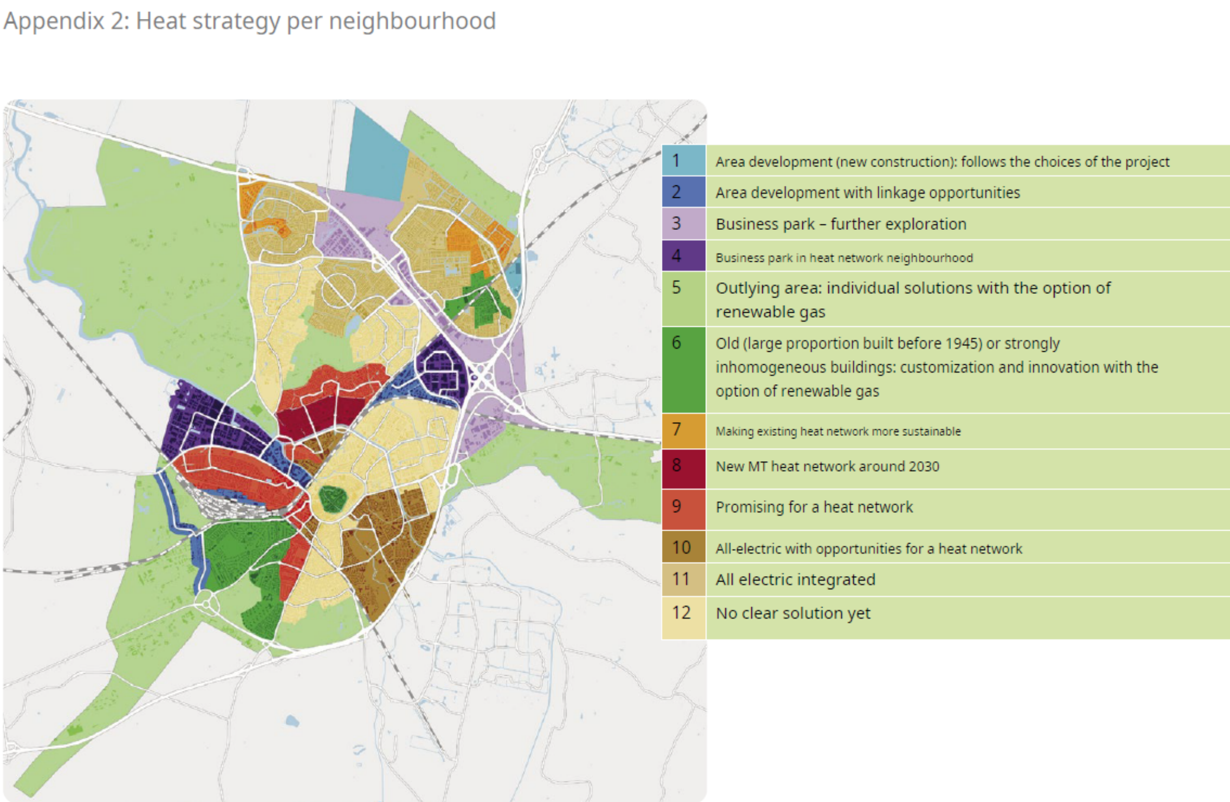

Figure 9: Heat strategy per neighbourhood
(Sparenburg et al., 2021)

Few members of the municipality also received training on how to use the energy models, that could assist them in the process. Interviewee P5 states, *" Well, I did do a short clinic in the ETM. So I know how the energy transition model works, wherein it just says how many companies do you have, how many households are involved or can be involved, and information on how are they heated. That's data that's pretty readily available. I think everyone should probably be able to figure it out because it's pretty intuitive."* Thus there has been effort to share expertise on how to work with the models and equip the municipality with adequate knowledge.

Case of Drechtsteden:

In the municipality of Drechtsteden, an online survey was circulated through various channels including social media, which was mentioned as the Denkmee.drechtstedenenergie.nl platform, and municipal newsletters. This survey was targeted at residents within the Drechtsteden region and involved a series of multiple-choice questions pertaining to the heat transition. The survey outcomes offer an understanding of residents' priorities in the heat transition and the decisions integral to the heat transition vision. With over 4,500 completions, the survey yields valuable insights into residents' inclinations regarding the shift towards living without natural gas (Geldhof et al., 2021)

The engagement platform facilitated residents and entrepreneurs in sharing their perspectives and

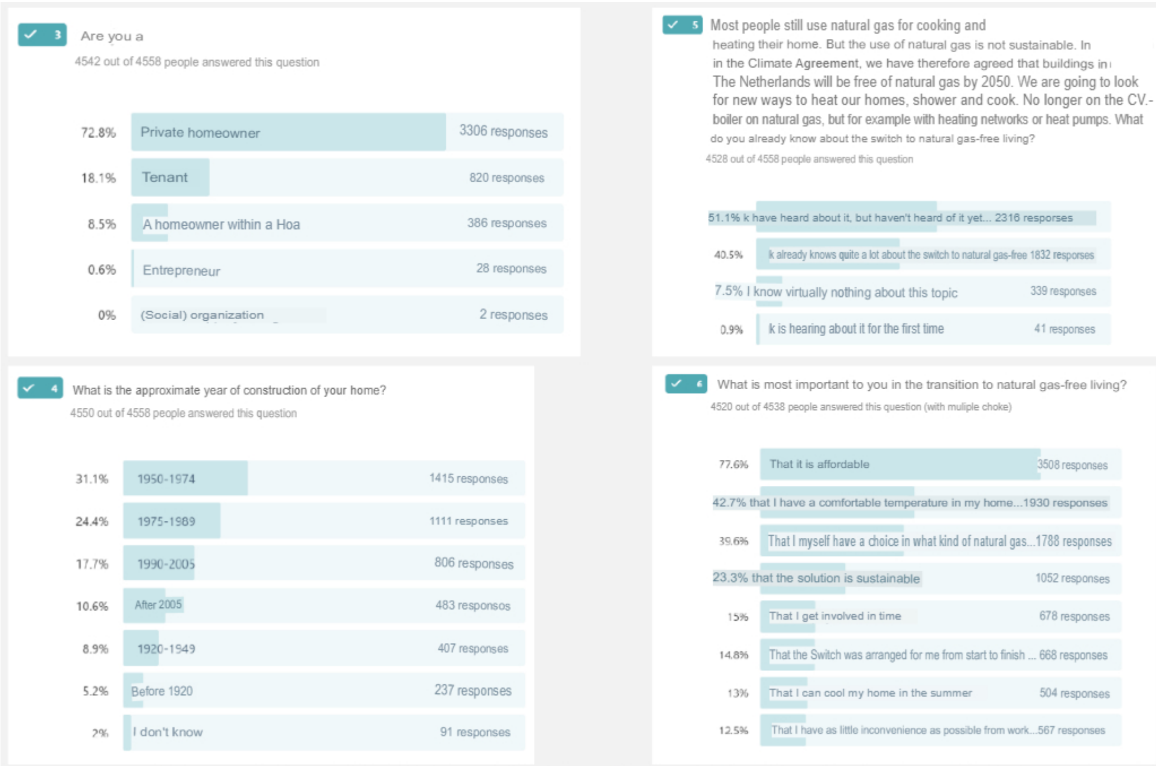

Figure 10: Survey Responses Municipality of Sliedrecht
(Geldhof et al., 2021)

ideas regarding the heat transition. Two inquiries were posed; firstly the selection criteria for identifying the most suitable neighborhoods to initiate the natural gas-free transition, and secondly, the factors that render the shift to natural gas-free appealing. Several recurring themes emerged from the discussions, notably the inclination towards emphasizing insulation, concerns about the viability and affordability of the transition, and the aspiration to maintain existing infrastructure. This was combined with considerations about forthcoming solutions, such as hydrogen and nuclear energy, which are not yet readily accessible.

