Master's Thesis – master Innovation Sciences

Use of data analytics applications by Dutch municipalities to support policy making on socio-economic aspects of the local energy transition

Utrecht University

TNO innovation for life

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Preface

This master thesis is the result of a study conducted in collaboration with TNO, where I had the opportunity to undertake an internship. TNO is a renowned organization that focuses on applied scientific research, and this thesis builds upon the work of Diran, a Scientist Integrator specializing in Energy Transition & Digitalization at TNO Strategy & Policy. The master thesis is an integral part of the "Socio-Economic Impact of Green Transitions" research program at TNO. Within this program, the thesis aims to contribute to a deeper understanding about the use of data analytics applications by Dutch municipalities to support policy making on socio-economic aspects of the local energy transition.

I would like to express my sincere gratitude to my supervisor, Iryna Susha, for her guidance, support, and mentorship throughout the thesis project. Given the novelty of the research topic, it was not without challenges to find a robust theoretical framework to use for this thesis. However, with Iryna's optimistic guidance and constructive feedback, I was able to overcome these hurdles and make a significant contribution with my thesis that is scientifically relevant to this field. Furthermore, I would like to extend my gratitude to all the members of the Strategy & Policy department at TNO, who made me feel welcomed and part of the team, despite not directly collaborating with all of them. Their insights, expertise, and shared enthusiasm for the subject matter greatly enriched my research journey. A special acknowledgment goes to Devin Diran for his valuable support during my internship. His guidance contributed to the success of this thesis. Devin not only served as an optimistic and constructive discussion partner, but also provided valuable assistance in navigating the organization and establishing connections with potential respondents. I would also like to thank all the employees from the municipalities who generously devoted their time and effort to participate in my research. Their insights and perspectives were crucial in enhancing my understanding of the socio-economic aspects associated with the local energy transition.

Reflecting on the evolution of the thesis project, it is an understatement to say that I have learned a tremendous amount. Beyond acquiring practical knowledge in the areas of data analytics, policy making and conducting interviews with a variety of individuals from municipalities, this research experience has increased my passion for sustainability and innovation, and has motivated me to continue pursuing this field in my future endeavours.

Abstract

Introduction: Municipalities play a crucial role in operationalizing and realizing the energy transition and are increasingly adopting data analytics applications to enhance their data-driven policy making (DDPM) process. However, there remains a gap in understanding how socio-economic aspects in data analytics applications informs policy and how knowledge from both data analysts and policy makers is integrated in energy transition policy making. To address these gaps the aim of this study is to analyse the use of data analytics applications that support policy making on socio-economic aspects of the local energy transition, taking into account the integration of knowledge from both data analysts and policy makers. **Theory:** The framework of H. van der Voort et al. (2021) and the associated activities were utilized to analyse how the knowledge integration from data analysts and policy makers in the process of DDPM. **Methods:** To address the abovementioned gaps, a multiple-case study was conducted of six Dutch municipalities, where two connected data analytics applications used for energy policy making were investigated in each case. The cases were compared using first a within-case analysis and then a cross-case analysis. **Results:** The extensive collaboration between data analysts and policy makers throughout the process of DDPM enhances their knowledge integration. The knowledge derived from the applications facilitate and inform policy makers by monitoring the energy transition initiatives, and aids in the formulation of effective policies. In addition, socio-economic aspects, such as energy poverty, are increasingly considered in the data analytics applications, enabling policy makers to make informed decisions for prioritization of neighbourhoods for implementing natural gas-free heating, and more targeted measures. However, implementing data analytics applications on socio-economic aspects encounters challenges such as acquiring accurate socio-economic data, integrating social and technical data in a single data analytics application, and privacy concerns. **Discussion/Conclusion:** It is emphasized that data analytics applications including socio-economic aspects, offer a powerful tool for Dutch municipalities in their pursuit of sustainable energy transitions. By enhancing the knowledge integration from both data analysts and policy makers, utilizing the created knowledge of data analytics applications on socio-economic aspects of the energy transition, and addressing the challenges involved, municipalities can make more informed decisions and promote socio-economic equity, and just transitions. Future research directions in this field are conducting structured literature review and more case studies that include the provincial and national level of government to generate a wider geographical scope of the research.

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1. Introduction

In order to address the impact of climate change, the Russian war, and to reduce the harmful effects of fossil fuel use on the environment and human health, a transition of the energy system is necessary (Liadze et al., 2022). The energy transition is moving away from using fossil fuels, such as coal and oil, to using cleaner, renewable energy sources (RES), such as solar and wind energy (Hoppe & de Vries, 2019). The 2018 Dutch Climate Agreement aims to achieve a reduction of 49% in CO_2 emissions by 2030, compared to 1990 levels, and to reduce greenhouse gas emissions by 95% in 2050 (Government of the Netherlands, 2019). The process of advancing the energy transition is characterized by substantial uncertainty and complexity, which introduces challenges in decision-making. It is complex for local policy makers and other stakeholders, whose cooperation and decisions are required to realize the Climate Agreement's energy transition ambitions (Diran, Henrich, et al., 2020).

The energy transition is bringing a lot of positive influences. The increased use of RES can help to reduce air pollution, which can improve public health (Sathaye et al., 2011). In addition, it can increase energy security by reducing dependency on fossil fuels, which can be a volatile and unpredictable market (Mikkonen et al., 2020). However, the energy transition has also led to several socio-economic challenges. One of the main challenges is the cost of transitioning to RES. Renewable energy technology is often expensive to implement, potentially leading to the development of new energy systems that may exclude people who cannot afford to adopt it (Hearn et al., 2021). Another related issue is energy poverty, a socio-economic state where, a person/family/household cannot access the necessary energy to power their home and meet basic needs due to insufficient living conditions or resources (Filippidou et al., 2019).

The energy transition in the Netherlands is being realized through a combination of policy documents and strategies, including legislation, regulations, and government programs. Other important measures are the Dutch energy label (Tambach et al., 2010) and subsidy schemes, such as the SDE[1]++ subsidy (Netherlands Enterprise Agency, 2022). Another key policy document in the Netherlands is the Energy Agreement for Sustainable Growth, which outlines the country's long-term energy and climate goals (Government of the Netherlands, 2013). The Dutch National Climate and Energy Plan mentions energy poverty, and wants to contribute to a just energy transition (Feenstra et al., 2021). Two other essential policy documents include the National Climate and Energy Outlook (Netherlands Environmental Assessment Agency, 2022) and the Climate Agreement (Government of the Netherlands, 2019). In addition to these national-level policy documents, there are also a number of local initiatives from provinces and municipalities in the Netherlands. For example, Amsterdam has developed energy plans and programs that outline specific actions and targets for reducing energy consumption and increasing RES (Municipality of Amsterdam, 2022). However, despite these policies, policy makers currently lack the necessary tools to manage the overall well-being of society effectively (Paradies & Sassen, 2022).

1.1. Research problem

Previous research on Dutch energy transition and policy were often focused on techno-economic aspects. However, the role central role of citizens is often neglected (Haarbosch et al., 2021), while energy transitions are not solely technological changes and involve societal impacts (Miller & Richter, 2014). Social aspects are aspects concerning the people's relationships and transactions within the energy system (Krumm et al., 2022). Despite their significance, social aspects have received insufficient consideration (Grafakos et al., 2017) and are poorly represented in current energy transition models and

[1] Stimulation of Sustainable Energy Transition and Climate Transition

decisions (Demski et al., 2019; Feenstra et al., 2021; Henrich et al., 2021; Miller & Richter, 2014). Additionally, a single policy option can influence multiple aspects of well-being, including employment, health, safety, and climate. It is therefore crucial for policymakers to have a better understanding of how policy decisions impact various elements of well-being and the effects on different groups within society (Paradies & Sassen, 2022). Good evidence is therefore important for addressing this societal problem and evidence-based policy making (EBP) is a promising one.

EBP pertains to the notion that policy making should be based on scientific evidence (H. T. O. Davies et al., 2012) and tries to complement experience and individual intuition of policy makers with scientific evidence (Choi et al., 2021). Policy should be supported by good analysis and, where appropriate, modelling (P. Davies, 2012). Following the advent of EBP, data-driven decision-making (DDDM) emerged, which is a process that relies on the extracted knowledge from data analysis in decision-making instead of individual experience and intuitions (Choi et al., 2021; Lu et al., 2019). Transitions are often accompanied by a complex context and a high degree of uncertainty. To reduce uncertainty, data and models can be useful because they can help predict possible future situations and can calculate the impact of certain policy measures (Huisman, 2017). Large Dutch municipalities use data extensively in their policy making cycle (Diran et al., 2022), while smaller municipalities often lack the time and resources to learn how to use models effectively (Henrich et al., 2021). As a result, data-driven decision support is not widely adopted in all governance processes, and governments make limited use of data processing and analysis tools (Diran, Hoppe, et al., 2020; Henrich et al., 2021). Basic descriptive data analytics are mostly used, which means that the full potential of data-driven applications is not yet realized (Diran et al., 2022). This indicates a gap between data analytics applications and their adoption in energy policy making (Brouwer, 2019; Diran, Hoppe, et al., 2020; Diran & van Veenstra, 2020). Due to complexity of data, policy makers may not have the necessary skills or resources to analyse the data effectively. This can make it difficult to fully utilise the potential of data-driven approaches in policy making (H. van der Voort et al., 2021). Another reason is that policy makers may be more comfortable relying on their own expertise and experience, rather than on the knowledge and information from data analysts (H. van der Voort et al., 2021). The creation of knowledge is very important in the whole data science process to allow for better decision making.

1.2. Research aim and question(s)

Improving decision-making for the energy transition requires the integration of knowledge from both data analysts and policy makers (H. van der Voort et al., 2021). The theoretical framework of H. van der Voort et al. (2021) amplifies and identifies synergies between domain professionals and data analysts instead of prioritizing one of them at the centre of the data science process. This framework was used in this research to further understand how to effectively integrate knowledge from both data analysts and policy makers in energy policy making, and how data analytics applications can shape policy making on socio-economic aspects. The aim of the study is therefore as follows: *Analysing the use of data analytics applications that support policy making on socio-economic aspects of the local energy transition, taking into account the integration of knowledge from both data analysts and policy makers.* In order to achieve this aim, the following research question has been formulated:

How and to what extent do data analytics applications create knowledge to inform policy making on socio-economic aspects of the energy transition in the Netherlands?

The main research question is supported by the following sub-questions:

- SQ1: How is the knowledge from data analysts and policy makers integrated in the process of data-driven policy making?

- SQ2: What challenges are present and to what extent are they present among Dutch municipalities in implementing data analytics applications on socio-economic aspects that inform local energy policy making?

1.3. Relevance

Scientific relevance

This research makes a significant contribution and is scientifically relevant as it describes and prescribes how to effectively integrate knowledge from both data analysts and policy makers in energy policy making, how data analytics applications can shape policy making on social aspects (Diran & van Veenstra, 2020). It addresses the importance of collaboration and knowledge creation in local energy policy making (H. van der Voort et al., 2021). The study of H. van der Voort et al. (2021) developed a framework that amplifies and identifies synergies between domain professionals (decision makers) and data analysts, and shows that it is important to take both of the knowledges into the decision-making process. This study applies the framework on Dutch municipalities involved in the energy transition of the Netherlands. The framework is tested, and if deemed necessary, expanded by incorporating any new elements that may arise from the cases being examined. By conducting this study, a valuable theoretical advancement within the discipline of Innovation Studies is created, as this study will add knowledge in the field of DDPM in the energy sector by filling the gaps on how knowledge from both data analysts and policy makers is integrated into energy transition policy making, and how socio-economic aspects are incorporated in the data analytic applications. The results of this study can inform and guide future policy making efforts in the local energy sector, potentially leading to more effective and socially beneficial policies.

Societal relevance

This research will focus on the local level of energy policy making in the Netherlands and therefore the results from this research are relevant for municipalities in the Netherlands. Adopting data-driven policy making that incorporates socio-economic aspects will help Dutch municipalities to make better informed decisions for energy policies. The inclusion of social aspects causes a change in the prioritization of decisions in energy policy making, resulting in decisions that are more socially responsible. Subsequently, by indicating how socio-economic aspects can be better applied in energy policy making will then also have a positive overall effect on the society. In addition, by indicating the challenges that are present among Dutch municipalities when implementing data analytics applications on socio-economic aspects, the results from this study will also be relevant for data analysts and policy makers because they gain insights on how to manage these challenges in developing the data analytics applications.

1.4. Thesis outline

Chapter 2 conducts an extensive literature review, synthesizing and analysing relevant scientific articles to establish the current state of knowledge and identify gaps. Building upon the literature review, Chapter 3 presents the theoretical framework that guides the study, integrating key theories and concepts to provide a conceptual lens for analysis. In Chapter 4, the research design and methodology are outlined, detailing the research approach, sampling techniques, data collection methods, and analytical procedures employed in the study. Chapter 5 presents the results derived from the analysis of case studies, presenting and interpreting empirical findings in relation to the research questions and theoretical framework. Chapter 6 critically examines the findings, engaging in a comprehensive discussion that highlights consistencies, discrepancies, limitations, and recommendations for future research. Finally, Chapter 7 concludes the thesis by summarizing the main findings and answering the research questions.

2. Literature

This chapter presents a comprehensive review of the existing literate review on the subject under investigation. It delves into the relevant literature to extract insightful information that contributes to the scientific understanding of the research domain. The literature review serves the purpose of identifying gaps in current knowledge and establishing the scope of the study.

2.1. Evidence-based policy making

The concept of using evidence to inform decision-making, known as evidence-based policy making (EBP), pertains to the notion that policy making should be based on scientific evidence and decoupled from politics and other threats to rationality (Choi et al., 2021). EBP has been debated in social sciences for over a decade. However, the idea of using knowledge to support decision making is not new. The interest in rational and logical reasoning grew in the 20th century, with the belief that the scientific method could be applied to policy making (De Marchi et al., 2016).

The EBP approach is increasingly being embraced by governments around the world as a way to improve the effectiveness and efficiency of public policies (Head, 2010). EBP places a strong emphasis on result-based policy making from a utilitarian point of view and seeks to complement or replace personal intuition and experience with scientific findings (Choi et al., 2021). By using evidence to inform policy decisions will help to build public trust and confidence in government by demonstrating that policy decisions are being made based on objective analysis rather than political expediency or personal beliefs (Head, 2010). On the other hand, some researchers may find EBP too technocratic, because of the implicit preference for quantitative precision and technical expertise over other types of knowledge, such as tacit knowledge and local expertise of the policy makers (Clarence, 2002; Head, 2010). In addition, research found that incorporating both academic research information and practitioner experience enhances the validity of the obtained data (Demir, 2020). Given the influence of other factors, such as values, beliefs, and ideology that shape the policy making process, it is challenging to envision evidence playing a dominant role. Furthermore, policymakers and researchers often hold divergent views on the definition and importance of evidence. Perhaps the most feasible approach for evidence to impact policy making is through its integration with these factors and direct communication between policy makers and researchers (P. Davies, 2012).

2.2. Data-driven policy making

Following the advent of EBP, the importance of data has grown significantly in the early 1990s and 2000s. Local governments have increasingly recognized the potential of employing data to enhance policy making, operational processes, and citizen-oriented service delivery (Diran et al., 2022). As a result, the field of policy analytics has emerged, denoting the data analysis process performed by data scientists to support policy makers (De Marchi et al., 2016). Policy analytics represents a field that combines data analysis and modelling techniques with policy research and decision-making processes (De Marchi et al., 2016). A key component of policy analytics is data-driven decision-making (DDDM), a process heavily reliant on the extracted knowledge from data analysis instead of individual experience and intuitions (Choi et al., 2021; Lu et al., 2019). According to recent DDDM claims, data analytics will help improve decisions, could potentially affect existing roles within organizations regarding the use of knowledge, and it may change decision-making, policy formulation, agenda setting, capabilities and incentive structures (Klievink et al., 2017; H. G. van der Voort et al., 2019). There is a large amount of literature on DDDM and decision-making is also relevant for policy making. Given the fact that policy making consists of a large amount of decision-making, the literature on DDDM is also applicable on policy making. Therefore, from now on the term data-driven policy making (DDPM) will be used. DDPM focusses on the use of big data, open data and data analytics applications within the three consecutive phases of policy making; (1) agenda setting, (2) policy implementation and (3) evaluation.

Data-driven policy can help to increase policy legitimacy, transparency and efficiency (Diran et al., 2022; Diran & van Veenstra, 2020).

Adding to the above, big data (BD) has quickly become a standard organizational activity. Using fast-moving, large-scale and complicated data has the potential to change the decision-making processes of organizations. BD refers to data that is both high and big in velocity and variety. However, the quality of the data is determined not only by the data itself, but also by the data collection and preparation process. Creating the data analytics applications often involve collaboration among multiple actors from different disciplines and practices (Janssen & Kuk, 2016), creating a chain of activities indicated as the 'big data chain', presented in Figure 1 below. The big data chain is defined as a set of actions required to generate valuable insights from data within a big data system (Janssen et al., 2017).

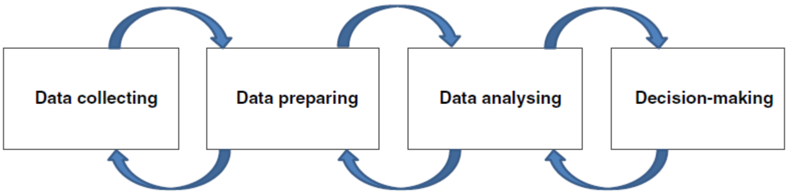

Figure 1. Steps and transfer points in the big data chain (Janssen et al., 2017).

Understanding the meaning and context of data is crucial for decision-making quality. However, it is unclear how data exactly influences decision-making quality and how it can be improved. Janssen et al. (2017) mentioned factors that impact the DDDM's decision-making quality. Relational governance and contractual governance were important for ensuring mutual understanding, clear responsibilities, and communication. Collaboration, knowledge exchange, process integration and standardization, flexible infrastructure, routinizing, data quality of the BD sources, staff and decision-maker quality also played crucial roles. Policy makers need to understand the outcomes of analytics and their implications, and it was found that the experience of the policy maker, influences the decision-making process in a positive way, enabling faster and better decision-making. Accurate data quality was also essential to avoid costly wrong decisions (Janssen et al., 2017). In addition, Dingelstad et al. (2022) identified the following required competencies for DDPM: teamwork, critical thinking, data literacy, domain expertise, engaging stakeholders, innovativeness, data analytical skills, and political astuteness. Examining these competencies among local governments' employees will determine whether these competencies truly improve DDPM.

2.3. Data-driven policy making to support the local energy transition

Local governments have an important role regarding the implementation of policies that facilitate the transition towards a more sustainable society (Diran, Henrich, et al., 2020; Fremouw et al., 2020). These policies are often focused on reducing emissions through measures such as reducing energy consumption or transitioning towards alternative renewable energy resources (Diran et al., 2022). However, the adoption of DDPM varies across different domains, with certain sectors such as the energy domain lagging behind in the implementation of data-driven applications (Diran et al., 2022). Nevertheless, governments are recognizing the benefits of using data to make decisions, particularly for complex societal issues (Diran et al., 2021, 2022). Using data and energy modelling can help decision makers understand the implications of system changes (Pfenninger et al., 2014).

DDPM emphasizes on the fact that data-driven models and tools are extremely important for policy makers to accurately predict and evaluate the future impact of energy transition policies in complex urban contexts and to conduct effective forecasting. Most existing policy evaluations consist of policymakers' technical judgements based on experience, which is less efficient than models and tools (Yang et al., 2023). Other benefits of DDPM in the energy transition include financial and socio-economic insights, transparency, and opportunities for meaningful discussions (Diran, Henrich, et al., 2020). In addition, insights on the sustainability progress can be gained by monitoring local energy policies (Diran, Henrich, et al., 2020). Moreover, data-driven applications can also assist in identifying the potential of RES[2] (Ramachandra, T. V. Shruthi, 2007; Schiel et al., 2016); mapping energy demand; planning building renovations; planning of heat and cooling networks and also data-driven applications focusing on citizen and stakeholder engagement (Diran et al., 2022).

To achieve the above mentioned intended purpose, various tools are required for these applications. For example, Matheus et al. (2020) propose the use of data-driven dashboards to facilitate decision-making in smart cities. Besides providing information, the dashboards should also collect feedback from citizens and stimulate interaction between them and the government (Matheus et al., 2020). Another interesting tool for policy makers is an energy model, which is a computer model that allows for structured consideration of the consequences of changing different parts of the energy system (Henrich et al., 2021). Energy models may be used for understanding the complexities within the energy sector and helps in designing energy transition policies (Diran et al., 2022; Henrich et al., 2021). In the Netherlands, GIS maps (Geographical Information Systems) are often used to present energy transition data. These GIS maps can show information on spatial development, characteristics of citizens and neighbourhoods, and the potential of RES. In addition, data from CBS[3], PBL[4], the national program RES[5] and data from the municipality are also relevant in order to gain more insight (Diran, Henrich, et al., 2020).

Furthermore, the type of data analytics used can offer valuable information regarding the type of support required for policy making. Four categories of data analysis are identified by Soares et al. (2018), each with increasing levels of value and complexity, that can be useful in policy making: 1) Descriptive analysis, which seeks to answer questions about the current situation and what has happened in the past, 2) Diagnostic analysis, which aims to identify the cause of a problem or situation, 3) Predictive analysis, which endeavours to forecast future trends and events, and 4) Prescriptive analysis, which focuses on determining how to achieve desired outcomes and implement change. In addition, this model can provide insight into the maturity of data-driven applications, as descriptive analysis is a more fundamental type of data analysis, while prescriptive analysis necessitates more advanced skills due to more complexity (Diran et al., 2022).

Large Dutch municipalities use data extensively in their policy making cycle (Diran et al., 2022), while smaller municipalities often lack the time and resources to learn how to use models effectively (Henrich et al., 2021). As a result, data-driven decision support is not widely adopted in all governance processes, and governments make limited use of data processing and analysis tools (Diran, Hoppe, et al., 2020; Henrich et al., 2021). Basic descriptive data analytics are mostly used, which means that the full potential of data-driven applications is not yet realized (Diran et al., 2022).

