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The Dutch Energy Model-Policy Interface in Crisis

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Preface

This master thesis report marks the end of an exciting period in my life as a student. In this context, it is fitting that throughout this research I learned about the challenges of applying theoretical knowledge to a practical world. The importance of perception and perspective is a theme from this research that will stick with me forever.

I would like to thank my supervisors for their support. Without their help, this thesis would not have been possible. I thank Dr. Pfenninger and Dr. Pesch for sharing their expertise and providing me with valuable feedback. My special thanks go out to Ema Gusheva, for her commitment to my work, encouraging words, and mentoring. Finally, I would like to thank my family and friends for their support throughout this journey.

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Abstract

Abstract

Due to climate change, energy-related issues are becoming increasingly important in shaping the future of our world. This, in turn, places energy policy at the forefront of many political agendas. Energy policymaking is characterized by complexity, as it seeks to combine the interests of many stakeholders in a complicated physical system. Energy system modeling may help policymakers in navigating this difficult task, and the use of these models in policymaking has given rise to a model-policy interface. The historically frequent and impactful nature of energy crises raises the question how these crises affect the model-policy interface. Therefore, this research set out to investigate the influence of crisis situations on the role of energy system modeling in energy policymaking, by studying existing literature and gathering insights from practice.

The answers to the research questions were found through a literature study and by conducting semi-structured interviews with experts from the model-policy interface, including modelers, energy industry professionals, and policymakers. These interviews were then processed through qualitative content analysis, which gave rise to three themes.

The first theme – *stakeholder's reflection on roles uncovers challenges* – explores from the roles of stakeholders in the model-policy interface, as perceived by the interviewed experts. Modelers viewed their role in policymaking as supportive, and policymakers highlighted the value of their interactions with modelers. The theme also discusses the challenges of this interaction, which arise from the complexities of modeling and policymaking, as well as a perceived gap in modeling expertise between stakeholders.

The second theme – *urgency modulates the role of modeling in policymaking during a crisis* – concerns the influence of crisis-induced urgency on the role of modeling in policymaking. Based on this perception and the comments of experts, I inferred two distinct crisis types, which I refer to as low- and high-urgency crises. The interview data suggests that both crisis types influence the impact that modeling has on policy development, albeit in different ways and to varying extents. In low-urgency crises, the model-policy interface sees increased alignment and cooperation between stakeholders. On the other hand, in high-urgency crises decision-making shifts from ministries to the political domain, which limits the administrative freedom of policymakers and disrupts the normal policymaking process. In this context, the room for well-informed policy trajectories shrinks in crisis situations.

The final theme – simply named *uncertainty* – reflects on the impacts of crisis-induced uncertainty. It shows ambiguity regarding the influence of crisis-induced uncertainty to the role of modeling in policymaking. On the surface, it appears that the uncertainty of crises increases the need for quantitative insights, which can be supplied by models. However, there are other points to be taken into account. Not all models are equally appropriate to address crisis-related issues, the uncertainty may already match existing uncertainties, and the time-consuming nature of modeling may make it less pertinent in crisis scenarios.

The findings were related to the insights identified in the literature. With regard to the roles of stakeholders in the model-policy interface and related challenges, the data overlaps with elements identified in the literature. Examples are the challenges related to the application of model results in policymaking, caused by the time-consuming nature of modeling, the ambiguity of policymaking, and a knowledge gap between modeling and non-modeling stakeholders. The studied literature also presented theories on the impact of crises, but these pertained to the impact on the policymaking process itself. These theories did highlight the importance of perception, specifically of urgency and uncertainty, in distinguishing crisis situations, which was identified in the interviews as well. The lack of theory underlines the relevance of this study, but makes comparison to the literature difficult. The literature does offer theories through which to frame the impact of crises on the role of modeling in policymaking. However, the limited scope and detail of the data make it difficult to assess the validity of these theories. It is suggested that future research studying the influence of crises on the role of modeling in policymaking may benefit from using an existing framework.

1. **Introduction**

1. Introduction

When I opened the bag that my mother had handed me after visiting my student home in The Hague, I discovered five fleece blankets. A gift for me and each of my room mates, to keep us warm during the cold winter months. The blankets helped, but they did not stop the bickering between me and my room mates about keeping the heat low, shutting the doors, and buying all kinds of utilities aimed at making our home more heat efficient[1]. What ensued was a period filled with discussions in and about the cold.

Discussions on the same subject, albeit with a different scope, were simultaneously taking place elsewhere in The Hague. Following the Russian invasion of Ukraine, energy prices skyrocketed (Koster, 2022). As a result, inflation escalated further and people soon found themselves facing difficult financial decisions. Their unrest was soon aimed at the government, with calls for policy interventions to aid struggling citizens.

This call was answered by the Dutch government on Prinsjesdag[2], when plans were announced on the introduction of a price cap on household energy (de Kruif, 2022). The aim of these measures was to protect Dutch citizens from extreme fluctuations in the energy market. While the announcement was conveyed by a few words from the King's mouth, many more words preceded it. Interviews with Dutch policymakers highlighted a period of intense challenges – designing an effective and affordable policy in a complex sector with many stakeholders, all the while energy prices kept increasing. Ultimately, their solution to the puzzle was presented by policymakers mere hours before the King's speech, and committed to the spending of billions of euros.

The story presented above presents an example of the difficulties of energy policymaking during a crisis. However, the development of energy policy is a complex process, regardless of the ongoing situation. It requires the balancing of interests between different stakeholders, an understanding of the technological possibilities and limitations, as well as an evaluation of the economic costs and benefits (Kaldellis, 2010). In other words, it is a process that is both technical and political in nature. In this context, energy system modeling plays an important role. Energy system models are tools used to simulate different energy scenarios and their potential impacts on various factors such as emissions, costs, reliability, etc. They allow policy makers to identify trade-offs and make informed decisions about which policies are most likely to be successful.

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[1] Unfortunately, we couldn't convince our landlord to install double-glazed windows.

[2] The day on which the reigning Dutch monarch presents a speech, outlining the government's plans for the coming parliamentary period.

However, the use of energy system models in policymaking is not without its challenges. One of the main challenges is the uncertainty that surrounds them. This uncertainty can be caused by a number of factors, including the assumptions that are made about future conditions, the data that is used to develop the models, and the inherent limitations of any model to accurately capture reality (PFENNINGER ET AL., 2014B). In times of crisis, this uncertainty can be magnified as stakeholders seek quick and definitive solutions to complex problems. As a result, decision-makers may be tempted to rely too heavily on energy system models, or to put too much faith in a single model's results.

The relationship between energy system models and energy policymaking, as well as the connections shared by corresponding stakeholders (i.e. energy system model developers and policymakers), gives rise to the model-policy interface. Like the overarching science-policy interface, the model-policy interface is a social process which encompasses "relations between scientists and other actors in the policy process", which allows for "exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making" (VAN DEN HOVE, 2007). Furthermore, the insights generated by energy system models are far from the only input in the policymaking process (WRIGHT, 2015, P. 288). As such, the model-policy interface is part of a larger process with the goal of policy development. Throughout the policymaking process, policymakers are guided or constrained by various factors such as available information, economic conditions, political convictions, and public sentiment. From this, the emerging policymaking system consists of a multitude of time- and context-dependent inputs and outputs, which interact with the outside world.

Despite its important role in energy policymaking, much about the nature of the model-policy interface remains unknown. Research by Süsser et al. shows that "energy modelling and policymaking influence each other", but this "interaction is highly context-specific" (SÜSSER ET AL., 2021, PP. 10–13). In the discussion of their work, the authors call for "dedicated research for when and under which conditions models affect policy".

The persistent connection between crisis situations and energy policymaking elicits further research on how the role of energy system models is affected by crises. For practical reasons, because future energy crisis will inevitably occur and require a fitting solution. Throughout history crises have acted as a catalyst to energy policy development, as “most of the major policy shifts on energy issues have come in response to energy crises” (CARLISLE ET AL., 2016). But also to gain insights in the energy policymaking process and better understand the balancing act between science, sentiment, and politics.

Specifically, this research intends to study the influence of a crisis on the role of energy system modeling within the Dutch energy policymaking process. As such, the following questions will guide this research:

1) How does a crisis influence the role of energy system modeling in Dutch energy policymaking?
   a) What can theory tell us?
   b) What can practice tell us?
   c) How do theory and practice align?

In this context, energy system modeling pertains to the use of energy system models to generate insights into the functioning and (future) configurations of an energy system. Energy policymaking concerns the process by a government to develop policies related to the energy sector. In this report, energy system modeling in energy policymaking will also be referred to as “modeling in policymaking” or the “model-policy interface”. For the purposes of this research the meaning of these is considered identical, unless it is stated differently when mentioned.

In the next chapter of this report, a conceptual framework is presented that will guide this research. Then, a theoretical overview is provided by highlighting and discussing literature relevant to the research. After this, the research method and case are explained. Ultimately, the results and their implications are discussed and followed by the conclusion.

2. Conceptual Framework

2. Conceptual framework

2.1 The abductive approach

Defining the appropriate approach to answer the research questions of this study is not a straightforward exercise, for multiple reasons. The lack of existing theory on the subject of this research, the interaction between energy system modeling and energy policymaking, as well as its specific focus**,** the impact of crisis situations on this interaction, inhibits deductive reasoning. On the other hand, the nature of the questions and the context to which they belong limit the type and amount of data available to formulate a suitable answer, meaning pure inductive reasoning may also be implausible.

These challenges related to a simultaneous lack of theory and meaningful data are far from unique. In fact, they seem to be inherent to qualitative research. In their book on research methodology for qualitative research Tavory and Timmermans detail the following allegory: *"Qualitative researchers navigate treacherous waters. On starboard side lurks an overly descriptive account. The researcher gather detailed narratives of people doing things, orders them according to broad themes, and lets the data speak for itself. (…) Equally problematic is the danger on the port side. The researchers aims to to fit ideas into a predetermined theoretical account, usually developed by some en vogue theorist"* (Tavory & Timmermans, n.d., p. 1). Solely focusing on either theory or observation may lead researchers to either remain stuck in existing theoretical frameworks or get lost in observations devoid of narrative. A balance between the two might be necessary to do justice to the premise of qualitative research.

This balancing act comes with dilemmas too, which are somewhat ironically related to the perceived benefits of the individual elements. One strength of qualitative research is its accessibility. Qualitative data is ubiquitous[3], meaning that researchers may gather data related to their research intent with relative ease. Document studies, interviews, or qualitative observation require little up-front investment and yield results almost immediately. *"A mountain of data quickly grows, allowing the researcher to describe the complexity of a particular social world"* (Tavory & Timmermans, n.d., p. 2). But returning to the scientific goal of the study may leave researchers in an uncomfortable position, as the formulating the implications that result from the observations means letting go of some descriptive accuracy or completeness that the data provides. The proper balance between observation and theory is not universal and finding it requires tuning to the context and problem at hand, i.e., a theoretical framework, which may not always be available.

[3] At least in the sense that almost anything can conceptually be labeled as qualitative data. The actual value of this data remains to be determined, of course.

As a possible relief from this dilemma, Tavory and Timmermans point to abductive reasoning, or *"abductive analysis"*[4], which *"provides a way to think about research, methods, and theories that nurtures theory construction without locking it into predefined conceptual boxes"* (Tavory & Timmermans, n.d., p. 4). Rather than justifying an existing theory or defining the strict consequences of observations, abduction aims to provide (a set of) likely explanations for the situation at hand. What abduction may lack in robustness, at least from a logical standpoint, it makes up for in flexibility[5]. Through abduction, researchers may break scientific deadlock by exploring themes and questions that might have been barred by strict interpretations of induction and deduction. In this role, abduction is not necessarily an alternative to induction or deduction, but rather constitutes a method that is more suitable in a specific application, i.e., the generation of hypotheses with the aim of theory development.

Considering the above, the abductive framework can be of great value to this research. At a first glance, the lack of existing theory and the unclear implications of observations retrieved from a qualitative research method might limit the value of this study. When justification of (scarce) earlier work or generalization of observations is improbable, questioning the benefit of this research is understandable. However, the purpose of this study is rooted in pragmatism. Getting a better understanding of how energy system models influence the policymaking process and vice versa is essential in tackling important problems that are affected by these interactions, such as the fight against climate change and the provision of energy security. Any progress toward this goal is worthwhile, even if it is gained through roads less traveled. Using the abductive framework, this research sets out to discover, explore, and develop ideas from existing theories as well as previous and new observations to further our knowledge on an important subject.

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[4] The origins of abductive analysis are found in the work of American philosopher Charles S. Pierce (BURCH, N.D.), who noted that the concepts of induction and deduction fit poorly in theory creation – a key aspect in the scientific method. Where much of the attention of 20th century philosophy of science was focused on the justification of existing theories, Pierce's work highlights the importance of creativity in the advancement of science.

[5] I don't mean to say that "anything goes" when applying abduction. The trick is to identify possible paths of further exploration and meaning in observations and theory.

2.2 The abductive approach in practice

Despite being lesser known, plenty of advice regarding the implementation of the abductive research methodology exists. An account of the abductive framework in practice provided by Conaty may serve as a template for this, who applied the framework in a qualitative case study in management accounting research (CONATY, 2021)[6]. In his work, Conaty explains how the abductive approach influenced the design and execution of his research, which is valuable input in developing the method for this study.

Initially, Conaty sets out to reiterate the differences between deduction, induction, and abduction. As an explanation of the three concepts is provided in the previous section, I will not go into further detail here. However, it is worth restating the outcome of an abductive research approach to highlight the alignment between the research method and goals: *"with abduction, hypotheses are developed from examining facts that infer; (i) that a new theory may have validity and can be accepted if no other explanation has greater validity, or (ii) that an existing theory may be further developed"* (CONATY, 2021, P. 3; HAIG, 2005; KAPITAN, 1992). This is in line with the goal of furthering our understanding of the model-policy interface by emphasizing the validity of existing theory and/or suggesting amendments and possible areas of improvement.

An initial theoretical frame of reference can be adopted at the start of the research (though this is not necessary). This theoretical background serves a different purpose here than in a deductive research method. It serves as a lens through which to view the contents of the study, rather than a framework that requires verification. In addition to an initial theoretical framework, the researcher's phronesis is considered[7], which may assist the research in distinguishing between the generalizable and the specific. Ultimately, the abductive approach is described as a dialogical approach. Throughout the research there is a continuous reflection (i.e., dialogue) between the existing theory and the researcher's phronesis, and the observed data. The result of this dialogue is theory development and the formulation of new hypotheses. **FIGURE 1** provides a visual overview of the abductive research method.

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[6] Conaty identifies similar concerns in qualitative research as Tavory and Timmermans: *"In the management literature, the debate, argument, and counter argument of the contribution of qualitative versus quantitative research is not abating. In particular, questioning continues on the manner in which the validity and generalizability of qualitative research is underpinned or undermined. (…) In this context providing illustrative examples of how qualitative research might be approached in a manner that addresses concerns of validity and fit is important"* (CONATY, 2021, P. 1).

[7] Phronesis is an ancient Greek word which relates to forms of practical wisdom, which guides decision-making and judgment based on prior experiences and knowledge (*The Oxford Review*, n.d.).

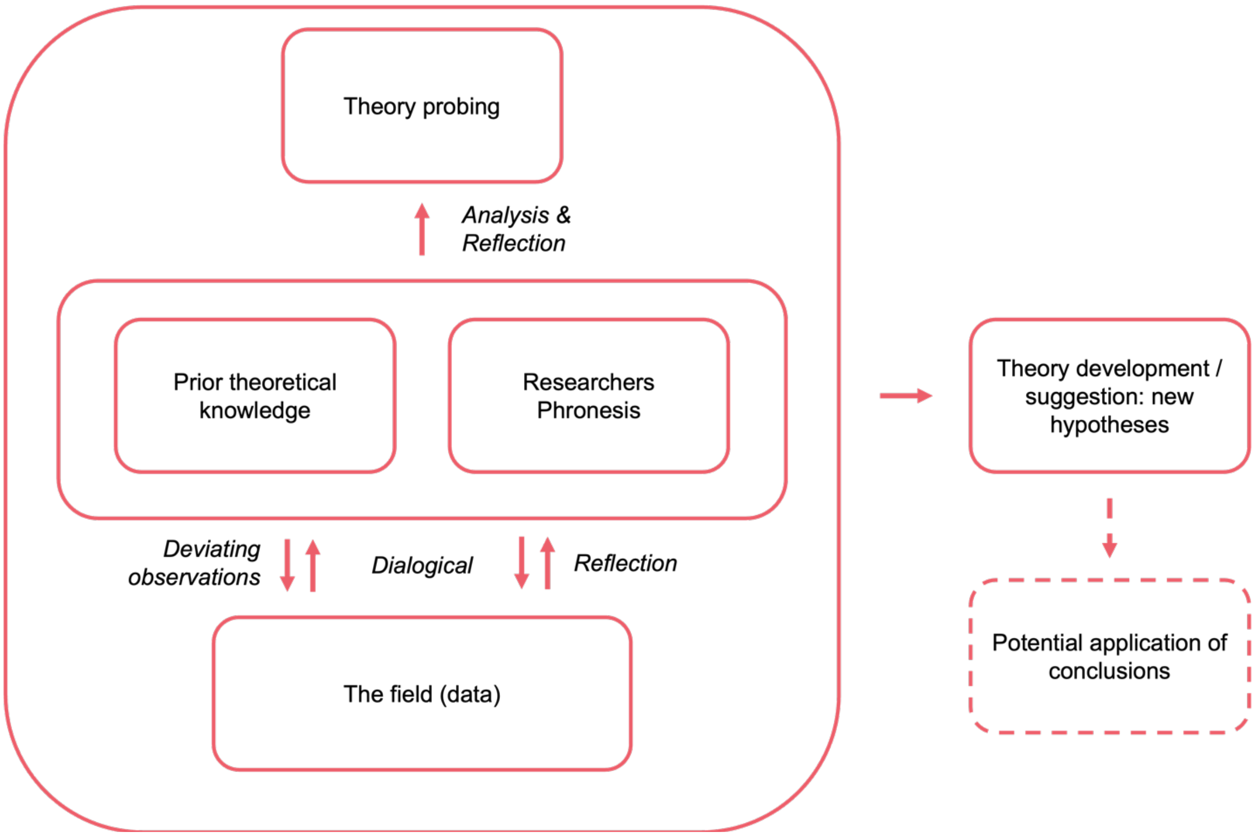

Figure 1: The abductive research process (Conaty, 2021, p. 4)

3. **Theoretical overview**

3. Theoretical overview

3.1 Introduction

This chapter serves multiple purposes. In the most general sense, it aims to facilitate the research by establishing a theoretical context. This context serves the abductional research method in which the researcher (i.e. the person conducting the research) compares existing literature with the available data and their own phronesis to determine the most likely explanation for the problem at hand. This could mean that the researcher uses theories from existing literature as 'lenses' through which to view the problem, or starts the analysis from an initial theoretical frame which is built upon throughout the research. Ultimately, this chapter should facilitate both possible uses. Besides this, the process of studying the literature familiarizes the researcher with the research subject and helps avoid redundancy.

3.2 Structure

This chapter is divided into four sub-sections. The first sub-section defines the questions that guide the literature study, while the second sub-section outlines the search process used to select relevant material. Answers to the questions provided by the literature are presented in the third sub-section. Ultimately, the answers are summarized and used to define hypotheses for the research questions in the final sub-section.

3.3 Guiding questions

The process of building a theoretical overview is guided by a number of questions. These questions are formulated by deducing which information is relevant in answering the research questions. For clarity, the research questions are repeated below:

1) How does a crisis influence the role of energy system modeling in Dutch energy policymaking?
    a) What can theory tell us?
    b) What can practice tell us?
    c) How do theory and practice align?