Another aspect when it comes to access of information is that the energy models that were used in both cases were of open access. That means that the software for the models was available publicly, and the information on how to add inputs to the models were open access through websites such as GitHub. This is identified only in the selected case, but it does not hold for all modelling approaches.
Interviewees have conveyed that information has been conveyed to the public through the specified communication channels in four general categories: details about the transition to gas-free alternatives and its consequences for their local municipality, including readiness for forthcoming changes;

insights into the municipality's favored resolutions and strategies, along with initiatives targeted at specific pilot neighborhoods; information about the expenses and advantages of different technological choices; and practical guidance for homeowners across all neighborhoods, such as counsel to delay investing in new heating equipment to prevent incurring unproductive expenses.

6.1.3 RESISTANCE

In the context of a just energy transition, resistance refers to opposition, push back, or reluctance encountered when implementing changes aimed at achieving more sustainable and equitable energy systems. This resistance can come from various sources, including individuals, communities, businesses, and even governmental or institutional entities. Resistance can also be interpreted as opposition to the use of specific models, or the way modelling is being used, but the justice framework defined resistance as only acts in the form of legal action, political lobbying, public demonstrations, digital campaigns or a combination of these, amongst others (Sovacool, Burke, Baker, Kotikalapudi, & Wlokas, 2017).
While resistance is complex and often subjective, some ways it could be operationalized in energy system models are by including economic factors that contribute to resistance, such as high upfront costs, uncertainty about returns on investment, and potential financial burdens on end-users. Another method could be to develop parameters such as an Acceptance Index, that represents varying levels of social acceptance and willingness to adopt new technologies, taking into account cultural and social factors that might influence resistance.

Case of Amersfoort:

One of the main obstacles in this sector that almost all the participants pointed out was with the investment that is required in the beginning. People are understandably not inclined towards making such large payments without the assurity that it would actually bring down their energy costs. Interviewee P6 states that, *"Now the resistance with the heat transition is really, really cost. The idea that you have to invest, and there were sometimes numbers floating around in the public domain stating that it's going to cost you €80,000 to get rid of natural gas. That's just an amount of money that people don't have. And don't want to spend, so that creates a huge resistance. And the government didn't have a solution at that point other than mentioning that we need to do it because of the Paris Agreement. That's changing now, but at that point it was really the big hurdle and only the people that were really motivated to change were willing to invest that much money in it. And of course, in the end these numbers weren't correct. They were not as high as they were mentioned, but that really did not help if you ask people to make such big investments and changes in their homes."*

Another form of resistance was reluctance to implement new changes because of the uncertainty of what could be achieved with the new technology. Interviewee P4 mentioned that *"I think our client was really progressive in that sense. They knew they had to create or deliver a heating transition vision to the governments, so they wanted to take steps. But of course, a lot of parties were quite hesitant and when we presented our plans, they said that it is not going to happen, not realistic enough. And I think another thing* *that kind of held back some plans was that you had this thing called Proefneming, like expert experiments. And if you had a nice plan for a neighborhood, for example, for heating network, you could ask for a subsidy with the governments. But I think in the end it turned out that the subsidy wasn't provided, so they had like a plan, but then they didn't get their funds. And it also held them back. This provided a lot of uncertainty and kind of messed up the whole timeline."*

People's personal opinion was also considered as a form of hindrance to providing just outcomes within a municipality. There were always people with opposing views about the options available, and also coming from different sects of society, they had a different mindset when deciding on such options. Thus it is hard for the municipality to come up with concrete solutions that would satisfy all parties involved. Interviewee P5 said, *"Community engagement is very tricky. In Schothorst, which is the first neighborhood we did this program called the Bakfiets Companion, where we talked to people about what they feel about the heating transition and what are important things for them and so on. So there were people that said they don't believe in changing from natural gas to anything else because it's more sustainable. I don't believe biomass is cleaner than natural gas and it will be so expensive. One person even said they would barricade their home if they if we would try to remove their gas from the home. So you have to really make sure that you're careful with such kinds of things."*

Case of Drechtsteden:

In terms of defining such resistances with the help of energy models, there was no factors that could be identified with the theme of resistance and not much involvement of these tools, because of the attribute being difficult to measure or to assign a value for. Interviewee P1 pointed this out, saying that, *"Potentially this is very dubious I think, because basically what you're looking for then is can you model public resistance, or can you predict public resistance? We are seeing an increase in data providers that provides you know social, psychological data about Drechtsteden, like these lifestyle profiles or are people very much into sustainability or not. I've always found this to be very un-scientific and unpredictable. In a building you can measure and energy efficiency and the technical stuff. You can easily measure, but how do you measure or how do you predict people's opposition. I've always been very reluctant to use that kind of data because I can hardly judge its merits."*

Within the heating transition, it is observed that there are no resistances in the form of protests against the installation of technologies, as could be seen in wind farm projects. The kind of resistances could be noticed only from an economic, political or legislative purpose.

6.1.4 SUSTAINABILITY

The principle of sustainability refers to designing, planning, and implementing energy systems that meet present energy needs while also considering the long-term well-being of both the environment and society. This involves making decisions that minimize negative environmental impacts, enhance resilience, and promote social and economic equity.
The modelling approaches used in both cases have been designed to provide insights into sustain-

ability, be it in the form of energy saving potential and the carbon emissions based on the solution selected for the heating transition. The most predominant indicators that display the focus to promote sustainability are schemes and incentives that stimulate the production of sustainable energy.

Case of Amersfoort:

The ETM is equipped with a "merit-order" parameter that allow to make a sustainable choice in the District heating system (Quintel, 2023). There are two categories of heat sources: those that can be activated or deactivated based on the current heat demand, referred to as dispatchable heat sources, and those that continuously provide heat to the network regardless of the heat demand, known as must-run heat sources. Dispatchable heat sources can be activated or deactivated as needed. The ETM computes the annual heat supply from both continuous and fluctuating sources for each hour. If the heat demand surpasses the available supply during a particular hour, the dispatchable heat sources will be activated to prevent any shortfall. With the ETM it is feasible to alter the priority sequence of dispatchable heat sources, determining which one gets activated first when there's a shortage of heat.

Another parameter which is the flexibility setting which supports the decision to balance the supply

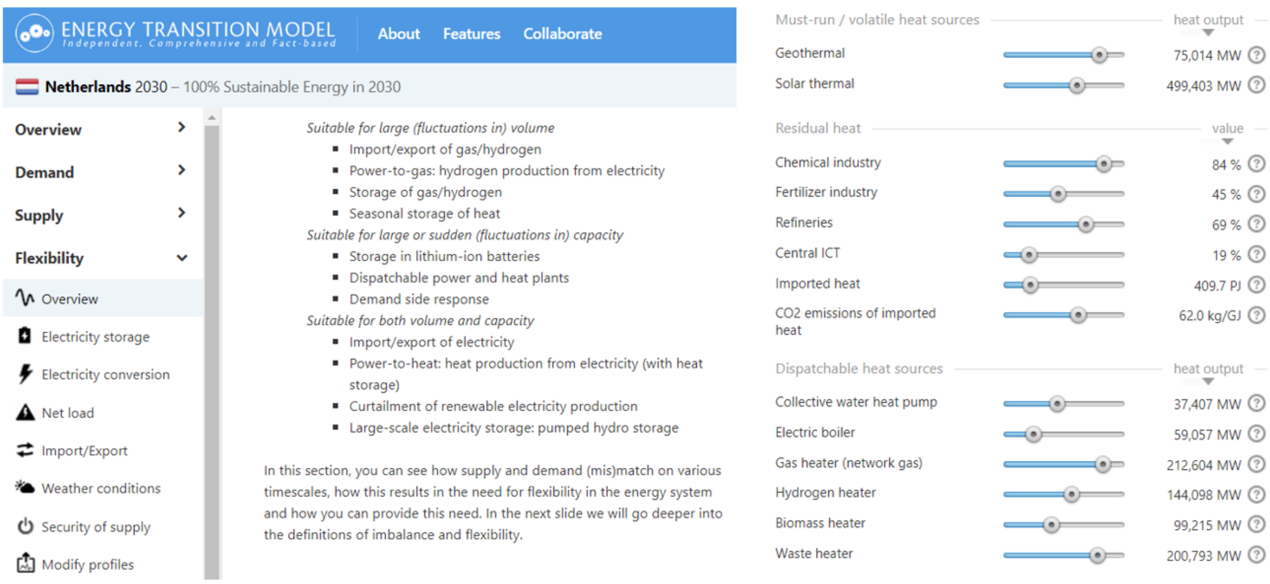

Figure 11: Energy Transition Model parameters for flexibility and merit order Quintel (2023)

