Model-informed Charging Policymaking

How does modeling evidence influence EV charging infrastructure policymaking in the UK and the Netherlands?

by

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TU Delft

Preface

This master thesis marks the end of my graduate studies. It is with great pleasure and a sense of accomplishment that I present this work to the committee and all those who have supported me along the way.

Undertaking this research project has been an intellectually stimulating and enriching experience. It has allowed me to delve into EV charging sector, a subject of personal interest, explore its complexities, and contribute to the existing body of knowledge. Throughout this journey, I have been guided by the expertise and wisdom of my thesis supervisors, Stefan and Wijnand, whose invaluable guidance and mentorship have played a vital role in shaping the outcome of this work. I would also like to express my gratitude to Ema, my thesis advisor. I am immensely grateful for your unwavering support, patience and encouragement throughout this process.

Additionally, I am indebted to my family and friends for their unwavering belief in me and their constant encouragement. Their encouragement and understanding have been a constant source of motivation during the challenging moments of this journey. Their belief in my abilities has inspired me to push beyond my limits and strive for excellence.

Xiwen Gu
Delft, July 2023

Abstract

The establishment of a well-developed charging infrastructure is imperative for the broader adoption of Electric Vehicle (EV) and necessitates the formulation of an effective charging infrastructure policy. To navigate the intricacies involved in the policymaking process, the incorporation of EV charging models can be advantageous. Existing research indicates that models have a significant impact on facilitating policymaking in the broader energy sector. Nevertheless, it remains unclear whether computer-based models exert a similar influence on the EV charging policies. Previous studies lack comprehensive insights into the practical application of models in EV charging policy processes and the resultant policy modifications due to the unique attributes of both EV charging models and policies. Furthermore, there exists a lack of systematic understanding regarding the utilization of charging infrastructure models. Given these gaps in knowledge, this research aims to investigate the following question: How does modeling evidence influence EV charging infrastructure policymaking in the UK and the Netherlands?

Drawing upon the theoretical framework encompassing the assessment of policy impact based on altmetric data and the policy cycle model, this study starts with a literature review of the evidence-informed policymaking in energy sector, then employs an embedded case study approach to examine the evidence- and model-informed policymaking process in two countries, namely the United Kingdom (UK) and the Netherlands. Within each case, a qualitative analysis is conducted on national, regional and local charging policy documents, followed by a scrutiny of two specific local policy processes as embedded units. Through this comprehensive analysis, the study captures overarching trends and common themes in evidence-informed charging policymaking, while gaining in-depth insights into the circumstances and contextual nuances that determine when and how models can lead to changes.

The literature review provides a comprehensive overview of how modeling evidence is utilized across different stages of policymaking, namely agenda/target setting, policy formulation and adoption, policy implementation and policy evaluation. Two guiding questions with corresponding propositions are formulated to direct the case study. The examination of charging policy documents in the UK and the Netherlands reveals that market and industry studies, modeling results and statistics are the predominant types of evidence cited in these documents. British documents demonstrate a broader utilization of various types of evidence, as evidenced by higher citation frequencies and a larger number of documents employing them. However, modeling evidence stands out as an exception, being more commonly used in the Netherlands than in the UK. In general, modeling evidence plays a more significant role in the latter, serving a wider range of purposes in British documents, such as forecasting future charging needs and exploring implementation options.

A focus on model-informed charging policies highlights the prominent association of modeling evidence with two key themes: forecasting future charging needs and exploring implementation options. In British documents, modeling evidence plays a significant role in ex-ante assessments, particularly in cost-benefit analysis and grid impact. However, on the national and regional levels, the influence of modeling evidence on decision-making is limited in both countries. While some documents explicitly cite modeling evidence as a justification for policy decisions, its overall impact remains minimal. In British non-local policies, modeling evidence occasionally shapes operational plans, while Dutch non-local policies primarily rely on it for strategic decisions. Overall, the impact of modeling evidence on policy decisions is tangible but varies depending on administrative scope and decision themes, with British documents demonstrating a wider range of applications.

The comprehensive examination of four local charging policies reveals the prominent utilization of modeling evidence across various stages, namely (1) identifying priorities, (2) enhancing understanding and exploring policy options, (3) simulating, monitoring, and optimizing operations, as well as engaging stakeholders, and (4) evaluating and improving policies. Furthermore, it is observed that EV charging

models have exerted a significant influence on policy consensus and content, encompassing targets, strategies, and actions, within the local policies of both countries. Additionally, the Dutch localities exhibit more substantial reliance on modeling evidence for agenda setting compared to their British counterparts, which can be attributed to the Netherlands' early adoption of charging models.