Given these research questions, the theoretical overview should provide information on the nature of energy system modeling, its role in policymaking, and the impact of crises on this role. This information is directly related to answering the first sub-question, but will also set the stage for gathering data for the second question. Finally, the theoretical overview should allow for a comparison between theory and practice. Therefore, the following questions will guide the development of this theoretical overview:

1. What is energy system modeling?
2. What is the role of energy system modeling in energy policymaking?
3. How can crises influence the role of modeling in policymaking?

3.4 Method

A challenge in answering the particular questions posed in this chapter is presented by the fact that the questions span multiple research domains. The search query must therefore be formulated in such a way that the literature it yields encompasses sufficient information to answer the questions. In addition to defining a suitable search query, the literature search is conducted iteratively. If the initial search does not result in the right kind of information, additional searches are conducted aimed at filling the information gap.

3.4.1 Sources

The papers in this theoretical overview are sourced from Web of Science and Scopus in October 2022 (access to these databases is granted through Leiden University and Delft University of Technology, respectively).

3.4.2 Search

The search in each database is completed using several specific inputs, as presented in **Table 1**. Using a Boolean operator, the search is limited to articles containing the words "energy system modeling policy making" in their title, abstract, and/or keywords. These search words fit the guiding questions of this literature overview, as they will likely yield specifically related to energy system modeling and its relation to policymaking. The term "policy making" is deemed more appropriate than "policy", as there are many articles that discuss the relation to some specific policies and but the policymaking process in general.

The articles resulting from this search were further filtered to contain review articles only. These articles offer condensed information on an extensive subject, making them ideal to find the most relevant insights relatively efficiently. Also, the discussions in review articles tend to be broader than a single specific subject, increasing the likelihood that themes relevant to this research are discussed. Filtering on publication date was not included in the search.

Table 1: Initial search results

Search terms	**Search limiters**	**Databases**	**Hits**
TITLE-ABS-KEY (energy AND system AND modeling AND policy AND making)	Reviews English	Scopus	84
		Web of Science	26
Total			110

Because only a handful of articles resulting from the search explicitly focused on the role of energy system modeling in policymaking and none concerned the influence of crises, a secondary search was conducted. This search was done by using two papers as input in Connected Papers. The first of these papers was found on Google Scholar by searching "crisis policymaking" (Grossman, 2015) and the second was shared by a thesis advisor (Royston et al., 2023). Ultimately, this secondary search yielded six additional articles, including the previously mentioned two. These can be found in **TABLE 5** (Appendix).

3.4.3 Selection

The selection process for articles to be included in the overview involved a series of steps. The initial search was built around the keyword "energy system modeling policy making", which yielded a total of 110 articles across the two databases. After screening the results by assessing their relevance in answering the guiding questions posed earlier and removing duplicates, a total of 13 articles remained. The omitted articles were either off-topic (e.g., battery technologies, urban water management) or too specific (i.e., focusing on a single model or setting). An overview of the selected articles can be found in **TABLE 4** (Appendix). The articles selected from the secondary search are presented in **TABLE 5** (Appendix).

3.4.4 Data extraction

To systematically extract relevant data from the papers, a spreadsheet was created in which the relation between each article and the guiding questions was noted. An example of an entry in the spreadsheet is provided in **TABLE 6** (Appendix).

3.5 Findings

Question 1 **What is energy system modeling?**

Summarized answer

Energy system modeling refers to the practice of constructing and/or using mathematical models to replicate the behavior of a real energy system. By using a simplified abstraction of reality, models are able to mimic the behavior of energy systems and simulate hypothetical configurations of these systems. There exists a wide range of energy system models, varying in underlying methodology, capabilities, and use-case. Energy system modeling is used by individuals and organizations, particularly in policymaking, to understand how interactions, such as policies, can shape the energy system. The cooperation between modelers and policymakers has spurred many innovations in energy system modeling, but some challenges still remain. Current paradigms and challenges of energy system models include temporal and spatial detail, uncertainty, complexity, and the lack of behavioral aspects. Possible solutions to these challenges include improved transparency, multi-objective optimization, and the inclusion of behavioral aspects in energy system modeling. Overall, energy system modeling is a field that shapes and is shaped by the interactions it shares with other domains.

Before presenting which answers the studied literature provides for this question, I want to state the distinction between this question and the next (*What is the role of modeling in policymaking?*). The answer to this question concerns the definition of energy system modeling from a modeling perspective, mostly discussing model categorization, capabilities, and challenges. While some aspects discussed here relate to the application of energy system models (e.g., models are sometimes categorized per use-case, changes to the modeling practice can be induced by external demand), how the output of the modeling process is utilized in policymaking specifically is discussed in question 2.

Most review articles introduce their specific purpose in energy system modeling research with a broader discussion on the origin and importance of the practice. As these discussions largely overlap in content and scope, a condensed version of the most relevant information from articles answering this specific guiding question is shared below.

Examining energy system modeling requires an understanding of energy systems. In its fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) defines an energy system as a *"system [that] comprises all components related to the production, conversion, delivery, and use of energy"* (ALLWOOD ET AL., 2014). In other words, an energy system consists of components that facilitate the transfer of energy from a place of origin (e.g., fossil fuel) to the point of consumption (e.g., heating a building).

A consequence of the broad nature of energy systems is ubiquity. Our deep-rooted dependence on energy means that energy systems are intertwined with many of humanity's greatest challenges, such as increasing our standard of living, maintaining peace, and combatting climate change (Ritchie & Roser, 2022). Challenges like these were the impetus to the inception of energy system modeling and remain at the heart of contemporary modeling efforts. Often-cited origin stories of energy system modeling and corresponding agencies are the 1973 oil crisis and liberalization of the energy markets in the 1980s and 1990s, during which policymakers were confronted with challenges in energy policy entailing long-term strategic energy planning (Helm, 2002; Hoffman & Jorgenson, 1977; Rezaiyan & Gill, 1980). These events, combined with an increase in available computing power (ROBISON, 2012), led to the creation of computer-based programs that aimed to model existing and possible future configurations of the energy system (Fishbone & Abilock, 1981; Kydes, 1980; Kydes & Rabinowitz, 1981).

The need for a better understanding of energy systems combined with the complexity behind the corresponding modeling efforts has given rise to an entire ecosystem of models, each with their own purpose, architecture, and background. The quantity and variety of models has led to a movement within the modeling literature to create groupings along areas of commonality to get insights into which types of models exist and what their purpose is. These categorizations are useful for getting a better understanding of energy system modeling, as they outline the scope, techniques, and purpose of this practice.

In fact, most review articles discussing energy system modeling used a form of model categorization, e.g., by model purpose (Hall & Buckley, 2016), capabilities (SAVVIDIS ET AL., 2019), and limitations (PFENNINGER ET AL., 2014A). The motivation behind these categorizations is to emphasize the relevance of specific models to specific use-cases, research questions, or policy issues. This is important as *"the description and information given about models is crucial to a wide audience (i.e., all actors within energy systems). Indeed it is often the model's purpose, structure and implicit assumptions that are the pertinent information. Without clear (and understandable) descriptions of model objectives and detail, it remains complicated for policy makers to decide on relevant tools to use for certain exercises"* (Hall & Buckley, 2016, p. 612). Linking types of models to particular applications has become increasingly relevant, as the number of energy system models has grown throughout recent decades and knowing which models to use in which situations is becoming less straightforward (PRINA ET AL., 2022).

In their study to identify the prevalent energy system models and tools in the UK, Hall et al. develop a classification schema to categorize and compare models (Hall & Buckley, 2016). Acknowledging that *"over the past two decades, many categorisation theories have been suggested, though none has been adopted as good practice"*, their schema incorporates elements of previous classification efforts while introducing novel categories that match practical needs identified in the literature. Ultimately, the schema is comprised of 14 categories, which are divided into three groups, being the model purpose and structure, the technological detail, and the mathematical detail. The 14 categories are presented in **TABLE** 7 (Appendix) for reference.

Despite being incomplete (or *"purposefully not comprehensive to the point of completeness"* (Hall & Buckley, 2016, p. 612)), the categories defined by Hall et al. provide some sense to the degree of variation in energy system models. This is of relevance to this research, as each of the categories represents a set of options that may change during a crisis. Depending on the prevalent modeling needs, stakeholders may be inclined to prefer one model over the other because it is suitable to the problem at hand. For example, time constraints may lead to a selection of models whose mathematical approach allows for faster computation, or a lack of available data could necessitate the use of models that are less data dependent.

Besides providing an overview of the diversity in energy system models, the work of Hall et al. also presents insights into the (relative) popularity of energy system models. After searching the academic literature for energy system models used in the UK and applying their schema to the results, the authors provide further detail on the frequency with which models are referenced, as well as the contexts of such references (all between 2008 and 2015). Interpreting the number of appearances (i.e., total number of mentions in the reviewed articles) as a measure for model popularity, it becomes clear that the distribution is heavily skewed toward a small set of popular models. A single group of models, the MARKAL type, leads the number of appearances by accounting for nearly 20 percent of the total. The top 10 most popular models make up half of the total number of appearances. From this, it appears that although the model ecosystem is diverse and extensive, a small subset of model species (specifically the MARKAL model) is dominant.

Most categorization efforts outlined in the other articles are in line with the schema presented by Hall et al. As explained earlier, these categorizations primarily exist to group and compare energy system models. This is a common practice *"to add robustness to the findings in energy system modeling"* (PRINA ET AL., 2022, P. 1), and is facilitated by various modeling forums such as the Energy Modeling Forum (US), China Energy Modeling Forum, and the Energy Modeling Platform for Europe (EMP-E) (*Energy Modeling Forum*, n.d.; *Energy Modelling Platform for Europe - ECEMP*, n.d.; Lugovoy et al., 2018). The comparison of energy system models is such a common practice, that Prina et al. set out to review the comparison techniques and assess their practicality and limitations. The results of this study are relevant to this research because the comparison techniques may highlight aspects of the modeling practice that are relevant to specific stakeholders, such as modelers, policymakers, or energy industry.

As the term 'model' is *"sometimes erroneously adopted in energy system modeling",* Prina et al. begin their study by establishing a working definition of frameworks, models, and scenarios. For completeness, their definitions are quoted here directly: *"An energy system framework is formulated in general terms and not reduced to a specific case, which allows replicability under different assumptions and input data. Furthermore, frameworks are characterized by certain mathematical formulations and structural boundaries. In contrast, an energy system model is defined as a specific application of a framework to a particular case study under specific assumptions and system boundaries. It is characterized by defined input data, assumptions (such as the level of resolution in time, space, techno-economic detail and sector-coupling) and system boundaries. A scenario is typically defined not only a model output, but also as a set of parameters and qualitative assumptions that influence model outcomes. Whereas a scenario result in energy system modeling is the result of an energy system model run"* (PRINA ET AL., 2022, P. 2). Prina et al. study the techniques used for framework, model, and scenario comparison. According to the authors, the comparison of frameworks is most relevant for both modelers and policymakers, while the comparison of models and scenarios is relevant for modelers and policymakers, respectively.

The research summarizes comparison techniques into qualitative, quantitative, and quantitative plus approaches. The qualitative approach compares theoretical characteristics of the framework, model, or scenario, whereas the qualitative approach investigates the results against a set of indicators. The qualitative plus method adds to the qualitative approach by also studying the deviation between results using a statistical analysis. It was found that the quantitative comparison approach was used most often, specifically by using indicators linked to energy and economy (such as cost deviations, direct comparisons of generation and demand, and direct comparison of cost and capacities). The results of Prina et al. may not be directly relevant to this research, but they do shine a light on the information that modelers and policymakers investigate to determine the best modeling practices. With regards to the impact of crisis situations, this research will investigate whether the decision criteria will remain the same, or if new priorities arise and alter the priorities. Furthermore, it remains to be seen whether all stakeholders are aware of the differences between various frameworks, models, and scenarios, and are equipped to make decisions on the most suitable candidates for a given situation.

So far, this section has discussed the origins, mechanics, and categorization of energy system models. The following paragraphs will focus on the alignment between energy system modeling and its application, and how areas of misalignment lead to challenges in energy system modeling.

An example of research on the alignment between energy system modeling and situations in which model results are applied is found in the review of Savvidis et al., who study the *"gap between energy policy challenges and model capabilities"* (SAVVIDIS ET AL., 2019, P. 503). As previously mentioned, the energy system modeling ecosystem has seen significant growth in both the number of models as well as their applications. However, *"despite their differences, many of the existing models are used to answer similar questions"* (SAVVIDIS ET AL., 2019, P. 503). This practice can be problematic, as different models may yield conflicting insights, which further complicates the decision-making process and may undermine the trust in models as a reliable source of information. To (re)align modeling efforts with the policymaking process and identify possible gaps between the two, the authors present a method to cluster and compare model capabilities and energy policy questions.

The criteria used to group models are similar to those found in previous categorization efforts, being divided into four categories: model-theoretic specifications, detail of modeling, market representation, and general information. As the method of clustering energy policy issues is novel and of particular interest to this research, it will be discussed in more detail here.

To study the capacity with which models are able to provide insights to specific policy issues, the authors developed the Energy Policy Issues Cluster (EPIC), which is depicted in **FIGURE 2**. The categories of the EPIC were determined through a literature study on policy issues in the electricity sector, from which prominent keywords were grouped into categories that made them comparable to model characteristics. These categories were then combined into three dimensions, being the object dimension, evaluation perspective dimension, and framework conditions. After formulating the EPIC, the authors defined twelve key policy research questions. The policy instruments associated with each policy research question were then mapped on the EPIC. The result was an overview of policy instruments related to the most pressing policy research questions. From this, models were assessed on whether they were able to implement the various policy instruments and, by extension, provide insights for the particular policy issue.

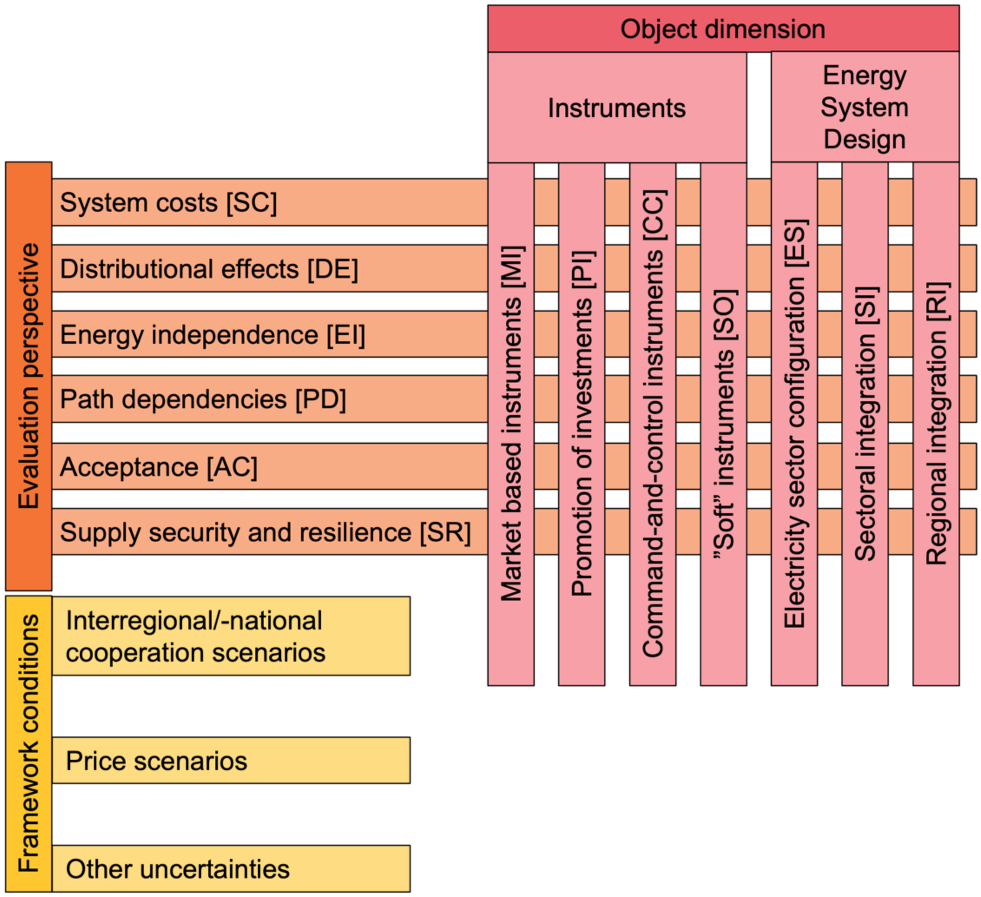

Figure 2: The Energy Policy Issues Cluster (EPIC)

The assessment was quantified by investigating the gap between the number of features required to address specific policy questions and the features available in the assessed model. The results demonstrate that *"critical features for policy questions are usually implemented in most models"* (SAVVIDIS ET AL., 2019, P. 515), but feature gaps exist in distribution grid modeling, endogenous demand modeling, technical flexibility of the energy system, and policy constraints. While the results are not generalizable, the work by Savvidis et al. offers a unique quantitative approach to the debate on the suitability of energy system modeling for policy development[8].

A similar effort in studying the alignment between modeling and its application is conducted by Horschig et al., albeit in a more qualitative fashion. The aim of the article is to *"provide a systemic overview of a set of modeling capable of evaluating renewable energy policies"* (Horschig & Thrän, 2017, p. 2). The authors justify their specific focus on renewable energy policies by

[8] Perhaps it should have been expected that model developers would come up with a quantitative approach to answering an originally qualitative problem, i.e., closing the gap between science and policymaking.

highlighting the side effects of building a renewable energy system. Most policies focus on renewables in a specific sector, overlooking the secondary effects that these measures may have on the overall energy system. Modeling may provide the tools to obtain a more complete overview, and studying how specific model types fit this task is the aim the article. The authors assess seven modeling methodologies using eight criteria, which were established from a literature review. In the end, the authors sum up the pros and cons of each modeling approach and conclude that *"policymakers should therefore strive for and promote a certain model plurality"* (Horschig & Thrän, 2017, p. 11). The main advantages of maintaining and using multiple modeling methodologies are a better fit between model capabilities and policy problems, and increased robustness of the results.

The findings presented by Horschig et al. and Savvidis et al. show how the needs of external parties, such as policymakers, induce to diversity in the model landscape and reshape the modeling practice. But when these needs cannot directly be addressed with existing modeling efforts, they can lead to challenges in the modeling sphere. Identifying these challenges within energy system modeling and assessing how this field of research should and does adapt is precisely the focus of the review by Pfenninger et al (PFENNINGER ET AL., 2014B).