and demand of heat energy during high capacity periods (Quintel, 2023). These capacity periods can be monitored with the ETM, and choices can be made on which technology is the most optimal.
The transition vision of the municipality also shows support to move to sustainable sources. Special attention is given to residents with limited or no capacity to independently invest in sustainability. Guidance is provided by the municipality towards alternative funding sources like European funds, national and provincial subsidies, prior to resorting to municipal funding.

Case of Drechtsteden:

As discussed earlier, the Energy tax and the SDE subsidy are some economic factors that are taken as inputs depending on the technology involved. The model also has a parameter known as the Investment criteria (van der Molen et al., 2021). Investments in sustainable heating solutions occur when they are both technically feasible and economically advantageous. In other words, the guiding principle is to allocate resources to sustainable heating options when the net present value (NPV) of investment initiatives is positive. When considering different choices for buildings, if multiple options yield a positive NPV, the one with the highest NPV is selected. This selection process shows that the most sustainable alternative may not be selected on most occasions and would not align with how sustainability is defined within energy justice.

Another input that is considered in the VESTA MAIS models is the Green Gas Factor (van der Molen et al., 2021). Green gas is biogas that has been upgraded to natural gas quality. In this case, the carbon dioxide becomes largely removed, increasing methane levels. The gas thus is elevated to Dutch natural gas quality and may be mixed into the natural gas network. In scenarios where the utilization of sustainable electricity, such as solar and wind power, is impractical—such as in historic city centers or remote regions with limited heat networks or electrification—green gas can serve as a substitute for natural gas. In these contexts, green gas plays a role in advancing the energy transition. The Dutch gas network transports both natural gas and green gas. Because they are functionally identical, they use the same infrastructure. At any given moment, therefore, a certain proportion of the gas flowing through the network is green gas. This parameter can be used to specify that share and is then used to reduce the calculated greenhouse gas emissions related to gas consumption (van der Molen et al., 2021)

6.1.5 CROSS CASE COMPARISON

In comparing the justice themes across the two model use cases, it is evident that both the models and heat transition visions address various aspects of affordability, transparency, resistance, and sustainability. However, there are differences in the depth and focus of their integration.

Heat Transition Amersfoort:

- The municipality in this case made use of inputs from scenarios created by the Energy Transition Model. This model considers economic factors only pertaining to the alternate technology chosen, and the volatility of fuel price effects, indirectly addressing affordability but not as detailed as the other case. While not explicitly focusing on end-user affordability, the model's consideration of economic impacts does take into account the potential cost implications for stakeholders. The transition vision document also displayed estimated end user costs based data such as the type of households and the heating technology that was proposed. These are all positive signs showing that the municipality was considering steps towards making the transition financially viable.

- The Energy Transition Model primarily focuses on energy key performance indicators and technical aspects. The model ensures transparency by providing open access to energy model software and data sources, allowing stakeholders to access and analyze the model's outputs, but it's transparency is centered only on energy-related data. Next there were collaborative sessions involving partners, stakeholders, utilized to ensure that decisions are made collectively and with open communication. The involvement of the Partner Working Group and Sounding Board Group, along with communication through various channels, contributes to making information accessible and facilitating engagement in decision-making processes.
- In terms of resistance, the model does not assist to recognize or measure any economic resistance, where stakeholders may oppose changes due to uncertainty and costs. The transition vision of the municipality recognizes the diverse opinions and concerns of stakeholders and considers economic, political, and legislative factors that could pose resistance to energy transition efforts. However there is no evidence of any measures that were taken to combat this issue.
- The Energy Transition Model considers energy-saving potential and carbon emissions, and that is the only factor aligning with sustainability goals. While it does not explicitly focus on sustainable energy sources, the model's consideration of energy efficiency and emissions reduction contributes to the broader sustainability objectives of the energy transition. The municipality has also made efforts to inform the society about using alternative technologies by discussing the benefits of their use. The focus on energy-saving potential and carbon emissions contributes to the municipality's commitment to sustainable energy choices.

Heat Transition Drechtsteden:

- In this use case the VESTA MAIS Model was used to simulate the scenarios, and it includes various parameters and incentives aimed at addressing affordability concerns. These include tax credits for energy users, energy investment allowances, and sustainable energy transition incentive schemes. These measures are designed to encourage investment in energy-saving technologies and reduce the financial burden on end-users. Additionally, parameters like the split incentive factor and rent reduction at the area option take into account the affordability of energy solutions for different stakeholders, such as renters and homeowners.
- The use case of Drechtsteden also scores high on transparency. Firstly the model used was of open access and all the data that was taken as input was from public sources. The municipality also discusses the various options with the residents through an interactive portal, but only after the initial decisions have been taken. This process engages the end user only during feedback and not in the decision making.
- In terms of resistance, the VESTA MAIS Model does not acknowledge challenges such as initial investment resistance and reluctance due to uncertainty of technology outcomes. The transition vision acknowledges some resistance from opposing views, which could stem from differing

perspectives on energy transition solutions. Resistance in this use case is mostly by the influence of legislative constraints, which can impact the feasibility and implementation of certain energy transition measures.

- Finally, the use of the VESTA MAIS Model promotes sustainability by incorporating parameters like investment criteria in renewable energy sources based on net present value (NPV). This ensures that investments in sustainable heating solutions are both technically feasible and economically advantageous. The model also considers the Green Gas Factor, which enables the substitution of sustainable green gas for natural gas in regions where sustainable electricity solutions are not feasible. The comparison of results is illustrated in the Table 7 below.

USE CASE / PRINCIPLE	CASE OF AMERSFOORT	CASE OF DRECHTSTEDEN
AFFORDABILITY	•Modeling mainly of fuel price effects •User costs calculated based on household type ●●●○○	•Multiple factors included in the model •Limited explicit focus on end-user affordability ●●●●○
TRANSPARENCY	•Sharing data and outcomes •Group involvement through various channels ●●●●○	•Open access energy model software and data sources •Transparent communication, and collaboration. ●●●●○
RESISTANCE	•Economic resistance due to high upfront costs •Political and legislative challenges ●○○○○	•Economic resistance and reluctance due to uncertainty •Resistance due to opposing views ●○○○○
SUSTAINABILITY	•Consideration only on energy-saving potential and carbon emissions ●●○○○	•Emphasis on sustainable energy sources and incentives for sustainable production. ●●●○○

Table 7: Case Comparison

In the table above, each justice principle was assigned a weighted priority as described in section 5.5. Based on the information collected from the interviews and documents, a score was assigned to each principle for both cases using a scale of one to five, with five being the highest and one being the lowest. The green dots in Table 7 represent these scores. On this assignment of scores and the weights, Heat Transition Drechtsteden has a higher total weighted score (3.69) compared to Heat Transition Amersfoort (3.23). Therefore, Heat Transition Drechtsteden performs better in terms of priorities assigned to each principle.