In summary, this study finds that EV charging models have exerted substantial influence across various stages of local policy cycles, significantly shaping decision-making processes. Such impact has predominantly concentrated on the practical and operational aspects of the models, primarily concerning the optimal number and spatial distribution of charging points. However, there remains a noticeable lack of attention to strategic considerations pertaining to broader energy transition and green transport initiatives. This oversight is particularly evident in the insufficient exploration of how EV charging infrastructure can be effectively integrated into a more extensive and long-term blueprint. This research highlights the need for a strategic-level approach to comprehend the interplay between EV charging networks and the larger energy transition agenda, encompassing themes such as renewable energy integration, smart grid compatibility and urban planning synergies. Consequently, policymakers and modelers should expand their planning of charging infrastructure to encompass the broader landscape and envision how EV charging models can harmonize with sustainable urban development, ensuring a cohesive and effective implementation within the overarching framework of environmental conservation and sustainable mobility.

Acronyms

CBA Cost Benefit Analysis. 12

CPO Charge Point Operater. 1

DSO Distribution System Operator. 1

EV Electric Vehicle. iii, 1

MSOA Middle Layer Super Output Areas. 30, 57

MSP Mobility Service Provider. 1

OEM Original Equipment Manufacturer. 1

UK United Kingdom. iii

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1 Introduction

The European Union is at the leading edge in the rollout of electric vehicles (EVs), with EVs accounting for approximately 20% of its new car sales in 2021 (European Environment Agency, 2022). Yet the adoption of EVs has been significantly associated with charging infrastructures. Bakker and Trip (2013) have identified the build-up of infrastructure as the most effective way to popularize EVs, recommending that the unimpeded infrastructure installation and the designated parking-and-charging area should be included in policies. Coffman et al. (2017) verified the importance of adequate charging facilities based on a wide array of results from peer-reviewed literature that evaluated the factors influencing EV adoption. They also pointed out that government should take further efforts to act upon such findings and improve the roll-out of infrastructure. Funke et al. (2019) drew the conclusion from 26 studies that the availability of charging infrastructure is a determinant of EV diffusion, underlining that countries should enable the combination of public and home charging based on their framework conditions such as population density and availability of home parking. Sæther (2022) emphasized that governments should prioritize the upgrade of charging infrastructure, especially fast public charging, and establish frameworks and regulations accordingly to motivate EV adoption. All these studies suggest that governments should undertake the role to expedite the ramp-up of charging infrastructure and thus transition to e-mobility.

When planning for charging network expansion, governments are faced with an intricate charging ecosystem (Figure 1.1). It encompasses a variety of entities (Netherlands Enterprise Agency, 2019): energy utilities, grid operators/Distribution System Operators (DSOs), hardware manufacturers, installation providers, Charging Point Operators (CPOs), Mobility Service Providers (MSPs), Original Equipment Manufacturers (OEMs) and end customers/EV drivers. Among them, CPOs and MSPs are critical deliverers of public charging services.

Apart from the complexity of the ecosystem, charging policies are also entangled in uncertainty that arises from the social-economical, technological and environmental landscapes like other policies aimed at decarbonization (Purkus et al., 2017). A foremost problem in all charging infrastructure plans is the target number of charging points. In the European EV Charging Infrastructure Masterplan developed by ACEA (2022), miscellaneous parameters are used in the calculation, such as EV population, regional archetype, user segmentation, energy demand and technology split. The report also demonstrates the divergence of numbers caused by two strategies: a demand-oriented strategy that focuses on the density of the network and a utilization-oriented strategy that focuses on the utilization of the network. The actualization of these aims is additionally impeded by the challenges concerning the siting and installation of the charging facilities. Moreover, the coordination of different charging networks that work seamlessly, which is essential for addressing range anxiety and promoting electric vehicle adoption, has also posed a challenge to policymaking (LaMonaca & Ryan, 2022). Standardization of plugs and sockets, vehicle-to-grid connection and roaming platform not only enhance the EV user experience but also serves as the foundation that future charging network will be built on (Coffman et al.,