The review is structured along four prominent groups of energy system models, being energy system optimization models, energy system simulation models, power systems and electricity market models, and qualitative and mixed-methods scenarios. For each of these groups, the authors identify current paradigms and challenges, as well as (proposed) solutions to address these items. The challenges related to energy system optimization models are primarily related to temporal and spatial detail. Optimization models are used to determine and assess possible (future) states of the energy system under study. These models are often based on large, bottom-up approaches, meaning a trade-off exists between the resolution that a model can achieve in its results and the necessary data and computational effort required to achieve this resolution. Alongside optimization models, energy system simulation models attempt to determine possible future states of an energy system. Rather than focusing on the ultimate states, simulation models determine the progression of an energy system through time. A key complication related to simulation models (and other models, too) is uncertainty in the model structure and end results. Pfenninger et al. distinguish two types of uncertainty, being epistemic and aleatory. The former is concerned with the uncertainty introduced by a model's 'mechanistic' limitations (e.g., input data, model structure), whereas the latter relates to the fundamental uncertainties of modeling, which is discussed in further detail. The uncertainty resulting from the inevitable introduction of assumptions in the modeling process combined with the random nature of energy system dynamics lead to models that are *"neither certain nor value-free"* (PFENNINGER ET AL., 2014B, P. 78; RAVETZ, 1999). This makes models and their developers prone to critique from stakeholders that use model results, such as policymakers. Questions about the legitimacy and relevance of models arise when the demand for clear and definite answers is met with assumption-laden and opaque modeling efforts. To counter this criticism, modelers *"could increase efforts to publicly release data and models"* (Pfenninger et al., 2014b, p. 78). While this raises difficulties on the part of modelers due the extra work resulting from a more transparent process (e.g., documentation) and the commercial interests associated with modeling, increased clarity on the modeling process could lead to more and better use of modeling results. Power systems and electricity market models constitute the third group in the review by Pfenninger et al. These models were traditionally developed within the utilities and power sector to assist decision-making on a range of topics, such as power generation and planning. With the increased importance of electricity (mainly following from commitments to reduce the emission of greenhouse gasses), power systems and electricity market models are gaining prominence in energy system modeling in general. However, aligning these models with the purposes associated with the 'original' large-scale models introduces issues related to complexity and optimization across scales. At the heart of this issue is the complexity associated with (the modeling of) energy systems. As these systems become progressively complex due to growing decentralization and diversity in energy sources, the level of modeling detail required to accurately represent the system's behavior increases too. This issue becomes even more pronounce when large scales (e.g., geographical scales) are modeled. A possible solution to this problem may be found by applying methods from complexity science, where complex systems, such as energy systems, may be represented as the sum of simplified, rule-based interactions between distinctive elements. Lastly, Pfenninger et al. discuss qualitative and mixed-method scenarios, which circumvent the intricacies of quantitative modeling efforts by taking a qualitative approach to scenario development. Using qualitative reasoning and relatively simple calculations, this approach can produce results without many of the computational difficulties associated with quantitative methods. Despite their relative simplicity, qualitative and mixed-methods scenarios are still primarily focused on incorporating technical and economic aspects, leaving out other elements that are important to the overarching goals of energy system modeling. An often-mentioned criticism of mainstream modeling efforts is the lack of behavioral aspects, which despite their essential role in the development and adoption of technologies are seldomly integrated into models (Huckebrink & Bertsch, 2021).

Pfenninger et al. conclude their review by referring to the essence of energy system modeling, namely providing *"crucial quantitative underpinning to scenarios, and more importantly, structured stories about the future based on an organized exploration of data and assumptions"* (Pfenninger et al., 2014b, p. 83). In the end, most challenges in energy system modeling can be related to this purpose. Ideally, modeling efforts should provide clear, relevant, and scientifically-sound insights to stakeholders who seek this information, which will require continuous improvement of the models and critical reflections on the modeling process and purpose.

Another challenge in energy system modeling is the inclusion of behavioral aspects related to the energy system, such as the acceptance of new technologies or weighing the cost of changing the energy system against other societal needs. Huckebrink et al. further investigate the challenge of including behavioral aspects in modeling and identify possible approaches to overcoming this obstacle (Huckebrink & Bertsch, 2021). This is done by a review that covers publications on energy system models as well as research studying behavioral aspects in energy systems. The review reveals that existing research on this topic is primarily focused on a few themes, being the acceptance of large-scale variable renewable energy sources (vRES) and transmission lines, as well as the implementation of behavioral aspects related to use of electricity micro-generation, EVs, or electricity service in optimization and simulations models. Besides calling for additional research, the authors conclude their review by reiterating the need for additional research on the inclusion of behavioral aspects in energy system modeling. Specifically, two improvements to modeling efforts are proposed, being the use of multi-objective optimization to allow for multi-dimensional impact assessments and the ability to generate real-time impact assessments to be used in decision-making settings.

Other difficulties arise from the modeling process itself, rather than the underlying models. In their research on *"participatory methods in energy system modelling and planning"*, McGookin et al. explore the groups of stakeholders involved in the modeling process through a systemic review of the literature (McGookin et al., 2021). Fifty-nine studies discussing participatory methods for energy system modeling were identified and subsequently split into two differing spatial scales and motivations: national policy-focused and local action-orientated research. The studies yielded insights into the composition of involved stakeholders in general, as well as for the two specific categories. In general, the stakeholders involved were primarily related to academia, with only ten articles noting some form of collaboration with non-academic stakeholders. At the national level, the emphasis on expert input is clear, with actors from the energy industry, government, and academia being involved prominently (in 67%, 63%, and 56% of the studies, respectively). The subnational level exhibits a more diverse stakeholder representation, with more involvement from non-academic, non-expert groups such as citizens, agriculture, and spatial planning. Overall, only ten out of the 59 investigated studies used some form of collaboration and *"in the vast majority of cases, the engagement process was solely a consultation to extract information and hat not allowed participants to shape the research direction or discuss and provide feedback on the results"* (McGookin et al., 2021, p. 12). The benefits of a participatory approach to modeling are increased legitimacy and robustness, knowledge-diffusion among participating stakeholders, and consensus building. Obstacles to successful participatory modeling efforts are the complexity of modeling, the inability of models to accurately capture reality, and practical considerations such as time, availability, and flexibility.

So far, the literature has been analyzed to explore the origins, nature, and challenges of energy system modeling. Part of this discussion revealed how the modeling practice is shaped by the interactions with other fields, such as policymaking, that use the output of the modeling process. This was mainly viewed from the perspective of modeling, in the sense that interactions with external parties shape energy system modeling. The next guiding question focuses on the role of energy system modeling in policymaking specifically.

Question 2 **What is the role of energy system modeling in policymaking?**

Summarized answer

The precise role of energy system modeling in policymaking is difficult to define, but the selected literature shows consensus on refuting the simplified view of modeling as a process that solely provides objective and neutral input. Instead, authors of various studies show how modeling shapes and is shaped by the context in which it takes places, a concept known as performativity. In the context of policymaking, various competing groups of stakeholders vying for hegemonic control over the energy system may utilize modeling to their benefit, for example by shaping political discourse, defining the relevance of stakeholders, and justifying political decisions. Combined, the literature paints the picture of modeling as both an advisory and a justification tool, where stakeholders use models and their results to both (re)define the problem at hand and the set of solutions to address it. The literature also highlights a number of issues related to the application of modeling results in policymaking, such as difficulties in using modeling across various levels of governance, a lack of knowledge on modeling among non-modeling stakeholders, the time-consuming nature and inherent uncertainties related to modeling.

Where the answer to the previous question provided an outline of energy system modeling and some challenges related to this practice, the answer to this question explores the role that energy system modeling plays in policymaking specifically.

While almost all articles discussed in this chapter address the overlap between energy system modeling and policymaking in some way, only a handful specifically focus on the nature of this interaction and the challenges that arise from it. One such study is provided by Süsser et al., who investigate the influence that these two domains have on each other. The background on energy modeling and policymaking presented in their article helps set the stage for the literature discussed in this sub-section.

What becomes clear from the work of Süsser et al. is that there is no straightforward answer to how modeling and policymaking do or should interact. The application of modeling results in policymaking are highly context-specific and open to interpretation. In the best case, models function as *"discursive or negotiation spaces, bringing together different social worlds – such as represented by scientists and policymakers*". In this context, models can help in exploring an uncertain future and creating consensus on policy problems and possible solutions. On a national level, this is often done through scenario studies conducted by modeling teams within governments, or outsourced to external research agencies or consultancies. Besides the need for insight into an uncertain future on the part of policymakers, the interaction between modeling and policymaking is also motivated by scientists' aim for policy impact. Research shows that the majority of modeling tools has a direct or indirect effect on policy. This raises the question of when and how models influence policymaking, and vice versa, and what this influence says about the role of modeling in policy development.

Süsser et al. identified a number of ways in which modeling impacts policymaking, being through the exploration future scenarios, target-setting, and the assessment of policies on their ability to meet these targets. Modeling results may also be used as negotiating tools in policymaking, but in this sense they do compete with other inputs. Also, it was found that the influence that modeling has on policymaking is dependent on a countries' experience in using energy models, as well as their general policy preferences. Countries with ambitious energy policy goals are more likely to utilize models to set targets and explore policy options than governments who lack this objective. Influence of policymaking in modeling was also found. Policymakers exert control over the modeling process especially by influencing the scope, objective, and assumptions, especially in commissioned work. In these cases, governments often commission *"known and acknowledged"* modeling teams, leading to skewed impact among model studies. Ultimately, the *"strongest influence"* that policymakers have on modeling is their control over if and how the results of modeling studies are implemented in policy.

While the work of Süsser et al. presents a number of mechanisms through which modeling and policymaking influence each other, the authors "can neither say to what extend models influenced final policy decisions, nor draw strong generalized conclusions for the conditions under which models are particularly impactful", in part because of the complexity of policymaking.

Another difficulty in determining the impact and role of modeling in policymaking is rooted in a concept called *performativity*, which states that a discipline, like energy system modeling, *"rather than simply describing or representing (...) activity, actively contributes to shaping it"* (Aykut, 2019, p. 14). In constructing an analytical framework for studying the interactions between modeling and policymaking, Aykut details the ways in which modeling performs the reality it seeks to replicate: *"They [models] propose the future-visions that populate public discourse, provide market actors and policy-makers with ontologies to understand energy systems, and shape wider policy networks in scenario-building exercises and through the circulation of models across social spaces. In doing so, they can stabilise dominant framings, practices, and policy assemblages, or rearrange and reorder policy worlds, thereby contributing to the formation of new assemblages that enact alternative conceptions of energy policy"* (Aykut, 2019, p. 27). In this context. Akyut proposes that disputes in energy policymaking do not purely entail political or ideological conflicts, but rather a competition between 'predictive policy assemblages'. These assemblages, made up of stakeholders, problem framings, and modeling practices, compete for a kind of modeling hegemony. The dominant assemblage ultimately determines how models help shape the energy system and who is involved in this process. Akyut concludes that models can induce policy change, if they successfully perform energy policy by generating alternative perspectives, facilitating new policy options, and shaping 'new predictive policy assemblages'.

The role of modeling in policymaking is also studied by Royston et al., who study the influence of politics on economic modeling within EU energy policy, as *"there has been little investigation of how political dynamics systematically influence these models' development and outputs, or the implications of energy strategies, targets and interventions"* (ROYSTON ET AL., 2023, P. 1). In their study, Royston et al. distinguish politics from policy; politics refers to *"cross-actor dynamics (…) which shape, and are shaped by, the development, mnaitenance and veluation of models"*, while policy is limited to *"codified outputs of political negotiation, such as rules, laws, standards, and protocols"*. The realm of politics, in this context, extends beyond policy institutions and covers relationships with other stakeholders, such as modelers. The study's results have a number of implications on the role of modeling in policymaking. First, it is concluded that the processes of evidence-making are deeply political. Models and the modeling process are not impartial and are shaped by politics through the framing of questions, scenarios, and purpose. In this sense, it could be the case that model significance comes at the cost of external influence – when modeling is used as an input in policymaking, political processes can shape this input. This can lead to the instrumentalization of modeling, as detailed by the theme identified by the authors, concerning the *"systematic exclusion of critical voices, and the use of models to reinforce the authority and legitimacy of established interests."* Second, the significance of models is not solely based on their ability to provide relevant information, meaning significance cannot be gained by only focusing on model improvement. The authors conclude their work with a number of recommendations, which are mainly centered around the need for awareness among those involved in developing and promoting models on their own role within the political process of evidence making. This recommendation will also be heeded in this research, as it is clear that the model-policy interface is not a utopian system with the sole aim of increasing the efficacy of policy through quantitative input. The role and interactions of stakeholders are shaped by their own agenda, and stakeholders can and do influence each other to reach their goals.

The works of Akyut and Royston et al. extend the role of modeling in policymaking beyond a process for providing helpful insights into a mechanism through which competing groups (or 'assemblages') shape the development of energy systems and policy, as well as their own position in this process. Interestingly, these concepts surrounding the interactions between modeling and policymaking are not new. In fact, it was described by Midttun et al. in 1986, more than three decades prior to the work of Akyut and Royston et al. Despite its age, this research continues to be relevant in today's context and it overlaps with recent studies discussed in this chapter.

Midttun et al. begin their article with refuting the image of modeling as a *"neutral"* technique with *"the aim (…) to predict an objective, societal development with the greatest possible accuracy"* (MIDTTUN ET AL., 1986, P. 219). Instead, the authors outline a field of contention in which various stakeholders use models to compete for control over the future energy system. According to Midttun et al., the (then) traditional social-engineering perspective is built on flawed assumptions[9]. *"By neglecting political reality, this perspective underestimates the complexity of interest groups, institutions, and ideologies, and of the conflicts between them, that characterize modern societies, and it oevrestimates the authority and effectiveness of administrative and political organs"* (MIDTTUN ET AL., 1986, P. 220). An improved perspective should incorporate three aspects: the complex of methodological and technical choices in modeling, the interplay between modeling and its institutional and professional environments, and the interplay between forecasting and political decision-making in general. Because these aspects shed light on the role of modeling in policymaking and the interrelations between the two domains, I will discuss each of them in more detail.

As discussed in the answer to Question 1, models form an abstraction of real systems. As such, the process of modeling an energy system includes making decisions about which elements from the real system to include in the model and how. These decisions concern the scope and detail of a model, the input data, and assumptions about the future. The methodological decision-making will always be shaped by the subjective perspective of modelers, which may in turn be politically biased. Discussions surrounding the role of energy system modeling in policymaking should be aware of bias in this phase of the modeling process, despite its technical and seemingly objective nature.

The second aspect presented by Middtun et al. concerns the institutional structures and networks in which modeling is embedded. Modelers, and the agencies they represent, operate in a network of organizations that influence each other's decision-making. Furthermore, the authors note a tendency among established organizational structures to maintain the status quo, by hindering newly emerging stakeholders. "*Economists (an example of forecasters) especially have managed to build 'iron triangles' where training and theorizing in academic institutes are integrated with data collection and model building in statistical bureau and with planning and economic decision making in ministries of finance and economics"* (Midttun et al., 1986, p. 223). As a result of these structures, modeling for policy impact can become a self-fulfilling prophecy, with modelers and policymakers feeding into each other's work and building forecasts on predetermined plans. In such cases, institutional changes may be just as responsible for altering model forecasts as a change in the energy outlook itself.

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[9] *"In this way the social-engineering perspective draws a picture of reality as if: there was only one correct model of society possible; knowledge of social processes was sufficient to formulate objective laws that could serve as a basis for exact prediction of the future; data were available to map such processes in detail; political and administrative organs were operating under consistent and stable goal structures, and were able to pursure long-term policies without fear of losing legitimacy; modelling and forecasting were purely technical activities, applying well specified norms and rules, relying on perfect data, and free from commercial and political considerations"* (Midttun et al., 1986, p. 220).

The final aspect focuses specifically on the role of modeling in policymaking, with the authors stating that *"the significance of models in societal planning rests on their acceptance in political decision making"* (Midttun et al., 1986, p. 224). However, this role extends beyond the supposed role of models in facilitating rational decision-making. The modeling process can influence political discourse, define the relevance of stakeholders, and be used to justify political decisions. In this sense, modeling constitutes a powerful tool which policymakers can use for their own benefit, by both defining the problems at hand and the corresponding set of solutions.

Through their work, Midttun et al. express the necessity to view the modeling practice in the social, or specifically political, context in which it takes place. This context influences the role of modeling, extending beyond purely providing scientific input, and changes the definition of 'good' modeling. *"The criterion for successful modelling is no longer so much to hit the correct future, but to reach reasonable compromises between affected interests"* (Midttun et al., 1986, p. 241). This in turn affects how modeling should be judged, for example by focusing on the inclusion of the interest of all relevant stakeholders as well as the neutrality and transparency of the modeling process.

The articles discussed so far have shed light on the role of modeling in policymaking, by clarifying the societal and political context in which it takes place, explaining how this context can be conceptualized into a framework, and highlighting how modeling and policymaking influence each other. From this, I will focus on some of the challenges related to modeling in policy development.

The role of energy system models on different levels of governance (e.g., national, state, local) is further explored by Hofbauer et al. Specifically, the question is addressed *"to what extent current modelling practices are able to foster coordination across national and subnational scales as part of an effective and efficient multi-level governance system"* (HOFBAUER ET AL., 2022, P. 2). This question follows from the increasingly important role that all levels of governance play in the fight against climate change, combined with the enduring salience of energy systems in energy policymaking. Similar to the findings of McGookin et al., the involvement of a diverse set of stakeholders is stated as being beneficial to the efficacy of energy system modeling in policy development. However, this can be particularly challenging in multi-level governance, where stakeholders from different governance levels lack overlap in capabilities and resources, and legitimate representation of large numbers of stakeholders is difficult. Salience across scales is presented as another challenge. As *"evidence is most likely to be used in policy when it is considered salient by relevant decision-makers"* (CASH ET AL., 2002; HOFBAUER ET AL., 2022, P. 7), the efficacy of energy system modeling is dependent on its ability to be relevant across multiple levels of governance. The final challenge was identified by Hofbauer et al. in transparency, which finds its roots in model-inherent limitations. While some level of uncertainty in the modeling process is acceptable, the manner in which this uncertainty is communicated is important. Transparency in the availability of specific information on the modeling process as well as a clear explanation of how model results can be interpreted is key in building trust in energy system models across various stakeholder groups.

The work of Hofbauer et al. presents the intricacies of the modeling in policymaking by emphasizing the effect that different perspectives have on the challenges that stakeholders face, despite their seeming overlap (e.g., various stakeholders may all be related to the government, but have significantly different viewpoints depending on the governance level). Research on the model-policy interface should therefore be careful when categorizing stakeholders, as easily overlooked simplifications may lead to incorrect results.

A similar theme is explored in a study by Amer et al., who study the role of energy system models in municipal decision-making in Denmark (AMER ET AL., 2020). By conducting interviews with municipal energy planners from three Danish municipalities, the authors investigate if and how energy system models are used by these stakeholders. This also sheds light on how the utility of modeling in this case is different from previously researched instances, such as national energy planning. The goal of this study is similar to that of other articles discussed in this review, in that it aimed to find insights that could help align modeling and policymaking processes. Although the generalization of the results found by Amer et al. *"should be done with caution"*[10] (AMER ET AL., 2020, P. 7), the work offers a frame of reference relevant to this research.

With regards to the use of energy system models in the investigated Danish municipalities, interviewees indicated that *"the competencies of running energy models do not lie within their respective municipality, but instead within heat supply companies, consultancies or universities"* (AMER ET AL., 2020, P. 4). While the article does not provide a direct cause for this, other parts of the study provide plausible reasons. Critique expressed by the interviewees on energy system modeling focused on the complicatedness, perceived narrow focus, and limited scope of models. Perhaps most strikingly, the interviewees mentioned *"a lack of need for municipalities to run models"* (AMER ET AL., 2020, P. 5), explaining that models owe their relevance in energy planning to their usefulness in the implementation phase. In this light, energy planners seem to have limited interest in the intricacies of modeling, with most emphasis placed on the direct applicability of the output of the modeling process. While the complexity and opaqueness of modeling as perceived by non-modeling stakeholders is echoed in other articles, this result highlights a new element in the model-policy interface. It could be that the ignorance on the modeling process on the part of non-modeling stakeholders may in part be conscious, i.e., a consequence of the prioritization of

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[10] The study covered energy planning actors in 3 of the 98 Danish municipalities. 6 individuals were interviewed in total.

applicability over comprehension[11]. This goes against other sentiment identified in the literature, expressed primarily by model developers, that sees a certain minimum level of understanding of the modeling process as critical to effective modeling for policy impact (e.g., (HOFBAUER ET AL., 2022; PRINA ET AL., 2022; SAVVIDIS ET AL., 2019)). The authors comment on this finding by stating that *"this situation raises questions as to what motivations drive the development of energy models, what benefit models can bring, and to whom. We began with the assumption that there was a goal to better tailor models to meet the needs of municipal decision-making. After conducting our analysis, it is unclear if that assumption fully holds"* (AMER ET AL., 2020, P. 6). Ultimately, the study concludes an emphasis on practicality in the use of modeling (results) by the interviewees, which could be supplemented by increased transparency and cooperation.