6.2 CHALLENGES OF INCORPORATING ENERGY JUSTICE

The low inclusion of energy justice in the models and in the decision making process were due to multiple reasons, that were identified through the interviews with the participants.

- **Varied Interpretation of Energy Justice:** Energy justice principles encompass a wide spectrum of ethical considerations, ranging from equity and affordability to participation and cultural rights. Various stakeholders interpreted these principles in unique ways based on their values, experiences, and priorities. This diversity of interpretations leads to challenges in consensus-building regarding the most appropriate measures to embed energy justice within models.
  In the context of energy justice, equity often refers to the fair distribution of the benefits and burdens of energy systems. Some stakeholders interpret equity as a primary focus on alleviating energy poverty, ensuring that low-income households have access to affordable energy services. Others emphasized equity in the context of transitioning to clean and renewable energy sources. One group advocates for immediate relief from energy poverty, while another insists on long-term sustainability. This leads to conflicts and disagreements on the best course of action.
- **Technical Emphasis vs. Social Dimensions:** Energy system models primarily center on technical aspects and often lack emphasis on addressing the social dimensions of energy transitions. The focus tends to be on presenting diverse energy system configurations and transition pathways, rather than exploring the intricate interplay of energy justice within these models.
- **Quantification of Ethical Concepts:** Ethical concepts like energy justice pose challenges in quantification and value assignment. The inherently complex nature of these concepts sometimes relegates them to lower priority, undermining their perceived significance in the modeling process.
- **Data Complexity and Uncertainty:** A significant hurdle lies in determining appropriate data for calculating attributes such as affordability or sustainability. The excessive number of information sources available, both at regional and national levels, leads to uncertainty about which source should be deemed accurate and reliable for such calculations. Interviewee P3 confirms this by stating, *"When we begin discussing how to formulate these policies, we face the difficulty of choosing an appropriate source to use data from, because there are multiple sources that claim to be accurate but there is still some differences on comparing them."*
- **Temporal and Regulatory Constraints:** Time and legislative constraints exert constraints on the effective utilization of energy models. Municipalities face pressures to swiftly produce results, often influenced by dynamic political decisions and shifting legal frameworks. This environment often redirects focus away from considerations like energy justice in favor of expediency and simplicity. Interviewee P6 agrees that time is a major limitation by stating that *" The big challenge is that if you want to make the next step after these transition visions, then you have to make plans for every neighborhood which is time consuming. For some municipalities, to have people participate and make a plan together with the citizens just takes a lot of time and effort, and the municipalities*

don't have that capability, so it's going still too slow. I think that's the big challenge to accelerate, and to scale up as well."

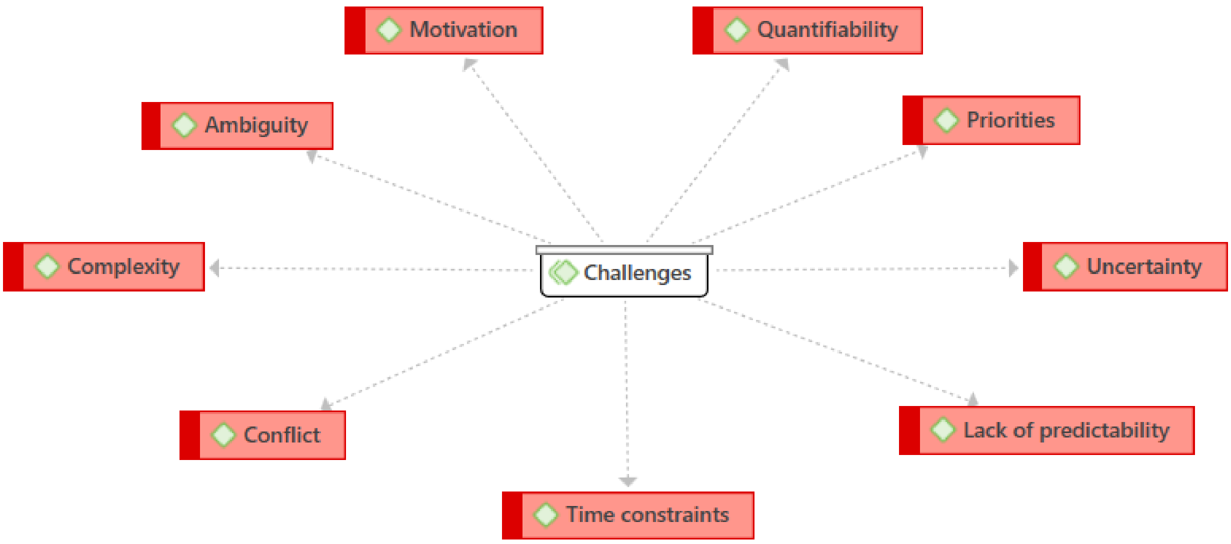

Figure 12: Network Diagram of codes under the theme Challenges

7 DISCUSSION

This section provides a detailed discussion of the findings obtained in chapter 6 from this study, and contextualizes them within the existing scientific literature, followed by the limitations of various components of the research.

7.1 INTERPRETATIONS

Integration of Justice principles

The integration of energy justice principles in these modelling approaches reflects a broader discourse found in the literature. Scholars such as Sovacool emphasize the importance of incorporating equity and fairness in energy transitions, aligning with the focus on affordability and transparency observed in the models (Sovacool et al., 2018). The call for transparency and stakeholder engagement, as seen in the VESTA MAIS Model, resonates with the literature's emphasis on public participation and democratic decision-making. Moreover, the models' recognition of sustainability through the consideration of energy-saving potential and carbon emissions aligns with the broader imperative to balance environmental and societal well-being. However, the limited explicit focus on social dimensions, especially in the Energy Transition Model, reflects a gap highlighted by scholars like Schlosberg and Collins, who stress the significance of incorporating social justice aspects in energy transitions (Schlosberg & Collins, 2014). The models' heavy reliance on technical and economic aspects, while valuable, underlines the ongoing challenge of quantifying and assigning value to ethical concepts like energy justice.

Both model use cases incorporate various aspects of energy justice, such as affordability, transparency, resistance, and sustainability, although with varying degrees of emphasis. The VESTA MAIS Model distinguishes itself through its detailed approach to affordability, utilizing mechanisms like tax credits, investment allowances, and subsidy schemes to alleviate financial burdens on end-users. Additionally, the transparency initiatives in the respective municipality, involving collaborative sessions and an engagement platform, exemplify a motivated effort to involve stakeholders in the decision-making process. The resistance and sustainability considerations in this model are also noteworthy, with emphasis on economic resistance and explicit support for sustainable energy sources through the Green Gas Factor. In contrast, the Energy Transition Model leans more towards addressing technical and economic aspects. While it does account for elements of affordability, transparency, resistance, and sustainability, its focus appears to be primarily on optimizing energy performance indicators, costs, and technological choices. The model's limited emphasis on end-user affordability and social considerations, however, suggests room for further integration of energy justice principles.

Distributive and Procedural justice

Throughout the course of this research, we have come across various definitions of justice. It was initially discussed that modelling would come under more of a procedural form of justice. The study highlights the active engagement of municipalities in the Dutch heating transition, employing energy system models to navigate complex decisions. The municipalities' role extends beyond being model users; they shape the models to align with their local contexts, incorporating data and insights to enhance accuracy and relevance. The collaborative approach involving various stakeholders emerges as a hallmark of the transition process and can be seen as an indicator of procedural justice (Williams & Doyon, 2019). Both the use cases included a participatory approach, bringing in consultants and other members of society together. This signifies the starting efforts to improve the legitimacy and robustness, and a sense of capacity building through mutual learning (McGookin, Ó Gallachóir, & Byrne, 2021). The work of Jenkins also further explained how procedural justice can be achieved, and state that mobilizing local knowledge, representation in institutions and greater information disclosure allows for more just outcomes (Jenkins et al., 2016). We could see in the case of Amersfoort that such efforts were made, where changes in the initial assumptions of the Start Analyse tool were executed to align the process to cater the local context.