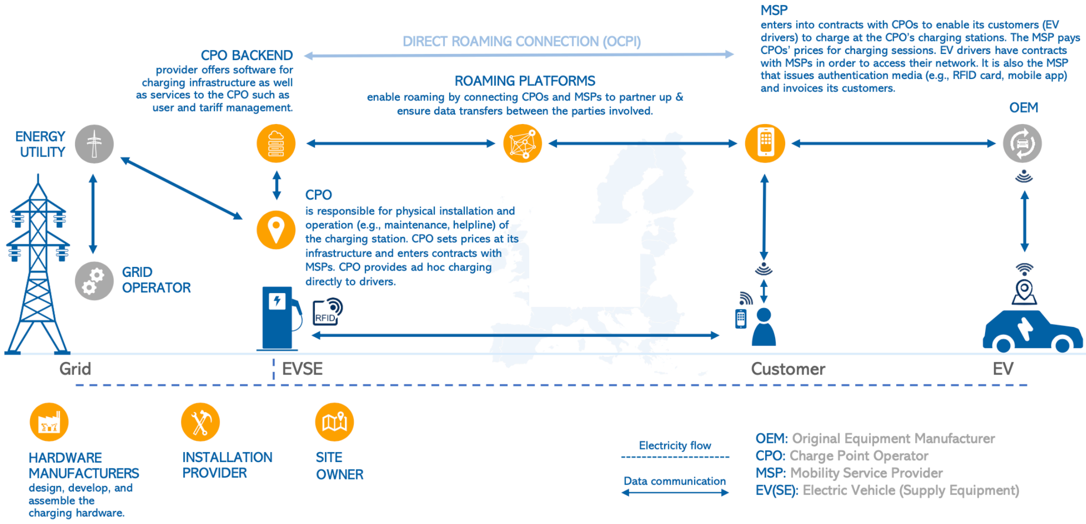

Figure 1.1: Illustration of EV charging ecosystem (ChargeUp Europe, 2022)

2017).

Since the stakes are high and it is impractical for policymakers to experiment with charging infrastructure in reality, they need to integrate a comprehensive set of factors and use solid evidence to substantiate their strategies and operation. Models have been used for such purpose, as observed in the charging policies in the United Kingdom (UK) and the Netherlands, on various levels of governments. For example, the Department for Transport in the UK set the ambition of implementing 300,000 public charging stations by 2030 in the Electric Vehicle Infrastructure Strategy, based on the results from their in-house Chargepoint Demand Model (CDM) (Department for Transport, 2022). Meanwhile, many Dutch municipalities are using a charging model called EV Prognose Atlas when creating local charging plans. These computational and simulation models offer predictive capabilities that are essential for understanding the complex and dynamic nature of EV charging systems and their potential impacts on various aspects, such as energy demand, infrastructure requirements and environmental outcomes. Models can further provide a systematic framework to integrate diverse elements like technological advancements, market trends, consumer behavior, and quantify their interactions accurately. By representing the real-world complexity in a structured manner, models can aid policymakers in understanding the potential consequences of their decisions in a holistic and data-driven manner. Therefore, it is interesting to see if models are used on a broader scale and what roles do they play in the government-led development of charging infrastructure.

1.1. Research Gap and Problem Statement

Evidence shows that models could facilitate policymaking in the general energy sector (Süsser et al., 2021; Thimet & Mavromatidis, 2022), one may wonder if it is also the case with EV charging industry. Although modeling evidence has been mentioned in a few EV charging policy documents, it remains unclear what specific effect do models have on them. There are two major types of studies on the policy impact of energy models and neither of them can answer this question. One type covers a broad spectrum of models and integrates various technical and political reviews on them, thus deriving the overall trends. For example, Savvidis et al. (2019) developed a classification scheme, based on which they compared 40 models to find a connection between model features and policy needs. Chang et al. (2021) revamped the scheme by adding more facets of societal impact, underlining the policy relevance of models as they found only two-thirds of them were used for policymaking.

These findings barely touch on how models are applied in policymaking or what policy alteration have been induced. The other type focuses on certain energy policies and models, generating insights on detailed model-policy interaction: Süsser et al. (2021) studied five policymaking processes where modeling evidence was involved; Henrich et al.(2021) examined the use of energy models, along with the advantages and limitations of such practice, in Dutch heating transition. These findings could be used as a reference but cannot fully explain the situation in EV charging sector due to the different attributes of both models and policies.

Furthermore, there exists little systematic understanding of the usage of charging infrastructure models. When and how modeling evidence is introduced into the policy process means different outcomes: Savvidis et al. (2019) observed that the diversity in modeling mechanisms, and consequently the characteristics of the generated results, does not necessarily align with policy requirements. McDowall and Britchfield (2020) argued that the extent to which modeling results influence policies heavily relies on policymakers' capacity to comprehend and effectively apply them. The complexity of models can hinder their comprehension or critical assessment, particularly when there is a lack of communication between decision-makers and modeling teams. Besides, Pfenninger et al. (2018) found that models used in energy policies tend to be untransparent in terms of data and code, which could have a negative impact on the public acceptance of new policies. These findings underscore the need to explore the application of models in EV charging policy processes and the subsequent decision-making based on them.