2.4. Socio-economic aspects

Energy plays a vital role in societal well-being, and significant challenges such as climate change, resource scarcity and fuel poverty leads to the fact that many countries will need to make significant adjustments in how energy is produced, governed and consumed. The study of (Demski et al., 2019)

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[2] Renewable energy sources

[3] CBS: Statistics Netherlands

[4] PBL: Netherlands Environmental Assessment Agency

[5] RES: Regional Energy Strategy

indicated that people view energy as basic right and need. This understanding of energy stems from its perceived importance in supporting good health, survival and a decent life. One of the key benefits of the energy transition is the positive impact it can have on societal well-being. For example, the increased use of RES can help to reduce air pollution, which can improve public health and reduce the risk of respiratory diseases (Sathaye et al., 2011). It can also help to reduce the amount of greenhouse gas emissions, which can help slowing down the velocity of climate change and protect the environment for future generations. In addition, the transition to renewable energy can help to reduce dependency on fossil fuels, which can be a volatile and unpredictable market, and increase energy security. The energy transition has also led to a number of socio-economic challenges. One of them is the cost allocation for the transition to RES. Although the cost of renewable energy has decreased in recent years, it is still generally more expensive than fossil fuels. Renewable energy technology is often expensive to implement, potentially leading to the development of new energy systems that exclude people who cannot afford to embrace them (Hearn et al., 2021). Additionally, the transition to renewable energy also requires significant infrastructure investments, such as the development of new power plants and transmission networks, which can be costly and time-consuming. There are also issues that have a significant impact on the quality of citizens' lives, such as energy poverty. Energy poverty is a socio-economic state in which due to inadequate resources or living conditions a person or household is unable to access the essential energy for powering their house and meet basic necessities owing to insufficient resources or living conditions (Filippidou et al., 2019). To address energy poverty, the deployment of low-carbon energy system innovations is progressively being pushed to become more people-centered. However, reducing overall energy consumption may conflict with addressing concerns of energy poverty. Specifically, reducing energy consumption by increasing costs does not protect society's poorest members (Hearn et al., 2021). Basic energy services enable people to realize and maintain minimal levels of well-being, yet subsidizing or remunerating energy for vulnerable people may increases the energy use and emissions (Hearn et al., 2021). This indicates that it is not only about energy transitions, but especially about just transitions (Hearn et al., 2021).

Previous research on Dutch energy transition and policy were often focused on techno-economic aspects. The creation of new jobs in the growing renewable energy sector can boost local economies and provide opportunities for economic growth and development (Mikkonen et al., 2020). However, the central role of citizens is often neglected (Haarbosch et al., 2021), while energy transitions are not solely technological changes and involve societal impacts (Miller & Richter, 2014). People, their transactions, and their interactions within the energy system are all examples of social aspects (Krumm et al., 2022). Despite their significance, social aspects have received insufficient consideration (Grafakos et al., 2017) and are infrequently included in energy policies (Miller & Richter, 2014).

According to Sovacool and Dworkin (2015)'s study, energy justice could be employed as a tool to support decision-making and assisting energy planners. In addition, the study of Hu (2022) investigated the influence of including social factors on the decision-making process in the Dutch heat transition. They indicated the following relevant technical and social aspects for the decision-making in the Dutch heat transition: 1) The technical aspects include energy labels, energy consumption, and the construction year of buildings; 2) The economic aspects include the costs to disconnect a neighbourhood from natural gas and 3) Social: energy poverty, public participation and public support. According to their findings, including social aspects has an impact on the decision-making process of policy makers in almost half of the neighbourhoods studied (nine out of 20) (Hu, 2022). In these particular neighbourhoods, the inclusion of social aspects causes a change in the prioritization of neighbourhoods, resulting in decisions that are more socially responsible. This outcome highlights the importance that Dutch policy makers assign to social aspects when making decisions for to the energy transition (Hu, 2022). Another interesting result from the study of Hu (2022) is that many policy makers, and consequently municipalities, exhibit divergent approaches towards the heat transition. These differences may stem from organisational characteristics or personal characteristics, such as personal values, professional experience, and educational background (Hu, 2022). Therefore, it is interesting to conduct further research on what motivates policy makers to adopt more socially responsible approaches and thereby solve this knowledge gap.

In recent years, policy makers have been taking non-economic factors such as health, inclusion, and climate into greater consideration when making policy decisions (Jenkins et al., 2016). However, they do not currently possess the necessary tools to effectively manage the overall well-being of society (Paradies & Sassen, 2022). There is still a wide gap between the possibilities of actually steering for well-being and practice. Concrete methods and instruments are lacking that can help policy makers at the local, regional and national levels to map the effects of their policies on well-being. Policy choices related to the energy transition often have differing impacts on societal well-being of various population groups. For instance, a policy measure that improves the well-being of one group may negatively affect the well-being of another group. Studies have indicated that excluding social aspects can hinder public support and the implementation of energy policies (Kallbekken et al., 2011). In addition, neglecting energy justice, which encompasses distributional, recognition-based, and procedural justice, can result in energy affordability problems (Williams & Doyon, 2019). A single policy option can influence multiple aspects of well-being, including employment, health, safety, and climate. It is therefore crucial for policymakers to have a better understanding of how policy decisions impact various elements of well-being and the effects on different groups within society (Paradies & Sassen, 2022).

2.5. Challenges

Transitions are often accompanied by a complex context and a high degree of uncertainty. Decision-making during times of uncertainty is not only challenging but also requires a different way of working. To reduce uncertainty, data and models can be useful because they can help predict possible future situations, can calculate the impact of certain policy measures and reveal blind spots (Huisman, 2017). However, there is a significant gap between the quantitative modelling world and the qualitative policy world. It is difficult to translate policy ambitions into quantitative model insights, and vice versa, to effectively implement results from model studies into policy. This gap makes collaboration difficult, causes miscommunication, and limits the ability to effectively apply quantitative insights (Heezen & van der Tuin, 2022). In addition, the study of Srivastava et al. (2019) mentions the lack of an adequate understanding on the use, expectations and barriers of data analytics in the decision-making process of the building energy management. After investigating what factors influence the building energy management professionals choice of adopting the data analytics applications, the study indicate that more and better training is required for the professionals, particularly for simulation tools (Srivastava et al., 2019).

The gap between data analytics applications and their adoption in energy policy making is significant (Brouwer, 2019; Diran, Hoppe, et al., 2020; Diran & van Veenstra, 2020) and municipalities face multiple challenges in using data for energy policy decision making. The first issue is legislative, as not all relevant data can be utilized due to legal restrictions (Diran, Hoppe, et al., 2020; Diran, van Veenstra, et al., 2020; Diran & Hoekstra, 2022; Diran & van Veenstra, 2020; Henrich et al., 2021). Secondly, due to complexity of data, policy makers may not have the necessary skills or resources to analyse the data effectively (H. van der Voort et al., 2021). Municipal organizations often lack a clear strategy for data-driven policy, internal collaboration, and in-house expertise to work with data, build models, or interpret their outcomes. As a result, they depend on external knowledge (Diran, Hoppe, et al., 2020; Henrich et al., 2021; Nielsen et al., 2019). The third challenge is related to the data itself, including poor data quality, incompatibility, missing or outdated information, scattered ownership of the data, and a lack of cooperation and clarity in links between datasets from different organizations (Diran, Henrich, et al., 2020; Diran, Hoppe, et al., 2020; Diran & van Veenstra, 2020; Diran, van Veenstra, et al., 2020). Fourth, problems occur with models that do not consider all factors policy makers deem relevant, including socio-economic factors, making them less transparent and creating additional complexity for decision-makers (Henrich et al., 2021). Finally, policy makers may be more comfortable relying on their own expertise and experience, rather than on the knowledge and information from data analysts (H. van der Voort et al., 2021). However, the creation of knowledge is very important in the whole DDPM process to allow for better decision making. Improving DDPM for the energy transition therefore requires the integration of knowledge from both data analysts and policy makers (H. van der Voort et al., 2021). H. van der Voort et al. (2021), presented a framework to identify and enhance the collaboration and synergies between data analysts and domain professionals.

All the above mentioned issues make it difficult for municipalities to effectively use data in their decision-making processes. Addressing them will require strategic planning, collaboration, and expertise both within and outside municipal organizations (Diran, Hoppe, et al., 2020; Henrich et al., 2021).

2.6. Data related challenges for socio-economic aspects

In a study on heating transition projects from Henrich et al. (2021) the municipalities concurred on the fact that socio-economic aspects are important and influence the effectiveness of heating transition initiatives. The investigated municipalities used the socio-economic data for determining the prioritization of neighbourhoods for heating transition activities and to indicate coupling opportunities. However, it was not claimed by the municipalities that the choice of heating alternatives was influenced by the socio-economic aspects. In fact, this choice was based on the lowest societal costs, as one of the primary challenges of the Dutch heating transition is perceived to be resident affordability (Henrich et al., 2021; Schellekens et al., 2019). The model developers mentioned that incorporating social aspects into energy models was impractical, but agreed on the fact that social data should be included in modelling reports. This was accomplished by gathering socio-economic data and presenting it alongside the results of the techno-economic data to offer contextual information for further decision-making, such as determining prioritisation of neighbourhoods (Henrich et al., 2021). This observation highlights the difference between data analytic applications and that it is important to select appropriate data analytics applications that allow for the integration of social aspects.

Moreover, accessing the socio-economic data was sometimes difficult due to privacy restrictions (Henrich et al., 2021). In addition, the researchers indicate that additional research into specific aspects, such as, the presence of energy cooperatives and income, could offer insight into the potential value of models that incorporate such factors and the association of these factors with heating transition project progress. This might be done by conducting practical case studies that examine socio-technical transition models and theories in the context of energy or heat transition projects (Henrich et al., 2021).

In conclusion, the importance of data has increased significantly from the start of EBP to the current DDPM. As a result, the use of data analytics applications has become highly relevant and new types of interactions have emerged within municipalities, with a particular emphasis on the interaction between data analysts and policy makers. However, municipalities are currently facing challenges to effectively integrate data analytics applications, leading to a gap between the availability of data analytics applications and their adoption in energy policy making.

Furthermore, there is a gap in terms of how knowledge from both data analysts and policy makers is integrated into energy transition policy making. Addressing these gaps and improving DDPM requires creating synergy between these two sources of expertise, rather than prioritizing one over the other. This is a novel insight within the literature and one empirical study that explores this knowledge integration is the study of H. van der Voort et al. (2021), which presented a framework to enhance and investigate the synergies between data analysts and domain professionals. The current state of research on this topic is emerging, indicating the need for additional research in this field.

Finally, despite their significance, socio-economic aspects have not received sufficient attention and are inadequately represented in current data analytics applications and decision-making processes. There remains a knowledge gap in terms of how socio-economic aspects are currently implemented into data analytic applications, necessitating further research and insights on this topic.

3. Theoretical framework

This section describes the theoretical framework and concepts that were used in this research.

Based on the literature review, it is clear that there is a gap in understanding how to effectively integrate data analytics applications, the knowledge from data analysts and the knowledge and ambitions from policy makers in energy transition policy making. Addressing these gaps and improving DDPM requires creating synergy between these two sources of expertise, rather than prioritizing one over the other (H. van der Voort et al., 2021). In a recent study conducted by H. van der Voort et al. (2021), two distinct views on data science have been identified: functional and institutional. The functional view emphasizes the importance of producing higher quality data to ensure accurate and efficient decision-making. However, this view tends to be more theoretical than practical and often neglects the role of domain experts in challenging data intelligence. For instance, data science is defined by Provost & Fawcett (2013) as "a set of fundamental principles that support and guide the principled extraction of information and knowledge from data". On the other hand, the institutional view places the behaviour of human actors at the center of analysis. In this perspective, data analysts and domain professionalism are seen as complementary sources of knowledge. The assumption that data is void of human bias is challenged from an institutional standpoint. The human interventions involved in the data science process can vary significantly in terms of knowledge and interests, making data science susceptible to human design, bias, and error (Crawford et al., 2014). However, an excessively institutional perspective tends to lack comprehensive rationality as it shifts focus towards negotiations among actors rather than a shared rationale. By considering professionals, in this case decision-makers, as autonomous agents rather than just recipients of improved information, the critical success factor for data science may encompass both rationales.

There are many different frameworks that try to indicate the interdependencies in DDPM. The first framework is the Cross Industry Standard Process for Data Mining (CRISP-DM). This is a prominent framework that aligns with the functional view. However, this model largely overlooks the interests and perspectives of the policy makers who are essential in utilizing the outcomes of data science efforts. The policy makers may possess knowledge that potentially contradicts or conflicts with the knowledge derived from data analytics (van der Voort et al., 2019). The second framework is the knowledge creation process model of Nonaka (2000), which is a widely recognized example of an institutional model. Its primary focus lies not in enhancing understanding through a rigid methodology, but rather in actors exchanging and sharing their knowledge. In addition, the applied research organization TNO has a research program called The Policy Lab that deals with data-driven policy by conducting policy experiments in collaboration with government organizations. The Policy Lab had an experiment for creating Natural Gas-Free Neighbourhoods. They developed a demo of a data-driven policy model that municipalities can use for decision-making on the transition to natural gas-free neighbourhoods (Diran et al., 2021). The data model consists of three parts; 1) Conceptual model that represents the various factors, and the relationships between them. It is both a way of conducting the strategic discussion and creating a shared understanding about reality, and a means of identifying knowledge gaps. 2) Data sources linked to the factors and relationships from the conceptual model, and necessary for policy formulation, implementation and monitoring; and 3) Analysis and visualization tools for processing the data and effectively deploying the knowledge for policy (Diran et al., 2021). Another interesting framework is created by H. van der Voort et al. (2021) that identifies and enhances synergies between data analysts and domain professionals, rather than prioritizing one over the other. Unlike the other frameworks, such as CRISP-DM and the knowledge creation process model of Nonaka, which focus on the functional or institutional view of data intelligence and analytics, the framework of H. van der Voort et al. integrates both perspectives. Since this study examines the interplay between data analysts and policy makers, it is the most suitable framework to use.

The framework, presented in Figure 2 below, encompasses all the activities from both models. The activities from the knowledge creation model primarily involve extracting knowledge from the organization (shown in orange), while the CRISP-DM activities revolve around transforming this knowledge into a data mining model (shown in blue). To simplify the model, overlapping activities from the two models were merged, and these merged activities are represented in yellow.

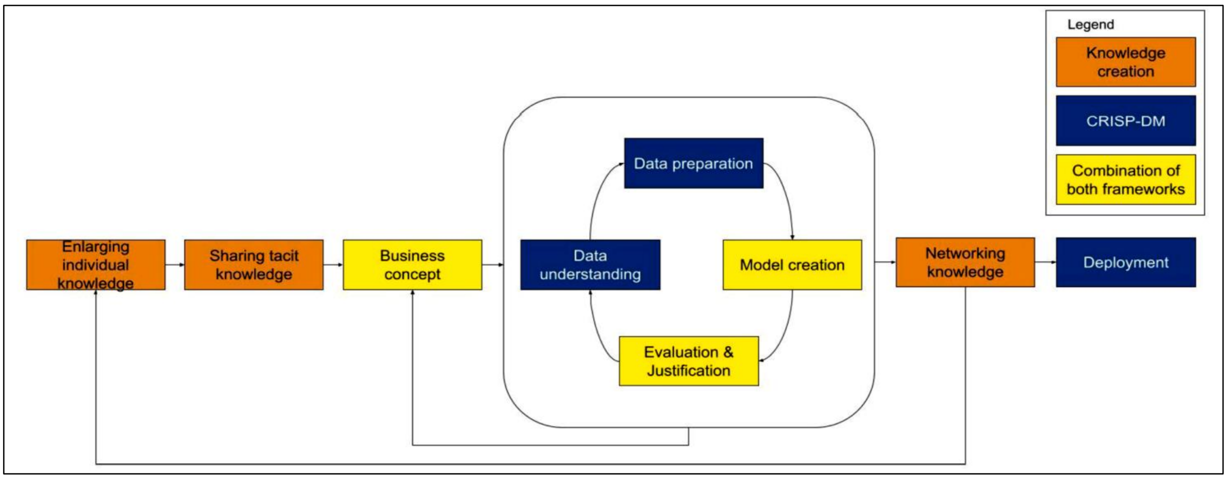

Figure 2. Knowledge creation model for data intelligence and analytics (H. van der Voort et al., 2021)

To explore the added value of the framework, the study of H. van der Voort et al. (2021) took the framework to daily practice and tested it for the development of a small-scale risk model at the Dutch Food and Safety Products Authority (the NVWA). In this research, the usability of the framework was tested for decision making processes for energy policies in municipalities. The framework and activities were used to analyse the use of knowledge from both the data analysts and the policy makers in the energy transition. As stated above, a significant challenge that municipalities face is that there is no clear strategy for data-driven policy, and in-house expertise to work with data or interpret their outcomes (Diran, Hoppe, et al., 2020; Henrich et al., 2021). Another important challenge mentioned is related to the data itself, including poor data quality, incompatibility, missing or outdated information, scattered ownership of the data, and a lack of cooperation and clarity in links between datasets from different organizations (Diran, Henrich, et al., 2020; Diran, Hoppe, et al., 2020; Diran & van Veenstra, 2020; Diran, van Veenstra, et al., 2020). In addition, current models do not consider all socio-economic factors policy makers deem relevant (Henrich et al., 2021). Investigating the stages from the framework will shed light on how the data is prepared and understood by the data analysts and policy makers and how this takes into account socio-economic aspects. It will also indicate which factors should be added to the model to make it more complete for the energy sector. Furthermore, it will specify if there is an implementation strategy of the data analytic application by the policy makers and data analysts. By applying the framework in the energy context and investigating it on these aspects an answer to the main research question can be given about how and to what extent data analytics applications create knowledge to inform policy making on socio-economic aspects of the energy transition in the Netherlands.

The framework was tested and extended according to the following aspects: (1) The extent to which the framework elements can also be identified in the cases, and (2) additions to the framework in terms of new concepts that may arise from the cases being examined. Using this framework for energy transition decision-making could narrow the gap between data analytics applications and their integration into energy policy making.

3.1. Operationalization of theoretical concepts

Operationalization directs the research and defines what was studied. It is the transition from theory to empirical research (van Thiel, 2014). The concepts that were researched are derived from the framework of H. van der Voort et al. (2021). Table 1 provides operational definitions for each concept in the context of local energy policy making on socio-economic aspects.

Table 1. Operationalization of the theoretical concepts from the framework

Concept	Operationalization
Knowledge enlargement	The enlargement of individual knowledge is being done through the interaction between data analysts and policy makers. It encompasses a range of activities aimed at expanding their understanding. This involves not only the acquisition of new knowledge but also the utilization of the distinctive expertise and insights offered by each party, ultimately contributing to the enhancement of policy development and implementation in a more robust and effective manner.
Sharing tacit knowledge	This encompasses the activities undertaken by data analysts and policy makers to share their tacit knowledge. Tacit knowledge is a form of knowledge that is difficult to codify, articulate or transfer to another person. In the context of policy makers and data analysts, tacit knowledge can refer to the expertise and insights that these professionals have gained through their years of experience in their respective fields. For example, a policy maker may have developed an intuitive understanding of how certain policies and programs are likely to impact different segments of the population. Similarly, a data analyst may have developed a keen sense of how to identify patterns and trends in complex datasets, based on their experience.
Development of business concept	A joint development of a business concept model by data analysts and policy makers will indicate what data they think should be added to the model. Researching this concept will map what data underlies the model.
Data preparation	Ability to clean, transform, and organize the data for analysis. It is important that this is done in a transparent and structured manner for the reliability of the model.
Data understanding	Both data analysts and policy makers should have a clear understanding of the data used to create the model for energy policy making. This will enable the data analysts to effectively use the data in the model creation process and allow policy makers to understand the composition of the model and use it more effectively.
Model creation	Creation of the data analytics application (model). When developing a model to inform decision making on societal well-being aspects of the energy transition, factors such as transparency, flexibility and robustness are important to take into account. In addition, the model should be developed in collaboration between data analysts and policy makers. The model should also be interdisciplinary, taking into account different fields such as energy, economy, environment, health, and social factors, to provide an extensive analysis of the impacts of different energy policies on societal well-being.
Evaluation and justification of the model	Determining whether the model is sufficiently adequate for adoption or requires further enhancements to be made. In cases where improvements are necessary, the process should be recommenced from category 3: Development of a business concept. Conducting interviews with policy makers and data analysts will help evaluate whether the model meets their expectations.
Networking knowledge of the model	Sharing of knowledge about the data analytics application (model) among relevant stakeholders to make them more inclined to use it.
Deployment	Implementation strategy to apply the model in the organisation, in order to effectively use it for decision making on socio-economic aspects of the local energy transition.

The concepts from the framework were grouped under three different phases for pragmatic reasons and to easily provide a clear overview of the results. The framework from Janssen et al. (2017), as shown in Figure 1, is used as inspiration for the manner in which the procedural steps in the model from H. van der Voort et al. (2021) are classified and organized. Figure 3 presents the three different phases with their corresponding concepts from the framework. The first two concepts in the preparatory phase focus on knowledge creation and sharing within the municipality. The third concept involves the preparation of the business concept. In the development phase there is a focus on transforming this knowledge and business concept into a data analytic application. The use phase describes how the knowledge from the application is networked and how the application is deployed within the municipality.