As mentioned by various authors, policymakers may use model results to their own benefit, for example by using specific results to underpin their political standpoint. An insight into how policymakers and politicians use energy systems models in their decision-making is provided by Scheer. Although Scheer acknowledges that *"energy scenario modelling has become a fundamental scientific tool and school at the science-policy interface"*, the lack of research actually assessing the impact of modeling on policymaking claimed by many scholars is stated as the motivation behind the study. By researching the German media coverage on energy system modeling the research *"contributes to establish systematic and empirical grounded modelling impacting policy-making"* (SCHEER, 2017, P. 1390), albeit within a specific domain, e.g., the public debate. In the literature review related to his research, Scheer identifies several insights relevant to this review question. Multiple articles discussing the challenges and shortcomings of energy system models at the science-policy interface are synthesized into simulation-based and contextual-based deficit aspects (SCHEER, 2013, 2015). Simulation-based deficits explain a deficient policy impact by modeling efforts by referring to the uncertainty, ambiguity and complexity related to modeling. The fact that models often cannot provide conclusive 'evidence' for specific policy options decreases the likelihood that policymakers will use model results as a key argument in their decision-making. When policymakers seek concrete advice, model results may be interpreted without proper nuance, potentially leading to incomplete or even contradictory implementation of science in policy. Contextual-based deficits focus on shortcomings related to the science-policy interface in general, and are therefore more diverse in nature. Scheer mentions three examples of contextual-based deficits, being a fundamental discussion on the *"disparate modes of operation of the science and politics system",* limited knowledge on model mechanics among policymakers, and the lack of interaction between scientists and policymakers. In all, several researchers have found a fundamental misunderstanding and misuse of energy system models in policymaking (Scheer references the following articles as examples

[11] I don't necessarily mean to say that non-modeling stakeholders don't want to be informed on the modeling process, but perhaps don't feel the necessity, i.e., "I don't need to know" versus "I don't want to know".

(Huntington et al., 1982; Laitner et al., 2003; Nilsson et al., 2011; Pilavachi et al., 2008; Strachan et al., 2009)).

The study's results highlight examples of the shortcomings identified in the literature. A key finding of the research is a general absence of energy scenario expertise in media coverage. This may be due to any of the identified shortcomings, such as a lack of transparency on model mechanics, the complexity of modeling science and its results. However, it was found that scenario modeling received media coverage when the topic was brought up by policymakers themselves. The reasons why policymakers decide to mention energy system modeling were synthesized by Scheer intro three types. The first is called the *generic factual knowledge claim*, which uses energy scenarios as the outset of an argument by presenting modeling results as *"unquestioned and coherent scientific evidence to guide readers or at least give them some orientation."* This finding of this claim is related to the instrumentalization of science by policymakers, where scientific input is used to legitimize existing viewpoints, sometimes stretching the scientific evidence beyond its limits of validity. A striking example of this was identified in the study, when findings revealed that energy scenarios were referred to by policymakers as the *"backbone"* of the arguments for the continuation of Germany's nuclear program, while no reference to modeling results were made in the aftermath of the Fukushima disaster. *Selective (in)consistency claims* are the second type defined by Scheer, in which reporting mainly focuses on specific elements of the modeling process. By highlighting (in)consistencies in a model's input or output, reporters question or emphasize the trustworthiness and independency of the modeling process and its corresponding agencies (e.g., reporters use model-inherent limitations, such as uncertainty in the results, to challenge the reliability of model input in policymaking). Lastly, the *scientific communication claim* constitutes reporting in which efforts are made to educate the readership on the scientific tools used in the policymaking process. Although few articles in the study adhered to this effort, it seems to be a unique pathway to explaining niche model mechanics to the wider public (at least beyond the expert community).

Concluding, Scheer's research demonstrates that policymakers use modeling results to underline the credibility of their views, at least in their communication toward the public. If credibility cannot be gained, or if other inputs such as public sentiment prevail, little reference to the role of modeling in policy development is made.

The literature related to this guiding question provides an overview of the role of modeling in policymaking, how this role shapes both domains, and what challenges arise from this interaction. It has also become clear that the interface between modeling and policymaking is complex and that an attempt to study these interactions, like the modeling process itself, requires simplifications of reality. The next question will focus on the influence that crisis situations can have on the role of modeling in policymaking.

Question 3 **How can crises influence the role of modeling in policymaking?**

Summarized answer

There were no articles directly discussing the influence of crisis situations on the role of modeling in policymaking, underlining the relevance of this research. Instead, a number of studies examined under what circumstances and how crisis situations can lead to policy change. Crisis operationalization was described as difficult. There is consensus on the importance of perception in distinguishing crisis situations from the status quo, especially the perception of uncertainty and urgency. During crises, individuals and organizations face the challenge of needing to act quickly in a situation where existing knowledge may no longer hold true. The complexity of policymaking combined with the unclear nature of crises has given rise to many theories concerning the impact of crisis on policymaking. What these theories say about the influence of crisis situations on the role of modeling in policymaking specifically remains unclear.

To answer this question, a number of articles discussing the influence of crises on (energy) policymaking were selected. Although these do not directly consider possible changes in the role of energy system modeling in policymaking, these changes can be inferred by combining the answer to this question with the findings presented above. Therefore, I will start by addressing the literature concerning the effect of crises on policymaking, beginning with an operationalization of crisis situations followed by a discussion of various framework used to study the impact of crises.

A review of crisis operationalization in a policy context presented by Grossman, who *"surveys theories and models of crisis policymaking in the social science literature and explores how well they illuminate the process and outcomes of energy policy efforts"* (GROSSMAN, 2015, P. 57), gives the most relevant account of crisis operationalization and its impacts on energy policymaking found in the literature. Below I share the author's summary of the theory discussed in their work:

"A crisis means that "normal" processes of policymaking have been disrupted—or at least that there is the perception of such a disruption. Officials, whether thought of as fully rational but ignorant, or as boundedly rational and thus limited in their ability to process information, due to widespread alarm, are confronted by a sense of urgency to act. But both the major issues of a given crisis and any solutions to it are at least unclear, and often conceptually and technically beyond their abilities (as well as those of the general public) to understand. In many cases, markets resolve the sense of crisis. But crises provide an occasion for major change (e.g. energiewende), particularly if the crisis seems to persist. Although why the same crisis experienced in different countries leads to paradigm shifts in one place but little change in another, is a question requiring much more analysis than a review article can accommodate" (GROSSMAN, 2015, P. 67).

The work of Grossman aligns with the goal of this research in building a better understanding of how crisis situations influence energy policymaking. Grossman begins his analysis by studying "what is meant by calling any event a crisis?" After providing a list of crisis definitions identified in the literature, the author continues the answer to this question by detailing specific aspects of crisis situations. The experience of urgency is deemed a crucial crisis indicator by several researchers. Urgency can lead to a sense of time compression, increasing the pressure on actors in policymaking to act on a problem. The perception of urgency does not always lead to an immediate urge to act. For example, the perceived threats of climate change have not uniformly led to direct action. Combined with a high degree of uncertainty, urgency can lead to a sense of helplessness as well as a tendency to policy recklessness. As a result, *"some actions taken in the midst of crisis probably should not have been taken, and would not have been taken except for the urgency of the moment"* (GROSSMAN, 2015, P. 58). Uncertainty is especially relevant in crises that are technically complex or difficult to understand, such as crises related to energy. *"Officials have seldom grasped the underlying causes of diminished availability or rising prices of energy supplies, nor have they compre- hended what to do to overcome them"* (GROSSMAN, 2015, P. 58).

Ultimately, the exact definition attached to the term "energy crisis" may be of limited relevance, as many of them are likely to refer to these situations in terms of an abstraction, without specifying its meaning. In this sense, it is assumed that what is meant by a crisis is uniformly understood and therefore requires no further explanation. This further underlines the importance of perception in crisis definition, leading the author to argue that *"there is really no such thing as an energy crisis"*, at least in the context of presenting an actual threat to society. *"What they [the words "energy crisis"] convey is ambiguous—but then so many of the tropes of energy policy—e.g. energy independence, energy security—are also indistinct, subject to multiple interpretations, and reflecting varying belief systems so as to make much of energy discourse a clash of monologues"* (Grossman, 2015, p. 59). Despite the unclear, conflicting, and at times non-existent crisis definitions, the perception of these situations can drive the policy process. Grossman continues his work by reviewing the theories and models of crisis policymaking, specifically in the context of energy policy.

The theory of incrementalism is posed as the starting point of the review. In this theory, policymaking is a process of slight iterations, in which policy is gradually and continuously adapted in alignment with the current policy goals. These steps are the result of a decision-making process which incorporates the views of all involved actors (e.g., politicians, the general public, special interest groups, etc.). Ultimately, majority coalitions of stakeholders determine the course of policy. Crisis situations present a clear break from this process, for which the theory's authors had no direct explanation. Throughout the past decades, several frameworks and theories have addressed this knowledge gap. To provide an understanding of how these frameworks and theories relate to each other and the definition of crisis as a whole, I present a summarization of the author's comments below. Grossman discusses eight theories and one framework in total and has categorized this material into four groups. My summary of Grossman's work follows the same categorization.

Non-incrementalist crisis models: addenda to incrementalist policy theory
The first category of theories addresses the shortcomings of incrementalism in explaining the impact of crisis situations on policymaking by amending through amendments to this theory.

Public satisfying-speculative augmentation (JONES, 1974)
The intensification of policymaking during a crisis is explained by public satisfying-speculative augmentation through the argument that during such situations proposed policies become increasingly extreme. This is the result of policymakers who face a problem that is beyond their comprehension but must be addressed as soon as possible. In an effort to satisfy public demands, policymakers propose stronger policy interventions which should portray increased engagement with the issue. The feasibility of such proposal is of lesser concern than the message they convey.

The issue-attention cycle (DOWNS, 1972)
By introducing five phases of crisis policymaking, the issue-attention cycle model adapts incrementalism to crisis situations. The stages are pre-crisis, the discovery of the crisis followed by euphoric enthusiasm, pessimism resulting from the projected costs, the decline of public interest, and post-crisis. While the theory's phases match some real-life instances, the model gives no real insight into how crisis situations impact the policymaking process. Furthermore, it also paints a picture in which all policy interventions are too expensive to address a crisis and therefore inherently ineffective.

Post-incrementalist theories of the policy process
As their name suggest, the post-incrementalist theories seek to address the shortcomings of incrementalism through an entirely new approach. Grossman discusses two theories and one framework that are classified by post-incrementalism.

Multiple streams (MS) (Kingdown & Stano, 1984)
MS theory has its conceptual origins in the "garbage can" model (COHEN ET AL., 1972), which describes the policymaking process as an ever-changing mix of stakeholders and ideological representations, i.e., the contents of the "garbage can" are continuously changing. This leads to a high level of ambiguity, as problems addressed by the "garbage can" decision-making could be addressed in many different ways. Introducing new information or stakeholders may reduce uncertainty, but will not decrease ambiguity. Decision-making is further complicated when further restrictions are introduced, such as during a crisis.

Incorporating the concept of free-flowing stakeholders and ideologies, MS theory defines three components that constitute the policymaking process: problems, policies, and politics. Each of these components exists on itself, but can also become entangled with the others. In this theory, external shocks, such as crises, can form "focusing events" through which one or more streams become coupled. This coupling is often a deliberate act of policy entrepreneurs, who use a focusing event as an opportunity to push their agenda, for example by combining their preferred policy to a problem. While this theory incorporates the chaotic and ambiguous nature of the policymaking process, it does not clarify when and how exactly external shocks induce a policy change (or not).

Punctuated equilibrium theory (PET) (Baumgartner & Jones, 2010)
According to PET, the policy domain is in an equilibrium in non-crisis times. An external shock can punctuate this equilibrium, leading to a rearrangement of policy priorities, or a change in the "policy image". It is not necessarily the case that all stakeholders involved in the policymaking process perceive the changes that a punctuation brings about similarly. Like MS theory, PET is unclear about whether and how an external shock leads to policy change. The theory does state that under certain circumstances policy topics can "catch fire", but understanding why a topic caught fire is often only possible after the fact.

Advocacy coalition framework (ACF) (Sabatier, 1986)
A framework is a conceptual background on which theories, possibly from various fields, can be compared and combined. ACF provides a context in which policy and policy change theories can be developed and compared. "Policy subsystems" – made up of stakeholders dealing with a policy topic – play an important role in ACF. Coalitions are groups within a subsystem that have a similar view on policy development, for example because of a common interest or background. ACF states that external shocks can affect policy in three ways: shocks can induce a redistribution of political resources, a minority coalition can utilize the circumstances to promote their agenda and become the dominant coalition, or a dominant coalition can change its stance on a policy issue.

While MS, PET, and ACF all provide a conceptual picture of the policymaking process in which decision-making is influenced by competing (groups of) stakeholders, the exact influence of external shocks, or crises, remains unclear.

Energy crisis models of policy change
The theory and frameworks discussed above can in essence be applied to the decision-making on any policy issue. There are also theories that specifically focus on energy policy, which are discussed here.

Ambivalent majoritarian (Ahrari, 1987)
In this model, energy policies that have been denied in normal situations gain large acceptance during a crisis. This is in large part because in the face of a crisis, objections to previous policy development are of a lower priority compared to what the current situation demands, which leads to a larger coalition support for previously halted policies.

The "do something" principle (Grossman, 2012)
The "do something" principle builds on Down's issue-attention cycle, but specifies how policy development changes during a crisis as a result of decision-making by policymakers and politicians. The public's call for action in the face of an ongoing crisis puts pressure on

political leaders to take action. Such pressure can spur policymaking in three stages, depending on how long the crisis lasts. Initially, policymakers will show engagement with the issue, but mostly in a rhetorical sense, since taking action carries the risk of being wrong or rash if the crisis disappears faster than anticipated. If the crisis continues, politicians will begin to make their intentions to act more clear, signaling a higher commitment to taking action. Ultimately, when the situation persists long enough, legislative action will be taken to appease constituents.

Economic crisis models

The final category of theories discussed by Grossman are traditionally part of the domain of economics, but can also be applied to energy policy.

Rational choice with ignorance (CONGLETON, 2004)

A fundamental assumption in many economic models is the rational choice of actors. This assumption is difficult to maintain in crisis situations, as the uncertainty and urgency of crises limit an actor's ability to make a rational decision. Ultimately, this leads to increased ignorance on the part of actors, but this does not mean that actors can no longer behave rationally. They will continue to do so, but will likely make systemic errors that result from their ignorance on the situation. As the circumstances of a crisis become better understood, the systemic error in the actor's decision-making is expected to decrease.

Crisis opportunism (HIGGS, 2009)

The second economic crisis model highlights the influence of opportunistic tendencies. Crisis situations often spur the creation of new ideologies, institutions, and laws, which are likely to remain after the crisis had passed. This is especially true for legislation, as there is often less interest in repealing an existing law than developing a new one. As a result, crisis situations can entice opportunistic actors to push their agenda and secure their interests in the present and in the future.

In all, Grossman's review provides an overview of theories and framework surrounding energy policy development during a crisis, but also highlights their limitations. Ultimately, the question of how crisis situations influence policymaking, specifically in the energy domain, remains largely unanswered, leading to the author's conclusion that *"energy policy requires its own framework."* This framework would encompass theories from multiple domains and place specific emphasis on how crises impact the energy policymaking process.

An effort to construct such a framework can be found in the work of Nohrstedt et al. (Nohrstedt & Weible, 2010). Their introduction presented echoes two previously discussed challenges related to studying the effect of crisis on policymaking. The first pertains to the difficult task of crisis operationalization, while the second concerns the complex nature of policymaking. Combing the two gives rise to research that aims to study the impact of an ambiguous phenomenon on a complex system. According to the authors, the contemporary theory is underdeveloped and lacks detail on "the nature of the event, the type of change, the contingent subsystem conditions conducive for change or stasis, and the causal mechanisms linking the external event and change". To address these shortcomings, Nohrstedt et al. build on the advocacy coalition framework (ACF), especially the concept of policy subsystems, to define pathways through which crises influence policymaking.

While previous theory stated that significant magnitude of a crisis, expressed in the impact it has on "core societal values", will alert stakeholders and potentially spur them into action, much remained unclear about the link between a crisis' magnitude and its exact impact. Nohrstedt et al. address this theoretical gap by introducing the concept of policy and geographic proximity. The concept poses that there is a positive relation between the proximity of a crisis, in either or both categories, and its impact. The authors provide a matrix overview of both proximity categories and corresponding examples, as shown in **TABLE 2**.

Table 2: Comparison of geographic and policy dimensions of a crisis with examples presented by Nohrstedt et al.

	Close Geographic Proximity	**Distant Geographic Proximity**
Close Policy Proximity	**Immediate Crisis** Example: Hurricane Katrina for the Louisiana crisis management subsystem	**Policy-Proximate Crisis:** Example: 9/11 terrorist attacks for European security subsystems
Distant Policy Proximity	**Geographic-Proximate Crisis** Example: Southern California wildfires for the California public health system	**Vicarious Crisis** Example: Swine-flu crisis for counterterrorism subsystems

Using the concept of proximity, Nohrstedt et al. define pathway scenarios outlining how crises with different proximities influence policymaking. Because these are ultimately summarized into broader mechanisms, I have added these pathways to **TABLE 8** in the Appendix. The categories of mechanisms of how crisis situations influence policy subsystems are through redistribution of resources, learning within the dominant coalition, exploitation by a minority coalition, defection from a dominant coalition, framing contests, and policy entrepreneurship.

Taken as a whole, the work of Nohrstedt et al. offers a lens through which to view the impact of crisis on policymaking. They provide a number of detailed scenarios and mechanisms through which crisis situations shape the policymaking process and its constituents.

The material discussed in the answer to this guiding question offers some insight into the conceptualization and operationalization of crises and how these situations influence the policymaking process. Urgency and uncertainty are described as two important aspects in crisis perception, which itself is presented as significant in distinguishing crisis for normalcy. However, what the theories pertaining to the influence of crises on policymaking imply for the role of modeling in policymaking is unclear. The impact of crisis situations on the modeling process and its role in policymaking might be described as a second order effect, dependent on the crisis' influence on policymaking and, in turn, the role of modeling in it.

For example, in Multiple Streams theory, modeling may gain significance in policymaking as a tool to frame problems, present solutions, and shape the political debate. At the same time, the opposite may be true if actors decide against the use of modeling for any of these purposes. The theories provide some context into how modeling may be influenced, but do not stipulate when or why. These questions will be discussed further in the final section of this chapter, and form the basis of the hypotheses following from this theoretical overview.

Summary and hypotheses

This section briefly reiterates the selected literature's answers to the guiding questions of this theoretical overview. Furthermore, a set of hypotheses regarding the research question of this study is formulated based on the literature.

Energy system modeling concerns the creation and use of mathematical models that replicate the behavior of a real energy system. Energy system modeling is used by individuals and organizations, particularly in policymaking, to understand how interactions, such as policies, can shape the energy system and what future configurations of energy systems may look like. In this context, energy system modeling supports the design process of policies.

However, various studies also show how modeling shapes and is shaped by the context in which it takes places, a concept known as performativity. In the context of policymaking, various competing groups of stakeholders vying for hegemonic control over the energy system may utilize modeling to their benefit, for example by shaping political discourse, defining the relevance of stakeholders, and justifying political decisions. Combined, the literature paints the picture of modeling as both an advisory and a justification tool, where stakeholders use models and their results to both (re)define the problem at hand and the set of solutions to address it.

Furthermore, the policymaking process is not static. External events, such as crises, may disrupt and reshape policy development. A number of studies examined under what circumstances and how crisis situations can lead to policy change. But defining what crisis situations are and how they assert themselves in the policymaking process is difficult. There is consensus on the importance of perception in distinguishing crisis situations from the status quo, especially the perception of uncertainty and urgency. During crises, individuals and organizations face the challenge of needing to act quickly in a situation where existing knowledge may no longer hold true. Ultimately, the complexity of policymaking combined with the unclear nature of crises has given rise to many theories concerning the impact of crisis on policymaking. What these theories conclude about the influence of crisis situations on the role of modeling in policymaking specifically remains unclear, but relating the advisory and justification function roles of modeling in policymaking to the uncertainty and urgency aspects of crisis situations can form a basis for hypotheses.