Having identified the research gap, this research aims to solve the following main question:
How does modeling evidence influence EV charging infrastructure policymaking in the UK and the Netherlands?

Centering on the main question, the following sub-questions are raised:

1. What is the state of the art on the impact of modeling evidence on energy policy?

2. To what extent are models and other types of evidence used for EV charging policy documents in the UK and the Netherlands?

3. What decisions and/or measures in those policy documents are related to modeling evidence?

4. How is modeling evidence used at each stage of local charging policy processes and what changes, if any, are brought by models?

1.2. Research Objectives

This research will provide insights into how models are used in EV charging policymaking and what policy impacts these models have, where no academic research has been found yet to the best of my knowledge. As EV charging policies are constantly being created or updated in the e-mobility transition, comprehending and evaluating how modeling evidence functions in policymaking could lead to more sophisticated use of models, thus more substantiated policies.

1.3. Research Significance

This research could add value to both EV policymaking and relevant modeling research. First, acknowledging why modeling evidence is chosen to inform decision-making under certain circumstances can help policymakers prioritize certain evidence according to the specific situation, who are constantly restricted to bounded time and resources (Giampietro & Bukkens, 2022). Second, if models are indeed used, lessons from previous practice could improve the selection, interpretation and reflection of modeling evidence; meanwhile, with key challenges identified in the current application of models, policymakers could make targeted improvement and better collaborate with modelers to use the evidence more effectively. Apart from the policymakers, researchers could also benefit from the findings of this study due to a better comprehension of the impact of their work on real-life political settings, thus navigating their research in more desirable direction.

1.4. Thesis Outline

This thesis report is structured as follows. Chapter 2 introduces theories on the conceptualization of models' policy impact and the policy cycle model, which serve as the framework of document analysis and the case study respectively. Chapter 3, the literature review, provides the contextual information on evidence-informed policymaking, modeling tools for energy transition, and the model-policy interaction in energy industry. Chapter 4 explains methods used in this study. Chapter 5 and 6 consist of two case studies of EV charging policymaking in the UK and the Netherlands respectively. Each of these chapters started with the qualitative analysis of model- or evidence-informed EV charging policy documents in the UK and Netherlands. The analysis intends to establish a high-level and overall perception of the how evidence, especially modeling results, is used in the policy documents. Then two specific charging policy processes are studied with depth for detailed activities related to the use of models in the policymaking process, leading to a thorough understanding of the decisions driven by models. The findings of these two chapters are compared in Chapter 7. Finally, the research findings are discussed, along with limitations of the rearch, are discussed in Chapter 8, followed by a conclusion on entire research .

1.5. Relevance to MOT Program

The Master program Management of Technology (MOT) enables students to identify, analyze and implement technologies that positively impact society. Graduates from this program are equipped with the analytical and managerial skills to drive social and economic value from technologies. This thesis project centers on modeling technology and its application in EV charging policymaking, a complicated socio-technical context. By investigating the influence of models on EV charging infrastructure policymaking across Europe, this research addresses the problem that how modeling technology affects the strategies and operation in e-mobility transition and sustainable development, which are important research domains in the TPM faculty.

Moreover, the knowledge and skills acquired in many MOT courses will play an important role in this research. For example, knowledge of innovation system, especially its structural components and functions, learned in Technology Dynamics is helpful to analyze how models that originate from the academic field eventually extend their influence over the political realm. Besides, EV charging policymaking is a typical case of decision-making in multiple-actor networks, where policymakers, researchers and stakeholders interact with each other. The techniques of decomposing decision process in a complex real-world problem learned from Inter- and Intra-organizational Decision-making could be applied to structure the analysis, identify the actors and organizations involved and information exchange among them.

To conclude, the orientation of MOT program is embedded in this research, during which the knowledge and skills learned in MOT courses will be put into practice.

2

Theoretical Framework

2.1. Policy Impact of Models Evaluated by Citation

Citation analysis has long been used as a traditional measure of research impact, particularly in academia. It involves examining how often a research paper is cited by other scholarly works, suggesting its influence within the scientific community. It has also been recognized that evaluating the broader societal impact of research, especially in relation to policymaking, requires looking beyond academic citations alone (Moed, 2006). Similar to assessing the scientific impact of research using academic citation analysis, the policy impact of research can also be measured by using altmetric data, which reflects the citation and reference of such information in policy documents (Bornmann et al., 2016).