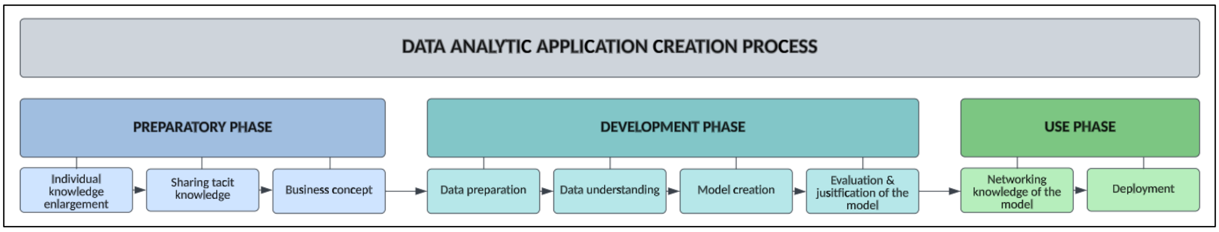

Figure 3. The data analytic application creation process

4. Research design and methodology

This section provides a comprehensive description of the research design and methodology. The six individual cases under investigation are described in detail, as well as the corresponding data analytics applications. First, the multiple-case study approach and selection process are thoroughly explained, highlighting the rationale behind the chosen cases. Subsequently, the procedural steps in data collection are outlined, and the data analysis process is described. Finally, the reliability and validity of the research methods are addressed.

4.1. Position in TNO research

The research is conducted together with an internship at TNO. TNO is the Netherlands organisation for applied scientific research. This master thesis will build on the research of Diran, who is a Scientist Integrator Energy Transition & Digitalization at TNO Strategy & Policy. In addition, the master thesis is part of the "Socio-Economic Impact of Green Transitions" research program at TNO, which has a running time from January 2023 until December 2026.

4.2. Research design: multiple-case study

This study has used a multiple-case study research design (Yin, 2009) to gain empirical insights from the Netherlands. The six cases that were investigated for this study include the municipality of Amsterdam, Utrecht, Rotterdam, Zoetermeer, 's-Hertogenbosch and Tilburg. The selection criteria resulting in these six cases address first of all the maturity of data analytics applications within local energy transition policy making. The first three municipalities have a longstanding collaboration in a platform called G4, the four largest municipalities of the Netherlands, and are frontrunners in data-driven local energy transition policy making (Diran et al., 2022). These three cities have more advanced digitalization strategies and are actively pursuing their energy transition vision. The other three municipalities are medium-sized and more in the starting phase to use data analytic applications for decision-making. In addition, the sample of six municipalities allowed for a good comparison between large municipalities and medium-sized municipalities on how the knowledge from both data analysts and policy makers is integrated in the development process of the data analytics applications in use. By studying six cases, similarities and differences between municipal institutional contexts were described. To gather the case data, the framework of H. van der Voort et al. (2021) presented in Chapter 2 was utilized. In this study, two connected data analytics applications used for energy policy making were investigated in each case, and all the stages from the framework of H. van der Voort et al. (2021) are examined for the applications. The inclusion criteria for the selection of the data analytics applications were the following; the data analytics applications must be related to energy policy making, in use by policy makers and involve socio-economic aspects.

For this study, data analytic applications for policy making are defined as applications that gather, produce, and utilize policy-relevant data to identify trends and patterns for the purpose of establishing feasible policy configurations, facilitating implementation and monitoring, and enhancing organizational efficiency in terms of time and resource requirements to design and implement a policy solution (Diran et al., 2022). These can be for instance a data model, visualization tool, but there are also reported documents that are based on data and become data analytic applications.

4.3. Case descriptions

The cases and the associated data analytics applications investigated in this study are described below, and Table 2 presents an overview including all relevant information for the study.

Amsterdam

The municipality of Amsterdam (population: 1,158,000, area: 219 km²) is recognized as a pioneer in the adoption of information technology within its municipal government for the purpose of policy making and the provision of public services (Noori et al., 2020). The data analytic applications that were investigated for Amsterdam are the Amsterdam Climate Neutral Roadmap. This is an ambition document that describes a long-term vision of the energy transition in Amsterdam, and short term actions. It includes 25 indicators that can be used to monitor the progress of the roadmap. The data analytic application Climate Report Amsterdam, is published once a year and is a monitor of the Roadmap. It is an instrument to create an overview of what is happening both inside and outside the municipality and shows how the indicators have progressed. Part of the purpose of the monitor is to allow the municipality to examine whether it is moving in the right direction in achieving its energy transition goals (Municipality of Amsterdam, 2022). In April 2020, a motion was passed for consideration of the Roadmap that more social indicators should be added. As a result, employment and participation were added as indicators in the Roadmap.

Utrecht

The city of Utrecht (population: 360,000, area: 99 km²) has created an open data platform that focuses on a wide range of topics, including culture, finance, housing, nature and environment agriculture, economy, migration, mobility, and physical space and infrastructure, as outlined by the Municipality of Utrecht (2023). The data analytics geared towards the selection and planning of energy transition strategies and policies begins with the Scenario analytics for Transition Vision Heat (TVH). The TVH indicate how Utrecht is transitioning to a sustainable way of heating in a feasible and affordable manner, and scenarios are calculated for each neighbourhood to determine the best solution for natural gas-free heating.. Social characteristics of a neighbourhood can be taken into account for the prioritization of the natural gas-free neighbourhoods. To perform the TVH, the municipality also developed the dashboard neighbourhood approach to natural gas-free. This dashboard is used by policy makers for better decision-making (Diran et al., 2022; Municipality of Utrecht, 2021).

Rotterdam

Rotterdam, with a population of 663,900 and an area of 324 km², is actively exploring the possibilities of digitalization for the city's future through the Digital City initiative. Central to this endeavour is the development of a digital Open Urban Platform that incorporates a three-dimensional Digital Twin of the city. Ongoing projects and pilot initiatives are being conducted to accumulate knowledge and leverage it to expedite these advancements. The data analytic applications constituting Rotterdam's Transition Vision Heat (TVH) and inform about energy transition policy making are the WHAT map, which identifies promising sustainable heat options for each district, and the WHEN map, which determines the sequencing of district-specific transitions. The determined most cost-effective alternative to natural gas for each neighbourhood are incorporated into the WHAT map, and the WHEN map serves as a planning tool for the WHAT map (Municipality of Rotterdam, 2021).

Zoetermeer

The municipality of Zoetermeer is a city situated in the Western Netherlands within the province of South Holland and has a population of 127,052. The municipality spans an area of 37,05 km². The municipality of Zoetermeer is aiming for a natural gas-free city by 2040. Zoetermeer has started making a TVH and this will provide the direction for carrying out the heat transition in the coming years (Municipality of Zoetermeer, 2021). In the TVH are maps made based on data. These include the maps that indicate which heat alternative is the best solution. The municipality will start working only when a heat technology is feasible and affordable. Subsequently, because residents, organizations and municipalities need each other at every step of the heat transition, towards 2040 and beyond it is not only about clear, relevant and reliable information and advice via various (communication) platforms and organizations, but also about social aspects, such as mutual contact, knowledge sharing, exchange and meeting of all involved: residents, organizations and municipality (Municipality of Zoetermeer, 2021). In order to do this as well as possible and implement energy policy decisions properly, the municipality has created a data model called Information Provision Energy Transition Zoetermeer, containing all the available energy data from the city, and modernizing this model from 2020 onwards. This model is mostly used by policy makers for addressing the energy transition and establishing energy policy measures. Therefore, the focus during this study was on this model, with the TVH serving more as a supporting document, to include the social aspects as well.

’s-Hertogenbosch

’s-Hertogenbosch is the capital of the province of North Brabant (population: 157,486, area: 39,98 km²). The Province of North Brabant has expressed its ambition to become more data-driven and to monitor mobility policy more concretely based on insights created from data. The municipality of ‘s-Hertogenbosch wants to remain habitable for future generations and therefore it is necessary to take steps towards a sustainability. They aim for a municipality that in 2045 is green and natural gas free. Together with residents, corporations, entrepreneurs and the grid operator, the municipality wants to look for the best solutions for the energy transition (Municipality of ’s-Hertogenbosch, 2023). Currently, there is an online sustainability monitor and an internal energy poverty dashboard available within the organization that communicates both visually and with text how sustainability and the energy transition is going and how the municipality incorporates socio-economic aspects (Municipality of ’s-Hertogenbosch, 2022).

Tilburg

Tilburg is a city and municipality in the Netherlands (population: 222,601, area: 88,79 km²) and is the second-largest city or municipality in North Brabant and the seventh-largest in the Netherlands as a whole. By 2045, Tilburg wants to be climate neutral and are gradually moving away from natural gas as a source of heating to a more sustainable way of heating. A plan has been made for this: the Transition Vision Heat. In consultation with all stakeholders, neighbourhoods, districts and villages the city will become natural gas-free. This will happen step by step, starting with new construction, restructuring or renovation (Municipality of Tilburg, 2021). The TVH is displayed on the website of Tilburg in story maps. Story maps are visual and interactive tools used to tell stories using maps, graphics and text. In addition, the municipality has created an informational map box for the energy transition. This map box will help policy makers to select neighbourhoods according to the TVH.

Table 2. Description of data analytic applications per municipality

Municipality	Data analytic application	Kind of application	Starting date	Description	Relation with socio-economic aspects
Amsterdam	The Roadmap Climate Neutral Amsterdam and the Climate report	Policy documents	2019	The Roadmap Amsterdam Climate Neutral 2050 is a strategic plan that aims to make the city of Amsterdam climate neutral by 2050. It includes	- Ensuring social justice in the transition to a climate neutral city. This includes reducing energy poverty, providing equal access to sustainable energy solutions and involving

				concrete measures and actions in the areas of energy conservation, sustainable energy production, mobility, circular economy and buildings. The climate report is a periodic evaluation of Amsterdam's progress in achieving this roadmap and climate goals.	diverse communities in decision-making. - The roadmap recognizes the need to create new jobs and retrain workers in green and sustainable sectors. It encourages green employment initiatives.
Utrecht	Scenario analytics Transition Vision Heat and dashboard neighbourhood approach to natural gas-free	Policy document, data model and dashboard	2020	The TVH is a policy document that sets out a realistic schedule for transitioning away from natural gas. With scenario analytics several scenarios have been calculated to help make choices about which renewable energy source is best. The dashboard neighbourhood approach to natural gas-free is used by policy makers for better decision-making	- Affordability is taken into account as everyone in Utrecht must have a comfortable and sustainably heated building, without paying more than when using natural gas. - Reliability is an important social aspect and indicates that people can be confident that they can always heat. Now and in the future. - Resident participation - Dashboard neighbourhood approach to natural gas-free contains techno-economic data and this is used next to social data of TVH, and a dashboard containing the energy poverty data for decision-making.
Rotterdam	Analytics for the WHAT map and WHEN map	Data visuals	2020	Used for energy transition strategy for prioritization of neighbourhoods and policy selection and planning	- The premise is that an alternative to natural gas must be feasible and affordable. - New jobs are created due to the energy transition which increases employment.
Zoetermeer	Transition Vision Heat and the data model Information Provision Energy Transition Zoetermeer	Policy document and data model	2020 the data model, 2021 the TVH	The TVH includes maps based on data and indicate which heat alternative is the best solution. The data model contains all the important information regarding energy and buildings.	- TNO has done research for the municipality to identify energy poverty. - Municipality is investigating how to take advantage of job opportunities created by the energy transition. - Social data from the TVH and from the Social domain of the municipality is presented next to the data from the data model to provide context for further decision-making, such as determining prioritisation of neighbourhoods.
‘s-Hertogenbosch	Sustainability Monitor and Energy poverty dashboard	Monitor and dashboard with textual explanations	2021	The a sustainability monitor is an online dashboard that communicates both visually and with text how sustainability is going in 's-Hertogenbosch, including climate adaptation and energy transition.	- Energy poverty actively tracked since last year. - Investigations are conducted to identify neighbourhoods with higher levels of energy poverty, to provide help in these neighbourhoods.
Tilburg	Transition Vision Heat story maps and the map box	Story maps and data visuals	2021	The TVH is presented in story maps and outlines how the city wants to become climate neutral. In	- Energy poverty is included in the applications. - The energy transition must be cost-neutral.

				addition, there is a map box with different maps that will help in selecting the neighbourhoods according to the TVH.	

4.4. Data collection

4.4.1. Secondary data

The collection of data in this study started with gathering secondary data through desk research. The desk research phase plays a crucial role in the start of the study and helped to identify the most relevant data analytics application used by the six Dutch municipalities to support policy making on socio-economic aspects of the local energy transition. After having identified the relevant data analytics applications, deeper knowledge about the applications is obtained by gathering all the relevant background information about the applications. This method involves gathering all the accessible online information about the development and implementation of the data analytics applications from each municipality. An example of this secondary data are the transition vision heats documents from the municipalities. An overview of the used documents for the secondary data can be found in Appendix B, Table B1.

4.4.2. Primary data

After having identified and described the relevant data analytics applications in the desk research phase, semi-structured interviews were the next phase for gathering data. The goal of these interviews was to gain more insight into how the data analytics applications were used by policy makers, what the challenges are and how the knowledge from both data analysts and policy makers was integrated in the development process of the data analytics applications. The interviewees were approached via direct contacts from TNO via mail and were also directly approached via LinkedIn. Besides that, the snowball sampling technique was also employed. Snowball sampling is a purposive sampling method that relies on the recommendations and referrals of initial respondents to identify and recruit additional informants who possess the desired characteristics or experiences relevant to the research inquiry. Snowball sampling involves asking each respondent for recommendations for other suitable informants to interview (Brayda & Boyce, 2014). Data analysts and policy makers were separately interviewed for each municipality. In preparation of the interviews, interview guides were prepared to partly structure the interviews (Bryman, 2016b). These interview guides can be seen in Appendix A. Before the interviews took place, the interviewees were asked for their consent to record the interview, using the informed consent form of Utrecht University. A total of 16 interviews were conducted online via Microsoft Teams. A list of interviewees is present in Table 3. All interviews were conducted in Dutch and translated to English. After conducting and recording the interviews, interview transcripts were made.

Table 3. Interviewees from the six Dutch municipalities

Interviewee ID	Municipality	Interviewee function and department	
		Data	**Policy**
I.1	Amsterdam	Data Analyst from the department Research & Statistics involved in the roadmap and climate report	
I.2	Amsterdam		Policy Advisor Heat Transition at the Sustainability Department involved in the roadmap and climate report
I.3	Utrecht	Data Scientist Energy Transition at the Research and Advisory Department	

		involved in the scenario analytics TVH and dashboard neighbourhood approach to natural gas-free	
I.4	Utrecht	Data Coach Energy Transition at the Research and Advisory Department involved in the scenario analytics TVH and dashboard neighbourhood approach to natural gas-free	
I.5	Utrecht		Strategic Advisor in the Energy program involved in the scenario analytics TVH and dashboard neighbourhood approach to natural gas-free
I.6	Rotterdam	External Data Scientist from consulting company involved in the WHAT and WHEN map	
I.7	Rotterdam		Policy Advisor on Heat at the Sustainability Department involved in the WHAT and WHEN map
I.8	Zoetermeer	ETL (extraction, transformation and load) developer at the Business Intelligence team involved in the data model Information Provision Energy Transition Zoetermeer	
I.9	Zoetermeer		External Policy Researcher Energy Transition involved in the TVH and the data model Information Provision Energy Transition Zoetermeer
I.10	Zoetermeer		Policy Advisor Green and Energy involved in the TVH and the data model Information Provision Energy Transition Zoetermeer
I.11	's-Hertogenbosch	Data Scientist at the Research & Statistics Department involved in the Sustainability monitor	
I.12	's-Hertogenbosch	Researcher at the Research & Statistics Department involved in the energy poverty dashboard	
I.13	's-Hertogenbosch		Policy Maker Energy Transition at the Economy & Energy Department involved in the Sustainability Monitor and energy poverty dashboard
I.14	Tilburg	GIS Advisor involved in the TVH story maps	
I.15	Tilburg		Policy Advisor Energy at the Department of Space involved in the map box
I.16	Tilburg		External Project manager involved in the TVH story maps

4.5. Data analysis

The transcribed interviews were coded using the program NVivo. An abductive approach was used in this study and the aim was to start with a deductive codebook and through the process of coding, extend the codebook (Timmermans & Tavory, 2012; Vila-Henninger et al., 2022). Therefore, the coding process started with the creation of a deductive codebook with codes based on the categories from the theoretical framework and literature review. The deductive codebook can be found in Appendix C, Table C1. The second step was open coding to allow for the creation of new categories that arise from the interview data besides the one from the framework (Corbin & Strauss, 1990). In this step first level codes were ascribed closely to the original words of the respondent. In stage two, second order codes were generated by categorising the earlier described first order codes into more interpretive second order categories. Axial coding is a technique that was used for this to further refine and elaborate on the categories and themes that have been identified (Corbin & Strauss, 1990). The second order codes were further grouped through top-level coding in stage three. Table 4 provides an example of the coding process. The quotes from the interviews are translated from Dutch to English. The final codebook is presented in Appendix C, Table C2.

Table 4. Example of the coding process

Top level	Second order	First order	Quote
Development phase	Data understanding	Understanding among policy makers where the data comes from	"*it is more important for them to know how good is the quality of the data than to know exactly where it comes from.*"
		Data quality	
Use phase	Deployment	Intuitive use	"*We try to make it so that it is usable by everyone and that no instructions are needed to use it.*"

The cases were compared using first a within-case analysis and then a cross-case analysis. The within-case analysis provided rich narratives of each case that ensured rich familiarity with the cases (Eisenhardt, 1989). The next step was cross-case analysis, where the information from the secondary data and information from the interviews with data analysts and policy makers of the six municipalities were compared and contrasted to identify any differences or similarities (Eisenhardt, 1989).

4.6. Validity and reliability of the research

First of all, the reliability of the interviews is ensured by creating an interview guide in advance. The questions are based on the theoretical framework, providing valuable insights and allowing for the replication of interviews. Interview transcripts are generated afterwards, securing further reliability of the data collection process. To enhance validity, desk research about the data analytics applications is conducted prior to the interviews to gain the necessary knowledge for engaging in meaningful conversations. In addition, semi-structured interviews are chosen over open interviews, to balance between structure and flexibility. This approach allows for exploring specific topics while maintaining consistency across respondents, facilitating data analysis and comparison. Secondly, to ensure reliability within the coding process, a deductive codebook is created by aligning the codes with the concepts and themes derived from the theoretical framework. The codebook was extended with codes that emerged from the interviews, incorporating the richness and complexity of the participants' perspectives, which further enhances the validity of the findings. In addition, a codebook ensures that the coding process remains consistent and reliable across different interview transcripts. The codebook presents clear hierarchies in the categorization of the codes, reducing the potential for subjective interpretation and increasing the reliability of the coding process. Moreover, data triangulation is employed by combining interview results with secondary data to enhance internal validity. This ensures mitigating potential biases and limitations. By comparing and analysing different sources of information, a comprehensive understanding of the research topic is achieved, strengthening the robustness of the findings.

Finally, the study includes multiple Dutch municipalities as cases, enabling comparisons and enriching the analysis. This comparative approach provides insights into similarities and differences between the municipalities, contributing to a deeper understanding of the subject. The inclusion of multiple cases enhances generalizability, allowing for potential application of findings to similar contexts. This enhances the external validity of the study, as it increases confidence in the applicability of the findings beyond the specific cases examined. However, it is important to note that the generalizability of the findings is still limited to the scope of the study, which focuses specifically on Dutch municipalities. The transferability of the findings to other contexts should be approached with caution, as local factors and contextual nuances can significantly influence outcomes.

5. Results Case Studies

This chapter provides an in-depth examination of the outcomes derived from a comprehensive multiple-case study encompassing six Dutch municipalities, namely Amsterdam, Utrecht, Rotterdam, Zoetermeer, 's-Hertogenbosch, and Tilburg. The study involved conducting interviews with stakeholders from both the data and policy domains to investigate the process of integrating knowledge from these two sides in the development of data analytic applications for the purpose of facilitating the energy transition. Furthermore, this chapter states the challenges encountered by Dutch municipalities in implementing data analytics applications pertaining to socio-economic aspects, which inform the formulation of local energy policies. The analysis is carried out through a comprehensive within-case analysis followed by a cross-case analysis.

5.1. Within-case analysis

The framework of H. van der Voort et al. (2021) and the associated activities were used to analyse how the knowledge from data analysts and policy makers is integrated in the process of data-driven policy making. The framework was utilized by examining specific data analytics applications for each municipality using each activity of the framework. The results and activities of the framework from the literature are divided into three main phases; preparatory phase, development phase and the use phase.

5.1.1. Amsterdam

The data analytic applications investigated for Amsterdam are the Roadmap Amsterdam Climate Neutral 2050 and the Climate Report Amsterdam. Together with residents, businesses and institutions, the municipality of Amsterdam is working intensively to change to a city that uses only renewable energy. The approach to this is described in the Roadmap Amsterdam Climate Neutral 2050. In 2019, the first version of the Roadmap was adopted by the college entitled: Invitation to the City. The final version was adopted in 2020. The Roadmap describes the long-term vision and strategy for Amsterdam's energy transition as well as short-term actions. The approach follows four paths: built environment, traffic and transport, electricity and port and industry. Each transition path consists of a number of pillars on which the approach rests, and where they describe their actions this college period to achieve the desired CO2 reduction (D.1). With the annual Climate Report, Amsterdam visualizes the measures that have an impact on the city's CO2 emissions. Based on implemented actions and measures, it reflects on the progress of the implementation of the Roadmap and describes what is or is not working and what can be improved (D.2). Amsterdam is also looking ahead based on a current CO2 audit carried out by the independent research company CE Delft. This allows Amsterdam to know whether the city is on track and whether additional actions are needed (I.2). In the applications are socio-economic aspects such as energy poverty also taken into account. To include these aspects in the application, the figures from CBS (Statistics Netherlands) and the research from TNO were used.