Through the information that was collected it shows that modelling was concentrated more on the distributional form of justice, because there were many indications of efforts taken to address the growing energy prices and also prioritize sustainability in the transition. The focus on calculating subsidies, and trying to factor in the end user costs in the models highlights the intention of the modelling outputs and the need to ensure that the final decisions positively affect on the end users investments. The literature also aligns with these actions, which suggests incorporating distributional justice into a modeling exercise is relatively straightforward because it is focused on outcomes and can be quantified more easily. In contrast, procedural and recognition justice pose greater challenges in terms of quantification and integration (Vågerö & Zeyringer, 2023). The case studies illuminate the pragmatic approaches undertaken by municipalities to ensure that the heating transition aligns with the principles of energy justice and broader sustainability goals.

Perspectives from Modellers and Policy makers

The interviews conducted with energy modellers and policy advisors revealed a difference of perspectives and priorities concerning energy justice and its integration into modeling. Modellers acknowledge the absence of a clear understanding of energy justice and agree that there have been minimal efforts to prioritize it. Understandably their primary objective is to provide decision-makers with optimized energy solutions, and so they focus on technical feasibility, efficiency, and economic considerations when designing models. In contrast the advisors and researchers have a much better understanding of justice and frequently emphasize on the social and ethical dimensions of energy transition. Most of them do agree that the models do serve as a great starting point to come up with solutions but they do not cover all the aspects needed for policy formulation. These perspectives are partly in line with the model based policy making discussed in Susser et al (Süsser et al., 2022), where varying viewpoints reflect the complexity of energy transition efforts and underline the importance of recognizing and reconciling diverse interests.

Further adding to the differences that were discussed above, there was another finding regarding modelling tools during this study. Modellers and Advisors have come to accept that certain modelling approaches are technical and economic in nature, and it is difficult to modify them and to tailor the contextual needs. To tackle this, they are making use of other tools along with the models to assist them in their decision making. Energy Savings Dashboards is an interactive map that provides more social data such as effective income of neighbourhoods, that municipalities use to make their own assessments and prioritize their energy savings program (ProvinceNoord-Holland, 2023). The Visie op Energie is a toolkit that shares characteristics of residents in a neighborhood and the risk of energy poverty (MSG-Strategies, 2023). It provides insight into the costs for residents of different technologies and therefore how attractive a heating network is compared to an all-electric option. This tends to indicate that the modelling approaches are still void of social factors, and displays a diverging perspective from the findings that modellers try to integrate social aspects of the energy transition to their primarily techno-economic modelling approach (Krumm et al., 2022) (Pfenninger, Hawkes, & Keirstead, 2014).

The scientific contribution from this research is the evidence of justice implementation in modelling approaches. This ads to the existing literature on the socio-economic nature of the energy transition, and also the efforts taken in understanding and incorporating distributive and procedural forms of justice. The findings collectively support the conclusion that while efforts have been made to integrate energy justice principles within energy system modeling, there remains a need for more comprehensive consideration of social, cultural, and political dimensions. The distinction between the models' approaches highlights the complexity of implementing energy justice in practice. Nevertheless, the efforts documented in this study represent important strides towards aligning energy transition goals with principles of fairness, equity, and sustainability. As the energy landscape continues to evolve, bridging the gap between technical modeling and social justice considerations will be essential for achieving a just and sustainable energy future.

7.2 LIMITATIONS

While this study has shed light on several key aspects, it is not without limitations.

- **Sample Size:** The research is limited to the perspective of two municipalities and their transition visions, potentially restricting the generalizability of findings. It can be broadened by including other municipalities, as well as study use cases from other energy sectors like the Electricity and Mobility sector, and make a comparison. The number of people interviewed for this study was few, and a larger group would definitely add on to the research findings.
- **Research Scope:** The study only focused on a selected few principles of the elaborate energy justice concept. There are seven more defined principles that can further add rigour to this study if included. Other frameworks on this topic can also be integrated to make the research more comprehensive. This study also focused on select modelling approaches.
- **Time Constraints:** The study was carried out within a fixed period of six months, potentially limiting the extent and scope of data gathering and analysis. A more extensive investigation conducted over an extended time frame could offer a more comprehensive insight into the intricacies of energy models and the process of a just heat transition.
- **Analysis of Data collected:** The thematic analysis of the data relied on the researcher's interpretation, where themes were derived from the connections and patterns perceived by the researcher within the data. Consequently, if another researcher were to conduct the analysis, they might identify distinct themes based on their own interpretations.
- **Research Method:** Additionally, the study relies heavily on interviews and document analysis, which may introduce bias and limitations in capturing the full complexity of energy justice integration. Surveys can provide a broader perspective and statistical insights that complement qualitative findings from interviews. Focus group discussions or workshops involve a small group of participants engaging in structured discussions led by a moderator. It can uncover shared values and concerns that might not emerge in individual interviews.

8 CONCLUSION

This chapter summarizes the key findings and presents conclusive remarks on each research question, highlights the scientific contribution of this study, acknowledges its limitations, and outlines future recommendations for further research and practice.

8.1 CONCLUDING SUMMARY

The Dutch heating transition stands as an example of the global endeavor to achieve sustainable and just energy systems. Dutch municipalities have been assigned a pivotal role in the heat transition, which involves replacing natural gas with sustainable heating options in buildings. However, it has become evident that the prevailing approach to this transition has predominantly focused on technological and economic aspects, neglecting its inherently social nature. The literature that covers this field is still in its infancy and there is much to be explored at the intersection of justice and modelling techniques.

This study delved into the interaction between energy system models and decision-making processes within the context of this transition. It also makes efforts to understand the multifaceted realm of energy justice principles in the context of energy system modeling for the transition towards more equitable energy systems. Through an extensive analysis of data collected from interviews and document analysis, the main research question posed at the outset of this study has been addressed, which was formulated as

"To what extent have energy justice principles been represented in Energy modelling employed in the Dutch Heating Transition?"

To help answer this, there were four sub questions that were framed. The first question formulated was:

"What are the principles of Energy Justice?"

There are many sources of literature that describe the concept of energy justice, and the paper by Sovacool and Dworkin provided a clear and accurate understanding of what this theory should address. The energy justice framework intertwines notions of justice that mainly includes distributional, procedural and recognition form justice. The principles of energy justice under these notions encompass affordability, ensuring that energy solutions are financially accessible; transparency, involving stakeholders in decision-making processes; resistance, understanding and addressing opposition to transitions; and sustainability, promoting environmentally responsible solutions. These principles collectively highlight the need to integrate social, economic, and environmental considerations into energy policy and planning.

The next question that was answered was:

"What types of energy models are currently used in policy making in the Dutch heating transition?"

The study reveals that policy-making in the Dutch energy sector relies on a diverse array of energy system models, with some models being used commercially and others to conduct research on various energy scenarios. The former was focused on further, revealing six widely used models out of which the Vesta MAIS and the Energy Transition Model were most predominant. These models simulate interactions within energy systems, providing insights into various aspects of the transition, from technological feasibility to economic viability and environmental impacts.
Consequently, the next question was:

"How are energy justice principles defined and executed in the context of energy system modelling in the heating sector?"

The exploration into the definition and execution of energy justice principles within energy system modeling revealed that while energy justice principles are not explicitly outlined in the models, several factors closely relate to the themes of affordability, transparency, and sustainability. Social and demographic factors play an essential role in energy models, influencing energy demand and consumption patterns. Transparency is evident through the accessibility of information and participatory decision-making processes adopted by municipalities. Sustainability, a fundamental tenet of energy justice, is addressed through indicators such as carbon emissions and energy-saving potential in the models.