The following hypotheses concerning the impact of crises on the role of energy system modeling in energy policymaking are inferred from the studied literature:

As urgency compresses the perceived availability of time to build a policy response, the room for conducting modeling studies is decreased. Therefore:

H1. Crisis-related **urgency decreases the advisory role** of energy system modeling in energy policymaking.

As urgency increases the demand for solutions, stakeholders may be inclined to use the results of modeling studies beyond their intended context. Therefore,

H2. Crisis-related **urgency promotes the justification role** of energy system modeling in energy policymaking.

As crises bring about new and uncertain circumstances, the demand for insights provided by energy system modeling will increase. Therefore,

H3. Crisis-related **uncertainty promotes the advisory role** of energy system modeling in energy policymaking.

When many aspects about the circumstances and consequences of a crisis remain unknown, the room for interpretation of model results increases. Therefore,

H4. Crisis-related **uncertainty promotes the justification role** of energy system modeling in energy policymaking.

4. **Method**

4. Method

4.1 Fit between abduction and the research method

In this section, I will explain how use of a case study and interviews matches the strengths of the abductive approach, outlined at the beginning of this report.

Case studies may serve various roles in research depending on the research question(s), which can be exploratory, descriptive, illustrative, and explanatory or causal (HOQUE, 2018). Similar to Conaty's research, the questions related to this study are multi-interpretable. For example, the main research question: "HOW DOES A CRISIS INFLUENCE THE ROLE OF ENERGY SYSTEM MODELING IN ENERGY POLICYMAKING?" could be interpreted solely as a *how* question. In this sense, the case study would be *descriptive* or *illustrative*, i.e., depicting an account of the influence crisis situations have on the model-policy interface and its constituents. However, because the model-policy interface is comprised out of stakeholders which may moderate the effect of crisis situations, the question also considers *why* stakeholders express this moderating behavior (i.e., what is the reasoning behind the stakeholders' decisions). Case studies combined with the abductive approach enable researchers to address multiple elements of a research question by providing enough flexibility through the dialogical approach. Abduction also addresses a fundamental challenge with case study research, where researchers should be aware of the limitations of the case study. When generalizability and validity are of concern, a research method allowing for the proper balance between theory and observation becomes key.

The reflective nature of the abductive approach also aligns with this study's primary source of data: expert interviews. Because the number of interviews is limited by the duration of the research, and the subjective nature of this data, reflecting on the meaning of the observations is fundamental. This includes careful interpretation of the results to minimize bias and linking the interpretation to the existing theory.

4.2 Data collection through expert interviews

Expert interviews constitute the primary source of data. Interviews fit the abductive approach of this research in that they allow for exploration of the subject matter in a flexible manner. This flexibility can improve reflection and creativity in both gathering and processing the data.

The interviewees will be selected using purposive sampling (SILVERMAN, 2021), aided by the input of various researchers at Delft University of Technology. The experts must be part of one or more of the model-policy interface stakeholder groups – scientific advisory organizations, the energy industry, or policymaking. Interviewees should have enough experience in energy system modeling and policymaking to be able to distinguish between crisis and non-crisis situations. An overview of the interviewees, their role in the model-policy interface, and their seniority is given in the Results section.

The interviews are semi-structured, with the purpose of gathering enough meaningful information from all interviewees while remaining open to emerging points of interest throughout the interview. The interview structure and the list of questions can be found in **TABLE 3**. Ultimately, data will be stored in the form of interview recordings and transcripts.

Table 3: An overview of interview topics and questions.

Section	Purpose	Question(s)
Introduction	Get to know the interviewee and introduce the research.	-
Background information	Get an understanding of the interviewee's position in the organization, as well as their background.	• What is your role in this organization?
Energy system modeling in the organization	Learn about the role and significance of energy system modeling in the organization. Gathering specific details on what the modeling process looks like.	• What is the role of energy system modeling in your organization? • What does energy system modeling look like in your organization? (types of models used, modeling results, cooperation with external parties, etc.)
Relationship with policymaking	Learn about the organization's relationship with the energy policymaking process.	• What role do you have w.r.t. the energy policymaking process? • What are your personal experiences with/in the energy policymaking process? • What are the biggest advantages in using energy system models in energy policymaking? • What are the biggest challenges in using energy system models in energy policymaking?
The effect of crisis situations on the role of energy system models in energy policymaking	Understand how model-policy interface stakeholders experience crises and learn about the observed impact of crisis situations on the organization's modeling process and their relationship to energy policymaking.	• How do you define a crisis? • What are examples of (energy) crisis situations you have experienced? • How do energy system models change as a result of a crisis? (model configuration, model selection, data, runtime, etc.) • How does the use of energy system models for energy policymaking change during a crisis? (purpose, stakeholder involvement, etc.) • How does the significance of energy system models for energy policymaking change during a crisis?

Extra	Further understand how stakeholders view the model-policy interface.	• Do you have any thoughts or remarks on the use of energy system models in policymaking in general? • Have any topics you expected not been addressed in this interview? Which?

4.3 Data processing through qualitative coding

The data collection will result in a number of interview recordings and transcripts. In order to extract meaning from these transcripts and find interconnecting themes, analyzing the interview data is facilitated by a qualitative coding process. This process is built on the work of Erlingsson and Brysiewicz (Erlingsson & Brysiewicz, 2017), who provide a detailed and pragmatic guide to interview coding. In essence, the process is aimed at structurally interpreting the meaning of an interview's contents and deriving insights from this data. To do so, the coding process guides the researchers from lower to higher levels of abstraction *("from manifest to latent content"* (Erlingsson & Brysiewicz, 2017, p. 94)). The former is related to the meaning of the interview data, while the latter identifies themes that may emerge. The levels of abstraction are discretized, being 'meaning unit', 'condensed meaning units', 'code', 'category', and 'theme' (from lower to higher abstraction). A visual overview of the levels of abstraction is given in **FIGURE 3**.

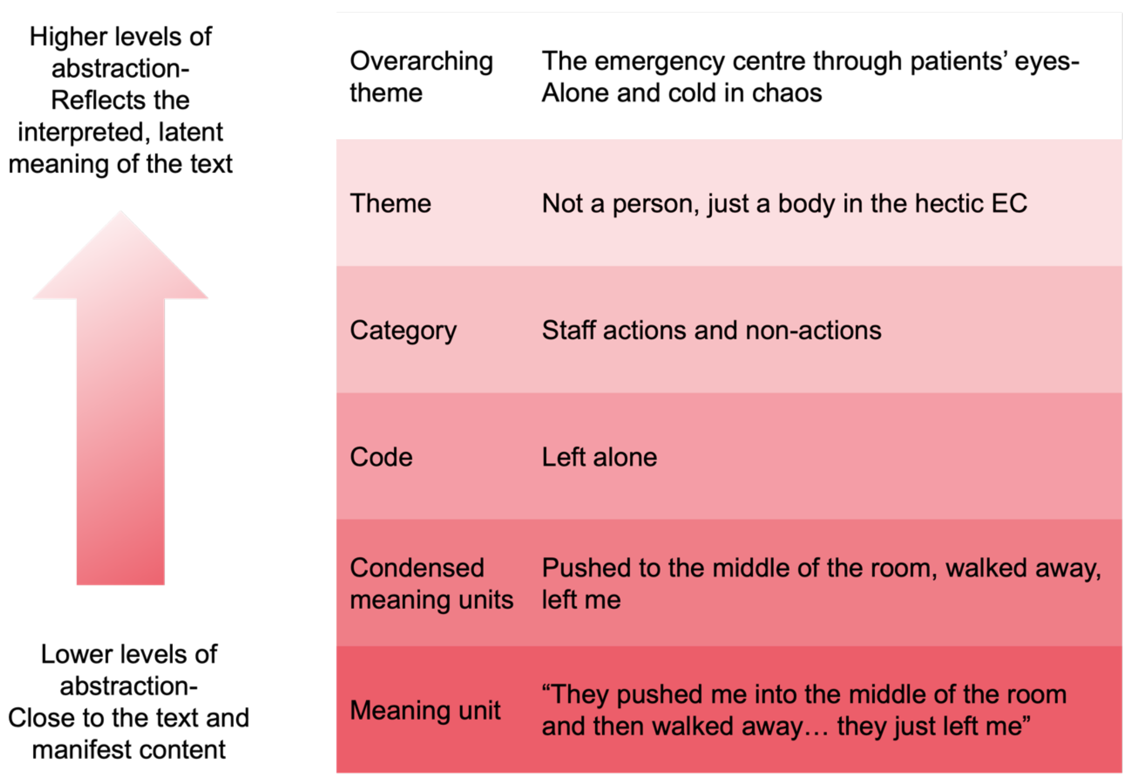

Figure 3: Levels of abstraction of the qualitative analysis (Erlingsson & Brysiewicz, 2017, p. 94).

4.4 Research scope

The scope of this interview is bounded by a case. This is partly due to reasons of practicality, but also because of the fit between the abductive research method and case study research. *"Case study research resonates with abduction as a methodological approach as it supports a depth of interaction between the researcher and the field and between data and theory"* (Conaty, 2021, p. 4). The use of a case study enables researchers to get close to the field of study and allows for flexibility with regards to data extraction. Furthermore, *"when the subjective perspective of organizational actors is central to the objectives of research, case studies are regarded as having significant utility, particularly when how or why questions are being posed, when the researcher has little control over events, and when the focus is on contemporary phenomenon in a real life context"* (Adams et al., 2018, p. 362). These circumstances, in which case studies have 'significant utility', manifest themselves in the scope of this research as it concerns itself with decision-making processes in real life crisis situations.

The case in which this research takes place is geographically delineated and concerns the Netherlands. Furthermore, the timing of this research (lasting from Q3 2022 to Q1 2023) places it in a significant context. Tensions between European countries and Russia following its invasion of Ukraine have strained the European energy market. As a result, energy prices have ballooned. Dutch consumers ended up paying twice as much for natural gas and three times as much for electricity in Q1 of 2022 (Koster, 2022). This situation has put pressure on legislators to enact policies to protect Dutch consumers financially and ensure the security of energy supply. In a response, the Dutch government started filling its gas reserves (Kraniotis, 2022) and developing a price cap legislation for household energy (de Kruif, 2022). These circumstances are expected to have an impact on the topics that arise during the interviews as well as the perception of the interviewees.

A number of additional aspects are relevant to note in introducing this case. The first concerns the plural nature of the Dutch political system, at times dubbed the "poldermodel", which is characterized by the cooperation and competition between a large number of stakeholders and organizations (Daalder, 1989). This also translates to the energy domain, where the will of a varied political sphere combines with the goals and requirements of an energy sector and the insights shared by a number of scientific advisory groups, such as the Planbureau voor de Leefomgeving (*PBL*, n.d.) and TNO (*TNO*, n.d.). Furthermore, the Dutch renewable energy market has been in development for over five decades, with varying success (van Rooijen & van Wees, 2006). Despite multiple government interventions, challenges remain on, among other things, effective goal setting, balancing local production and importing green energy, and determining the right path toward public participation – challenges in which energy system modeling can be of value. The Netherlands has a longstanding history in energy system modeling, with early efforts in modeling dating back to the 70s (Midttun et al., 1986). Early work by Midttun et al. explored the nature of energy forecasts in the context of Dutch politics, noting that *"contrary to its strong tradition in* *centralized economic planning, the Netherlands (...) had considerable extra-governmental opposition in energy forecasting. It seems that the brittle corporative political structure here overrules the administrative planning capacity, and provides a basis for unauthorized opposition and a relatively dramatic revision of energy forecasts*" (Midttun et al., 1986, p. 240). These remarks provide a historical context of energy forecasting in the Netherlands and its interactions with the Dutch political system.

5. Results

5. Results

5.1 Introduction

This chapter contains the results of the research and is divided into two sections. The first section provides summaries of all interviews, highlighting the most essential topics. The second section details the themes that were developed from the coding process, as previously described in the Method chapter.

In all, interviews were conducted with three researchers working with energy system models in research agencies, one professional from the energy industry, and two policymakers from the government. The interviews lasted about 60 minutes and were conducted in Dutch. The transcripts were translated into English.

5.2 Interview summaries

Researcher1

The interviewee has worked at a Dutch research agency for 8 years, primarily working on questions related to national and international energy systems. Recently the interviewee has worked on the development of a report outlining the progress of the Dutch energy transition. The interviewee cooperates with energy system modelers and understands how these models operate, but does not work with models directly in their current occupation.
They have a background in Climate Studies.

The agency's goal is to improve the quality of political decision-making by providing relevant information. A periodic report on the Dutch energy transition forms an important element in this regard and takes up much of the team's capacity. When asked whether the contents of this report cover the questions posed by policymakers, the interviewee mentioned that the report is a monitoring instrument. Where it is able to outline the current situation, it is beyond the report's scope to discuss solutions that can or should be developed to improve the situation. To address this, the agency maintains multiple projects specifically aimed at generating knowledge required for closing the gap between the status quo and the Dutch climate goals.

Reflecting on the role of energy system modeling in their work, the interviewee mentioned a number of aspects. They have facilitated recurrent meetings between researchers from the agency and their counterparts in the government. The aim of these meetings was to be up to date on policy development and its implications on the agency's modeling work. The agency uses this input to determine which policies will be included in their studies. In their work on the periodic report, the interviewee coordinated the development of various chapters which included the results of scenario studies. Special emphasis was placed on the presentation of modeling results to prevent misinterpretation, for example through the use of margins and further explanation on the results' validity.

Energy system modeling was described as an important input for the development of energy policy, especially because it helps detail interactions and second-order effects in the energy system. A drawback of this input is the ability for relevant stakeholders to hide behind the numbers, in the sense that they may be regarded as the absolute truth. To counter this, the agency attempts to be clear about how their quantitative input can be interpreted: "We deliver input. Ultimately, the decision on what this means is up to policymakers and politicians."

The interviewee's perception of crisis situations was split into short-term and long-term crises, e.g., the COVID pandemic and climate change. They made this distinction with regard to energy system modeling because these models tend to be focused on the long-term and may have low temporal resolution. This makes it difficult to incorporate the effects of a relatively brief event.

The impact of crisis situations on modeling is multi-faceted. Little change is perceived in the role of energy system modeling in policymaking. This kind of input is generally regarded as valuable, and this perception seems to remain constant despite an ongoing crisis. The same is true for the modeling process itself, with the exception of data input, models for the built environment, and scenario elaboration. For the first time, data from the European Commission was used as input for the models and questions from municipalities about methods to decrease their dependency on natural gas led to further development of models for the built environment. Furthermore, the periodic report specifically included multiple scenarios highlighting the impact of various price assumptions, ranging from low to high.

During the ongoing energy crisis, the agency did reflect on its role within the energy policymaking process by considering if and how they could add to the debate. This was in line with their objective to provide "solicited and unsolicited advice". When asked whether the crisis produced more or different questions from policymakers, the interviewee answered that they wouldn't be surprised if questions regarding strategic decisions increased in frequency, albeit on a different management level within the agency than their own.

Researcher2

The interviewee has worked with energy system models since 2012 at multiple Dutch research agencies. The interviewee's work is centered around modeling energy systems, such as electricity and gas markets, to support energy policy development.

In their introduction, the interviewee reflected on the changing nature of energy system modeling and its relation to policymaking. An increased sense of political urgency around energy related issues combined with the growing complexity of energy systems has placed extra emphasis on energy system modeling in the policymaking process. The interviewee mentioned multiple resulting challenges and how these are addressed in their work.

The agency's primary goal is to facilitate the policymaking process by providing information relevant to policy decision-making. Translating the results from modeling studies to a format that is applicable in policymaking is challenging, in part because of the uncertainties regarding the (future) energy system. These uncertainties are inherent and can at best be minimized. The agency is tasked with exploring possible configurations of the energy system and corresponding policy options, as well as highlighting the interactions and uncertainties within the energy system. Ultimately, it is up to the policymakers to decide if and how this input is incorporated into energy policy.

The amount of required elaboration on modeling results is dependent on the policymaker's understanding of the meaning and applicability of such results. In the experience of the interviewee, the level of understanding on this subject can vary within the government. While familiarity with (modeling of) the energy system may differ between policymakers, there are policymakers with a high level of expertise on this matter. In general, the rotation of people in the government is more frequent than in research agencies, where individuals typically retain their role for a longer period of time. The interviewee stated that as a result of this, knowledge retention is more constant in the agency than in the government, which allows the agency to take on the role of an educator. Ultimately, mutual understanding between policymakers and research agencies is important in improving the quality of the policymaking process.

When asked about the perceived benefits of energy system modeling for policy development, the interviewee stated: "what's the alternative?" They elaborated that modeling may be the only viable method to understand an increasingly complex energy system. The recurrent questions from policymakers may be indicative that they share the same sentiment, according to the interviewee. They added that the relevance of modeling is limited by its own applicability, for example when policy issues are more related to non-quantifiable aspects. The perceived drawbacks were mostly related to a dependence on the quality of data. Reliable data can be especially difficult to find when modeling aspects that are dependent on company decision-making. Opaqueness on the part of corporations means that modelers must make assumptions about their decision-making, further increasing the uncertainty.

Urgency was stated as a relevant crisis characteristic. However, urgency may be perceived differently by actors, making it difficult to define crisis situations. Examples of crisis situations named by the interviewee were the ongoing increased energy price, the Fukushima nuclear disaster, and the 1973 oil crisis. The interviewee added that a distinction can be made between crises with a temporal or structural impact. Where a temporal impact may only be relevant for modeling activities with a certain temporal resolution or horizon, structural impacts can have an effect on modeling practices in general. "When the rules of the energy system change, you may have to alter the model's code. That takes time." The interviewee explained that this was especially difficult when the perceived urgency was high and changes to the modeling practice had to be made quickly. The effect of a crisis can also be positive, in that it stimulates creativity and forces actors to prepare for future crisis events. “Sometimes you need a crisis to wake everyone up.” However, the impact of the current crisis on modeling practices in the agency was limited. The crisis did start a discussion on underlying assumptions, but did not alter the model selection or the models themselves.

Further reflection on the research subject led the interviewee to return to the topic of urgency. They elaborated that research takes time, which may clash with the policymaking process when the available time to find a solution is limited. Not wanting to leave policymakers emptyhanded, the agency then attempts to find a suitable middle ground. As an example of a situation where urgency generated questions regarding the development of energy policy, the interviewee mentioned the Dutch price cap legislation as a response to the increased energy prices. The interviewee was unsure whether PBL was consulted for the development of this legislation, and added that designing such policies doesn’t necessarily fit the tasks of the agency.

In their final remarks, the interviewee added that stakeholders connected to energy system modeling for policy development have become better integrated over time, especially after the Klimaatakkoord. The stakeholders are more aware of what’s going on. This increased understanding of the energy system and the role of other stakeholders has resulted in better questioning on behalf of stakeholders.

Researcher3

The interviewee has over two decades of experience in energy system modeling and has worked at multiple Dutch research agencies. During this period, they were responsible for managing research groups and conducting studies themselves. Besides this, they have worked in the energy industry and have a background in Chemical Engineering.

The goals of the interviewee’s research group can be split into an implicit task to filling knowledge gaps in facilitating the energy transition and explicit task to answer specific questions posed by policymakers. As a result, the research group conducts scenario studies commissioned by external parties as well as their own. The latter category is primarily comprised of long-term studies to critically assess policy development and draw attention to subject that might be overlooked by policy. This degree of freedom has resulted in studies that were regarded as a welcome addition to the energy policy debate. The results of these studies have also led to further research commissioned by the government.