1. Preparatory phase

The preparatory phase starts with the individual knowledge enlargement. The policy advisors and data analysts interacted a lot with each other. Their knowledge enlarges through their work experience and interactions with colleagues and other stakeholders. The policy advisor also stated that: "*if you work on such a topic together for a longer period of time, that has an advantage, because then you increase your knowledge.*" (I.2). The data analyst also indicated that individual knowledge enlargement was created through "cross-pollination" given that the policy department not only gets their information internally from the data analysts, but also through external parties who in turn share the knowledge with the policy department and they in turn share that with the data analysts. The data analyst and policy maker share their tacit knowledge through project meetings. However, the data analyst stated that the level of detail of knowledge shared depends on the other person's knowledge of the topic. In the case of the municipality of Amsterdam, the policy advisor has a lot of knowledge also about data which allows them to share more complicated knowledge with each other. In addition, the policy advisor had put in a lot of time to properly understand the CO2 audit, but did not find it convenient to be the only one that possess the knowledge. Therefore the knowledge was shared with the data analysts, since they also have much better data bases. The third activity in this phase is the creation of a business concept. By developing the business concept of the application is taken into account that it is consistent with the needs and goals of the municipality. This is done by the policy department that discussed the goals with the city council, and the city council also indicated what they wanted to have in the roadmap and report. The policy department then discussed this in turn with the data analysts to discuss how to collect all the data for this to meet the goals. In doing so, the data analyst also indicated: "*it is important to work very closely together.*" (I.1). Working very closely together facilitates the creation process of the applications. Gathering all the relevant information was achieved through collaborative efforts between the data analyst and policy advisor. They engaged in a comprehensive step-by-step process, deliberating on decisions, data sources, and the availability of better alternatives. The policy advisor had already amassed substantial data in collaboration with CE delft, facilitating smooth data transfer to the data department. In the case of Amsterdam, the policy advisor has a proficient understanding of data, and therefore led the entire application creation process. The applications draw data from diverse sources, encompassing both internal and external reservoirs. Four primary thematic areas, aligned with the expertise of colleagues within Amsterdam, were prioritized for inclusion in the applications. These subject matter specialists play a vital role in ensuring the incorporation of all relevant data pertaining to their respective domains. However, the inclusion of pertinent data undergoes dynamic changes, necessitating ongoing discussions within the municipality (I.2).

Pillar 18 in the roadmap and climate report describes how the municipality is working towards a climate-just energy transition and includes socio-economic aspects (D.1 & D.2). The college emphasizes the need for an equitable and fair transition without undermining certain groups. To assess public perspectives on the energy transition, a public support survey was commissioned by the policy department and conducted by the Research and Statistics department. The municipality also indicated what jobs are needed to make that energy transition possible (I.I). The 'Sustainable City, Sustainable Jobs' program is presented as linking investment in sustainable measures with job creation, expanding networks and career pathways in collaboration with internal and external partners in education and the labour market (D.2). Moreover, the municipality addresses energy poverty, incorporating data from CBS and research from TNO. The municipality claims to work with CBS data to access microdata and analyse at the household level (I.2). Intensified efforts include online webinars on energy conservation, and an energy coach approach that provides residents with savings tips and implements energy-saving measures, particularly in neighbourhoods with high levels of energy poverty. The !WOON foundation provides resident support to tenants who seek to propose energy-saving measures to their landlords (D.1). During the period from April 2021 to July 31, 2022, the target was set to issue a total of 2,250 energy advisories through the !WOON foundation but in the period April through December 2021, 927 of these were realized. Due to COVID-19 measures in the winter, fewer energy advisories could be given. Subsequently, by April 2022, !WOON had furnished a cumulative total of 1,600 energy advisories (D.2). The number of jobs in Amsterdam within the energy transition between January 1, 2020 and one year later has increased by 600. Furthermore, there was a decline in the proportion of low-income households experiencing energy poverty in 2021 compared to 2019. However, it is expected that energy poverty rates have risen again in 2022 due to increased energy prices. Additionally, the proportion of Amsterdam residents expressing a positive inclination towards transitioning to renewable energy has risen to 85%, as indicated by a measurement conducted in February 2022 (D.2). These empirical figures provide substantiating evidence for the municipality's initiatives, affirming actual progress and efficacy in addressing socio-economic challenges within the context of the energy transition.

The integration of socio-economic aspects in data analytic applications presents certain challenges pertaining to data availability in the energy domain. Specifically, there have been instances where a recognized need for data arose, but the requisite information was not readily accessible. An illustrative example is the absence of data concerning the number of homes that have transitioned to natural gas-free alternatives in recent years. To address this data gap, proactive measures were taken by engaging with the grid operator to acquire the necessary insights (I.2). The municipality endeavours to acquire more recent energy data from the grid operator. However, another challenge arises due to the fact that the energy data is aggregated, whereas social data is collected at the individual household level. Consequently, the analyses necessitate being conducted at the neighbourhood level, which poses difficulties in making conclusive statements about the distinct individuals within the neighbourhood (I.1). A major impediment in this regard pertains to privacy concerns, as the grid operator is not allowed to disclose energy data at the household level, safeguarding individual privacy (I.1). Moreover, in recent years, efforts have been made to obtain additional information regarding gas consumption from the grid operator. This initiative has been prompted by escalating gas prices and the pursuit of gas reduction strategies. However, this undertaking presents a challenge in terms of reliance on an external organization, as well as the considerable time and effort required to acquire the desired data (I.2). The task of striking a balance between current needs and available data poses another significant challenge, as outlined by the policy advisor. Despite the substantial potential embedded in data and the increased abundance of data in contemporary times, not all individuals have recognized the imperative to capitalize on it. However, a significant shift occurred last year, wherein there emerged an overwhelming demand for insights. Consequently, there were instances where data completeness was delayed, as acquiring meaningful insights from data invariably demands dedicated effort, time, and resources. It is not merely a matter of meeting existing requirements; there is an aspiration to engender enthusiasm among individuals regarding the possibilities offered by data and to proactively anticipate data-related advancements. Nonetheless, it is crucial to exercise prudence in avoiding excessive forward thinking that may result in unnecessary expenditures. Simultaneously, it is imperative to avoid an insufficient response, as failure to meet emergent needs can result in obsolescence. Thus, the fundamental challenge remains centred on facilitating convergence between these two domains (I.2).

2. Development phase

In addition to data from their own research centres, the municipality of Amsterdam works extensively with external consulting firms. In the preparation process of the external data for utilization in data analytic applications, it is customary to undertake certain modifications. These modifications typically involve performing calculations, reclassifications, and merging of specific categories. Based on the insights derived from the conducted interviews, policy makers demonstrate a perceived understanding of the origins of the data. It is noteworthy that both the data analyst and the policy advisor concur on the notion that policy makers do not necessarily require exhaustive familiarity with every intricate detail associated with the data. The policy advisor also stated that: " *I think it is never necessary for a policy maker to know everything behind the decimal point in too much detail, but they also need to trust that those data analysts are doing a fine job of it*." (I.2). On the other hand, highlighted the significance of facilitating a connection between data and policy in a particular manner, which formed an integral aspect of their role. In addition, in order to enhance the understanding of data among policy makers, it is imperative for data analysts to generate clear and visually intuitive representations of the data.

The people involved in the creation process of the applications are diverse. Grid operators, external research companies, the department Research and Statistics, which includes the data analysts from Municipality of Amsterdam. Within the policy domain itself different people who work on the four different topics; built environment, traffic and transport, electricity and port and industry, which are included in the applications, are also involved in the creation process (I.2). Involving various parties in the creation process of the applications will bring advantages such as a more comprehensive outcome and diverse expertise. On the other hand, it also presents challenges related to conflicting interests and the potential for coordination difficulties. Different stakeholders may have divergent priorities, objectives, and agendas, which can lead to disagreements and challenges in reaching consensus. It is therefore important to make efforts to manage and address these challenges effectively to ensure a productive and inclusive decision-making process.

The data analytic applications are evaluated on the basis of indicators and measures implemented. In total there are 20 different pillars on which the roadmap is evaluated and these are described in the climate report. The policy advisor mentions the following about the evaluation process: "*Every year that is discussed with the city council. And yes, so far that's just to the satisfaction of both the council and the alderman and also the directors.*" (I.2). Throughout the process of data integration, the municipality assesses the prospective value of incorporating new data in order to optimize the applications. If the new data is deemed beneficial, it is incorporated accordingly. In situations involving a substantial volume of new data, the policy advisor may delegate some of the workload to data analysts. With regard to missing elements, both parties acknowledge that the existing applications are well-constructed. The consensus among both data analysts and policy advisors regarding the overall well-constructed nature of the existing applications suggests that the City of Amsterdam has successfully established a robust framework for integrating data into their applications. This acknowledgment reflects the city's adeptness in effectively incorporating data-driven insights, indicating a commendable level of stability and proficiency in leveraging data for informed decision-making processes. Nevertheless, the data analyst expresses a desire to assume greater control over updating indicators rather than relying on external companies. According to the data analyst the ideal situation would be: "*I think that we as research and statistics of the municipality should actually be aware of all the key figures that our municipality and the departments use*." (I.1). However, this matter also entails considerations of capacity, as there comes a point where it becomes infeasible to handle all figures for every department and that is why certain measurements of indicators are made elsewhere.

3. Use phase

To network the knowledge derived from the roadmap and climate report, the applications are internally shared through e-mail and made accessible on the organization's Intranet, accompanied by relevant presentations. In terms of external networking, the roadmap and climate report are published on the municipality's official website. However, prior to public release, they are shared with relevant stakeholders, such as electric utility companies, for the purpose of soliciting their input. This will ensure alignment between the municipality and the stakeholders.

The information obtained during the interviews shows that there are no clear guidelines or courses to implement the applications in the organization. However, the municipality has established standard procedures for informing the alderman, the college, and the council about the applications. Policy makers use the Roadmap Amsterdam Climate Neutral 2050 and the Climate Report as guiding documents and reference points in developing and implementing policies to make the transition from fossil to renewable energy in Amsterdam. The policy makers use the application as a roadmap for implementing specific policies. The roadmap provides guidelines and strategies that help design and implement policy instruments, such as subsidies, regulations, planning and partnerships. It allows policy makers to ensure consistency and align their actions with the overarching vision of a climate neutral Amsterdam. The Climate Report is mainly implemented within the municipality as an important tool for policy makers to track the progress of Amsterdam's climate goals. As the policy advisor stated: "*Once a year, the climate report gives us another finger on the pulse of whether or not things are going in the right direction and whether or not we should do more or less*". (I.2). The annual climate report provides a comprehensive overview of all measures impacting the city's CO2 emissions. The evaluation of executed actions and measures allows for an analysis of the progress made in implementing the Roadmap, facilitating the identification of effective practices and areas requiring improvement. Furthermore, a forward-looking perspective is gained by utilizing the current CO2 assessment conducted by the independent research institute, CE Delft. This enables an assessment of whether the city is on track and determines the need for additional actions (I.2 & D.2).

The roadmap and climate report create knowledge for policy making on socio-economic aspects of the energy transition by incorporating pillar 18, which outlines the municipality's efforts for a climate-just transition. The college emphasizes equity and fairness, while a public support survey assesses public perspectives. The reports identify necessary jobs and link sustainable measures to job creation, while addressing energy poverty through data analysis, webinars, energy coaching, and tenant support. Empirical figures validate progress and efficacy, substantiating the municipality's initiatives. The integration of knowledge from data analysts and policy advisors in the roadmap and climate report was extensive. They collaborated closely, exchanging information, and leveraging each other's expertise. Challenges included data availability, privacy concerns and coordination among stakeholders.

5.1.2. Utrecht

The data analytics applications investigated for Utrecht are the Scenario analytics for Transition Vision Heat part I and II and the dashboard neighbourhood approach to natural gas-free. The Heat Transition Vision Part II is the follow-up to Part I, which was adopted by the council in 2021. In part I, they presented the WAT maps. These show the most logical alternative to natural gas for each neighbourhood and the expected heat demand. It also described the public values used to build collective heat networks. Finally, Part I contained the criteria used to choose the order of neighbourhoods (robustness, affordability and least hassle). In Transition vision Heat Part II, the criteria were further developed and an order of neighbourhoods was determined. The approach goes from WHAT to WHEN and HOW;

- WHAT: An overview indicating the best alternative heating solutions for each neighbourhood instead of using natural gas (part 1) (D.3).
- WHEN: The neighbourhoods are divided into three blocks. Utrecht will begin in block 1 in 2022, with block 3 being completed no later than 2050 (part 2) (D.4).
- HOW: A step-by-step plan for the transition to natural gas-free heating (part 2) (D.4).

Various scenarios were computationally derived through data analysis to ascertain the optimal alternative to natural gas. By systematically examining multiple possibilities, the municipality employed quantitative methods to evaluate and compare potential solutions. This rigorous approach enables evidence-based decision-making and enhances the ability to identify the most suitable course of action in transitioning away from natural gas (I.3 & I.5). In addition, the dashboard neighbourhood approach to natural gas-free is used by policy makers for better decision-making.

1. Preparatory phase

The enlargement of individual knowledge differs between the interviewees. The primary role of the data coach involves eliciting relevant questions from policy makers while also delineating the possibilities and limitations associated with the data. Furthermore, the data coach mentions that through interactions with data scientists and policy makers, new sources of data are discovered. The data scientist emphasizes the significance of formulating precise and specific questions in order to effectively address the needs of the stakeholders. The policy advisor stresses the importance of ongoing communication once data is obtained, to fully comprehend its implications. In order to gain a more comprehensive understanding of the neighbourhoods under study and derive accurate conclusions, policy advisors actively engage with the data department. The data coach shares his tacit knowledge by leveraging personal networks to access datasets that are not readily available to the municipality, subsequently sharing them with the data scientist. The policy advisor's experience has provided her with a more effective approach to formulating well-defined questions for potential ideas presented to the data scientist. The data scientist knowledge and experience in the field helps in choosing appropriate natural gas-free solutions. Brainstorming sessions involving multiple stakeholders were also conducted and that helps in the knowledge sharing process and decision-making process, as also indicated by the data scientist: "*These were, for example, residents' initiatives, people from the heating company, people from Stedin, from the infrastructure, housing corporations, with a whole group we had a discussion session about how they look at it and in that way, of course, you also get a lot of other information about it*." (I.3).

The development of the application's business concept takes into consideration its alignment with the municipality's needs and objectives. In order to facilitate the transition towards a vision of heat sustainability, a team consisting of up to eight individuals, including both data and policy experts, conducted numerous consultations to determine the sequential prioritization of neighbourhoods. The data scientist highlights the utilization of municipal assumptions to calculate the number of households that need to transition away from natural gas within a specific timeframe. The findings indicate the initiation of the process in neighbourhoods where a favourable solution is ensured, while the remaining neighbourhoods are scheduled for future implementation. The policy advisor emphasizes that the municipality developed the dashboard in-house. This ensured that it was aligned with their neighbourhood approach. Furthermore, during the early versions of the dashboard, a network meeting was organized to collectively establish criteria for selecting the initial neighbourhoods. This meeting involved various stakeholders such as residents, housing corporations, installers, grid managers, and other entities involved in the city's sustainability initiatives. The steps to include all relevant data was discussed extensively by internal and external parties. The politicians emphasized the importance of considering affordability and convenience in the decision-making process. Achieving affordability appears more feasible in certain neighbourhoods compared to others, and the same applies to the level of inconvenience associated with the transition. Neighbourhoods with visible affordability and minimal hassle are given priority. Moreover, extensive communication and collaboration with external entities, including grid operators, housing corporations, and an energy corporation, were conducted to incorporate pertinent data. The entire data science process was frequently deliberated with these external parties, enabling the determination of required datasets. Subsequently, the data scientist enriched these external datasets with local data.

Socio-economic aspects are also taken into account. In the TVH is acknowledged that the energy transition must be affordable and reliable for the residents (D.3 & D.4). To engage with residents in these neighbourhoods, various strategies have been implemented, including the deployment of energy coaches, distribution of energy boxes (comprising energy-saving products and personalized tips for reducing energy consumption), and the establishment of joint purchasing campaigns (D.4 & I.4). Furthermore, the municipality has actively sought ways to involve residents in the transformation of their neighbourhoods. To achieve this, walk-in evenings have been organized, offering citizens a platform to voice their opinions and actively participate in the decision-making process (I.3). This approach ensures that residents' perspectives are considered and that they have a meaningful role in shaping the process. Subsequently, the municipality takes into account data on energy poverty and prioritizes neighbourhoods where they can provide support in terms of insulation and reducing energy costs. However, the information on energy poverty is displayed in a separate dashboard and the information is used alongside the information from the Natural gas-free neighbourhood approach dashboard with the more technical-economic data to determine the prioritization of the neighbourhoods (I.5). This is also evidenced by the following statement from the data coach: "*The decisions are initially focused on finding the lowest societal costs for different heating alternatives and therefore the dashboard neighbourhood approach to natural gas-free does not include the social aspects*". (I.4).

It is important to note that the utilization of energy poverty data presents challenges. The availability of up-to-date data on energy poverty is limited, resulting in a lag in the information. Privacy restrictions pose another obstacle, as although the municipality can access household-level data from CBS (Statistics Netherlands), they are not permitted to fully exploit this data. Consequently, obtaining and utilizing data in the desired manner becomes difficult. Additionally, there is a significant lack of data on individual homes themselves, such as whether modifications have been made. The policy advisor further emphasizes the complexity associated with effectively targeting specific audiences, indicating that it remains a challenging task.

2. Development phase

In relation to data preparation, the data scientist highlights the significant effort involved in data cleaning, which constitutes a major aspect of their work. The data obtained from external sources frequently lacks congruence with the BAG (Basic Registration of Addresses and Buildings) data, necessitating extensive time and effort to establish linkages between these datasets. Moreover, in order to enhance the data understanding among policy makers, training sessions will be conducted on utilizing the dashboard. An added advantage of this is that feedback is generated at the same time about additional desired features or possible improvements for the dashboard. However, the policy advisor states the following about the understanding of the data among policy makers: "*it is more important for them to know how good is the quality of the data than to know exactly where it comes from*." (I.5). The policy advisor further asserts that data understanding does not significantly impact the policy formulation process, as the source of data is not overly complex.

The key stakeholders engaged in the development process of the applications include the policy advisor, as well as the data scientists and researchers responsible for data analysis and model creation. Additionally, the end users of the application, represented by project managers working in the neighbourhoods, actively participate in the creation process, providing valuable input regarding the inclusion of relevant components within the model. The advantage of involving multiple stakeholders in the creation process are more comprehensive and effective solutions for their natural gas-free neighbourhoods. By incorporating diverse perspectives and expertise, the resulting application can better address the needs and requirements of all stakeholders involved. In addition, there are short lines of communication within the project team which facilitates the application creation process. Regarding the evaluation of the data analytic applications, formal end-evaluations are absent, with an emphasis placed on continuous evaluations conducted throughout the process. Prompt feedback is provided to the data scientist once outcomes are generated, indicating whether the policy makers are content with the results or if adjustments are required. This iterative feedback loop enables agile adjustments and ensures the application remains up to date. Additionally, the data scientist emphasizes the importance of testing the dashboard on the actual user interface to mitigate potential usage errors. This allows usability issues to be identified and proactively addressed. The policy advisor indicates that there are no specific metrics to assess effectiveness of the applications and states the following: "*the data analytic applications help to make your approach better, but ultimately you don't implement anything with it. So to what extent, then, can you measure whether you are effective or not.*" (I.5). To facilitate a fluent creation process, a designated colleague has been assigned the role of product owner. This individual is responsible for addressing queries and arranging user sessions, wherein diverse stakeholders convene to deliberate on challenges, desired modifications, and prioritization considerations. This collaborative approach proves highly valuable in ensuring a streamlined development process. Additionally, it is noteworthy that the TVH is updated at least once every five years. This periodic review incorporates the latest insights, developments, and experiences, allowing for adjustments to the vision and a reassessment of the neighbourhood sequence.

An examination of the existing applications reveals certain deficiencies, namely the absence of address-level data and the need for improved data accuracy. The data scientist expresses the desire for a regular periodic update of all data to ensure its timeliness. At present, the integration of new data is undertaken by the data scientist personally.

3. Use phase

The dashboard and TVH are publicly available. The responsibility for networking the knowledge of the application rests with the data coach and the policy advisor, who possess an extensive network. In instances such as meetings, they directly explain the significance of the dashboard to project managers and users, as well as demonstrate how to extract information from it. Besides a basic training and explanation, no specialized training courses are offered for application usage, as both the data scientist and the policy advisor assert that the dashboard is not excessively intricate to necessitate such instruction. Regarding the implementation strategy of the dashboard, the data scientist provides the following statement: "*We do have regular meetings where we show what you can do with it, how to work with it and how to interpret it.*" (I.3). The product owner assumes the responsibility of providing guidance and assistance to individuals seeking clarification regarding the dashboard. The application serves the purpose of offering insights into the costs associated with various scenario solutions, and these costs per neighbourhood serve as the basis for determining the prioritization of neighbourhoods. Additionally, the policy advisor mentions that the dashboard's efficient data filtering and selection capabilities facilitate policy decision-making. By leveraging scenario analytics, a determination was made regarding the initial neighbourhoods to prioritize for the transition to natural gas-free environments. The municipality has already made substantial progress in solidifying these plans and is actively collaborating with project teams to start working in the designated neighbourhoods. Subsequent neighbourhoods will be addressed at a later stage, taking into account the availability and pricing of renewable resources, with the expectation of accessing updated information.

To conclude, the applications generate knowledge for policy making on socio-economic aspects of the energy transition, by incorporating aspects such as energy poverty. The municipality supports neighbourhoods by providing insulation and reducing energy costs. Strategies like deploying energy coaches, distributing energy boxes, and organizing walk-in evenings engage residents and incorporate their perspectives. However, challenges arise due to limited availability of up-to-date energy poverty data, privacy restrictions, and a lack of information on individual home modifications. Effectively targeting specific audiences remains a complex task for the municipality.

5.1.3. Rotterdam

Rotterdam is rapidly evolving into an urban centre that embraces sustainable practices and seeks to eliminate reliance on natural gas. Consequently, the city is transitioning away from employing natural gas as a primary heating source for residential houses and exploring viable alternatives from sustainable heat sources. A pertinent query arises: which alternative is most suitable for a given neighbourhood or specific residential archetype? To get an idea of that, the municipality has now made a so-called WHAT map. The WHAT map indicates promising sustainable heat options for each district and is connected with the WHEN map (D.5). The WHEN map shows where the opportunities are for Rotterdam to get started with area approach natural gas-free and determines the order and planning until 2030 with which neighbourhoods will be started (D.6). Together, both maps constitute Rotterdam's Transition Vision Heat (TVH), made in 2021. Currently, the online version of the WHAT map available is version 2.0, which was released in 2021. However, the distribution on the map is not yet fixed, but is expected to be regularly adjusted by new technological knowledge and insights. There are ongoing efforts to develop and update the WHAT map into a system map, which will be the upcoming version 3.0 (I.6). At the moment, Power BI is being used to visualize the results on the WHAT map. In the future, the WHAT map will be further developed and possibly integrated into a 3D viewer of the city of Rotterdam.