The final sub question was:

"What are the challenges, limitations and best practices in incorporating energy justice principles into energy system models?"

Incorporating energy justice principles into energy system models presents a series of challenges. Stakeholders' varied interpretations of energy justice can hinder consensus-building. Balancing the technical focus of models with the intricacies of social dimensions poses a challenge. Quantifying and assigning values to ethical concepts within models can be complex. Data complexity and uncertainty surrounding accurate data sources hinder precision in calculations. Time and regulatory constraints often shift the focus away from energy justice considerations, prioritizing expediency.
Energy justice has received the attention of many energy modellers and policy advisors, but it's representation in the form of justice principles is still not visible to a large extent. In this context, consistent reconsideration of assumptions and methodology is crucial to comprehend the function and constraints of models in promoting equitable energy systems for the future.

8.2 RECOMMENDATIONS

Building upon the insights gained from this study, several recommendations emerge for future research and practical application.

- This study can be taken forward by analysing model use cases with the other principles that have been defined in the justice framework. This study forms a base from which modelling approaches can be analysed from principles of responsibility, equity, availability and so on.
- Using the similar framework and methods, the study can be expanded to look into the other municipalities and highlight any similarities or differences. By altering the selection criteria, this study can be expanded to other energy sectors, and also to countries that are along the same transition trajectory.
- One of the challenges that were recognised in this study were the complexities of interpreting energy justice. It would help research to develop standardized definitions and metrics for energy justice principles to foster a common understanding and streamline integration into modeling frameworks. Energy modelling can be designed to incorporate concepts even if they lack standard definitions. However, having standardized definitions and metrics for key concepts can significantly enhance the precision and comparability of energy modeling efforts.
- A practical proposition would be to undertake long-term impact assessments to evaluate the effectiveness of energy justice considerations in shaping sustainable energy transitions and addressing societal concerns. Energy transitions impact society in various ways, and societal concerns can evolve over time. By regularly assessing the impact of justice considerations, decision-makers can remain responsive to changing societal needs and priorities. This will create a feedback loop that fosters ongoing engagement and responsiveness. Conducting impact assessments allows for greater accountability in energy transition processes. When discrepancies or unintended consequences arise, they can be addressed, and lessons can be learned for future decision-making.
- The study suggests that values of social factors like public participation and public support play a crucial role in making decisions about heat transition. The right to a fair process is not limited to simply being included in decision-making, but also involves a demand for active participation in achieving a more equitable outcome (Jenkins et al., 2016). Through the interviews, some of the participants explained that there were efforts to assemble the public and get them involved in the process, but there was backlash from certain sects of the society. The reasons were related to financial burdens, no real necessity to change and just lack of knowledge about the transition. Further investigation is necessary to thoroughly examine these indicators and bridge the gap in comprehending which factors would help increase the involvement of the end users.
- Modellers and users have divergent needs. While modellers aim to enhance existing models, users share this goal but also require innovative modeling approaches. These approaches should prioritize models that prominently feature societal and political factors. Research can

be conducted to identify steps needed to encourage increased collaboration between modellers and users, and enhancing the practical value of models. This collaborative approach involves customizing models and model runs to suit the specific requirements of distinct cases and contexts. By adopting these collaborations, it can unlock the potential of models to facilitate justice and steer the transition effectively.

8.3 RELEVANCE TO MOT PROGRAM

The study on the representation of energy justice principles in energy system models holds significant relevance to the Master's program in Management of Technology. The curriculum of the program, especially the courses "Preparation for the Master Thesis," "Research Methods," "Technology Dynamics," "Social and Scientific Values," and "Inter-Intra Organizational Decision Making," played a pivotal role in facilitating the essential knowledge and skills required to carry out this study. The "Research Methods" course empowered me to construct and conduct comprehensive interviews with participants, while also aiding in the interpretation and analysis of the qualitative data gathered throughout the research journey. Through the "Thesis Preparation" course, I acquired the necessary tools and frameworks to craft a well-organized research proposal and identify the research objectives effectively. "Technology Dynamics" delves into the intricacies of technical innovations and technological advancement, viewing them as products of human decision-making. This course formed the base foundation needed to discern how socio-technological changes transpire and how innovative agents can effectively guide new technologies towards aligning with societal needs and values. The contents of the course "Social and Scientific Values" directly relates to the study's investigation, which delves into the notions of responsibility and ethics in technology management. The exploration of normative ethical theories, such as utilitarianism and deontology within the course provides valuable knowledge for evaluating the ethical foundation of incorporating justice principles into energy system models. The course "Inter-Intra Organizational Decision Making" puts emphasis on understanding decision-making strategies and tactics, as well as the exercise of power among interdependent actors, directly relates to the study's exploration of how energy justice principles are advocated for and negotiated within decision-making processes.

References

Afman, M., & Rooijers, F. (2017). Grid for the future - a background report. *CE Delft*. Retrieved from https://cedelft.eu/wp-content/uploads/sites/2/2021/04/CE_Delft_3L53_Achtergrondrapport_Bijlagen_Net_voor_de_Toekomst.pdf

Balta-Ozkan, N., Amerighi, O., & Boteler, B. (2014). A comparison of consumer perceptions towards smart homes in the uk, germany and italy: reflections for policy and future research. *Technology Analysis and Strategic Management*, *26*(10), 1176-1195. Retrieved from https://doi.org/10.1080/09537325.2014.975788 doi: 10.1080/09537325.2014.975788

Bernard, A., & Vielle, M. (2008). Gemini-e3, a general equilibrium model of international–national interactions between economy, energy and the environment. *Computational Management Science*, *5*, 173-206. Retrieved from https://doi.org/10.1007/s10287-007-0047-y

Bouw, K., Noorman, K. J., Wiekens, C. J., & Faaij, A. (2021). Local energy planning in the built environment: An analysis of model characteristics. *Renewable and Sustainable Energy Reviews*, *144*, 111030. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032121003208 doi: https://doi.org/10.1016/j.rser.2021.111030

Bowen, G. (2009). Document analysis as a qualitative research method. *Qualitative research journal*, *9*(2), 27-40. Retrieved from https://www.emerald.com/insight/content/doi/10.3316/QRJ0902027/full/html

Brouwer, M. (2019). Het ene model is het andere niet; zes rekenmodellen voor de energietransitie in de gebouwde omgeving onderzocht. *Province Zuid Holland*. Retrieved from https://www.talentvoortransitie.nl/wp-content/uploads/2019/05/201905-Rekenmodellen-energietransitie.pdf

Diran, D., Henrich, B., & Geerdink, T. (2020). Supporting municipal energy transition decision making. *TNO Reports*. Retrieved from https://www.newenergycoalition.org/custom/uploads/2020/12/20-12-17-ESTRAC-D.1.2-Supporting-Municipal-Energy-Transition-Decision-making.pdf

European Commision. (2022). A european green deal. Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

European Environment Agency, E. (2022). Share of energy consumption from renewable sources in europe. Retrieved from https://www.eea.europa.eu/ims/share-of-energy-consumption-from

Geldhof, R., van 't Hek, J., Iossifidis, D., & Oudejans, J. (2021). Heat transition vision: Municipality of sliedrecht. Retrieved from https://www.sliedrecht.nl/Wonen_omgeving/Omgeving/Duurzaam_Sliedrecht/Energietransitie?utm_source=Rx.Front&utm_medium=redirect&utm_campaign=energietransitie

Gemeente-Amersfoort. (2023). *Heat transition vision amersfoort.* Retrieved from https://www.amersfoort.nl/amersfoort-aardgasvrij#transitievisie-warmte-6275