The research agency develops and operates a multitude of models, such as models for specific sectors, e.g., the built environment, and geographic areas. Depending on the research question at hand, one or multiple models will be used in the study. When asked if the agency uses commercial models, the interviewee answered that this generally wasn’t the case, as these models often lag in development and may limit the agency’s freedom in adapting the models.

The interviewee primarily works with integrated models focused on the Netherlands.

In reflecting on the benefits of energy system modeling for policy development, the interviewee mentioned that their modeling methodology offered specific benefits. In their scenario studies, the interviewee applies a cost-optimization method, which leads to results that are aligned with the goal of developing cost-effective policy. To facilitate political decision-making, the agency develops multiple scenarios which outline various options in reaching the policy goal. A drawback of this approach is the fact that society doesn't necessarily base its decision-making solely on cost-optimization. There may be policy options that work in theory, but pose hurdles when applied in reality. These hurdles can be modeled by adding more constraints, but at the cost of introducing new uncertainties in the form of assumptions.

In one of their answers, the interviewee mentioned that there was criticism on their method. When asked whether this criticism was voiced by the government, the interviewee replied that policymakers usually don't voice criticism and that critique was more often posed by industry parties. For example, when a model is tasked with modeling a path toward sustainability for the existing industry in an area, it is difficult to include a potential decision of companies to leave the area and look for an alternative location where environmental policy is more favorable.

Generally, policymakers lack knowledge on energy system modeling. "You have to explain a lot, which is a drawback." This can be a hindrance when interpreting model results, where understanding how and why a model provides a certain result is key. Building a knowledge base is further complicated by the relatively short duration for which policymakers keep a specific position. Exceptions to this are a few individuals working in policy with a background in modeling, such as people who used to work for a research agency.

Generally, crises that influence energy system modeling produce an increase in energy prices, which influences the modeling process in a number of ways. The increased price in itself isn't necessarily a problem, as different prices can be used as input variables for the models. The effects of a price increase on the economy, and in turn the demand for energy, can also be modeled, for example through assumptions on average economic performance or applying economic models. Modeling for policy impact is more complicated when looking at aspects related to security of supply. "There are many questions in between, where experts say, 'it is difficult to exactly determine the economically optimal action to address disruptions [in energy supply].'" In these aspects, modeling may help shed light on some specific questions, but will not be able to provide a comprehensive answer for the entire problem at hand.

The interviewee also reflected on the recurrent nature of the security of supply theme. More than a decade ago, similar questions about the security of the European energy supply were addressed by the interviewee. However, the theme lost political attention. "You see that it [the security of supply theme] disappears and doesn't get attention. Only once a crisis comes along, the question is posed whether there should be a policy response. But defining this policy response isn't straightforward."

In general, the impact of energy crises on the modeling work itself may be limited. "Energy system modeling is focused on the long-term in which you don't really consider all kinds of disruptions. What you do explore is the fact that the future might look different. In that future, too, we want to reach our goals." 'What if'-analysis may help in this exploration, for example in studying the effect of prices changes using energy market models. The interviewee conducted a study in 2007 which explored the impact of an interruption of Russian gas on the gas price. When this kind of interruption became reality at the beginning of 2022, the study's results showed similarities to the actual price development.

In response to the interrupted supply of Russian gas, the Dutch government commissioned the research agency to study short-, medium-, and long-term scenarios in which Russian gas wouldn't be available. The agency studied these scenarios, including the energy dependence and demand of various sectors, and reported the results. Among the reported results were previously conducted studies, which found that dependency on gas would decrease considerably in the long-term.

Energy crisis can alter the questions asked by policymakers for policy development. To support legislation such as an energy price cap for households, separate analysis is conducted. "Where knowledge on the energy system is important. Without energy system models, we would have a worse understanding of the energy system and its composition." This knowledge is especially relevant in identifying potential second-order effects of policy instruments. "That is typically something policymakers can overlook, … their thinking is very linear at times." Another question concerns energy imports, which become more important during an energy crisis. Separate analysis highlight what these imports can look like and what storage might be suitable. These items are typically addressed by short-term policies, to which long-term energy system modeling is of limited relevance.

When asked about the significance of modeling for policy impact during a crisis, the interviewee mentioned that coming up with numbers becomes more important. When things change as a result of a crisis, modeling tools may help in understanding what the future impact of these changes can be. Explaining this impact is valuable to policymakers and improves their understanding of the energy system.

Industry1

The interviewee has worked at a large Dutch energy company for 12 years. In their current position, they lead a team which builds the company's long-term scenarios and commodity price projections. This information is used by other departments within the company in decision-making processes, e.g., for strategic purposes. Extreme price fluctuations over the past two years have placed the interviewee's team in the spotlight.

The company uses multiple types of models. A distinction can be made between models used for short-term and long-term analysis. The former category is primarily used for trading purposes, while the latter provides insights into the long-term evolution of the energy system. While most models are developed inhouse, some commercially available models are also used, albeit with custom input and output processing. Open-source models are not used by the company, because of a lack in accountability and quality assurance.

When asked about their role with regard to the energy policymaking process, the interviewee mentioned that there is bidirectional interaction between energy industry and government. When the company's modeling efforts reveal information that impacts their expectations of their future, these aspects are addressed in conversations with industry associations and the government. "Sometimes policy changes, sometimes it doesn't. Sometimes it's on the basis of gut feeling or conversations – sometimes it's based on model output." The interaction may also be initiated by the government. An example is a consultation on offshore wind power commissioned by the government, attended by multiple major power suppliers of the Dutch market. The interviewee also mentioned interactions through informal networks.

Industry associations have significant influence in the Dutch energy policymaking landscape. Alignment in modeling results found by the association's members helps in defining the course of the association itself. Not all information is shared, because of commercial and competitive reasons, but "you have to share enough to determine whether you agree on the size, urgency, and impact of a problem." The question of what information energy companies would and were allowed to share played a role during the development of the price cap on energy. "You can't share everything, but you have to find a solution on the implementation and details."

In answering whether model results are an effective input in the policymaking process, the interviewee agreed and mentioned climate models as an example. While determining their exact impact on policy development is difficult, these models help determine the course of climate policy. "There is a reason why the Dutch goals for 2030 are more ambitious than 5 years ago." There are many more influences in the policymaking process, with which modeling results compete. The interviewee did mention that model results may help change public opinion, which can in turn influence policymakers.

The interviewee mentioned multiple challenges in using modeling for policy development. The first was transparency on the capabilities and limitations of models. While a model's capabilities are often clear, understanding the nuances and limitations of a model requires closer inspection. Another aspect was the assumption of rational behavior, while in reality decision-making is more unruly. The fact that every person with a model thinks they are right and may have tunnel vision was also mentioned. Finally, the biggest challenge is the difficulty in accepting uncertainty on the part of policymakers. Modeling may yield multiple viable policy options, while policymakers are searching for a clear and specific solution. The interviewee mentioned that much can be gained in accepting this uncertainty and having a discussion on how to properly evaluate the various policy options presented by models. So far, this discussion is missing, and the interviewee wasn't sure whether reports discussing this uncertainty are used or "end up in the drawer."

When asked what sets crisis situations apart from the expected uncertainties in their work, the interviewee answered that a realization that the company might go under made the difference. Bankruptcy is always an option in the tail-end of a distribution, but during the COVID pandemic and Russian invasion of Ukraine the feeling was more urgent. In response to these situations, the long-term becomes less important and the priorities shift to understanding what is going on, how exposed the company is, and what the worst-case scenario looks like. Once these questions are sufficiently addressed, the discussion becomes more nuanced and action oriented. An increased understanding of the situation leads to an improved risk assessment and allows for the exploration of opportunities. "Having a different perspective than others in the market presents business opportunities, regardless of which way the market moves."

The impact of crisis situations on the modeling process itself is limited. Additional sensitivity analysis can be done to assess the impact of extreme prices on the development of the energy system. In some crises a policy response is expected, but uncertainty about the details of this response leads modelers to stick to what they know. "Specifically for our work – you don't abandon your expectations of the 2060 price expectations because of short-term noise." While it might be tempting to immediately alter your expectations, they remain reserved in this respect.

Crisis situations change the significance of the near future. During the COVID pandemic and current energy crisis "today and tomorrow became more important than next year, let alone the next 10 years. (...) No one is interested in your brilliant insight for 2050." The survival of the company comes first, while strategy and long-term planning move to the background. This shift in priorities can influence plans for the (near) future, which might make long-term goals (specifically climate policy) less attainable. In turn, additional measures will be needed to address the delay.

When asked about the influence of scientific input in energy policymaking, the interviewee mentioned that academia is underrepresented or completely absent in energy policy development. There is interaction between the energy industry and research agencies, but the interviewee wasn't sure about the link between academia and policymaking. From their perspective, the policymaking course is primarily determined by the government and industry parties. "There are no academics present in my meetings in The Hague. That is a missed opportunity." If policymaking were solely informed by industry parties, it would make for a "very one-sided conversation." The interviewee wasn't aware if there were differences in how academia and industry parties conducted their modeling work. Under the same conditions and assumptions, similar models will yield similar results. The interviewee did think that industry parties have an edge in data availability and insights into future policy development. Differences in the output of the modeling process will result from differences in the input. Given this relation, confidence in the validity of this input is import and should be part of the conversation.

Policy1

The interviewee has one year of experience as a policy officer, previous work experience in policy consulting, and has a background in Energy Science. The work of the interviewee is primarily focused on developing long-term policy strategies for the Dutch energy system. The interviewee is part of multiple inter-departmental and inter-organizational groups that include energy system modeling experts.

During the introduction, the interviewee mentioned that elements of the ongoing energy crisis (referring to the consequences of the current increase in energy prices) are not directly related to their department. The interviewee associates energy system modeling with scenario studies and sees no direct link and use for those studies for addressing the energy crisis. According to the interviewee, the current crisis is mostly related to energy prices and security of supply, to which scenario studies are of limited relevance.

The interviewee is part of multiple inter-departmental and inter-organizational groups that include energy system modeling experts. One of these groups is a cooperation between network operators, research agencies, and the government. The group's participants discuss their modeling results, methodology, and underlying assumptions. Participation in these groups keeps the government up to date on the scientific consensus and allows the government to provide feedback on what it deems most useful for policy development in the modeling context.

The primary benefits of modeling as perceived by the interviewee are the ability to describe and compare future scenarios in a systematic and transparent manner. Modeling also allows policymakers to look at the entire energy system at once. This is especially helpful in policy development, where tunnel vision on sub-systems or conflicting objectives can occur.

There were multiple perceived drawbacks in modeling for policy development. First, only a limited number of scenarios can be studied and therefore the modeled outlook will never contain all options. Uncertainties about the future and the impact of singular events are also hard to model. Some methodologies are perceived as risky. For instance, cost optimization may lead to a singular dominant path or technology, while reality is more heterogeneous and does not solely optimize with regard to cost. Finally, some models lack the level of detail necessary to address practical limitations within the energy system, such as network congestion.

When discussing the influence of the ongoing crisis on energy system modeling for policymaking, the interviewee mentioned multiple aspects. A lack of understanding of how the crisis will shape out and what it will affect presumably causes little to change at first.

Furthermore, certain consequences of the crisis align with pre-existing uncertainties, such as the future development of industry, meaning that the future outlook might not change much. Energy system modeling is “a relevant source of information, but you should never base your entire policy on it. That wasn’t our approach before, and that still isn’t our approach.” However, the interviewee acknowledges that sometimes scenario studies are biased in their starting point or scope, which can then be used to support certain policy directions while they do not provide the entire picture, adding that “I think this is a bad practice, but it does happen.”

During crisis situations, decision-making is very political. In the past, political focus has been more on energy affordability, there now is a shift towards more emphasis on energy independence. There may also be a stronger emphasis on the perception of benefits by the voters, versus the “technical” efficacy of the legislation.

Political urgency is stated as another important influence in crisis situations, which leads to more detailed decisions on policy interventions, with stronger directions on the design of the policy instruments and less room for technical or scientific input. “It is a political reality, that it [policy] is not always based on the best possible option. It’s simply what has been determined as the best option at that moment.” This is in contrast with the normal situation, where public authorities are able to provide more detailed information to facilitate a well-informed debate and when there is more time for decision-making.

When reflecting on the subject of the research, the interviewee added the concern that government and science can be two separate worlds. While some teams are composed of individuals with a background in modeling, departments that lack this knowledge may be at risk of erroneously interpreting modeling work and its meaning within policy development. At the same time, research studies sometimes fail to sufficiently take political and legal barriers into account.

Policy2

The interviewee has worked in policymaking since 2020 and has a background in economics. In their tenure as a policy officer, the interviewee primarily worked on long-term strategies for the Dutch energy system as well as the policy instruments to execute those strategies. More recently, the interviewee worked on a project to fill the Dutch gas reserves as well as the Dutch price cap for consumer prices for gas, heat, and electricity. These projects were labeled by the interviewee as examples of crisis projects.

From the perspective of the interviewee, the influence of energy system modeling on the policymaking process is varied and dependent on the situation. In the status quo, referred to as “staand beleid”, modeling finds its way into the interviewee’s work in the form of reports presented by various external parties (primarily research agencies). This input is regarded as highly valuable, as it provides insights that the interviewee’s organization is not able to obtain by itself. However, at times this leads to a situation where the organization is dependent on external input that may be biased and therefore of limited use, especially if the research is not provided by governmental research bodies.

In general, the quantitative work done within the interviewee's team cannot be labeled as modeling. It primarily concerns calculating the cost of various political decisions or plans and does not always require modeling a system or study the effects of political decisions on a system. "I don't want to call it back of the envelope calculations, but it's essentially two policy officers making calculations in Excel." Modeling may not even be necessary at times, as the consensus on some aspects related to the energy transition is that "more is better". However, the interviewee does recognize a tipping point where optimization becomes necessary. An example is the sustained push for increased solar power which can be impeded by a congested power grid. The interviewee did mention the development of a team dedicated to maintaining and processing data within the organization.

When asked about if and how energy system modeling finds its way into the interviewee's work, the response was "barely". This is especially the case during crisis situations, where political urgency limits the available resources needed for standard policy development. Once political urgency to address an issue arises, assessments of the possible options take place. After a political decision has been made, there is no more room for negotiation and the goal is to execute the decision. "Even if you have 10 models which indicate that a different option is better, there can be no negotiation, period. In that sense, the scientific reality is overtaken by political will." In such cases, e.g., after the options have been assessed and a decision has been made, there is no room for changes because of practical limitations and the accepted political course.

Developing the price cap policy required some level of quantitative input (e.g., in determining where the gas price should be capped). This was achieved using data from CBS and CPB to explore various price cap options and their cost to the government in Excel. The numbers in the final version of the price cap legislation deviated from these calculations due to political decision-making. During the development of the price cap legislation no further consultation with research agencies that use modeling was conducted. This was partly due to limitations in available time and the perceived simplicity of the legislation.

Executing the price cap legislation required extensive cooperation with the energy industry, a stakeholder in the model-policy interface. When it turned out that the usual implementation method of the policy was impossible within the desired timeframe, the Dutch government decided to cooperate with energy suppliers to reach their policy goal of helping Dutch citizens lower their energy bill. While the interviewee acknowledged that this cooperation could allow parties from the energy industry to favorably influence the legislation, it is unlikely that information asymmetry resulting from modeling efforts was of benefit to the industry parties in this process. The conversations between the government and the energy industry parties mostly concerned the execution of the policy, rather than the policy itself.

In their final remarks, the interviewee reflected on how their work was portrayed to and perceived by the general public. After stating that they enjoyed sharing their perspective in the policymaking process, they added that “normal people don’t see this, of course. They think that 3000 policy officers thought about this long and hard, but sometimes it’s just four policy officers sitting in a room saying ‘this is how it is’”.

5.3 Themes

The themes presented below are the result of processing the interview data using qualitative coding, as outlined in the Method chapter. After reading the interview transcripts multiple times, initial themes emerged from the notes. A back and forth between the transcripts and these themes led to categories, which in turn sharpened the themes. Figma, a visualization tool, also turned out to be useful in creating an overview of quotes, categories, and themes. Repeatedly listening to the interview recordings helped in understanding the meaning of the data, on which intonation had a strong influence.

The categories used to group elements of the interviews and underlying the themes were:

1. Role of Stakeholders
2. Benefits of Energy System Modeling
3. Challenges of Energy System Modeling
4. Role of Modeling in Decision-Making
5. Crisis situations
6. Impact of Crisis on Modeling in Policymaking
7. Impact of Crisis on Policymaking
8. Relevance of Modeling in Crisis

Stakeholder's reflection on roles uncovers challenges

Categories: role of stakeholders, benefits of energy system modeling, challenges of energy system modeling, role of modeling in decision-making

Throughout the interviews, stakeholders with various background in modeling and policymaking reflected on their roles and responsibilities in the model-policy interface. Their comments demonstrated the challenges that arise from the inherent complexities of modeling and policymaking, as well as areas of misalignment between the two domains.

When asked about their role with regard to policymaking, all modeling experts described their function as supportive. In fact, the research agencies find their origins in this supportive role and maintain their goal of aiding, or even "improving the quality of", policy decision-making. This supportive role primarily involves providing relevant information, mainly in the form of (recurringly) commissioned work. Additionally, two researchers stressed that their role involves generating both solicited and unsolicited advice, underlining a level of independence. There is also variation in what the work looks like, ranging from monitoring the Dutch energy system through periodic reports to answering ad hoc questions from policymakers. Policymakers describe their interactions with the modeling practice as resulting from a desire to stay up to date on the scientific consensus, to obtain insights that they cannot generate themselves, and provide feedback on how to align modeling with policymaking.

Despite a longstanding working relationship between modelers and policymakers in the Netherlands, moving from the realm of modeling to that of policymaking remains far from straightforward. The inherent uncertainties associated with the modeling process make the application of its output complex. Properly incorporating model output into policy requires in-depth knowledge on the modeling practice and the context in which it takes place. At the same time, modeling presents limitations as to what can be included in analysis. To address this, stakeholders have adapted their way of working, but the interview data shows that challenges in applying modeling in policymaking still remain.

Modelers have emphasized the difficulties of transforming model results into policy decisions during the interviews. This is partly because of the intrinsic complexities of modeling, as well as a lack of understanding about modeling on the part of policymakers. "You have to explain a lot. That is a disadvantage" (Researcher3). To deal with this, modelers have changed their reporting style to incorporate the subtleties and implications of their work. However, detailed reporting may not always offer a viable solution when policymakers have limited time to assess these reports, especially when their contents are foreign to them. Researcher2 expressed their commitment to educate policymakers, especially juniors, on modeling in order for them to be able to accurately comprehend and use this information. The knowledge and experience gained from this in the policy domain are often short-lived, as policymakers tend to change positions frequently, resulting in the expertise being lost periodically and needing to be rebuilt. It is noteworthy that the discrepancies in knowledge among stakeholders was a common theme to all modelers, coming from both research agencies and the energy industry. A risk associated with a misaligned understanding on modeling is that model results are taken as absolute, which can lead to hiding behind the numbers, as mentioned by Researcher1.

The interviews with policymakers also indicated the challenges of assimilating modeling expertise in policymaking. Policy1, having a background in modeling themselves, was pleased to be part of a team that included people with similar modeling experiences, but they noted that this was unusual in their immediate environment. Policy2 indicated that steps are being taken to introduce modeling knowledge into the organization, but the effect of these actions is yet to be seen. In their reflection on the challenges pertaining to the use of modeling in policymaking, Policy1 mentioned the limited scope and detail that modeling can provide, as well as the uncertainty inherent to modeling as limitations to using this input in policymaking. Awareness of these shortcomings can and does shape how modeling results are used in policy development, with Policy1 explaining that once you understand the workings of models, you understand their limitations. In this sense, they are a relevant source of information, but shouldn't be the sole base of policy.