1. Preparatory phase

The policy advisor in the municipality of Rotterdam enhances her knowledge through regular interactions with colleagues from the sustainability department and data scientists, appreciating effective communication channels and mutual engagement. Indeed, the policy advisor said the following during the interview: *"But I also sit here in the office on Wednesdays with all the data scientists together and that works incredibly well because the lines of communication are very short."* (I.6). They also adopt the Agile Scrum methodology, gathering weekly for collaborative discussions. Similarly, the data scientist actively participates in meetings and discussions with the policy advisor and other project stakeholders to translate decisions into computation rules. The policy advisor's expertise in data analytics enables her to bridge the gap between colleagues from the policy department and the data scientists, facilitating effective collaboration. The data scientist's tacit knowledge is shared with the policy advisor through discussions, documentation, and routine code transfer. The importance of capturing and recording ideas and insights beyond the standard routines of documentation and code sharing is recognized. The policy advisor acknowledges the varying levels of knowledge among data scientists and emphasizes the need to educate them on topics related to sustainability and system components. Their educational approach is based on individual needs, which sometimes requires more time and guidance.

The data scientist and policy advisor concur that the alignment between the WHAT map and the objectives and needs of the Rotterdam municipality is primarily achieved through the involvement of the policy advisor. The policy advisor works closely with a group of stakeholders, including sustainability advisors and other colleagues from various departments, to define the analysis objectives, formulate questions, and outline the project requirements. The process of incorporating all the relevant information into the WHAT map was facilitated through the utilization of the Scrum methodology, which involved breaking down tasks into tangible and manageable units known as tickets. Throughout this process, there was extensive interaction and feedback moments between the data scientist and the policy advisor, enabling the implementation of adaptable modifications when deemed necessary. This iterative approach ensured a collaborative environment that fostered effective communication and facilitated the incorporation of diverse perspectives and insights into the development of the WHAT map. The data scientist also indicates that it is important for them to be present at many discussions and mentions: "*They want a lot of things in terms of data but there must also be a critical look at whether this is possible*." (I.7). The policy advisor indicates the significant fragmentation of internal data within the organization, which poses challenges in terms of accessibility and time required for acquisition, particularly when relying on external sources. Addressing these challenges necessitates a concerted effort to consolidate all relevant data into a unified data lake, with specific emphasis on its integration with the 3D viewer. Furthermore, discussions have been initiated to establish collaborations with grid operators and heat companies, aiming to enhance data accessibility on a broader scale across the Netherlands. The pursuit of extensive cooperation and effective coordination becomes imperative in order to achieve these objectives and overcome the complexities associated with data acquisition and management. The WHAT map incorporates socio-economic aspects, encompassing non-financial factors such as sustainability indicators. These indicators may encompass various aspects, including the presence of green spaces within the city or the impact of specific interventions on CO2 emissions. Moreover, the map encompasses data on energy poverty, as the policy advisor stated: "*we now have insight into where in Rotterdam there is more or less energy poverty*" (I.6). This allows for the consideration of socio-economic disparities and the identification of areas where additional support in terms of energy affordability and accessibility may be required. By incorporating such socio-economic data, the WHAT map provides a comprehensive framework for understanding and addressing socio-economic considerations within the context of urban planning and policy making. The WHAT map also take socio-economic aspects into account by analysing what the impacts are of the alternatives to natural gas on greenery in the area.

The incorporation of socio-economic data in the WHAT map poses certain challenges, primarily stemming from the presence of missing data. In the absence of comprehensive data, assumptions must be made, potentially influencing the accuracy and reliability of the calculated outcomes. Consequently, these assumptions can have significant implications for the formulation and effectiveness of policy measures. To address energy poverty concerns, the municipality of Rotterdam has established an energy poverty expert. Currently, energy poverty data is visualized at the neighbourhood level. However, there is a desire to obtain more detailed data, enabling policy makers to develop targeted interventions and provide tailored assistance to individuals in need. By accessing more precise data, policies can be refined and resources can be directed in a more focused and impactful manner.

2. Development phase

The responsibility for data preparation within the context of the WHAT map is shared between data engineers and data scientists, with data cleaning primarily falling under the purview of the former, unless it has significant implications for decision-making. The data scientist assumes the role of determining the logical aspects of data utilization, making assumptions and decisions based on the available data. The data incorporated into the WHAT map is sourced from various providers, including the BAG, housing associations, CBS, energy utilities, grid operators, and internal datasets. However, the policy advisor notes that policymakers may not always possess a comprehensive understanding of the data sources, resulting in potential misunderstandings and frustrations regarding data availability. Consequently, the policy process may be prolonged, requiring the policy advisor to invest additional time in clarifying these issues to colleagues. To enhance data comprehension among policymakers, a comprehensive presentation effectively explains the data analytic application. Since January, the WHAT map has been visualized using Power BI, offering a dashboard format. Given the novelty of dashboards for many policymakers, explanatory sessions are conducted to familiarize them with the dashboard's functionality and the interpretation of its content.

The model creation process involves a collaborative effort among key individuals who assume distinct roles and responsibilities. A data engineer plays a crucial role in ensuring the availability of raw data, while the data scientist undertakes the necessary calculations and modelling tasks. The resulting outcomes are then passed on to a business intelligence (BI) specialist, who works closely with the policy team to identify any potential gaps or adjustments required in the model. The involvement of multiple stakeholders is emphasized by the policy advisor, who mentions that colleagues from the sustainability department, consultants, and policy staff who will utilize the model are also involved in the creation process. Acting as a mediator, the policy advisor facilitates effective collaboration and understanding between the stakeholders and the data experts. By actively engaging with stakeholders and data experts, the policy advisor can help align their perspectives, clarify expectations, and bridge any gaps in knowledge or understanding. This can lead to more productive and meaningful interactions, enabling the stakeholders to provide valuable insights and input while ensuring that the data experts can effectively incorporate their expertise into the decision-making process. Ultimately, this collaborative approach can enhance the quality of the application, improve the relevance of the model's outcomes to the policy context, and increase the chance of successful implementation of data-driven policies. The data scientist underscores the importance of continuously verifying assumptions and computational rules to evaluate and justify the model's effectiveness. In line with this, the policy advisor stated the following: "*So far we have only conducted intermediate evaluations, giving presentations to assess whether the model meets the requirements and wishes. We are also exploring new possibilities in addition to the requirements and wishes already set. We notice that some policy advisors have certain requirements but are not used to using dashboards and visualizations. Therefore, it is sometimes necessary to think ahead and consider what they would like to see, as they may not be familiar with the capabilities of tools such as Power BI. But once they are working with it, they are very happy that it is available*." (I.6). The policy maker notes that the data scientist and BI specialist provide input on selecting interesting indicators to incorporate. The inclusion of new data depends on its type, with regularly received data being automatically incorporated while irregularly delivered data necessitates more adjustments due to its dynamic nature. Additionally, the policy advisor underscores the desire for improved accessibility and quality of data from external stakeholders, recognizing its direct impact on the analysis as can be seen from the following statement: "*The better our data is that we have, the better our analysis will be as well.*" (I.6).

3. Use phase

According to the data scientist, the WHAT map is made accessible to all pertinent stakeholders through its publication on a public website and the provision of freely available online visualizations. The data scientist further highlights that communication about the WHAT map, especially at the policy level, is prioritized and emphasized during meetings, announcing the availability of new versions. Furthermore, the visibility and dissemination of the WHAT map are expected to be enhanced through legislative modifications and subsidies that are informed by the insights derived from the map. In a similar vein, the policy advisor recognizes that while data scientists have access to neighbourhood-level data and specific calculations from engineering firms, these are not accessible to residents viewing the map. The policy advisor underscores that residents primarily observe the cost disparities between alternative options. Currently, the WHAT map is accessible online in the form of a PDF file. Internally, knowledge regarding the WHAT map is disseminated through channels such as the Intranet and email, ensuring that pertinent stakeholders, particularly those involved in sustainability, remain well-informed (I.6). The utilization and implementation of the WHAT map within the municipality vary across departments, and each discipline considers what the WHAT map means for them (I.7). Guidelines are available, providing documentation regarding the content and usage of the WHAT map (I.6). A manual for the dashboard, authored by the BI specialist who created it, will also be provided. The primary objective of the WHAT map is to identify opportunities for transitioning Rotterdam to a natural gas-free city by determining the most cost-effective alternative to natural gas for each neighbourhood. Additionally, policy makers can utilize the WHAT map to make informed decisions regarding the allocation of subsidies. The WHEN map serves as a planning tool for the WHAT map, outlining the priority areas to be addressed until the year 2030.

The determined most cost-effective alternative to natural gas for each neighbourhood are incorporated into the WHAT map, which presents the identified solutions. It is important to note that the adoption of these solutions is not obligatory, as building owners retain the freedom to choose their preferred methods for cooking, heating, and cooling without the use of gas. The analysis reveals that, for the majority of neighbourhoods in Rotterdam, connecting to district heating emerges as the most economical option for residents, landlords, and businesses. To prepare for the transition to district heating, individuals can take proactive measures such as energy conservation and insulation in their homes or premises. Furthermore, transitioning from gas stoves to electric cooking is advisable. The municipality supports these preparatory actions by implementing regulations, providing advice, offering subsidies, and facilitating access to loans (D.5). To conclude, the applications generate knowledge for policy making on socio-economic aspects of the energy transition, by including sustainability indicators and energy poverty information. The integration of this data allows for a comprehensive framework to address inequalities and identify areas requiring additional support. However, challenges arise from missing data, necessitating assumptions that may affect the accuracy of outcomes. In addition, obtaining more detailed data is desired to enable targeted interventions and tailored assistance. This would enhance policy refinement and resource allocation for greater effectiveness.

5.1.4. Zoetermeer

The municipality of Zoetermeer and the Zoetermeer housing corporations have been collaborating for several years to make housing corporations and municipal buildings more sustainable, where possible in conjunction with homeowners' associations (VvE's) and private homeowners. Zoetermeer's approach to energy transition is particularly property-oriented. The approach focuses on clustering properties based on characteristics, technical possibilities, and planned maintenance to determine the most effective strategy for sustainability improvements. Data exchange between the municipality and stakeholders has facilitated joint planning, leading to specific action plans for various neighbourhoods. To extend this approach city-wide, a modernized and automated data collection process is necessary to save time and enhance data accuracy, security, and accessibility. The upgraded system will support collaborations, explore collective heat sources, generate progress reports, and create maps and data exports for analysis (I.10). The Heat Vision, developed in collaboration with residents and organizations, outlines the goal of achieving a natural gas-free Zoetermeer and was adopted by the Council in 2021 (D.7). Therefore, in the period 2020-2022, work was done to develop the data model "Information provision Energy Transition Zoetermeer", and ongoing efforts in 2023 will focus on filling it with desired data and developing user-friendly dashboards. The model serves multiple purposes, including monitoring progress, informing municipal planning, identifying cooperation opportunities, facilitating communication with stakeholders, and promoting internal collaboration between departments. Social aspects of the energy transition, such as addressing energy poverty and reducing neighbourhood disparities, are increasingly considered by integrating data from the Social Domain (I.9 & I.10).

The interviewees from the municipality of Zoetermeer include an ETL (extraction, transformation, and load) developer, a policy advisor from the department Green and Energy and an external policy researcher, contracted to facilitate the model's creation. The external policy researcher, who possesses expertise in energy transition, initiated the project and will eventually transition it to the policy advisor for further development.

1. Preparatory phase

The first activity from the preparatory phase is individual knowledge enlargement. The ETL developer acquires additional knowledge through active engagement with policy makers during meetings, aiming to comprehend the required components and reporting procedures of the data model. Initially, the policy advisor played a more passive role, attentively listening and trying to understand the intricacies of the model's development. In order to expand their individual knowledge, the policy advisor emphasizes the importance of pursuing new Python courses as a means of professional growth and skill development and also stated; "*You will also learn the better data terminology from the data analysts*" (I.10). The significance of conducting meetings is emphasized as a means of fostering effective communication and knowledge acquisition. Through engaging in dialogues, individuals have the opportunity to clarify and understand each other's perspectives, leading to the acquisition of new knowledge and insights. The second activity in this phase is sharing tacit knowledge. The ETL developer actively contributes to the construction of the data model by sharing his tacit knowledge and explaining the rationale behind his decision-making process to the policy researcher and advisor. Similarly, the policy advisor contributes tacit knowledge in addressing energy poverty. The external policy researcher highlights the necessity of collaborative efforts to facilitate the sharing of tacit knowledge. Additionally, the policy advisor assumes a crucial role in ensuring that the business concept of the data model aligns with the municipality's objectives and requirements. The ETL developer, taking on a more technical role, seeks guidance from the policy advisor regarding the desired outcomes and eventual dashboard functionalities. The policy advisor affirms that the data model effectively addresses the municipality's needs and goals, as it has been tailored to specifically meet their requirements. The external researcher who initiated the data model project acknowledges the initial absence of awareness regarding the necessity of such an information facility. However, through iterative processes and the demonstration of the data's potential in two initial neighbourhoods, awareness regarding its significance gradually emerged. The project was initiated with a defined set of goals to work towards, and subsequent iterations facilitated the development of the data model (I.9).

The policy advisor indicates that the process of filling the model involved a clear identification of desired data and subsequent exploration of available public sources or data that could be derived through calculations or reasoning based on existing information. The external subject matter expert on energy transition played a key role in determining the relevance and collection of data in consultation with the policy advisor, and the ETL developer relied on their expertise. Initially, a list of questions to be answered through the data model was compiled. Subsequently, the origins of the data were documented and shared with the team, seeking feedback and input. While some data was already accessible internally or obtained from open data sources, certain data required additional steps, such as navigating through an approval process, to gain access to non-public information.

The municipality of Zoetermeer possesses knowledge about neighbourhoods affected by energy poverty, obtained through research conducted by TNO. In addition, in the TVH is stated that the municipality is investigating how to take advantage of job opportunities created by the energy transition (D.7). However, the focus of the data model is specifically on buildings and energy-related factors, which indicates a more technical-economic focus. Individuals receiving welfare or energy allowances are not incorporated into the data model. To include social aspects in decision-making and prioritize interventions to address energy poverty, the municipality juxtaposes the social data from the TVH with the technical data from the data model, to determine the process approach, such as determining the prioritization of neighbourhoods. This approach ensures that energy poverty remains within the scope of the overall energy transition strategy. Defining the precise population affected by energy poverty and experiencing related difficulties remains challenging. Recently, the municipality received state funding to combat energy poverty and established a project employing fixers who provided energy advice and implemented small energy-saving measures on-site. After evaluating the project, there is a proposal to shift the focus towards larger-scale measures, such as cavity insulation, while utilizing information from the data model to determine the most appropriate starting points for implementation (I.10).

2. Development phase

The development phase of the model starts with the preparation of the data. The municipality endeavours to acquire data from various open sources and existing municipal databases to minimize data collection efforts. All three interviewees actively contribute to the data preparation process. Previously, the external expert assumed responsibility for data collection, but it has now transitioned to the policy advisor's role. The policy advisor is also responsible for updating data in excel files, while the ETL developer handles the process of reading these excel files into the data warehouse. One particular challenge encountered during data collection relates to obtaining data from housing associations. The policy advisor further highlights that the policy makers may not possess comprehensive understanding regarding the sources of data incorporated into the data model, stating the following: "*... for them it's also not a big deal where things come from.*" (I.10). Therefore, there are also no implications for the policy process. Dashboarding will become the main activity to support the use of the data model and the understanding for policy makers. The creation of dashboards will be done in collaboration between the data and policy side.

The people involved in the development of the data model encompass the external policy researcher responsible for initiating and overseeing the model's establishment. Additionally, the BI team consists of the ETL developer, who handles the data warehouse and data model, as well as GIS specialists who contribute to the creation of dashboards. The policy makers and advisors from the Sustainable and Green department are also actively engaged in the model creation process. The policy advisor, in collaboration with the external researcher, conducts a content evaluation to identify the essential elements to be incorporated into the model. Technical modifications are undertaken by the ETL developer. Furthermore, the policy advisor notes that the evaluation of the model occurs annually in consultation with grid operators and housing associations. The policy advisor mentioned also: "*But now if someone has a question, then we look for information to go with it. Anyway, it's still not quite full the data model but that's all going to run this year and those GIS maps as well*." (I.10). There is a lot of interaction between the policy staff and the data side and also the intended users. From all the sources in the data model, a lot is read automatically, but there are also things that require manual work, and in that area has been chosen to update it annually. An example of this is the data from housing associations on how often renovation plans and schedules change. The integration of new available data runs through the policy advisor now and tells the ETL specialist what needs to be added to the model. The policy advisor and external policy researcher mentioned both the same missing element. Currently, there is no good data available on whether a house is natural gas-free or not. The policy advisor also expresses the desire to have data on whether a property is 'natural gas-free ready': "*We are still mainly reactive at the moment, but what we really want is to detect opportunities. In other words, how big is our task in Zoetermeer?*" (I.10). This is important to take into account for more targeted management and implementation of policies.

3. Use phase

The TVH of Zoetermeer is publicly available and accessible online. The external policy researcher mentions the following about people who have access to the model: "*We have described in the note for the directors who has access to the data model in functions of the people and we update that annually*." (I.9). The dissemination of knowledge regarding the data model primarily occurs through the policy advisor, who serves as the central networking hub. The project group members are granted access to a dedicated Geographic Information System (GIS) platform, which provides them with data accessibility. The GIS platform acts as an intermediary portal connecting to the underlying data model, which is exclusively accessible to the ETL developer. The policy advisor is equipped with an Excel-based extraction that facilitates their access to the data. Notably, the GIS maps accessible to the project group differ from the forthcoming GIS maps intended for resident use (I.9 & I.10).

The primary purpose of the model is to address inquiries pertaining to the energy transition, specifically focusing on identifying the appropriate locations for energy poverty initiatives. The responsibility of collecting and consolidating the necessary information to address these queries lies with the policy advisor. She is responsible for the dissemination of pertinent knowledge to relevant parties, acknowledging the importance of sharing information as deemed necessary. However, access to the model is limited to a select group to ensure efficiency, as this constitutes the adopted implementation strategy. The policy stated the following about this: "*In any case, we have now arranged it this way: access to the model for the partners who fill the model, and that is the municipality, but only the people working on the energy transition. Because this model is also defined for that purpose.*" (I.10). The ETL developer helps explaining ambiguities to policy makers if necessary. The guidelines for the dashboard and GIS maps that will be made available are not explicitly defined, but emphasis is placed on ensuring clarity in their design. The inclusion of a summary alongside any selection made aims to provide immediate clarification. It is crucial that members of the energy transition group, who will utilize the GIS maps, are aware of the appropriate channels for addressing any queries they may have. This is facilitated by the shortened communication pathways between the policy and data teams. To delineate the scope and limitations of the model, this information is documented in a note, the data model itself, and a data sharing agreement. These resources outline the specific data categories that are considered sensitive and warrant special attention.

Despite the fact that the model is not yet completely finished and neither are those GIS maps, it is already being used as a tool that helps to make decisions and to implement policies. In addition, the model is used for feedback to the council and already used for the TVH. The data model serves a dual purpose in terms of its utilization. Firstly, it functions as a tool for monitoring various aspects related to the energy transition. This involves tracking and assessing the progress, outcomes, and performance indicators associated with the transition efforts. Secondly, the data model serves as a means to identify and explore potential opportunities. By analysing the data and extracting relevant insights, stakeholders can uncover areas where interventions, improvements, or innovative approaches can be implemented to further advance the energy transition goals. To conclude, the applications generate knowledge for policy making on socio-economic aspects of the energy transition by juxtaposing the results from the data model with the demographic information to identify areas of overlap and prioritize interventions for addressing energy poverty. Defining the precise population affected by energy poverty and experiencing related difficulties remains challenging.

5.1.5. ‘s-Hertogenbosch

By 2050, 's-Hertogenbosch wants to be a sustainable municipality. They are working towards that in achievable steps. The municipality created the sustainability monitor in 2021 to show how they are doing. The sustainability monitor is regularly updated with new insights and a new version is currently under construction. 's-Hertogenbosch is working towards a healthy, green and climate-resistant living environment, a CO2-neutral municipality, value preservation of raw materials and sustainable mobility. These four ambitions are central to the monitor (D.8). In addition, in terms of socio-economic aspects, there is also a separate dashboard available which deals with energy poverty. Due to high energy prices new working groups were formed, and one of those working groups was about strengthening information position. The question was whether it is possible to bring together all the figures related to social security and, in particular, energy poverty to indicate trend developments. There was also an impact energy team looking at what can be done in terms of energy poverty, what measures can be deployed and what the effects are (D. 9 & I.12). The interviews about the sustainability monitor involves both a data scientist and policy maker. In addition, the policy researcher who knows more about energy poverty was also interviewed.

1. Preparatory phase

The individual knowledge enlargement is the first step in the preparatory phase. The data scientist emphasizes the importance of effective coordination with policy makers in the initial stages of a project. Understanding the specific information needs of the client enhances knowledge acquisition. The data scientist actively engages with policy makers by participating in sustainability conferences, fostering a connection and deepening expertise in the field. This reciprocal exchange of knowledge and understanding is deemed crucial. The policy maker acknowledges the increasing alignment between policy and data, with policy makers possessing valuable insights into neighbourhoods and districts. Tacit knowledge sharing is facilitated through collaborative brainstorm sessions involving individuals from diverse policy departments and data teams. The data scientist stated: “*Then, of course, you all share your own knowledge*”. (I.11). The policymaker also stated that through iterations with each other you share tacit knowledge.