Hanke, F., Guyet, R., & Feenstra, M. (2021). Do renewable energy communities deliver energy justice? exploring insights from 71 european cases. *Energy Research Social Science*, *80*, 102244. Retrieved from https://www.sciencedirect.com/science/article/pii/S2214629621003376 doi: https://doi.org/10.1016/j.erss.2021.102244

Heffron, R. J., & McCauley, D. (2017). The concept of energy justice across the disciplines. *Energy Policy*, *105*, 658-667. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421517301593 doi: https://doi.org/10.1016/j.enpol.2017.03.018

Henrich, B. A., Hoppe, T., Diran, D., & Lukszo, Z. (2021). The use of energy models in local heating transition decision making: Insights from ten municipalities in the netherlands. *Energies*, *14*(2). Retrieved from https://www.mdpi.com/1996-1073/14/2/423 doi: 10.3390/en14020423

Horschig, T., & Thran, D. (2017). Are decisions well supported for the energy transition? a review on modeling approaches for renewable energy policy evaluation. *Energy Sustainability and Society*, *7*. Retrieved from https://doi.org/10.1186/s13705-017-0107-2

IEA. (2020). The netherlands 2020, paris. *Energy Policy Review*. Retrieved from https://www.iea.org/reports/the-netherlands-2020,License:CCBY4.0

Jenkins, K., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. (2016). Energy justice: A conceptual review. *Energy Research Social Science*, *11*, 174-182. Retrieved from https://www.sciencedirect.com/science/article/pii/S2214629615300669 doi: https://doi.org/10.1016/j.erss.2015.10.004

Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, *72*(12), 2954-2965. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/jan.13031 doi: https://doi.org/10.1111/jan.13031

Kerkhoven, J., Wirtz, A., & Kruip, C. (2015). Images of a co2-low dutch society in 2050, explorations for the council of the living environment and infrastructure. *Quintel Intelligence*. Retrieved from https://www.rli.nl/sites/default/files/beelden_van_een_co2-arme_nederlandse_samenleving_in_2050_-_quintel_intelligence.pdf

Krumm, A., Süsser, D., & Blechinger, P. (2022). Modelling social aspects of the energy transition: What is the current representation of social factors in energy models? *Energy*, *239*, 121706. Retrieved from https://www.sciencedirect.com/science/article/pii/S036054422101954X doi: https://doi.org/10.1016/j.energy.2021.121706

Loulou, R., Goldstein, G., & Noble, K. (2004). Documentation for the markal family of models. *Energy*

Technology Systems Analysis Programme, 65-73.

Mandle, J., & Reidy, D. (2015). *The cambridge rawls lexicon*. Cambridge University Press. Retrieved from https://www.jstor.org/stable/24693852

McCauley, D., Ramasar, V., Heffron, R., Sovacool, B., Mebratu, D., & Mundaca, L. (2019, January 1). Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research. *Applied Energy*, *233-234*, 916–921. doi: 10.1016/j.apenergy.2018.10.005

McGookin, C., Ó Gallachóir, B., & Byrne, E. (2021). Participatory methods in energy system modelling and planning – a review. *Renewable and Sustainable Energy Reviews*, *151*, 111504. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032121007838 doi: https://doi.org/10.1016/j.rser.2021.111504

MIDAS, & EU. (2023). Primes energy system model fact sheet. Retrieved from https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/model-primes-print

Milchram, C., Hillerbrand, R., van de Kaa, G., Doorn, N., & Künneke, R. (2018). Energy justice and smart grid systems: Evidence from the netherlands and the united kingdom. *Applied Energy*, *229*, 1244-1259. Retrieved from https://www.sciencedirect.com/science/article/pii/S0306261918312091 doi: https://doi.org/10.1016/j.apenergy.2018.08.053

Miller, D. (2017). Distributive justice: What the people think. *Stanford Encyclopedia of Philosophy Justice*, 135–173. Retrieved from https://plato.stanford.edu/archives/fall2021/entries/justice/

MSG-Strategies. (2023). *Visie op energie.* Retrieved from https://www.visieopenergie.nl/

Netherlands Enterprise Agency. (2022). Sustainable energy transition subsidy scheme. Retrieved from https://business.gov.nl/subsidy/sustainable-energy-production/

Nussbaum, M. C. (2011). *Creating capabilities: The human development approach*. Harvard University Press. Retrieved 2023-05-09, from http://www.jstor.org/stable/j.ctt2jbt31

Näsström, S. (2011). The challenge of the all-affected principle. *Political Studies*, *59*(1), 116-134. Retrieved from https://doi.org/10.1111/j.1467-9248.2010.00845.x doi: 10.1111/j.1467-9248.2010.00845.x

Ottinger, G., Hargrave, T., & Hopson, E. (2014, 02). Procedural justice in wind facility siting: Recommendations for state-led siting processes. *Energy Policy*, *65*, 662-669. doi: 10.1016/j.enpol.2013.09.066

PBL. (2023). Vesta spacial planning model. Retrieved from https://www.pbl.nl/modellen/vesta

Pesch, U., Correljé, A., Cuppen, E., & Taebi, B. (2017). Energy justice and controversies: Formal and informal assessment in energy projects. *Energy Policy*, *109*, 825-834. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421517303956 doi: https://doi.org/10.1016/j.enpol.2017.06.040

Pfenninger, S., DeCarolis, J., Hirth, L., Quoilin, S., & Staffell, I. (2017). The importance of open data and software: Is energy research lagging behind? *Energy Policy*, *101*, 211-215. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421516306516 doi: https://doi.org/10.1016/j.enpol.2016.11.046

Pfenninger, S., Hawkes, A., & Keirstead, J. (2014). Energy systems modeling for twenty-first century energy challenges. *Renewable and Sustainable Energy Reviews*, *33*, 74-86. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032114000872 doi: https://doi.org/10.1016/j.rser.2014.02.003

Prina, M. G., Manzolini, G., Moser, D., Nastasi, B., & Sparber, W. (2020). Classification and challenges of bottom-up energy system models - a review. *Renewable and Sustainable Energy Reviews*, *129*, 109917. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032120302082 doi: https://doi.org/10.1016/j.rser.2020.109917

ProvinceNoord-Holland. (2023). *Dashboard energy savings.* Retrieved from https://cijfers.noord-holland.nl/dashboard/energietransitie/

Quintel. (2023). *Energy trasition model.* Retrieved from https://energytransitionmodel.com/scenario/flexibility/flexibility_overview/what-is-flexibility

Rasch, E. D., & Köhne, M. (2017). Practices and imaginations of energy justice in transition. a case study of the noordoostpolder, the netherlands. *Energy Policy*, *107*, 607-614. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421517301817 doi: https://doi.org/10.1016/j.enpol.2017.03.037

Rawls, J. (2001). Justice as fairness: A restatement. *Harvard University Press*. Retrieved from https://books.google.nl/books?hl=en&lr=&id=AjrXZIlbK1cC&oi=fnd&pg=PA1&dq=rawls+justice+as+fairness&ots=sdwoTFb2ik&sig=yjRa3oMdrt10qPjqvugTN-iHP9Q&redir_esc=y#v=onepage&q=rawls%20justice%20as%20fairness&f=false

Sari, R., Voyvoda, E., Lacey-Barnacle, M., & Karababa, E. (2017). Energy justice: A social sciences and humanities cross-cutting theme report. *Shape Energy*. doi: 10.13140/RG.2.2.33861.35043

Saunders, M., Lewis, P., & Thornhill, A. (2007). Research methods. *Business Students 4th edition Pearson Education Limited, England*, *6*(3), 1-268. Retrieved from https://www.researchgate.net/profile/Mark-Saunders-10/publication/330760964_Research_Methods_for_Business_Students_Chapter_4_Understanding_research_philosophy_and_approaches_to_theory_development/links/5c53056f299bf12be3f0e2cf/