In conclusion, the interviews with stakeholders in the model-policy interface have shown that the relationship between modeling and policymaking is complex and multifaceted. There is consensus on the role of modeling in policymaking, mostly being described as supportive with the aim of improving the quality of policy decision-making. All interviewed experts underlined the value of modeling in building an understanding of a complex physical system. At the same time, the interviews also uncovered the challenges in applying modeling insights in the policy domain. Some of these challenges are related to limitations inherent to modeling or policymaking, such as the limited scope and detail, and uncertainty of modeling, and the task of evaluating multiple interests in policy development. Other challenges can be attributed to misalignment between modeling and policymaking, such as a knowledge gap between stakeholders, which can lead to the application of modeling in policymaking outside its context.

Urgency modulates the role of modeling in policymaking during a crisis

Categories: crisis situations, impact of crisis on modeling in policymaking, impact of crisis on policymaking

The interview data revealed a second theme – the role of urgency as an important characteristic of the perceived effects of a crisis on modeling in policymaking.

In this context, urgency is a state in which there is heightened pressure on decision-making processes, such as policymaking. This urgency is closely linked to the perception of available time to address the issue, with urgency being heightened when the time available for policy formation is thought to be limited. This section explores the nature of urgency, its relation to crisis situations, and how it affects the role of modeling in policymaking.

The topic of political urgency emerged during the interviews from a discussion on crisis perception and its effect on modeling in policy development. There was agreement among interviewees on features that set energy crisis circumstances apart from regular ones, such as increased uncertainty and extreme market conditions. Of the discussed features, the perceived time available to build a policy response was deemed to be the most impactful. From the data, I infer two distinct crisis types, which I will refer to as low- and high urgency crises.

A crisis such as the climate crisis, which is characterized by a lower but continuous political urgency and a longer perceived response time, is an example of a low-urgency crisis. On the other hand, high-urgency crises are characterized by increased levels of political urgency and short perceived response time. An example of a high-urgency crisis is the Russian invasion of Ukraine and its influence on the energy market. Although there are other differences between the two types of crises, the perceived response time is the most relevant aspect for this research.

The interview data suggest that both crisis types influence the impact that modeling has on policy development, albeit in different ways and to varying extents. With low-urgency crises, the model-policy interface tends to be adapted progressively, resulting in an increasing alignment between the stakeholders. An example is the improved alignment between the model-policy interface stakeholders in the implementation and aftermath of the Klimaatakkoord (Climate Agreement), as mentioned by Researcher2. They reported a perceived increase in cooperation on energy related issues between industry, research agencies, and the government after this bill was enacted. The bill's CO2 levy placed energy-related issues higher on the industry's agenda, resulting in increased transparency and, in turn, more engagement with the modeling process. Industry1 mentioned the more ambitious target-setting related to the climate crisis as an example of the impact of modeling during a crisis. "It's not for nothing that we have much more ambitious goals in the Netherlands than five years ago" (Industry1). However, they did add that while models have repeatedly predicted the shortcomings of policies in addressing climate change, the policy response was generally limited. As such, finding a direct relation between modeling and policy impact remains difficult.

Where low-urgency crisis may push modeling and modeling-related practices to the forefront, high-urgency crises appear to have the opposite effect on the role of modeling in policymaking. In these situations, additional constraints are introduced in the model-policy interface. According to both policymakers, a shift in the control of legislative content has been seen in these circumstances, with decision-making moving from ministries into the political sphere. This high-level decision-making shapes the boundaries in which policy can be drafted, limiting the "ambtelijke vrijheid" (administrative freedom) of policymakers and disrupting the normal policymaking process. When political urgency to address an issue arises, assessments of the possible options take place, often is a shortened timeframe. Once the political is set, there is very little room for change, even if other inputs to the policymaking process might recommend alternatives. In referring to the political decision to build price cap legislation, Policy2 stated that "when politics has decided on that [price cap legislation], then there is actually no more room." Both policymakers mentioned a "political reality", in which political decisions can overrule decision-making based on other considerations. It remains unclear how informed politicians are in such situations and how they balance other political considerations, like the public's perception of policy. Concluding, Policy1 added that they expect the room for well-informed policy trajectories to be smaller during crisis situations.

Additionally, Industry1 highlighted a change in priorities resulting from high-urgency crises, specifically a shift toward the short-term. This in turn affects the role of forecasting within the organization. "Today and tomorrow become more important than next year, let alone the next 10 years. (...) No one is interested in your brilliant insight for 2050" (Industry1).

Concluding, the interview data presents a number of insights into how crises influence the role of modeling in policymaking. To start, there was agreement among experts on the distinguishing features of a crisis, such as increased uncertainty and extreme market conditions. Urgency was deemed the most influential feature, and discussions on its nature led me to discern low- and high-urgency crises.

Uncertainty

Categories: crisis situations, relevance of modeling in crisis

The third theme that emerged from the interview data concerns the uncertainty resulting from crisis situations and its impact on the role and relevance of modeling in policymaking.

Besides urgency, uncertainty arose from the interviews as a second major defining feature of crisis situations, albeit in a more indirect fashion. In the face of unknown circumstances, questions arise about how the current situation can be explained and whether assumptions about the future still hold. All modelers noted an increase in questions posed by policymakers in crisis situations, for example concerning the dependency of the Dutch energy system on Russian natural gas or the feasibility of existing policy targets. The uncertainty of crises also leads to reflection among modelers, as previous assumptions about the energy system may no longer hold or the configuration of the energy system has changed. Researcher2 added that crises can also spark creativity in the modeling process, hinting at the perceived positive impacts crises may have.

The exact impact that a perceived increase in uncertainty has on the role of modeling in policymaking remains unclear. First, because not all crises impact all modeling efforts equally. Researcher2 and Industry1 mentioned that disruptions caused by crises, such as extreme market conditions, have limited perceived influence on the long-term scope of certain modeling studies. Industry1 also explained that the uncertainty brought about by crisis leads modelers to stick to what they know, meaning they automatically alter all previous assumptions. Second, there is ambiguity around the relevance of modeling in dealing with specific crisis situations. In addressing the current crisis related to increased energy prices, Policy1 saw no direct use for energy system scenario studies. In the context of developing the Dutch price cap legislation, Policy2 mentioned that the corresponding calculations weren't too complicated and Researcher2 questioned whether aiding in the design of such policies was part of their agency's tasks. On the other hand, stressing the perceived value on the part of policymakers of coming up with numbers during a crisis, Researcher3 mentioned conducting analyses commissioned by the government pertaining to the dependency of the Dutch energy system on Russian natural gas. Finally, Policy1 stated that some uncertainty resulting from crisis situations aligns with aspects that were already uncertain before the crisis, which raises the question if this uncertainty leads to a change in the modeling process.

In conclusion, the influence of the uncertainty brought about by crisis situations on role of modeling in policymaking remains unclear. The interview data contains examples of how uncertainty can impact the modeling process, for example by challenging the validity of existing assumptions. However, the temporal nature of this uncertainty has a different perceived impact on different models. For models studying the long-term, short-term disruptions will be less significant. Furthermore, the relevance of models in addressing the uncertainty resulting from crisis is ambiguous. Multiple experts questioned the relevance of modeling, specifically energy system modeling, in addressing the ongoing crisis of increased energy prices. This is partly due to the purpose of energy system models, as well as the limited complexity surrounding the design of the Dutch price cap legislation.

6. **Discussion**

6. Discussion

6.1 Introduction

This chapter presents a discussion of the results of the study. These findings encompass the outcome of the theoretical overview as well as the summaries and themes resulting from interviews with modeling and policymaking practitioners.

This chapter provides an analysis of the findings and explores their implications in the context of theory and practice. I begin by summarizing the main findings of the study in light of the research questions. As the main research question encompasses the sub-questions, it is discussed last. Finally, I discuss the limitations of the research, provide practical recommendations for the stakeholders of the model-policy interface, and suggest areas for future research.

6.2 What can theory tell us?

The first research sub-question – What can theory tell us? – aims to get an overview of the role of modeling in policymaking and crisis definitions in the context of policymaking. From this, hypotheses concerning the impact of crises on the role of modeling in policymaking can be inferred.

To answer this question, a theoretical overview was constructed. A literature search was conducted in two phases. The initial phase used the keywords "energy system modeling policy making" to identify literature related to the role of energy system modeling in policy development. While this resulted in relevant material, a second phase focused on finding literature related to the influence of crises on this role. This was done in a more manual fashion by selecting articles on Google Scholar and via Connected Papers. A total of 19 articles were ultimately selected.

The theoretical overview provides an overview of the practice of energy system modeling, its role in policymaking, and a discussion of how crisis situations can influence policymaking. The definition of energy system modeling was primarily explored through review articles pertaining to the classification of model types according to purpose (Hall & Buckley, 2016), capabilities (Savvidis et al., 2019), and limitations (Pfenninger et al., 2014a). It was concluded that energy system modeling refers to the practice of constructing and/or using mathematical models to replicate the behavior of a real energy system. These models are used to understand the mechanisms of an energy system and the influence of interactions on it, such as policies. In this context, models are a valuable tool for policymakers in assisting the design and implementation of energy policy.

However, the literature warns against this simplified view of modeling as a process that provides objective and neutral input (Midttun et al., 1986). Instead, the political influence on modeling through methodological choices, institutional and professional environments, and the policymaking process are presented as mechanisms that shape the role of modeling in policy development, challenging its purported image of “neutral” scientific input. In this sense, models can be a tool used to assess and design policy options, as well as justifying already made political decisions (Süsser et al., 2021). The complex nature of modeling and policymaking has led to theories and frameworks aimed at capturing their interactions. These theories compartmentalize the modeling and policymaking processes in various ways, often defining groups competing for control over (future) policy development (Aykut, 2019; Midttun et al., 1986). Ultimately, defining the role of modeling in policymaking is difficult because of the complex nature of both processes and the interactions they share. However, I have tried to characterize the duality in the role of modeling in policymaking by distinguishing its advisory and justification functions.

None of the selected articles directly discussed the influence of crisis situations on the role of modeling policymaking, underlining the relevance of this research. Instead, a number of studies examined under what circumstances and how crisis situations can lead to policy change. A review by Grossman shed light on crisis definition and provided a number of theories related to crisis-induced policy change (Grossman, 2015). This work highlighted the importance of perception, particularly of urgency and uncertainty, in defining crisis situations. It showed how the complexity of policymaking leads to many interpretations of the influence of crises. So, in deriving hypotheses about the influence of crisis situations on the role of modeling in policymaking, I focused on the dual role of modeling in policymaking and the aspects of urgency and uncertainty of crises. The defined hypotheses are presented below:

- H1. Crisis-related **urgency decreases the advisory role** of energy system modeling in energy policymaking.
- H2. Crisis-related **urgency promotes the justification role** of energy system modeling in energy policymaking.
- H3. Crisis-related **uncertainty promotes the advisory role** of energy system modeling in energy policymaking.
- H4. Crisis-related **uncertainty promotes the justification role** of energy system modeling in energy policymaking.

6.3 What can practice tell us?

The second sub-question – What can practice tell us? – explores the view of practitioners on how crises influence the role of modeling in policymaking. The answer to this question is built from the data obtained from interviews with experts from modeling, energy industry, and policymaking. These results were processed via a qualitative coding process, which gave rise to three themes, concerning 1) how the experts view their roles in the policymaking process and challenges related to this, as well as how crisis-induced 2) urgency and 3) uncertainty influence the role of modeling in policymaking. Following the order over these themes, I will discuss what practice, as presented through the interviews, can tell us about the influence of crisis situations on the role of modeling in policymaking.

During the interviews, the experts reflected on their role in the model-policy interface. There was consensus among modeling experts about their supportive role in policymaking, detailing that the aim of their work and organizations was to aid policymaking by providing information relevant to policy decision-making. Interviewed policymakers described their interactions with the modeling process as resulting from a desire to stay up to date on the scientific consensus, to obtain insights that they cannot generate themselves, and to provide feedback on how to align modeling with policymaking.

Despite a longstanding working relationship between modelers and policymakers in the Netherlands, challenges remain in this regard. Some of these challenges are inherent to the complex modeling and policymaking processes, such as the intrinsic uncertainty of models and their results, and the difficulty of assessing and implementing a multiplicity of inputs in policy development. Other challenges can in part be attributed to misalignment between modeling and policymaking. An example is the knowledge gap between modelers and policymaking on the modeling process. As the application of model results in policymaking is far from straightforward, this knowledge is important. To deal with this, modelers and policymakers have adapted their work relationship, for example through detailed reporting and cooperative working arrangements.

From the first theme, the image emerges of the role of modeling in policymaking as a valuable input, as it helps policymakers to understand the complex energy system and the effect of policies on it. The extent to which it can help, is in part limited by the uncertainty of models and the ability of policymakers to properly process this input.

The second theme explores the impact of crisis-induced urgency on the role of modeling in policymaking. Urgency emerged as one of the major indicators of crisis situations, and it was explicitly mentioned by most interviewed experts. In this context, urgency is closely linked to the perceived availability of time to address a situation, with higher urgency meaning less perceived available time. Based on this criterion and the comments of experts, I infer two distinct crisis types, which I refer to as low- and high-urgency crises. An example mentioned by experts that falls into the former category is the climate crisis, whereas the ongoing Dutch energy crisis of increased energy prices fits the latter.

The interview data suggests that both crisis types influence the impact that modeling has on policy development, albeit in different ways and to varying extents. In low-urgency crises, the model-policy interface sees increased alignment and cooperation between stakeholders. An example provided by Researcher2 highlights the increase in transparency and cooperation between energy industry, government, and research agencies after the enactment of the 2019 Dutch Climate Agreement. The narrative is that through policy, such as CO_2 tariffs, energy related issues rise in priority among industry parties, which raises questions among these stakeholders that can potentially be addressed by energy system models. On the other hand, high-urgency crises appear to have an opposite effect. In situations of high-urgency, policy decision-making shifts from ministries to the political domain, which limits the administrative freedom of policymakers and disrupts the normal policymaking process. In this context, the room for well-informed policy trajectories shrinks in crisis situations.

The second theme suggests that crisis situations have varying effects on the role of modeling in policymaking. Crisis with relatively low urgency, such as the climate crisis, can induce increased cooperation and transparency among stakeholders, and can lead to modeling-related questions. These situations could lead to an increased significance of the advisory role of modeling during and after a crisis. On the other hand, crisis with relatively high urgency, such as the ongoing Dutch energy crisis from increased energy prices, can shift policy decision-making from policymakers to politics. This can decrease the administrative freedom of policymakers, disrupts the normal policymaking process, and decreases the room for well-informed policy development. This suggests a decrease in the significance of the advisory role of models.

The final theme outlines the impact of crisis-induced uncertainty. Crises were described in the interviews as situations where previous assumptions are questioned and uncertainties about the (future of the) energy system arise. At a first glance, this could have a positive effect on the significance of modeling, as the uncertainty of crisis situations can lead to modeling-related questions. It may also promote creativity and innovation in modeling, as mentioned by Researcher2. While crisis can lead to a demand for quantitative input, as explained by Researcher3, modeling, or at least not all models, are suited to provide this input. In part because of their capabilities, but also because of the time-consuming nature of modeling, which clashes with crises when both uncertainty and urgency arise simultaneously. Finally, some of the uncertainty arising from crisis situations aligns with already existing uncertainties, meaning that the significance of the role of modeling during a crisis may not fundamentally change.

The last theme shows ambiguity regarding the influence of crisis-induced uncertainty to the role of modeling in policymaking. Where initially it seems that the uncertainty of crises leads to a demand for quantitative insights, which can be provided by models, there are further considerations. Not all models are equally suitable to address crisis-related questions, the uncertainty may already align with prior uncertainties, and the time-consuming nature of modeling may make it less relevant in crisis situations.

6.4 How do theory and practice align?

The final sub-question – How do theory and practice align? – aims to identify points of overlap and separation between elements identified in the literature and seen in practice. This discussion can roughly be divided into two subjects – theory concerning the model-policy interface in general, and literature specifically related to the impact of crisis situations.

The first theme of the results is primarily concerned with the model-policy interface in non-crisis situations. It is centered around the role of stakeholder groups, e.g., modeling, industry, and policymaking, in the model-policy interface and the challenges related to this. Theory tells us that the role of modeling in policymaking is complex (Midttun et al., 1986), and shapes and is shaped by its environment (Süsser et al., 2021). This narrative can be identified in various parts of the interview data. The complexity of modeling in a policymaking context emerged from the interviews from discussions on the benefits and challenges of modeling in policymaking, as well as the roles of various stakeholders. The value, or seeming necessity, of using modeling for policy-related insights was underlined by all interviewees, primarily in the context of understanding a growingly complex energy system. However, translating this perceived value into real impact is difficult. The meaning of model results is not always clear and requires detailed knowledge to apply to different contexts. This is where a number of challenges arise, which were identified in this study as well as other research – the time-consuming nature of modeling, its inability to answer specific policy questions, and the uncertainty inherent to the modeling and policymaking processes (Kolkman et al., 2016). The interactions between modelers and policymakers were also identified, mostly taking the form of questions from policymakers or cooperative working arrangements. These interactions shed some light on the relevance and significance of modeling in policymaking, but the data is not detailed enough for an analysis of the exact character of these interactions, as presented by Süsser et al. The scope of the research also inhibits a thorough assessment of competing interests between stakeholder groups, like the one presented by Akyut. However, varying control over the role of modeling in policymaking was identified, with the perceived role of policymakers allowing them to determine if and how modeling results end up in policy. This was described by Süsser et al. as *"the strongest influence of policymaker on modeling".* A shift in control over policy decision-making was also identified, especially in crisis situations.

The interviews yield areas of overlap with theory on the impact of crises, in that *"'normal' processes of policymaking have been disrupted – or at least that there is the perception of such a disruption"* (Grossman, 2015, p. 67). The data suggests that what these disruptions look like depends on the context. For crisis-induced urgency, I have divided this context into low- and high-urgency situations, similar to the definition of *"creeping crises"*, related to the perceived availability of time, by Rosenthal et al. (Rosenthal & Kouzmin, 1997). The data suggests that low-urgency crises have a positive impact on the significance of modeling, primarily through increased cooperation and transparency among stakeholders in the face of such situations, as well as the modeling-related questions that arise. In this sense, the policymaking process seems similar to incrementalism, as there is enough perceived time to build a policy response through well-informed policy trajectories. When low-urgency crises remain on the policy agenda long enough, significant policy change can be seen, such as the formation of the 2019 Dutch Climate Agreement. In some sense, these results refute Downs' issue-attention cycle theory, which suggests no meaningful crisis-induced policy change. High-urgency crises, on the other hand, see a shift in control over policy decision-making from policymakers to politics, disrupting the policymaking process and limiting the administrative freedom of policymakers. The theory offers a number of frames through which to view this finding. Given the complexity of modeling in policymaking and ambiguity in the nature and impact of crises, it is difficult to assess the validity of the results in a theoretical context. However, I will provide an example as to how the results can be framed by existing theory.

The advocacy coalition framework, as discussed by Grossman and Nohrstedt et al., presents such an opportunity to fit data to theory. Because the interviews were mostly focused on modeling in policymaking, the political coalition and decision-making are largely beyond the scope of the data. Therefore, identifying coalitions with competing political interests is difficult. However, the role of modeling in policymaking could be shaped by these coalitions, for example when crises shift the control to a coalition that uses models either as advisory input or a tool for justifying their agenda. A more detailed comparison to this theory can be done by looking at the mechanisms linking crises and subsystem change or stagnation, as defined by Nohrstedt et al. The change in the role of modeling, for example expressed by shifts in relevance in decision-making or fit with policy-related crisis issues, can be viewed as a redistribution of resources. Coalitions can deliberately redistribute decision-making control, limiting model significance, or use the perceived scientific authority of models to frame their crisis decision-making as less haphazard. Models could also be used in framing contests, by highlighting specific parts of the energy system as more or less relevant, depending on their interests. However, the exact fit between the advocacy coalition framework and the data remains unclear, mostly because of the scope of the data.