To ensure that the application is in consistent with the needs and goals of the municipality the sustainability monitor is set up according to the four ambitions described. The policy maker expresses the need to assess the progress made in achieving the objectives outlined in the TVH. To determine relevant indicators, the policy researcher engages in discussions with a select group consisting of the Economics and Energy Department, as well as the Financial Services. The data scientist highlights the municipality's utilization of both internal and external data sources. However, due to data unavailability, it is not feasible to incorporate all data into the sustainability monitor. The policy maker stated the following about this; "*it's also a matter of sometimes, because this is such a new topic, to just try it out and make a first version of something.*" (I.13). This indicates that even though the monitor is not yet complete in terms of data they are already running a first version and are going to supplement it with new data over time. Regarding socio-economic aspects, the policymaker emphasizes that energy poverty and heat networks are the two main focal points in the heat transition. The municipality has recently commenced active monitoring of these aspects, specifically identifying neighbourhoods with higher instances of energy poverty. Efforts have been made to promptly address and assist affected individuals while ensuring equitable participation in the energy transition. Privacy poses a significant challenge in integrating socio-economic data into analytical applications. Although information such as income and utility bills is known, privacy restrictions prevent their aggregation, limiting the municipality's ability to provide optimal support. Furthermore, uncertainty remains prevalent, with substantial data gaps. While energy poverty analysis is currently conducted at the neighbourhood level, it offers limited insight into individual circumstances at the household level. Significant uncertainties persist within the data, discouraging overreliance on models, as this tends to neglect individuals who do not conform to the established parameters. As for a municipality, the primary objective is to cater to residents who often face greater challenges or constraints. Accordingly, diverse strategies should be employed to engage with these individuals, with the aim of consistently identifying suitable and tailored approaches. This results in many different methods which is difficult to capture in one model or summary.

2. Development phase

The data scientist highlights that data preparation for the sustainability monitor is good manageable. The policy researcher explains that when dealing with energy data from utilities, there may be instances where non-residential buildings such as stores or restaurants exhibit high energy consumption. To address this, filters are applied to include only residential properties. Furthermore, the data must be checked for outliers and missing values, and appropriate handling methods must be implemented. The policy maker acknowledges limited understanding among their peers regarding the data sources. While they possess knowledge about data related to their own involvement, such as energy poverty data, they have less familiarity with more general aspects like the sustainability monitor. The policy makers generally do not delve into the specifics of data sources, relying on the assumption that the data has been obtained from reliable sources. Nonetheless, this lack of detailed knowledge does not impede the policy process. To facilitate data understanding, the data scientists emphasize the importance of presenting graphs in a straightforward manner and incorporating accompanying textual explanations. In addition, the policy maker mentions: "*I think that's why they hired me because I do have some data background, data knowledge and also some experience visualizing data, especially geo-data, and then I can take this and communicate it to the rest of the team*." (I.13).

The sustainability monitor encompasses not only the energy transition but also broader sustainability and climate adaptation aspects. The creation process involves the collaboration of multiple teams, including those focused on mobility, sustainability, energy, and potentially specialized teams within the broader sustainability domain, along with the research and statistics department. Regarding the dashboard development for energy poverty, key participants include policy makers, representatives from the research and statistics, economics and energy departments, as well as a stakeholder from the financial services industry. The evaluation of the sustainability monitor involves the active involvement of policy departments, who are responsible for determining the relevance of indicators. The data scientists also have a role in providing input on indicator selection. Additionally, the sustainability monitor is regularly reviewed in relation to the goals established by the council, and necessary actions are identified to progress towards these goals. The identification of relevant indicators is an iterative process conducted through meetings, as highlighted by the policy researcher. The integration of new available data for the sustainability monitor is still mainly done manually by the data scientist. The policy researcher from energy poverty dashboard stated: "*Basically that dashboard is set up so that some data is loaded automatically. For example, if there are new data from CBS, those are loaded automatically and some things we really have to add manually*". (I.12). Quantifying what impact certain measures have had or will have is something the policy maker would still like to add to the monitor.

3. Use phase

To network the knowledge of the applications, the data scientist stated the following, "*The sharing of monitors or otherwise products, is actually usually the responsibility of the client, so not the research and statistics department, but the policy department that put out the order to us*." (I.11). The sustainability monitor is available on the municipality's website. This approach ensures accessibility and transparency of the monitor for both internal stakeholders and the general public. Contrary to the monitor, the energy poverty dashboard is only shared internally due to confidential information. By publishing the monitor publicly, the municipality can transparently demonstrate how they are doing with the energy transition.

The data scientist acknowledges a lack of awareness regarding the specific utilization of the monitor but according to the policy maker, the current functionality of the monitor is communicating both visually and with text how sustainability and the energy transition is going. However, it does not provide detailed insights into the effectiveness of specific measures or their impact. Presently, there are no explicit guidelines provided regarding the application's usage. The data scientist emphasizes the objective of ensuring usability for all users, eliminating the need for instructional materials. Additionally, the municipality possesses an internal Google Maps and a visualization page where individuals interested in utilizing these tools can undergo training. The policy researcher energy poverty also indicates that there are no guidelines for this dashboard and stated: “*We call it a dashboard, but on the one hand it is a piece of reporting so to speak so some numbers that don't change that much just have a kind of reporting form. The dashboard piece is more in it that you can filter and put things together*.” (I.12). To conclude, the applications generate knowledge for policy making on socio-economic aspects of the energy transition in the following way; the sustainability monitor is primarily used to convey numerical information to the council, which plays a pivotal role in policy formulation. The dashboard specifically focusing on energy poverty serves as a tool to identify areas affected by energy poverty based on quantitative data, determining the initial points of intervention for the municipality. It facilitates the planning of subsequent actions and enables the evaluation of the appropriateness and effectiveness of these measures.

5.1.6. Tilburg

To achieve climate neutrality by the year 2045, the municipality of Tilburg has formulated a comprehensive plan known as the Transition Vision Heat. This plan outlines a gradual transition away from natural gas within the municipality from 2022 to 2045. The proposed sustainable alternatives for Tilburg include the implementation of heat networks, the adoption of 'all-electric' solutions, and the utilization of green gas as viable options for meeting heating needs (D.10). The TVH is in Tilburg under the name "Tilburg to the New Heating". This is an initiative of the City of Tilburg to make the city's heat supply more sustainable. The project aims to replace traditional natural gas-fired heating systems with innovative and sustainable alternatives, such as heat networks, geothermal and other forms of renewable energy. In doing so, Tilburg aims to reduce CO2 emissions and contribute to the transition to a climate-neutral city (D.10). The TVH is displayed on the website of Tilburg in story maps. Story maps are visual and interactive tools used to tell stories using maps, graphics and text. At the moment, the policy advisor Energy from the department of Space is working with the data employees to collect data to create an informational map box for the energy transition. This map box will help to select neighbourhoods according to the TVH. Included in the map box is the multi-year program, the replacement task of housing associations and information on natural gas replacements and urban development areas. The 2023-2026 Multi-Year Program (MYP) shows the plans for major and minor interventions in public spaces in the years 2023, 2024, 2025 and 2026. With all these map layers, insight can be gained into which areas are priorities and where important developments are occurring. This information allows the municipality to make informed decisions about starting the transition in certain neighbourhoods (I.15).

1. Preparatory phase

Extensive collaboration between the data and policy domains is evident, characterized by frequent and regular meetings. The data scientist emphasized their active involvement in all meetings pertaining to the TVH, ensuring their continuous presence and active participation throughout the process. Their aim is to be fully engaged in the decision-making process and contribute to the synergy between data-driven insights and policy development. The policy advisor also stated about enlarging individual knowledge: "*I would rather do it together so that I also get knowledge about the city, than that I outsource it and I get a product, because then you don't have that interaction and knowledge.*" (I.15). The external project manager conducted an in-depth analysis of the data models employed by the municipality to gain a comprehensive understanding of their content and relevance to the local context. Additionally, the models underwent rigorous evaluation by various experts and agencies, contributing to the municipality's internal knowledge enhancement. Consequently, valuable insights and cross-disciplinary collaborations emerged from this process. The GIS advisor emphasizes the importance of tacit knowledge sharing, particularly when exploring data insights as a collective effort. The policy advisor acknowledges the active exchange of in-depth knowledge on energy generation with data scientists. Moreover, internal discussions and brainstorm sessions involving various stakeholders, as facilitated by the external project manager, have fostered a shared understanding of the process approach for the Transition Vision on Heat (TVH). As a result, this collaborative environment ensures comprehensive awareness and alignment among the involved parties.

The GIS advisor highlights the role of policy makers in aligning the applications with the needs and goals of the municipality of Tilburg. Initial ambitions are formulated by the municipality, followed by detailed discussions on the necessary actions and projects to realize those ambitions. This iterative process ensures that the applications effectively support the municipality's goals and contribute to their achievement. The external project manager stated the following: "*What we did initially was writing down the preconditions and the principles along which we are going to draw up this vision and share them with a steering committee. The steering committee includes the alderman, the director of the housing associations, someone from Tilburg University and a delegation from the energy associations. This will then also be recorded in the college and to the council.*" (I.16). Subsequently, the inclusion of relevant data entails a series of steps, commencing with the processing of extensive datasets originating from diverse sources. Subsequently, the newly acquired data is transformed into a usable format, followed by iterative discussions among stakeholders to assess the accuracy and validity of the outcomes derived from the data analysis, particularly employing multicriteria analysis. Notably, the municipality was granted access to the electricity and gas consumption records of all Tilburg residents, enabling an examination of the anticipated changes that would occur upon adopting alternative heating methods. This has been extracted from the CEGOIA (Comprehensive Energy Generation Optimization for Individual Assets) models. CEGOIA is a mathematical model developed by CE Delft. It calculates the national costs of sustainable heating options. In addition, data was gathered from TNO and PBL, which was subsequently compared with the data obtained from the CEGOIA model. This process involved translating the abstract data into concrete implications and insights specific to the context of the municipality of Tilburg. With respect to the map box, new map layers are added over time, as the policy advisor also describes: "*it is actually a kind of growing entity*." (I.15).

As for the socio-economic aspects, the municipality has emphasized the importance of cost-neutrality in the energy transition and takes energy poverty into account. The municipality's objective is to ensure that sustainable heating and cooling solutions are affordable for all residents of Tilburg. To achieve this, solutions must be "cost-neutral" for end-users, meaning that the savings on energy bills should equal or surpass the costs of implementing sustainable measures or potential rent increases. The "Energy Household Book of the Tilburger" serves as a tool to assess current energy costs, the costs of sustainable alternatives, and the projected expenses if no action is taken, such as lack of insulation and continued reliance on natural gas. In addition, energy coaches and energy boxes are provided. This applies to both homeowners and tenants and is an initiative of the municipality together with three housing associations. Moreover, all tenants of three Tilburg housing associations also received a voucher worth about €85 from the municipality of Tilburg, which they can use to purchase energy-saving measures from affiliated stores (D.11). Currently, a large-scale transition to natural gas-free alternatives is deemed unaffordable. Nonetheless, inaction is not a viable option due to climate concerns and increased costs. Thus, Tilburg is actively pursuing insulation initiatives and the promotion of renewable energy generation. However, challenges arise in determining the scope of data to be used and the appropriate level of abstraction. Another challenge lies in reconciling data on individuals' preferences and readiness to transition away from natural gas with technical data, which proves to be complicated (I.14). Outdated data on energy poverty further complicates the situation (I.14). The policy advisor underscores the notion that data provides an educated estimation but not an absolute truth, highlighting the necessity of conducting home visits to gather more precise information and enhance the effectiveness of decision-making processes.

2. Development phase

The municipality of Tilburg adopts a transparent approach to ensure that the entire process can be easily replicated. In the TVH, detailed information is provided regarding the sources of data and the specific datasets utilized. To facilitate data preparation for the TVH, a Jupiter Notebook was created, documenting each step taken to process the data. This approach enhances repeatability and transparency in data handling. Regarding the understanding of data among policy makers, it is observed that individual preferences and working styles greatly influence their level of interest and engagement with data. Some policy makers prefer a visual representation of data through data visualizations, enabling them to form a clearer picture. On the other hand, there are individuals who prefer to have the data analysis conducted externally, with only the final results presented to them. This variability in data understanding and preference highlights the need for diverse approaches to effectively communicate and present data insights to different stakeholders. To support the data understanding among policy makers, the GIS advisor mentions the following: "*It is important that everyone can open and see the data in a way that they can understand themselves*". (I.14). In particular, this is done through data visualization tools, such as dashboards, online maps, graphics and printouts. There is also the possibility of taking an infoGIS course.

The creation process of the TVH involved a diverse set of individuals, each contributing their expertise and perspectives. The core team consisted of the policy advisor, who also served as the project leader for the TVH, two external project staff members, a data scientist, and a GIS advisor from the data department. Additionally, a steering committee was established, comprising representatives from housing corporations, who actively participated in brainstorming sessions and provided valuable input. For the development of the map box, a separate team was formed, which included a data analyst, a data worker responsible for visualizations and map setup, a policy advisor, and a strategic advisor. This multidisciplinary team worked collaboratively to ensure the effective implementation and visualization of spatial data within the map box. The involvement of these various individuals from different roles and backgrounds highlights the importance of collaboration and expertise integration in the creation of the TVH and map box, facilitating a comprehensive and informed decision-making process.

The evaluation and justification of the TVH and the map box involve a systematic process that encompasses collaboration between the policy makers, data analysis and research department, and the

GIS advisor. The policy maker initiates the evaluation and integration of new data by requesting updates on specific aspects of the TVH, such as the vision, figures, or dashboards, in response to new data or insights. This request prompts the revision and updating of the TVH every five years to ensure its relevance and accuracy in light of emerging information. Similarly, the evaluation of the map box involves communication channels between the data department and policy advisors. The policy advisors are informed of any changes or updates in the map box through regular communications. They assess the current status of the map layers and determine whether they remain relevant or require modification. To incorporate new map layers, the policy makers generate a notification through a service point system, signalling the need to include specific map layers to the data analysts. The assignments are then distributed and prioritized within the system. Regarding potential missing elements in the applications, the GIS advisor identifies the potential value of utilizing more accurate energy poverty data for neighbourhood implementation plans during the concrete implementation phase. This highlights the importance of incorporating relevant data to enhance the effectiveness of neighbourhood-level initiatives. Furthermore, the policy advisor expresses the desire for more predictive data, particularly in response to new policy changes, as it would facilitate informed decision-making and planning processes. The evaluation and improvement processes undertaken by the municipality of Tilburg emphasize the iterative nature of the TVH and map box, allowing for periodic updates and data-driven insights.

3. Use phase

Networking the knowledge of the model for the TVH is the responsibility of the communication department. They are responsible for strategically networking and effectively communicating the model's insights to various stakeholders. This involves devising communication strategies, such as creating story maps, to effectively convey the information encapsulated in the TVH model. The communication department also coordinates communication campaigns aimed at raising awareness and promoting understanding of the TVH among the target audience. The story maps developed for the TVH are made accessible to the public through the municipality of Tilburg's website. This platform serves as a centralized repository where individuals can access and explore the story maps, facilitating widespread dissemination and knowledge sharing. By making the story maps readily available to all, the municipality aims to promote transparency and ensure that the information reaches a broad audience. In contrast, networking the map box primarily occurs through email correspondence. Individuals within the data department responsible for managing the map box actively add relevant personnel who require access to the map box. As the map box is a specialized tool tailored specifically for energy transition purposes, access is limited to individuals directly involved in the municipality's energy transition initiatives. This restricted access ensures that the map box remains accessible only to those stakeholders who have a direct involvement in the energy transition efforts.

The implementation strategy of the Transition Vision on Heat (TVH) follows a targeted approach, resembling a butterfly pattern (D.10, I.14 & I.16). This involves a comprehensive analysis of the city to identify similar areas and determine the optimal starting points for the implementation strategy. The areas already encompassed by the AVA plant, representing the low-hanging fruit in terms of feasibility and readiness, are prioritized for initial implementation. The TVH serves as a crucial tool for providing transparency and accountability to both the council and the citizens of Tilburg. It outlines the municipality's planned actions, spanning months and years, and the rationale behind these decisions. In addition, it helps policy makers in prioritizing neighbourhoods for the implementation of natural gas-free heating (I.16). However, there are currently no explicit guidelines available for utilizing the TVH effectively. To ensure successful integration of the map box within the organizational framework, it is presented during team meetings where its functionality and potential applications are explained. This serves as a means to familiarize staff members with the tool and enable them to harness its capabilities. Furthermore, policy makers have the opportunity to receive training from infoGIS on how to utilize the map box effectively. By leveraging the map box, stakeholders are empowered to gain insights and the map box helps policy makers to select neighbourhoods according to the TVH.

To conclude, the applications generate knowledge for policy making on socio-economic aspects of the energy transition by focusing on cost-neutrality in the energy transition, ensuring affordability for all residents. The "Energy Household Book of the Tilburger" assesses current energy costs, sustainable alternatives, and projected expenses. In addition, the municipality provides energy coaches and energy boxes (D.10 & I.14). Challenges include customized data, reconciling social data with technical data, and outdated energy poverty data. Transparency and aggregated energy bills aid decision-making. Home visits are necessary for precise information. An energy box and conversation with the energy coach is not yet available to everyone in Tilburg. Currently, invitations are sent out on a district-by-neighbourhood basis. The neighbourhoods are chosen based on data on energy poverty and WOZ (Real Estate Valuation) value of homes, and always in consultation with the housing corporations (D.11 & I.16).

5.2. Cross-case analysis

In addition to the within-case analysis, the six municipalities are also compared to each other. The concepts from the three phases of the framework were compared between the municipalities and this section discusses the key similarities and differences. This will shed light on the most common and striking outcomes of the municipalities. The key findings of the three phases for each of the six municipalities are presented in Table 5, 6, and 7.

Table 5. Key findings of the six municipalities within the preparatory phase

Municipality	Preparatory phase					
	Individual knowledge enlargement	Sharing tacit knowledge	Business concept			Challenges
			Needs and goals of the municipality	Steps to include all relevant data	Socio-economic aspects	
Amsterdam	- Enlargement through work experience and interactions with colleagues and other stakeholders. - Cross-pollination of knowledge between the policy department, data analysts, and external parties.	- Sharing through project meetings. - Policy advisor's data proficiency facilitates complex knowledge exchanges.	- The policy department discusses goals with the city council and incorporates them into the business concept.	- The data analyst and policy advisor collaborate in a step-by-step process to gather relevant information, deliberate on decisions, and identify data sources. - Subject matter specialists responsible for data pertaining to their respective domains.	- Pillar 18 of the roadmap and climate report focuses on a climate-just energy transition. - Energy poverty data from CBS. - Public support surveys - Addressing energy poverty through programs and initiatives.	- Accessing specific data. - Privacy concerns of household-level data. - Aggregated data hinders detailed analysis at the household level. - Balancing the current need for data with future possibilities.
Utrecht	- Data coach and data scientist	- Accessing datasets through	- Consultation between data and policy	- Extensive discussions	- Neighbourhood prioritization based on energy	- Limited availability of up-to-date energy

	emphasizes precise questions. - High engagement between policy advisors and data scientist.	personal networks. - Data scientist's knowledge and experience helps in choosing solutions.	department to prioritize neighbourhoods - In-house development of dashboard with stakeholder input.	- Consideration of affordability and convenience. - Collaboration with external entities. - Data scientist enriches external datasets.	poverty data. - Strategies to approach energy poverty include energy coaches, energy boxes, and joint purchasing campaigns. - Residents actively engaged in decision-making.	poverty data. - Privacy restrictions. - Lack of individual home data. - Targeting specific audiences is complex.
Rotterdam	- Regular interactions and discussions - Agile Scrum methodology - Knowledge transfer documentation and routine code transfer. - Educating data scientists on sustainability and system components.	- Discussions, documentation and routine code transfer. -Policy advisor educates data scientists on sustainability and system components.	- The policy advisor ensures alignment between the applications and the objectives and needs of the Rotterdam municipality - Policy advisor collaborates with stakeholders to define objectives and outline requirements..	- Utilizing Scrum methodology - Extensive interaction and feedback moments enable adaptable modifications. - Collaboration with grid operators and heat companies.	- Sustainability indicators - Indicates energy poverty distribution within Rotterdam. - Impacts of alternatives to natural gas on greenery in the area.	- Missing socio-economic data - The accuracy and reliability of calculated outcomes. - Energy poverty data at the neighbourhood level.
Zoetermeer	- Actively engagement between data and policy during meetings. - The policy advisor seeks professional growth and skill development by pursuing new Python courses. - Dialogues	- The ETL developer's knowledge helps in decision-making for the data model. - Guidance from the policy advisor on desired outcomes and dashboard functionalities.	- The initial awareness of the data model's significance emerged gradually through iterative processes and the demonstration of the data's potential in two neighbourhoods	- Public sources or derived data are explored. - Key role of external policy researcher - A list of questions to be answered through the data model is compiled. - Access to non-public information may require additional steps,	- Social data from TVH is juxtaposed with the data model's results to prioritize interventions for addressing energy poverty.	- Defining the population affected by energy poverty. - Combining social data with techno-economic data.
's-Hertogenbosch	- Effective coordination between policy and data. - Engagement in conferences.	- Collaborative brainstorming sessions. - Iterations	- Sustainability monitor aligns with municipality's goals. - Progress assessment of TVH objectives.	- Utilization of internal and external data sources. - Initial implementation of sustainability monitor while supplementing with new data.	- Active monitoring of neighbourhoods with energy poverty. - Efforts for equitable participation and prompt assistance.	- Privacy restrictions limit data aggregation. - Uncertainty and data gaps in socio-economic data. - Overreliance on models neglects those not conforming to established parameters.
Tilburg	- Active involvement of data scientists in TVH meetings. - Collaborative knowledge	- In-depth knowledge exchange among policy departments, data teams,	- Formulating ambitions, aligning applications, and discussing actions with stakeholders.	- Processing extensive datasets, transforming data into usable format.	- Energy poverty data - Energy household book, energy coaches and boxes, and vouchers for	- Reconciling individual preferences with technical data. - Outdated energy poverty data.

	sharing and interaction between data analyst and policy maker.	and data scientists. - Iterative discussions - Collaborative efforts for comprehensive understanding.	- Sharing preconditions and principles with a steering committee for approval.	- Iterative discussions to assess accuracy. - Access to electricity and gas consumption records for analysis.	energy-saving measures. - Energy transition must be cost-neutral.	- Determining data scope and appropriate level of abstraction. - precise information.