Research-Methods-for-Business-Students-Chapter-4-Understanding-research-philosophy-and-approaches-to-theory-development.pdf

Schepers, B., Rooyers, F., & Meyer, M. (2016). A climate-neutral heat supply for the built environment update 2016. *CE Delft*. Retrieved from https://ce.nl/publicaties/een-klimaatneutrale-warmtevoorziening-voor-de-gebouwde-omgeving-update-2016/

Schlosberg, D., & Collins, L. (2014). From environmental to climate justice: Climate change and the discourse of environmental justice. *Wiley Interdisciplinary Reviews: Climate Change*, *5*. doi: 10.1002/wcc.275

Segers, R., Niessink, R., van den Oever, R., & Menkveld, M. (2020). Warmtemonitor 2019. *TNO Report*. Retrieved from http://resolver.tudelft.nl/uuid:a74e5140-a8a2-42eb-8c88-e99a9ad33d73

Slingerland, E., Terlouw, W., & Lohuis, J. O. (2016). Quantification of future scenarios for the built environment. *Ecofys*. Retrieved from https://adoc.pub/kwantificering-van-toekomstscenario-s-voor-de-gebouwde-omgev.html

Sovacool, B. K. (2016). How long will it take? conceptualizing the temporal dynamics of energy transitions. *Energy Research Social Science*, *13*, 202-215. Retrieved from https://www.sciencedirect.com/science/article/pii/S2214629615300827 (Energy Transitions in Europe: Emerging Challenges, Innovative Approaches, and Possible Solutions) doi: https://doi.org/10.1016/j.erss.2015.12.020

Sovacool, B. K., Axsen, J., & Sorrell, S. (2018). Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design. *Energy Research Social Science*, *45*, 12-42. Retrieved from https://www.sciencedirect.com/science/article/pii/S2214629618307230 (Special Issue on the Problems of Methods in Climate and Energy Research) doi: https://doi.org/10.1016/j.erss.2018.07.007

Sovacool, B. K., Burke, M., Baker, L., Kotikalapudi, C. K., & Wlokas, H. (2017). New frontiers and conceptual frameworks for energy justice. *Energy Policy*, *105*, 677-691. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421517301441 doi: https://doi.org/10.1016/j.enpol.2017.03.005

Sovacool, B. K., & Dworkin, M. H. (2015). Energy justice: Conceptual insights and practical applications. *Applied Energy*, *142*, 435-444. Retrieved from https://www.sciencedirect.com/science/article/pii/S0306261915000082 doi: https://doi.org/10.1016/j.apenergy.2015.01.002

Sparenburg, P., van Keimpema, N., & Maas, N. (2021). Heat transition vision: Municipality of amersfoort. Retrieved from https://www.amersfoort.nl/sites/default/files/Transitievisie%20Warmte%20Amersfoort_1.pdf

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, *13*(8), 1819-1835. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032108001949 doi: https://doi.org/10.1016/j.rser.2008.09.033

Süsser, D., Ceglarz, A., Gaschnig, H., Stavrakas, V., Flamos, A., Giannakidis, G., & Lilliestam, J. (2021). Model-based policymaking or policy-based modelling? how energy models and energy policy interact. *Energy Research Social Science*, *75*, 101984. Retrieved from https://www.sciencedirect.com/science/article/pii/S2214629621000773 doi: https://doi.org/10.1016/j.erss.2021.101984

Süsser, D., Gaschnig, H., Ceglarz, A., Stavrakas, V., Flamos, A., & Lilliestam, J. (2022). Better suited or just more complex? on the fit between user needs and modeller-driven improvements of energy system models. *Energy*, *239*, 121909. Retrieved from https://www.sciencedirect.com/science/article/pii/S0360544221021575 doi: https://doi.org/10.1016/j.energy.2021.121909

UNCC. (2015). Paris agreement process and meetings. Retrieved from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

UNDP. (1990). United nations development programme; human development report 1990. *UNDP (United Nations Development Programme)*. Retrieved from https://hdr.undp.org/content/human-development-report-1990

van Beeck, N. (1999). Classification of energy models. *FEW Research Memorandum; Operations Research*, *777*. Retrieved from https://pure.uvt.nl/ws/files/532108/777.pdf

van Berkel, P. (2019). Realising a just transition to gas-free heating in the dutch social housing sector. *Environmental System Analysis*. Retrieved from https://edepot.wur.nl/524777

van der Molen, F., van Polen, S., van den Wijngaart, R., & Tavares, J. (2021). Functional design vesta mais 5.0. *PBL*. Retrieved from https://www.pbl.nl/sites/default/files/downloads/pbl-2021-functioneel-ontwerp-vesta-mais-5.0-4583.pdf

Vågerö, O., & Zeyringer, M. (2023). Can we optimise for justice? reviewing the inclusion of energy justice in energy system optimisation models. *Energy Research Social Science*, *95*, 102913. Retrieved from https://www.sciencedirect.com/science/article/pii/S2214629622004169 doi: https://doi.org/10.1016/j.erss.2022.102913

Waser, N. (2023). *Characteristics of smart energy cities model.* Retrieved from https://www.smartenergycities.nl/karakteriseren-sociaal/#Sociale-wijkgegevens

Williams, S., & Doyon, A. (2019). Justice in energy transitions. *Environmental Innovation and Societal Transitions*, *31*, 144-153. Retrieved from https://www.sciencedirect.com/science/article/pii/S2210422418301588 doi: https://doi.org/10.1016/j.eist.2018.12.001

Wright, G., & Goodwin, P. (2009). Decision analysis for management judgment. *Operational Research Society*. Retrieved from https://doi.org/10.2307/2584371

Yin, R. K. (2009). Case study research: Design and methods. , *5*. Retrieved from https://books.google.nl/books?hl=en&lr=&id=FzawIAdilHkC&oi=fnd&pg=PR1&ots=l_5V7alQ-x&sig=PbCF66aY7jEawyTjo8FcGQ1FTxY&redir_esc=y#v=onepage&q&f=false

Appendix A

Questionnaire for Case Study Interview

1. Could you please provide some background on your role as a policy advisor / modeller in the heat transition in the region of Amersfoort / Drechtsteden?

2. Could you explain how the energy models were utilized to support decision-making in the project? What were the end goals?

3. How were the scenarios constructed and then selected? In terms of inputs and assumptions, were there any other considerations other than technical and economic factors? Any social aspects?

4. Could you provide an overview of the key stakeholders who are involved in the decision-making process? Does the model help to take all perspectives into consideration? Are the decision-making processes and outcomes accessible to the public? If yes, in what ways are they communicated? [TRANSPARENCY]

5. How do you balance different objectives, such as cost-effectiveness, social equity, and technical feasibility? In what ways are these taken into account to aid decisions? [AFFORDABILITY]

6. Some technologies or installations are not accepted by certain sections of the population (NIMBY). Does the model take any of this resistance into account? How do you deal with the fact that some of the model's projections may be made infeasible because of such resistance? [RESISTANCE]

7. How do you prioritize sustainability factors, such as reducing greenhouse gas emissions, promoting renewable energy, or enhancing energy efficiency, when evaluating different pathways? Are there specific criteria or indicators used to assess the sustainability of different options or scenarios? [SUSTAINABILITY]

8. What are the main challenges and limitations to incorporate such aspects? Any factors that you would say are the reason for not incorporating such aspects?

   Extra questions:

9. The transition may also have implications for the future changes. Are decisions taken for immediate use or for future as well? Are factors like a discount factor considered? [INTER EQUITY]

10. Certain areas are prioritised for implementation of the transition. In this process do some areas get neglected? [AVAILABILITY]

11. Is there anything you would like to add that might be helpful for this research?