Ultimately, each of the theories discussed by Grossman could be used a framework in which to fit the data. This is in part because of the room for interpretation of both theory and data, as well as the limited scope and detail of this research's data. Additional research is needed in order to assess the ability of specific theories in explaining the impact of crisis situations on role of modeling in policymaking. However, from my point of view, there will always be room for interpretation in interpreting the workings of complex systems like the role of modeling in policymaking and the influence of crises, meaning it will be difficult to judge which representation is most valuable. That being said, the representation of the advocacy coalition framework as presented by Nohrstedt et al. offers a good starting point for further research. The crisis mechanisms defined in this work could each offer a subject for research.

As a final reflection on the overlap and separation between theory and practice I look at the hypotheses defined at the end of the theoretical overview. What the data says about the hypotheses is discussed below.

H1. Crisis-related **urgency decreases the advisory role** of energy system modeling in energy policymaking.

This hypothesis was primarily based on the assumption that the perceived lack of time to build a response to crisis situations limited the relevance of time-consuming modeling studies. To some degree, this is confirmed by the data. Both policymakers and Researcher2 mentioned the perceived time crunch and its influence on the role of modeling. Policy1 concluded that the room for well-informed policy trajectories becomes smaller in the face of a crisis, and Policy2 stated that external consultation was almost impossible under the time-constraints surrounding the development of the Dutch price cap legislation. However, Researcher3 did mention that they conducted commissioned research on the impact of an embargo on Russian natural gas on the Dutch energy system during the ongoing crisis. These analyses may be less time-intensive than 'normal' modeling studies, which suggests that urgency doesn't impact all modeling activities equally.

H2. Crisis-related **urgency promotes the justification role** of energy system modeling in energy policymaking.

The second hypothesis assumed that urgency pressures politicians and policymakers to come up with a solution. Under this pressure, political stakeholders may be tempted to use model results outside of their context to justify their decision-making. However, because the data contains only limited reference to this role of modeling, the answer to this hypothesis remains unknown.

H3. Crisis-related **uncertainty promotes the advisory role** of energy system modeling in energy policymaking.

The third hypothesis builds on the assumption that crises induce uncertainty, which can be addressed by modeling. The data suggests that this is true, but it remains unclear to what extent. Modelers noted an increase in questions from policymakers during crises, suggesting an increased significance of the advisory role of modeling. However, not all of the questions concerning crisis situations can be addressed by modeling, and combined with the urgency of crises there may not be time for 'normal' modeling activities. Furthermore, the uncertainty of crises can overlap with existing uncertainty, meaning the significance of modeling may be unaffected.

H4. Crisis-related **uncertainty promotes the justification role** of energy system modeling in energy policymaking.

The final hypotheses states that crisis-induced uncertainty promotes the use of models to justify prior decision-making, because high uncertainty complicates assessing the validity of these justifications. However, similar to H2, the data contains limited reference to the use of models as justification. Therefore, it remains unknown whether this hypothesis holds.

6.5 Implications for Practice

A number of practical implications can be inferred from the study's findings. I present these implications in the form of recommendations to practicioners, e.g., modelers, professionals, and policymakers, with the aim of defining areas in which improvement can lead to a more effective use of modeling for policy development.

It was established in the thematic representation of the results that the policy domain is key in determining the role of modeling in policy development. Policymakers and politicians ultimately decide which inputs are used in policy development and how these inputs are weighed against each other. The results also expressed that transforming the technically complex output of the modeling process into a clear and applicable input for policymaking is not straightforward and requires a certain degree of knowledge on modeling. Multiple interviewed experts perceived a gap in modeling expertise between stakeholder groups. The risk of this gap is that modeling input is mistakenly applied in policy. Thus far, steps have been undertaken to address this issue, such as more detailed reporting and frequent cooperative engagements, but the challenge remains. One contributing factor is the high turnover among policymakers, leading to a periodic drain in modeling expertise. Therefore, a clear recommendation for the stakeholders in the policy domain is to improve and retain modeling knowledge in their organization. Modelers could also assist in diffusing modeling expertise in policymaking through other channels, such as politicians and the media. An increase in modeling knowledge among politicians becomes especially relevant during crisis, when politicians are perceived to play a more important role in policy decision-making. It should be noted that this already takes place to some extent, such as the comments of Researcher3 about sharing their work directly with the House of Representatives. Industry can also play a significant role in sharing knowledge on modeling and promoting its role in policymaking. The interview data reveals that energy industry has a unique and important position in the model-policy interface, as both a provider of modeling information and an actor in developing and implementing energy policy. Through energy industry parties, the benefits of modeling for policy development can be further displayed.

6.6 Limitations

While I have done my best to define and conduct this research in a manner that leads to scientifically robust and valuable results, limitations to my approach can be identified.

The first is related to the research method of this study, and as such, qualitative research in general. The subjective accounts on which the interview data is built are not generalizable, in the sense that they offer no definitive answer to the research questions. Neither is the interview data exhaustive, as the information gathered from six interviews is always an incomplete story, despite the expertise that the interviewees had. That being said, the overlap in experiences shared by the stakeholders working at researcher agencies suggests that their story, as represented in this study, is relatively coherent. The important influence that policymakers have on shaping in the role of modeling in policymaking was found in both the literature and the interviews with modelers, prompting me to gather extra data from their side.

Furthermore, I am not an expert in the field of modeling for policy impact. In fact, this study marks my first real experience with this subject. This remark is not a disclaimer from possible inaccuracies in the approach or results of this study, but rather an indicator to which context surrounds this research. Throughout the study I found myself learning more about the subject at hand, which had a recursive effect on the research. Where possible, I have adapted earlier work to reflect my newfound insights. In other cases, such as ideas that arose at the end of the study, I will have to defer to future research. However, expertise may come with tunnel vision, or conversely, a lack of experience can lead to a fresh take on the subject, free from bias. This is in line with the exploratory nature of this study, which did not aim to verify a previous theory, but rather to elicit new insights.

Lastly, given the diverse yet unique nature of crisis situations, the insights gathered during study are strongly related to only a handful of crises. While it was established that crisis perception can be used an indicator for crisis situations, benefits can be derived from interviewing individuals that have experienced multiple crises. These benefits include a broader understanding of how various types of crises may have differing impacts and building a more systemic approach to crisis operationalization.

7. Conclusion

7. Conclusion

As energy-related issues become increasingly significant in shaping our world, energy policy development takes center stage. Despite its importance, much remains unclear about the dynamics of energy policymaking – a process characterized by complexity. It combines the complicated physical nature of energy systems with the unclear workings of policy development. Fortunately, tools like energy system modeling may help policymakers in exploring viable policy options. The interactions between modeling and policymaking have given rise to a complex model-policy interface, which is shaped by and shapes both domains. However, energy systems and energy policymaking processes are not constant. Crises have historically presented major disruptions in either process, but have simultaneously formed catalytic events for the development of energy policy. Given the frequent and consequential nature of crises in energy policymaking and the relevance of modeling in this process, the research in this report set out to study the influence that crisis situations have on the role of energy system modeling in policy development.

An abductive approach was chosen as a conceptual framework for the research. Abduction can prove valuable in areas of research with limited existing theory and complex subjects. A core element of this framework is reflection by the research between existing theory and data. The result of this reflection is theory development and the formulation of new hypotheses. With this in mind, the research set out to build a theoretical overview, gather data from experts, and define ways in which theory and practice can be combined.

The study yielded insights on the model-policy interface in general, which governs the interactions between modeling and policymaking, as well as the impact that crisis-induced urgency and uncertainty have on this interface. To answer the research question of how crisis situations influence the role of energy system models in the model-policy interface, existing literature was studied, and interviews were conducted with experts from the modeling community, energy industry, and policymaking domain. The results of these interviews were synthesized into three themes through a qualitative coding process.

The first theme – *stakeholder's reflection on roles uncovers challenges* – followed from the roles of stakeholders in the model-policy interface, as perceived by the interviewed experts. Modelers described their role of supportive, in the sense that the aim of their work was to aid the decision-making of policymakers. Policymakers described the motivation behind their interactions with modeling from a desire to stay up to date on the scientific consensus, to obtain insights that they cannot generate themselves, and to provide feedback on how to align modeling with policymaking. The theme also discusses challenges that arise from the interactions between modeling and policymaking. These can be related to the complexity of modeling and policymaking, as well as perceived misalignment between the two domains. The most notable misalignment is the perceived knowledge gap on modeling between modeling and non-modeling stakeholders.

The second theme – *urgency modulates the role of modeling in policymaking during a crisis* – concerns the influence of crisis-induced urgency on the role of modeling in policymaking. Urgency, closely linked to the perceived availability of response time, emerged as one of the major indicators of crisis situations. Based on this perception and the comments of experts, I inferred two distinct crisis types, which I refer to as low- and high-urgency crises. An example mentioned by experts that falls into the former category is the climate crisis, whereas the ongoing Dutch energy crisis of increased energy prices fits the latter. The interview data suggests that both crisis types influence the impact that modeling has on policy development, albeit in different ways and to varying extents. In low-urgency crises, the model-policy interface sees increased alignment and cooperation between stakeholders. The narrative is that through policy, energy related issues rise in priority among industry parties, which raises questions among these stakeholders that can potentially be addressed by energy system models. On the other hand, high-urgency crises appear to have an opposite effect. In situations of high-urgency, policy decision-making shifts from ministries to the political domain, which limits the administrative freedom of policymakers and disrupts the normal policymaking process. In this context, the room for well-informed policy trajectories shrinks in crisis situations.

The final theme – simply named *uncertainty* – reflects on the impacts of crisis-induced uncertainty. It shows ambiguity regarding the influence of crisis-induced uncertainty to the role of modeling in policymaking. On the surface, it appears that the uncertainty of crises increases the need for quantitative insights, which can be supplied by models. However, there are other points to be taken into account. Not all models are equally appropriate to address crisis-related issues, the uncertainty may already match existing uncertainties, and the time-consuming nature of modeling may make it less pertinent in crisis scenarios.

The study's results have a number of theoretical and practical implications. In order to improve the impact that scientific input, such as modeling, has on policy development, a better understanding of the motivations and decision-making of policymakers is required. Furthermore, the findings of this research follow from a relatively small set of crisis experiences and would benefit from a comparison to other instances as well as a broadened temporal and spatial scope.

The findings were related to the literature discussed in the theoretical background. The complexity pertaining to the role of modeling in policymaking described in the literature was reflected in the data. While there was consensus on the perceived roles of stakeholders in the model-policy interface, such as the supportive role of modeling and the decisive role of policymaking, the complex nature of both domains leads to apparent challenges. Examples of such challenges also found in the literature are the time-consuming nature of modeling, the uncertainty inherent to modeling and policymaking, and missing capacities in institutions to make use of modeling. The research's findings on the influence of crisis found fewer direct overlap with the theoretical background, because of the lack of theory on this subject in general and the ambiguous nature of such theories. Existing frameworks, such as the advocacy coalition framework, can be used as lenses through which to view the data, but the data is lacking in scope and detail to evaluate the suitability of specific theories. It is suggested that future research studying this subject could aim at assessing specific theories.

Finally, the data was related to the hypotheses defined in the theoretical overview. The hypotheses suggested that crisis-related urgency and uncertainty could, respectively, promote and decrease the advisory and justification role of energy system modeling in energy policymaking. The advisory role relates to the use of models as scientific input, whereas the justification role pertains to the use of models to justify prior decisions. The data suggests that crisis-related urgency decreases the advisory role of energy system modeling, while crisis-related uncertainty promotes it. However, there is limited reference to the use of models as justification, so the impact of crisis on the justification role of energy system modeling remains unknown.

Concluding, this research addresses a gap in the literature pertaining to the role of energy system modeling in policymaking by studying the influence of crises – disrupting events with a historical impact on the energy system and energy policy. The results show that the impact of crisis is highly context dependent. A first categorization of this context into low- and high-urgency crises and the use of urgency and uncertainty as indicators and mechanisms of crisis situations may form the basis of further research in the future.

It is my hope that this research forms a humble contribution to both energy and policymaking research and that it may offer some insights relevant to solving the great energy challenges that lay ahead.

8. References

8. References

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Appendix

Appendix

Table 4: An overview of the articles resulting from the initial search, discussed in the theoretical overview.

Author(s)	Year	Title	Purpose
Bale, C.; Varga, L.; Foxon, T.	2015	Energy and complexity: New ways forward	Review the application of complexity science methods in understanding energy systems and system change.
Hall, L.; Buckey, A.	2016	A review of energy system models in the UK: Prevalent usage and categorization	Identifying the prevalent energy system models and tools in the UK.
Hofbauer, L.; McDowall, W.; Pye, S.	2022	Challenges and opportunities for energy system modelling to foster multi-level governance	Review energy system modelling studies and identify challenges and opportunities for the energy modelling community to take into account and facilitate multi-level governance systems.
Horschig, T.; Thrän, D.	2017	Are decisions well supported for the energy transition? A review on modeling approaches for renewable energy policy evaluation	Reviews energy policy evaluation approaches on their capability to estimate a successful implementation of renewable energy policies.
Huckebrink, D. Bertsch, V.	2021	Integrating Behavioural Aspects in Energy System Modelling – A Review	Provide an overview of state-of-the-art energy system models and research studying behavioral aspects in the energy sector.
Lopion, P.; Markewitz, P.; Robinius, M.; Stolten, D.	2018	A review of current challenges and trends in energy systems modeling	Review national energy system models that incorporate all energy sectors and can support governmental decision making process.
Nielsen, S.; Karlsson, K.	2007	Energy scenarios: a review of methods, uses and suggestions for improvement	Describe how and for what purposes scenarios about the future energy system are used in energy research as well as in energy foresight, policy-making, planning and business strategy activities.
Pfenninger, S.; Hawkes, A.; Keirstead, J.	2014	Energy systems modeling for twenty-first century energy challenges	Discuss challenges related to energy systems modeling and make recommendations of how these challenges may be addressed.

Prina, M.; Nastasi, B.; Groppi, D.; Misconel, S.; Garcia, D.; Sparber, W.	2022	Comparison methods of energy system frameworks, models and scenario results	Review existing methods and techniques to compare energy system frameworks, models, and scenarios results regarding their final results.
Ridha, E.; Nolthing, L; Praktiknjo, A.	2020	Complexity profiles: A large-scale review of energy system models in terms of complexity	Examine the relationship between the purpose of energy system models and their complexity.
Savvidis, G.; Siala, K.; Weissbart, C.; Schmidt, L.; Borggrefe, F.; Kumar, S.; Pittel, K.; Madlener, R.; Hufendiek, K.	2019	The gap between energy policy challenges and model capabilities	Systematically assess the ability of energy system models to answer major energy policy questions.
Scheer, D.	2017	Communicating energy system modelling to the wider public: An analysis of German media coverage	Research communication of energy scenario modelling to the wider public by means of a media coverage analysis.
Subramanian, A.; Gundersen, T.; Adams II, T.	2018	Modeling and Simulation of Energy Systems: A Review	Review the major development in the simulation of energy systems and propose two ways to categorize the diverse contributions.

Table 5: An overview of the articles resulting from the secondary search, discussed in the theoretical overview.

Author(s)	**Year**	**Title**	**Purpose**
Aykut, S.C.	2019	Reassembling Energy Policy: Models, Forecasts, and Policy Change in Germany and France	Presents an analytical framework for studying entanglements between predictive practices and policy-making.
Middtun, A; Baumgartner, T.	1986	Negotiating energy futures	Presents core elements of a sociopolitical and institutional perspective with which to analyze the generation of assumptions that underlie energy models and forecasts.
Nohrstedt, D.; Weible, C.M.	2010	The Logic of Policy Change after Crisis: Proximity and Subsystem Interaction	Presents a re-conceptualization of external events and identifies the mechanisms that link disruptive crisis to policy change.

Grossman, P.Z.	2018	Utilizing Ostrom's institutional analysis and evelopment framework toward an understanding of crisis-driven policy	Examines the institutional dynamics of policymaking in a crisis.
Grossman, P.Z.	2014	Energy shocks, crises and the policy process: A review of theory and application	Surveys theories of crisis policymaking from the social science literature and considers their application to changes in energy policy.
Royston, S.; Foulds, C.; Pasuqalino, R.; Jones, A.	2022	Masters of the machinery: The politics of economic modelling within European Union energy policy	Illuminate the politics of economic modelling within European Union energy policymaking.

Table 6: Entry example of the spreadsheet used to analyze the literature.

ID	**Title**	**Goal**	**Results**	**GQ1**	**GQ2**	**GQ3**
Hofbauer2022	Challenges and opportunities for energy system modelling to foster multi-level governance of energy transitions	Review modelling studies to identify challenges and opportunities to facilitate multi-level governance systems.	Most modelling practices focus on a single scale, overlooking the multi-level nature of energy governance.	Provides a categorized overview of models	Provides and overview of energy governance and discusses the role of modeling in multi-level governance	None

Table 7: Model categorization by Hall et al.

Purpose and structure	1. Purpose of the model	General • Forecasting • Exploring • Backcasting Specific • Energy demand • Energy supply • Impacts • Environmental • Appraisal • Integrated approach Modular build-up
	2. Structure of the model	Degree of endogenization Description of non-energy sectors Description of end-uses

		Description of supply technologies • Supply and Demand analysis tool
	3. Geographical coverage	Global Regional National Local/community Single-project
	4. Sectoral coverage	Energy sectors Other specific sectors Overall economy
	5. The time horizon	Short Medium Long term
	6. The time step	Minutely Hourly Monthly Yearly Five-yearly User-defined
Technological detail	Renewable Technology Inclusion	Hydro Solar (PV and thermal) Geothermal Wind Wave Biomass Tidal
	8. Storage Technology Inclusion	Pumped-hydro energy storage Battery energy storage Compressed-air energy storage Hydrogen production/storage/consumption
	9. Demand Characteristic Inclusion	Transport Demand • Internal-combustion vehicles • Battery-electric vehicles • Vehicle-to-grid electric vehicles • Hydrogen vehicles • Hybrid vehicles • Rail • Aviation Residential Demand • Heating • Lighting • Cooking • Appliance usage • Smart Appliances & Smart metres Commercial Demand • Offices • Warehousing Retail Agricultural Demand
	10. Cost Inclusion	Fuel prices Fuel handling Investment Fixed Operations & Maintenance (O&M)

		Variable Operations & Maintenance (O&M) CO_2 costs
Mathematical description	11. The Analytical Approach	Top-Down Bottom-Up Hybrid Other
	12. The Underlying Methodology	Econometric Macro-Economic Economic Equilibrium Optimization Simulation Stochastic/Monte-Carlo Spatial (GIS) Spreadsheet/Toolbox Backcasting Multi-Criteria Accounting
	13. The mathematical Approach	Linear programming Mixed-integer programming Dynamic programming Fuzzy logic Agent based programming
	14. Data Requirements	Qualitative Quantitative Monetary Aggregated Disaggregated

Table 8: Categories of mechanisms linking crises and subsystem change or stagnation, as defined by Nohrstedt et al.

Mechanism	**Explanation**
Redistribution of resources	The degree that the crisis can be exploited to redistribute resources, examples including changes in the coalition supports through greater mobilization, changes in access to amiable venues and decision-making authority, changes in the allocation of private and public financial resources, shifts in the attention of scientific and technical experts, and shifts in the attention of the general public.
Learning within the dominant coalition	The degree to which dominant coalition members revise their belief system as a consequence to the crisis.
Exploitation by a minority coalition	The degree to which a minority coalition can skillfully exploit the crisis.
Defection from a dominant coalition	The degree to which members of the dominant coalition reconsider their policy core beliefs and defect through learning and belief change.
Framing contests	The degree that crisis can be framed as a threat to, or supportive of, coalition belief systems and policies of the policy subsystem.
Policy entrepreneur(s)	The presence of one or more skillful policy entrepreneurs.