As can be seen in Table 5, the enlargement of knowledge is mainly being realised through actively engagement between data and policy department during meetings. This emphasizes the importance of regular interactions between these parties to enable individual knowledge enlargement. Sharing tacit knowledge is mainly done through discussions, brainstorm sessions, and collaboration between data analysts and policy advisors, and higher levels of data proficiency facilitate more complex knowledge exchanges. To ensure that the data analytics applications are in line with the needs and goals of the municipalities was mostly the role of the policy advisor/maker. Furthermore, to include all relevant data collaboration with both internal and external partners is important. Municipalities rely on external companies for their energy data, which takes considerable time and effort as well to acquire the desired data. Addressing energy poverty through programs and initiatives seems to be a key similarity of the municipalities about including socio-economic aspects. Energy poverty is also increasingly taken into account in prioritizing neighbourhoods. However, the inclusion of socio-economic aspects occurs at a higher level of abstraction compared to the technical-economic dimensions due to privacy concerns. Consequently, integrating both sets of aspects within a single application, such as in dashboards, poses challenges, as highlighted by the municipalities of ’s-Hertogenbosch, Utrecht, and Zoetermeer. Accessing more specific data, privacy restrictions, and limited availability of up-to-date energy poverty data are common challenges among municipalities.

Table 6. Key findings of the six municipalities within the development phase

Municipality	**Development phase**						
	Data preparation	**Data understanding**	**Model creation**	**Evaluation & justification of the model**			**Challenges**
				Target values and indicators	**Integration of new data**	**Missing elements**	
Amsterdam	- Modifying external data through calculations, reclassifications, and category merging.	- Policy makers have a perceived understanding of the data. - Policy maker with data background. - No implications for the policy process. - Data visualizations to enhance understanding.	- Various parties - Policy advisor leading role	- Evaluation of roadmap based on indicators described in the climate report. - Evaluation of climate report involves discussions with the city council.	- If new data is deemed beneficial, it is integrated accordingly. - Primarily done by policy advisor.	- Capacity considerations limit the ability for data analyst to handle all figures for every department.	- Divergent priorities, objectives, and agendas among stakeholders
Utrecht	- Data cleaning - Establishing linkages between	- No complex data sources enhance the data understanding	- Multiple teams involved, - Policy advisor	- Continuous evaluations and prompt feedback	- Primarily done by data scientist.	- Address-level data and - Data accuracy	- Accurate data

	external and BAG data	among policy makers - Training sessions to improve user's understanding - No implications for the policy process. - Data coach as bridge between data and policy	leading role	- Usability testing mitigates errors. - TVH updated every five years.			
Rotterdam	- Data cleaning	- Clarifying data sources and comprehensively explaining the data analytic application. - No implications for the policy process. - Policy maker with data background.	- Various parties - Policy advisor leading role	- Inter-mediate evaluations - Input from data scientists and BI specialists in indicator selection.	- Regularly received data is automatically incorporated. - Irregularly delivered data requires adjustments.	- Clarifying data sources to policymakers	- Ensuring data availability and quality. - Adjusting to dynamic nature of irregularly delivered data.
Zoetermeer	- Open data sources and municipal databases used. - Policy advisor and ETL developer responsible for data preparation and updating.	- Policy makers do not need to possess comprehensive understanding regarding the data. - No implications for the policy process. - Data visuals will be used for supporting understanding	- Various parties - External policy researcher and policy advisor have leading role	- Annual evaluation with grid operators and housing associations. - Interaction and feedback between policy staff, data side, and intended users.	- Manual and automatic data integration. - Policy advisor guiding role	- Data on natural gas-free ready houses.	- Obtaining data from housing associations.
's-Hertogenbosch	- Data scientist responsible for data preparation – Applying filters on energy data from utilities. - Checking outliers and missing values.	- Limited understanding among policy makers about data sources - No implications for the policy process. - Presenting graphs and textual explanations. - Policy maker with data background.	- Multiple teams involved.	Policy departments evaluates indicators. - Data scientists provide input on indicator selection. - Regular reviews.	- Manual integration of new data in sustainability monitor by the data scientist. - Automatic and manual data updates for energy poverty dashboard.	- Quantifying the impact of measures in the sustainability monitor.	- Limited insights into measure effectiveness.
Tilburg	- Detailed data processing steps documented in a Jupiter Notebook.	- Individual preferences and working styles influence policy makers' engagement with data.	- Multiple teams involved in the creation process.	- Periodic updates and evaluations - TVH updated every five years.	- New data and updates to the TVH and map box are requested from the policy	- More accurate energy poverty data - Predictive data	- Incorporating accurate data on energy poverty to enhance the effectiveness of neighbourhood-level initiatives.

		- GIS tools and an infoGIS course support data understanding.			makers to the data analysts.		- Gaining more predictive data in response to new policy changes.

Table 6 shows the key findings of the development phase. Most data preparation work is in modifying external data to the internal data base the municipalities use. A striking remark is the fact that Tilburg shows again their open transparent approach by documenting in detail their data processing steps. The municipalities agree on the fact that the policy makers do not need possess comprehensive understanding regarding the data sources within the applications. This has no further implications on the policy making process. Overall, the understanding of the data is supported with basic training sessions and/or clear visual representations. Subsequently, to create a better collaboration between the policy and data department, the municipalities Amsterdam, Rotterdam and ‘s-Hertogenbosch all have a policy advisor/maker who is very knowledgeable about data and can therefore ensure good translation and between data and policy. In Utrecht, this role is fulfilled by the data coach. However, in Zoetermeer, an external person was hired with high expertise on energy transition and data, and is now transferring the knowledge to the policy advisor by working closely together on the application. Within the municipality of Tilburg, the policy advisor who works with the map box and the external project manager from TVH application also show high affinity to work with data. Furthermore, the model creation involves collaboration among multiple teams and stakeholders in all municipalities, with policy advisors playing a facilitating role. The involvement of these various individuals from different roles and backgrounds highlights the importance of collaboration and expertise integration in the creation process, to facilitate a comprehensive and informed decision-making process. Continuous evaluations and iterations are very important to ensure that the data analytics applications keep up to date. The role of the integration of new data differs between the municipality, in which half indicate this is done by the policy advisor, and the other half indicate it is done by the data analyst. Moreover, the missing elements and challenges are most of the time related. The main challenges include accurate energy poverty data, ensuring data availability, and divergent priorities among stakeholders. Overall, the municipalities strive to improve data quality by for example, spending effort in obtaining more recent energy data from grid operators and enhance understanding among policy makers with data visuals.

Table 7. Key findings of the six municipalities within the use phase

Municipality	**Use phase**			
	Networking the knowledge of the model	**Deployment**		
		Implementation strategy	**Guidelines on the use**	**Use purpose of the application**
Amsterdam	- Soliciting stakeholder input for alignment. - Internal and external sharing (via website).	- The Roadmap and Climate Report accessible to the public. - Open and transparent process.	- No usage guidelines - Standard procedures inform key stakeholders.	- Roadmap provides guidelines and strategies that helps policy making. - Climate report serves as a monitor of the Roadmap.
Utrecht	- Data coach and policy advisor network and explain the dashboard's usage in meetings to the users. - Dashboard and TVH are publicly available online.	- Regular meetings held to demonstrate usage and interpretation of the dashboard. - Product owner provides guidance and assistance for clarification.	- No specialized guidelines needed. - Basic training and explanation provided.	- Dashboard provides cost insights for scenario solutions, guiding neighbourhood prioritization. - Dashboard’s efficient data filtering and selection capabilities facilitate policy making.

Rotterdam	- Internal and external sharing (via website). - Networking emphasized in meetings and through legislative modifications and subsidies. - Neighbourhood-level data not accessible to residents.	- The public availability indicates a transparent implementation strategy of the applications. - Utilization varies across departments.	- Guidelines and manual available for content and usage of WHAT map.	- WHAT map identifies cost-effective alternatives to natural gas per neighbourhood. - Helps policymakers allocate subsidies. - WHEN map serves as planning tool, outlining priority areas until 2030.
Zoetermeer	- TVH is publicly available. - Only internal sharing of the data model and access is defined in a note for directors, updated annually. - Policy advisor serves as central networking hub.	- Selected group with access to data model to enhance efficiency and short communication links. - Note defines access to the data model for partners working on energy transition.	- Scope and limitations of data model documented in a note, in the data model itself, and in the data sharing agreement.	- Data model monitors energy transition progress and serves as a decision-making tool. - Identifying energy poverty initiative locations.
's-Hertogenbosch	- Policy maker is responsible for sharing the monitor and related products. - The monitor is publicly available on municipality website. - The energy poverty dashboard is only available internally due to confidential information.	- By publishing the monitor publicly, the municipality can transparently demonstrate how they are doing with the energy transition.	- No explicit guidelines needed for both applications. - Internal training available for visualization tools.	- Sustainability monitor conveys numerical information to council for improving policy formulation. - Energy poverty dashboard identifies areas affected by energy poverty, determines intervention points, facilitates planning and evaluation of measures.
Tilburg	- Communication department responsible for networking of both applications. - Story maps are publicly accessible through the municipality's website.	- Butterfly pattern approach used for TVH implementation. - Prioritize areas already encompassed by AVA plant. - TVH provides transparency and accountability for planned actions.	- No explicit guidelines available for TVH utilization. - Map box functionality explained in team meetings. - Possibility to follow infoGIS course for policy makers to effectively utilize the map box.	- TVH provides transparency to both the council and residents on planned actions and helps policy makers to prioritize neighbourhoods. - Map box helps policy makers to select neighbourhoods according to the TVH.

Table 7 presents the key findings of the six municipalities within the use phase of the data analytic application creation process. To network the knowledge of the data analytic application, some municipalities adopt a more open approach, such as sharing the data analytics application on a public website. This is a positive observation, since an open approach enables transparency, accessibility and knowledge sharing of the applications. On the other hand, some municipalities adopt a more selective approach in networking knowledge. This also applies to the implementation strategy of the municipalities. The type of data analytics applications plays a crucial role in here. This can be seen, for example, at the municipality of 's-Hertogenbosch where the energy poverty dashboard is only shared internally due to confidential information about residents. Another key finding is that in general all the municipalities agree on the fact that the data analytics applications do not need an explicit guideline on the usage. This indicates the importance of accessibility and enhances the validity of the applications. Additionally, an interesting remark is the use purpose of the data analytics applications. Most of the applications are created to support policy makers in the prioritization of neighbourhoods for implementing natural gas-free heating, in which energy poverty is also often included. This can be explained by the fact that in most municipalities the TVH is investigated, which has as its main goal to make municipalities climate-neutral and natural gas-free. Monitoring and evaluating the progress of the energy transition initiatives represents another common use purpose.

Subsequently, another interesting variation among the municipalities lies in the varying levels of maturity observed in their data analytics applications. Mature data analytics applications demonstrate stability and require minimal feedback and improvements, exemplified by the cases of Amsterdam, Utrecht, and Rotterdam municipalities. As Rotterdam, for example, is already working on a third version of the WHAT map. In addition, the kind of application also specifies the maturity. The municipality of ‘s-Hertogenbosch and Tilburg are becoming more advanced in the field of data-driven work, illustrated by the implementation of their sustainability monitor and story maps. These initiatives signify a remarkable level of expertise in data skills, allowing data to be used and presented effectively in a meaningful way. The municipality of Zoetermeer is more in the starting phase to use data analytic applications for decision-making. Zoetermeer is currently working on developing a dashboard alongside the data model and indicates a developing application that is in progress and not yet fully matured.

5.2.1. Knowledge creation by data analytics applications

The data analytics applications in each municipality contribute to knowledge creation for informing policy making on socio-economic aspects of the local energy transition. In Amsterdam, the data analytics applications provide valuable insights by gathering and analysing data related to the built environment, traffic and transport, electricity and port, and industry. In addition, social data is also included, such as data on energy consumption and energy poverty. The information generated through these applications contributes to the understanding of the current state of the city's energy transition, identifies potential barriers or opportunities, and aids in the formulation of effective policies.

The data analytics applications employed by the municipality of Utrecht use scenario modelling and calculations, data visualization, and analytical techniques to assess different alternative heating options to natural gas. It evaluates the impact of specific interventions, and identifies optimal strategies for achieving local energy transition goals. The insights gained from these applications inform policy making by providing data-based recommendations and enabling policy makers to make informed decisions for prioritization of neighbourhoods.

Additionally, the data analytics applications from Rotterdam involve spatial analysis, mapping, and visualization techniques to understand the distribution of energy infrastructure, assess the readiness of different areas for transition, and identify priority locations for intervention. The knowledge derived from these applications helps policy makers in Rotterdam identify specific areas and sectors where socio-economic aspects of energy transition require attention, facilitating targeted policy-making.

In Zoetermeer, the data analytics applications integrate various energy data sources and function as a tool for monitoring various aspects related to the energy transition. By analysing the data and extracting relevant insights, areas are uncovered where interventions, improvements, or innovative approaches can be implemented to further advance the energy transition goals. By juxtaposing the results from the data model with the social demographic information helps policy makers to prioritize interventions for addressing energy poverty.

The data analytics applications of the municipality of ‘s-Hertogenbosch gather data on sustainability indicators, energy consumption, and energy poverty metrics to monitor the city's progress in sustainable development and identify vulnerable communities that may require targeted interventions. The insights derived from these applications facilitate and inform policy makers by monitoring the energy transition initiatives and identifying energy poverty areas which allows for the implementation of more targeted measures.

The data analytics applications Tilburg employs utilize spatial analysis, storytelling techniques, and data visualization to communicate the socio-economic aspects of the heat transition in Tilburg. They provide policy makers and stakeholders with a visual and interactive understanding of the challenges, opportunities, and potential impacts of different energy transition strategies, thereby informing policy-making processes. The applications generate knowledge on socio-economic aspects by focusing on cost-neutrality in the energy transition and ensuring affordability for all residents. By analysing data related to energy poverty, such as household energy consumption patterns, income levels, and social vulnerability, policy makers can identify neighbourhoods that are most in need of interventions and support. This data-driven approach enables the municipality to allocate resources and implement measures in a targeted manner, addressing the socio-economic aspects of energy poverty within specific communities.

5.2.2. Knowledge integration from data analyst and policy makers in DDPM

The data analytic application creation process is a part of DDPM. In the context of all municipalities studied, active collaboration, regular meetings, and knowledge sharing sessions, such as brainstorming, play a critical role in the during the phases of the data analytic application creation process. The extensive collaboration between data analysts and policy advisors enhances knowledge integration. These collaborative efforts aim to address socio-economic factors, facilitate data understanding and data preparation, and integrate external data sources while engaging relevant stakeholders. Challenges encountered during the data analytic application creation process encompass data availability and accuracy, privacy concerns regarding social data, and the need to strike a balance between the current need for data with future possibilities. During the phases of the data analytic application creation process, continuous evaluation, feedback, and improvements are consistently prioritized, indicating a dynamic and iterative approach to DDPM. Notably, the recurring emphasis on collaboration, interaction, and regular meetings by both data analysts and policy advisors/makers indicates a significant integration of knowledge from both parties within the DDPM process of the municipalities.

5.2.3. Challenges

The implementation of data analytics applications on socio-economic aspects to inform local energy policy making in Dutch municipalities presents several challenges. These challenges vary in their extent and impact across municipalities due to their different kind of applications and available resources within the municipality. Firstly, one significant challenge revolves around acquiring accurate and reliable socio-economic data. Municipalities often encounter difficulties in obtaining pertinent data from diverse sources, ensuring its quality, and addressing issues such as missing or incomplete data. Secondly, integrating diverse datasets from various sources poses challenges in terms of data compatibility, formatting, and consolidation. Combining data from different departments or external sources requires efforts in data cleaning and linkage to establish a cohesive dataset. Additionally, the combination of social data with technical energy data poses a notable challenge, leading some municipalities to employ separate data analytic applications for energy data and social data, including energy poverty data. This can for example be seen at the municipality of ‘s-Hertogenbosch who have a separate dashboard on energy poverty and the municipality of Utrecht also indicated to have two separate dashboards, one including the neighbourhood approach to natural gas-free, and one containing the energy poverty data. Thirdly, adhering to privacy regulations, and ethical guidelines when handling sensitive socio-economic data is crucial. As a result, it was not always possible to analyse and manage at the household level, so analyses had to be done at the neighbourhood level. This hampers the ability to gain detailed insights into individual household circumstances, hindering the precise identification of areas affected by energy poverty and thereby impeding the targeting of policies to address these specific needs. Moreover, smaller municipalities, such as ‘s-Hertogenbosch, express a deficiency in measuring the effectiveness of implemented policies on socio-economic data compared to the larger municipalities. The findings also indicate that large municipalities have greater capacity and more financial and human resources allocated specifically towards data analytics efforts. Moreover, these municipalities have larger data departments and have established robust collaborations with external partners that allow them to access data from external companies more quickly. Conversely, small municipalities face constraints in terms of in-house expertise and resource availability, resulting in potential constraints in the scope and sophistication of their data analytics applications.

These challenges underscore the complexity of implementing data analytics applications in the context of local energy policy making. Overcoming these obstacles requires collaborative efforts in data acquisition, integration, privacy preservation, and policy evaluation, particularly in smaller municipalities where resource limitations and expertise gaps may be more pronounced.

6. Discussion

This chapter critically examines the empirical findings from this study in relation to the existing literature, identifies limitations encountered during the research process, highlights the significant contributions made by this study, and provides recommendations for future studies.

6.1. Empirical findings next to literature

The application of the theoretical framework represents a crucial aspect to be addressed. The study of H. van der Voort et al. (2021) tested the framework for the development of a small-scale risk model at the Dutch Food and Safety Products Authority (the NVWA). In this study, the framework's usability was tested in the context of decision-making processes for energy policies in municipalities. Notably, the framework was adequate applicable in the context of energy transition, but some extensions were made to enhance the framework's relevance and applicability. Additional subcategories of specific primary concepts were added to the framework to provide more clarity on what is expected of certain primary concepts, and to better align with energy transition policy making. Importantly, the extended framework now encompasses socio-economic aspects in addition to techno-economic energy data. The elaborated theoretical framework is illustrated in Figure 4, and the extensions are represented by the red contours. The Figure is presented additionally in Figure 5 in Appendix D, which excludes the red contours.

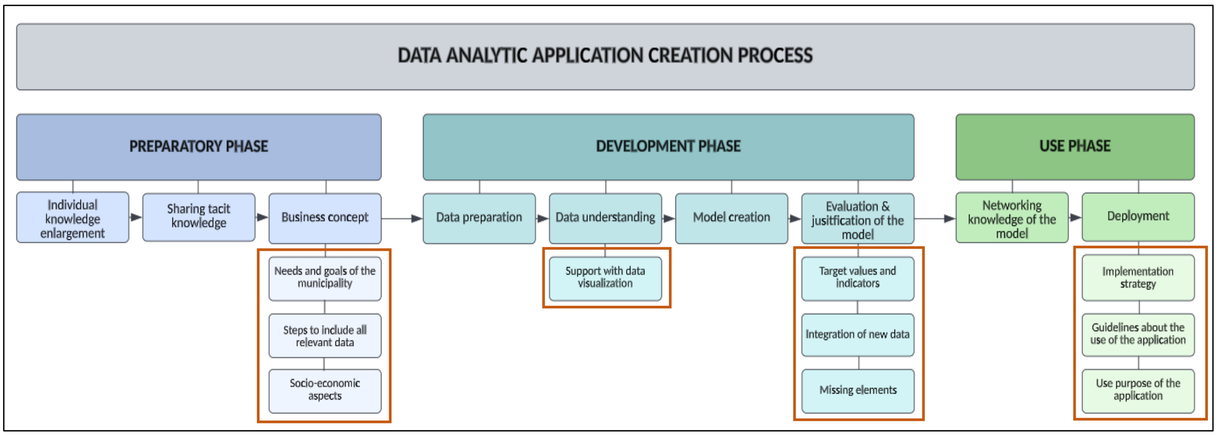

Figure 4. Final theoretical framework of the data analytic application creation process

Previous research found that policy makers need to understand the outcomes of analytics and their implications, and it was found that the experience of the policy maker, influences the decision-making process in a positive way, enabling faster and better decision-making. Accurate data quality was also essential to avoid costly wrong decisions (Janssen et al., 2017). In addition, the study of Dingelstad et al. (2022) identified the competencies teamwork, critical thinking, data literacy, domain expertise, engaging stakeholders, innovativeness, data analytical skills, and political astuteness, crucial for DDPM. From the present study it can be confirmed that these competencies are emphasized within the Dutch municipalities, as these competencies are important concepts mentioned by the municipalities in the phases of the data analytic application creation process. However, accurate data quality seems to be still a challenge across the municipalities.

Moreover, the present study has provided a more complete image on how the data analytic applications in each municipality contribute to knowledge creation for policy making on socio-economic aspects of the energy transition. The literature review showed that data analytics can help improve decisions, could potentially affect existing roles within organizations regarding the use of knowledge, and may change decision-making, policy formulation, agenda setting, capabilities and incentive structures (Klievink et al., 2017; H. G. van der Voort et al., 2019). The present study confirms these claims, as the municipalities indicated that the data analytics applications are changing decision-making by making decisions for certain policies now based on data and not only relying on experience and intuition of the policy maker. The data analytics applications function as guiding documents for policy implementations and neighbourhood prioritization, tracking progress towards the energy transition and facilitate policy decision-making.

In addition, literate review revealed that data-driven applications can assist in identifying the potential of renewable energy sources (Ramachandra, T. V. Shruthi, 2007; Schiel et al., 2016); mapping energy demand; planning building renovations; planning of heat and cooling networks and also data-driven applications focusing on citizen and stakeholder engagement (Diran et al., 2022). In the present study the cases enabled also the function of planning of heat and cooling networks as most of the applications function as guides to plan where to start with natural gas-free heating. In addition, the data analytics applications are seen as decision-support tools, with these new functions that they offer. The applications give insight on all the information regarding the energy data, which helps in making decisions for planning building renovations and prioritization of neighbourhoods to natural gas-free alternatives. To gain even more insight into the potential of renewable energy sources and assess public perspectives on the energy transition, for example, a public support survey was commissioned by the municipality of Amsterdam. In most of the cases the data analytics applications were actively involving citizens and stakeholders in the creation process of the application to ensure are more comprehensive and effective solutions for their natural gas-free neighbourhoods.

Furthermore, previous research found that there is awareness among Dutch municipalities on the fact that social aspects influence heating transition projects but could not always be included in their respective energy models. The study suggested that it would be better to present these aspects alongside the techno-economic data to identify coupling opportunities and/or to determine prioritization of neighbourhoods (Henrich et al., 2021). This partly overlaps with a few cases from the present study. In the municipalities of Utrecht, Zoetermeer and 's-Hertogenbosch, technical energy data and social data related to energy poverty are not integrated within the same data analytics applications. The municipalities compares the results from both aspects to identify areas of overlap, prioritize interventions for addressing energy poverty, and for the prioritization of the natural gas-free neighbourhoods. Similarly, the municipality of Tilburg expresses challenges in combining social data with technical data, as these domains are perceived as distinct and separate entities. In contrast, the municipality of Amsterdam and Rotterdam experienced no difficulty in combining the social and more technical energy data. This can possibly be explained by the fact that the municipalities employ very different kinds of applications. For some applications it is more feasible or appropriate to combine these types of data than for others. For instance, the data analytics applications employed by Amsterdam encompass policy documents, which facilitate the inclusion of both social and technical data by means of descriptive results. However, the integration of these data types within a single dashboard turned out to be difficult due to varying levels of data aggregation. Privacy restrictions necessitate that social data must be presented at a higher abstract level than technical data, which makes the data integration in a single dashboard more complex.

6.2. Limitations

This study encompasses four limitations. First, there was a focus on six municipalities in the same country. Therefore, the generalizability of these findings to other geographical, cultural and political contexts might be fairly limited.

Second, limited access to background information on some data analytic applications, such as in the case of the data model from the municipality of Zoetermeer and the energy poverty dashboard from the municipality of ‘s-Hertogenbosch, limited the reflection on the applications reviewed in the case studies. In the present study, the knowledge integration of data analysts and policy makers, and the incorporation of socio-economic aspects were only investigated at the surface level, based on publicly available data and the interviews. However, this is justified by the fact that the current state of research on this topic is emerging, and therefore it was deemed appropriate to employ an exploratory research approach. This approach enables the exploration and initial examination of key aspects and variables, providing a foundation for future in-depth studies.

Third, the data collection tools chosen, interviews and abductive coding, also have their respective limitations. Interviews and abductive coding are research tools that require a high degree of interpretation from the researcher. However, the creation of interview transcripts and a code book enhances the reliability of the data collection process, and ensured that the coding process remains consistent and reliable across different interview transcripts.

Fourth, in five of the six cases, both the policy maker/advisor and the data analyst involved in the development of the same application were approached. However, only for the municipality of Tilburg was this not successful. Due to personal circumstances, the policy maker could no longer be interviewed. For this municipality it was therefore decided to speak to another external project manager about the Transition Vision Heat (TVH) application to still gather more information about the policy side. However, this makes it impossible to assess whether the policy maker of the TVH also has a data background, which helps in the cooperation between data and policy and the development and implementation of the application, as observed in the other cases.

6.3. Recommendations and contributions

The application of this framework in the context of the energy transition represents a novel contribution to the scientific field. By adapting and extending the framework, incorporating additional activities and considering socio-economic aspects alongside techno-economic data, new dimensions are introduced that enrich the framework's applicability and relevance. A scientific recommendation is to further explore and validate the extended framework's effectiveness by conducting comparative studies to evaluate the framework's performance against alternative frameworks or methodologies used in the energy transition context. This would contribute to a deeper understanding of the framework's unique value. Additionally, it would be valuable to conduct longitudinal studies to assess the framework's adaptability and resilience in evolving energy transition contexts. As the energy landscape continues to evolve, the framework's ability to capture and integrate new insights and data becomes crucial.

Based on the findings of this study, practical recommendations can be made to enhance the use of data analytics applications by Dutch municipalities in supporting policy making on socio-economic aspects of the local energy transition. These include strengthening knowledge sharing mechanisms, such as brainstorm sessions and discussion. Fostering interdisciplinary collaboration between data analysts and policy advisors is also recommended, as it was noticed from the cases that an extensive collaboration between data analysts and policy advisors enhances knowledge integration. In addition, privacy restrictions regarding social data were one of the most common challenges across the municipalities, and therefore it is recommended to identify effective strategies to address these privacy concerns. Conducting regular evaluations and feedback loops about the applications also proved to be highly important for successful development and use of the data analytics application. By implementing these recommendations, Dutch municipalities can improve their policy making processes and enhance socio-economic equity and just transitions.

Furthermore, the present study focus exclusively on applications in the local energy transition context, but the energy transition is much broader. Structured literature review and more case studies are recommended to better substantiate the research gaps identified in this study, by including the provincial and national level of government, and a wider geographical coverage.

Overall, this study emphasizes the significance that data analytics applications including socio-economic aspects, offer a powerful tool for Dutch municipalities in their pursuit of sustainable energy transitions. By harnessing the potential of these applications and addressing the challenges involved, municipalities can make informed decisions, promote socio-economic equity and just transitions, and foster a more sustainable future.

7. Conclusion

Previous research on Dutch energy transition and policy has predominantly focused on techno-economic aspects, neglecting the central role of citizens (Haarbosch et al., 2021). However, energy transitions encompass more than just technological changes and involve significant societal impacts (Miller & Richter, 2014). Municipalities play a crucial role in operationalizing and realizing the energy transition, yet there remains a gap in understanding how socio-economic aspects in data analytics applications informs policy and how knowledge from data analysts and policy makers is integrated in energy transition policy making. To address these gaps and improve policy making processes, the creation of a synergy between these sources is necessary. This study utilized and extended the framework developed by H. van der Voort et al. (2021) to analyse the knowledge creation of the data analytics applications, and the use of knowledge from both the data analysts and policy makers in the data analytics application creation process.

In order to gain insights into the use of data analytics applications by Dutch municipalities, specifically in informing policy making on socio-economic aspects of the local energy transition, a multiple-case study was conducted. The study focused on six Dutch municipalities: Amsterdam, Utrecht, Rotterdam, Zoetermeer, 's-Hertogenbosch, and Tilburg. In each of the cases, two connected data analytics applications used for energy policy making were investigated. The main research question addressed in this study was: "*How and to what extent do data analytics applications create knowledge to inform policy making on socio-economic aspects of the energy transition in the Netherlands?"* This main question was supported by the following sub-questions: (1) **"**How is the knowledge from data analysts and policy makers integrated in the process of data-driven policy making?" And (2) **"**What challenges are present and to what extent are they present among Dutch municipalities in implementing data analytics applications on socio-economic aspects that inform local energy policy making?"

The findings of this study reveal the valuable contribution of data analytics applications in Dutch municipalities towards knowledge creation for policy making on socio-economic aspects of the local energy transition. First of all, the municipalities have created a transition vision heat that outlines how the municipalities plan to become natural gas-free and climate-neutral by 2050. This is one of the most common data analytics applications used by the municipalities. Additional applications include policy documents, data models and data visualizations. The information generated through these applications contributes to the understanding of the current state of the municipalities' energy transition, identifies potential barriers or opportunities, and aids in the formulation of effective policies. In addition, socio-economic aspects are increasingly considered in the data analytics application. For example, energy poverty is often included, which enables policy makers to make informed decisions for prioritization of neighbourhoods for implementing natural gas-free heating. Furthermore, the knowledge derived from these applications facilitate and inform policy makers by monitoring the energy transition initiatives and identifying energy poverty areas, which allows for the implementation of more targeted measures. However, combining the social and technical energy data in one data analytics application was not always possible. This can possibly be explained by the fact that the municipalities employ very different kinds of applications. For some applications it is more feasible or appropriate to combine these types of data than for others. The integration of these data types within a single dashboard turned out to be difficult due to varying levels of data aggregation. Privacy restrictions necessitate that social data must be presented at a higher abstract level than technical data.

Secondly, there is a significant integration of knowledge from data analysts and policy makers within the DDPM process of the municipalities. During the phases of the data analytic application creation process both the data analysts and policy makers emphasize the importance of active collaboration, regular meetings, and knowledge sharing sessions, such as brainstorming. The extensive collaboration between data analysts and policy advisors enhances knowledge integration. Continuous evaluation, feedback, and improvements are consistently prioritized, indicating a dynamic and iterative approach to DDPM.

Thirdly, implementing data analytics applications on socio-economic aspects that inform local energy policy making encounters challenges. These challenges vary in their extent and impact across municipalities due to their different kind of applications and available resources within the municipality. The most common challenges were acquiring accurate socio-economic data, integrating social aspects and technical aspects in a single data analytics application, and privacy concerns. Smaller municipalities face additional limitations in measuring the effectiveness of implemented policies. Overcoming these obstacles requires concerted efforts in data acquisition, integration, privacy preservation, and policy evaluation.

Future research directions in this field are conducting comparative studies to evaluate the framework's performance against alternative frameworks or methodologies used in the energy transition context. An additional direction is to conduct longitudinal studies to assess the framework's adaptability and resilience in evolving energy transition contexts. The implications on practice for Dutch municipalities include strengthening knowledge sharing mechanisms, fostering interdisciplinary collaboration between data analysts and policy advisors, identify effective strategies to address privacy concerns regarding social data, and conduct regular evaluations and feedback loops about the applications, to improve their policy making processes and enhance socio-economic equity and just transitions. Furthermore, it is recommended to translate this study to a wider geographical coverage, by including also the provincial and national level of government.

All in all, this study highlights the importance of integrating data analytics applications that contains socio-economic aspects and knowledge from data analysts and policy makers in informing local energy policy making in Dutch municipalities. It emphasizes the need to address the challenges associated with data acquisition, integration, and privacy concerns to enhance decision-making processes and promote a successful energy transition. By understanding and leveraging the synergies between data analysts and policy makers, municipalities can effectively utilize data analytics applications to inform policy making on socio-economic aspects of the energy transition.

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Appendix A

Interview guide - Policy maker

<u>Introduction</u>

Good day, first of all thank you for taking the time to do this interview. Now let me introduce myself briefly; I am Claire van der Sanden, currently following the master Innovation Sciences at the University of Utrecht and working on my Thesis in combination with an internship at TNO. My Thesis is about the use of data analytics applications by Dutch municipalities to support policy making on socio-economic aspects of the local energy transition. I want to investigate how data analysts and policy makers/advisors are involved in the development of the data analytics application by conducting interviews with both.

Before I start, I would appreciate it if I could make an audio recording of the interview. Is that OK with you? I have sent the informed consent form via mail already. The recording will be deleted after transcribing the interview. The results will be utilised for the Thesis.

Opening questions

1. Can you briefly introduce yourself by means of your functions and experience?
    a. What knowledge do you need to perform your function?
2. Can you tell me more about how [xx application] is developed and used?

Enlarging individual knowledge

3. Different actors have different sources of knowledge and all these sources of knowledge may be valuable in the data science process for the creation of [xx application]. How do you personally seek to enlarge your own knowledge through the interactions with data analysts?

Sharing tacit knowledge

4. Both data analysts and policy makers possess a type of knowledge that is hard to express, document, or transfer to others. This is commonly referred to as tacit knowledge. This form of knowledge is acquired through personal experiences, observation, and is deeply rooted in an individual's mindset and values. Can you describe some actions or activities that you have participated in to facilitate this sharing of tacit knowledge with data analysts?
    a. What kind of tacit knowledge?

Business concept

5. How did you ensure that the concept of [xx application] was aligned with the needs and goals of the municipality?
6. What steps were taken to ensure that all relevant data or information for you as a policy maker were included in [xx application]?
    a. Which socio-economic aspects are included in [xx application]?

Data understanding

7. To what extent is there a good understanding among policy makers of where the data from [xx application] comes from?
    a. What are the implications of that on the policy making?

Data preparation

8. What has been done to support the understanding and use of [xx application] for policy makers?

Model creation

9. Which persons were involved in the model creation process of [xx application] and what was your role as a policy maker in it?

Evaluation and justification of the model

10. How do you evaluate whether [xx application] meets your expectations? Are there any specific features or functionalities that you look for in this application, or any particular metrics that you use to assess their efficacy?
11. Are there any additional elements that you would like to see added to [xx application], and how might these enhancements help to further inform and support policy decisions?
    a. If new data becomes available, how will it be incorporated into the model?

Networking knowledge

12. How do you ensure that relevant stakeholders are aware of and have access to [xx application]? Can you describe any specific measures or processes that have been implemented to facilitate networking of this application?

Deployment

13. How is [xx application] currently implemented in your organization?
14. Are there guidelines or courses provided on the use and interpretation of the application?

Challenges

15. What are some of the challenges you face on implementing data analytics applications on socio-economic aspects that inform local energy policy making?
16. What is currently being done by policy makers to overcome such challenges?
17. What do you think is necessary to overcome such challenges?

<u>Closure</u>

We have come to the end of the interview. Do you have any further questions for me?

Thanks a lot for your time and the interesting insights for my research. In connection with further information gathering, I was wondering if you might know other relevant people I could approach for an interview?

Finally, I think it would be nice to organize a workshop with different municipalities at TNO in which I would explain the results of my research. In this way the municipalities also have the possibility for further discussions with each other about this topic. Would you be interested in attending this workshop?

Interview guide – Data analyst

<u>Introduction</u>

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3. Different actors have different sources of knowledge and all these sources of knowledge may be valuable in the data science process for the creation of [xx application]. How do you personally seek to enlarge your own knowledge through the interactions with policy makers?

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    a. What kind of tacit knowledge?

Business concept

5. How did you ensure that the concept of [xx application] was aligned with the needs and goals of the municipality?
6. What steps were taken to ensure that all relevant data or information for you as data analyst were included in [xx application]?
    a. Which socio-economic aspects are included in [xx application]?

Data understanding

7. Where did the data come from and how was it collected?
8. What has been done to support the understanding and use of [xx application] for policy makers?

Data preparation

9. How is the data prepared (e.g. data cleansing) to ensure easy usage for in the model?

Model creation

10. Which persons were involved in the model creation process of [xx application] and what was your role as a data analyst in it?

Evaluation and justification of the model

11. How do you evaluate whether [xx application] meets your expectations? Are there any specific features or functionalities that you look for in this application, or any particular metrics that you use to assess their efficacy?
12. Are there any additional elements that you would like to see added to [xx application], and how might these enhancements help to further inform and support policy decisions?
    a. If new data becomes available, how will it be incorporated into the model?

Networking knowledge

13. How do you ensure that relevant stakeholders are aware of and have access to [xx application]? Can you describe any specific measures or processes that have been implemented to facilitate networking of this application?

Deployment

14. How is [xx application] currently implemented in your organization?
15. Are there guidelines or courses provided on the use and interpretation of the application?

Challenges

16. What are some of the challenges you face on implementing data analytics applications on socio-economic aspects that inform local energy policy making?
17. What is currently being done by data analysts to overcome such challenges?
18. What do you think is necessary to overcome such challenges?

<u>Closure</u>

We have come to the end of the interview. Do you have any further questions for me?

Thanks a lot for your time and the interesting insights for my research. In connection with further information gathering, I was wondering if you might know other relevant people I could approach for an interview?

Finally, I think it would be nice to organize a workshop with different municipalities at TNO in which I would explain the results of my research. In this way the municipalities also have the possibility for further discussions with each other about this topic. Would you be interested in attending this workshop?

Appendix B

Secondary data

Table B1. Overview of the secondary data documents

Document ID	Municipality	Document
D.1	Amsterdam	Roadmap Climate Neutral Amsterdam
D.2		Climate report Amsterdam
D.3	Utrecht	Transition vision Heat Part I
D.4		Transition vision Heat Part II
D.5	Rotterdam	WHAT map
D.6		WHEN map
D.7	Zoetermeer	Heat Vision 2022 (Transition Vision Heat).
D.8	‘s-Hertogenbosch	Sustainability Monitor 2021
D.9		Sustainability Annual Report 2022
D.10	Tilburg	Storymap Towards The New Heating in Tilburg
D.11		Appendix Toolkit Addressing Energy Poverty Best Practice

Appendix C

Codebooks

Table C1. Deductive codebook

Second order codes	First order codes
Role interviewee	Data analyst
	Policy maker
Knowledge requirement	Knowledge about current situation of the municipality
	Data analytic knowledge
	Knowledge about the energy domain
Individual knowledge enlargement	Collaboration during the project
	Reading new publications and articles
	Project meetings
Sharing tacit knowledge	Meetings
	Brainstorm sessions
	Workshops
Kind of application	Dashboard
	Monitor
	Document
	Open data platform
Business concept	Needs and goals of the municipality
	Social aspects
	Economic aspects
Data understanding	Data sources and types
	Data visualization
Data preparation	Data cleaning
	Data reduction
	Data merging
Model creation	People involved in creation process
	Important aspects to include
	Collaboration
Evaluation and justification	Testing indicators
	Target values for indicators
	Integration of new available data
Networking knowledge	Project meetings
	Via client
Deployment	Implementation strategy for the model
	Guidelines for using the model
Use purpose of data analytic application for policy makers	Policy selection
	Planning
	Forecasting
	Monitoring
Data related challenges for decisions about societal aspects of energy transition	Data gaps
	Data quality issues
	Privacy issues
Actions to overcome challenges	

Table C2. Final codebook

Top level codes	Second order codes	First order codes
Municipality	Role interviewee	Data analyst
		Policy maker
		Policy advisor
		Data coach
		Project manager
		GIS advisor
		Policy researcher
	Work activities	Planning
		Policy making
		Advising
		Data collection
		Data analysing
		Creating data visuals
	Team size	
	Introduction organization	
Preparatory phase	Knowledge requirement	Knowledge about current situation of the municipality
		Data analytic knowledge
		Knowledge about the energy domain
		Knowledge about policy making
		Deep understanding of the subject and related studies
		Data collecting skills
		Research skills
	Individual knowledge enlargement	Actively engagement between policy and data department
		Reading new publications and articles
		Project meetings
		Interactions with colleagues and stakeholders
		Following courses
		Cross-pollination of information
		Conferences
	Sharing tacit knowledge	Project meetings
		Brainstorm sessions
		Work experience
		Depends on other person's knowledge level of the topic
		Explaining the rationale behind decisions
		Leveraging personal networks to access datasets
		Documentation and code sharing
	Business concept	Needs and goals of the municipality
		Included socio-economic aspects
		Steps to include all relevant data
		Other included aspects
Development phase	Kind of application	Dashboard
		Monitor
		Documented reporting
		Data visuals
		Data model
		Computing model
	Data approach	
	Data understanding	Data sources and types
		Data collecting
		Understanding among policy makers where the data comes from
		Implications for policy process
		Supporting data understanding
	Data preparation	Data cleaning
		Data reduction

		Data merging
	Model creation	People involved in creation process
	Evaluation and justification of the data analytic application	Testing indicators
		Target values for indicators
		Integration of new available data
		Missing elements
Use phase	Deployment	Implementation strategy
		Guidelines for using the application
		Use purpose of data analytic application
		Intuitive use
		Access to the application
		Current state of data analytic application
	Networking knowledge of the application	Via client
		Private network within an organization
		Via product owner
		Via policy advisor
		Internal communication
		Communication department
		Meetings
		Public disclosure
Challenges	Data related challenges for decisions about societal aspects of energy transition	Data accuracy
		Data gaps
		Data quality issues
		Privacy concerns
	Other kind of challenges	
	Actions by data analysts to overcome challenges	
	Actions by policy makers to overcome challenges	
	Actions needed to overcome challenges	

Appendix D

Theoretical framework

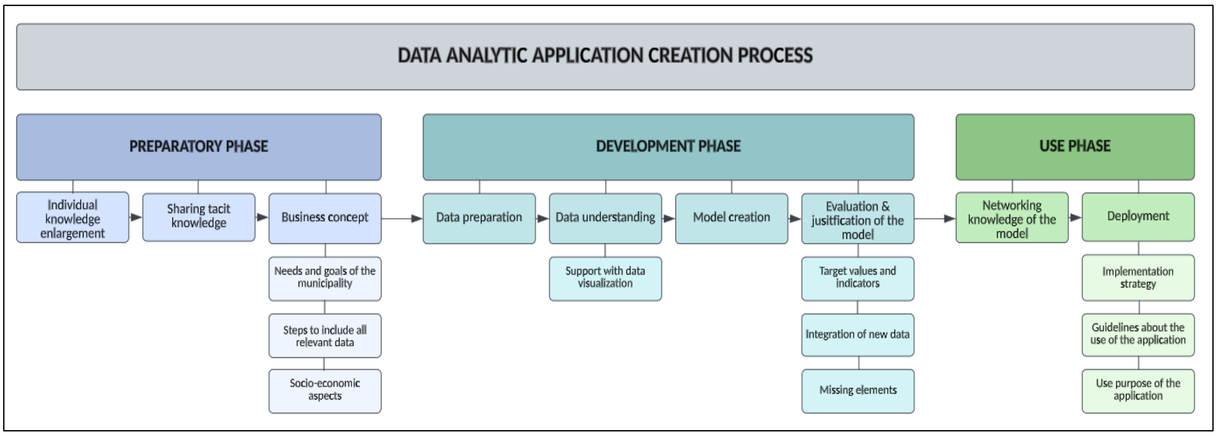

Figure 5. Final theoretical framework of the data analytic application creation process