Based on this theory, Bornmann et al. (2022) studied the societal impact of climate change research findings using citation and reference of them in policy documents. This research highlighted the relevance of considering policy documents as valuable sources for measuring the societal impact of research, as they provide insights into how scientific knowledge is incorporated into policy decisions related to climate change. Chang et al. (2021) shared a similar perspective when studying the policy relevance of energy models, distinguishing two types of policy effect: direct effect, which is indicated by the citation of models in policy documents; and indirect effect, which is indicated by the policy discussion, evaluation or iteration triggered by modeling evidence.

In short, policy citation of a specific research indicate that it has been considered relevant and reliable in the policymaking process, providing policymakers with valuable information on a minimum level. Bornmann (2016) further propose the methods to evaluate the magnitude and characteristics of such impact:

1. The number of policy citations indicates the extent and breadth of the impact of scientific researches.
A high number of citations across multiple policy documents indicates widespread recognition and adoption of a research. This suggests that its influence goes beyond a single policy decision and becomes a trusted source of information for policymakers in a greater scale.

2. The content and context of the citations reveal how the researches have been used for decision-making.
For example, if the citations are used to support specific policy recommendations or to justify regulatory measures, it indicates a direct and tangible impact of the models on policy formulation. On the other hand, if the citations are used more generally to provide background information or to acknowledge the scientific basis of the policy document, it suggests a more indirect but still important influence of the models on the overall policy landscape.

Therefore, the policy contribution of models could be conceptualized as how often they are used in

EV charging policy documents or policymaking activities. For example, the formulation of EV charging plans and/or agendas could be investigated to see if they cited or referred to the qualitative outputs of models, such as the number of required charging points, necessary capital investments, new grid capacity to be reinforced, and amount of renewable energy sources. Based on this evaluative framework, analysis could be conducted on which policies and what part of them are informed by modeling as well as other types of evidence.

2.2. Policy Cycle Model

The policy cycle model is used as the framework to study how models are incorporated into the EV charging policymaking process. Lasswell (1971) has laid the foundation of stages heuristics by specifying five stages in policymaking process: agenda setting, policy formulation, policy adoption, policy implementation, and policy evaluation. Although variations have been created in the number and description of stages in the subsequent studies, those five stages remained as core elements that have been widely acknowledged (Hupe & Hill, 2006).

This section first provides the definition and expected policymaking activities of all four stages (considering policy formulation and adoption as a one stage); then explains how this framework can be used to study the use of evidence at each stage.

2.2.1. Four stages of policy cycle

Agenda/target setting
Agenda setting is the initial stage of the policy cycle. It involves identifying and defining a problem or issue that requires attention from policymakers, which sets the direction and scope for the following stages. The activities at this stage include problem identification, issue framing and raising awareness of the problem among policymakers and the public (Lasswell, 1971). Target setting, on the other hand, involves establishing specific goals, objectives, or desired outcomes that policymakers aim to achieve through policy interventions. Targets are often defined based on the identified problems and priorities on the policy agenda, providing a clear direction and guide policy formulation by defining the desired results and measurable indicators of success (Bemelmans-Videc et al., 2011).

Despite the their distinct scope of attention, it is important to emphasize target setting as part of the agenda setting stage, as it helps define policy priorities by providing clear objectives and measurable outcomes. Setting specific targets can shape the policy agenda by emphasizing particular issues and directing attention and resources towards them. It has been observed that policymakers often incorporated target setting within the agenda setting stage to ensure that the identified issues align with the desired policy outcomes (Cairney, 2016). The process of defining a target usually has a clearer theme and sets of tools, making it more traceable compared with the broader agenda setting. For example, when studying agenda setting stage of multiple energy policies,Süsser et al. (2021) focused on the pathway by which policymakers reach a clearly articulated goal, which steered them through the vast expanse of policymaking activities and discerning crucial events that wielded significant impact.

Policy formulation and adoption
Policy formulation is the stage in which potential policy options or alternatives are developed to address the identified problems, concerns and propositions. It involves the analysis of various policy options, considering their feasibility, costs, benefits and potential impacts. At this stage, policymakers explore policy alternatives, conduct research, gather evidence and engage in consultations with relevant stakeholders. From an arrange pf policy options, a selected one is endorsed and approved by the relevant decision-making body, such as a legislative body or executive authority. This process often involves solitical negotiations and consensus-building among policymakers, as well as consideration of public opinion and stakeholder interests (Birkland, 2019).

Some scholars make a distinction between the formulation (of alternative actions) and the final adoption (the formal resolution to adopt the policy). However, due to the fact that policies are not always concretely manifested into separate programs and a clear-cut separation between formulation and decision-making is often infeasible, they can be treated as constituent sub-stages within a singular phase of the policy cycle (Jann & Wegrich, 2017). Hupe and Hill 2006 also viewed the policy formulation and adoption as an intertwined and iterative process. The feedback and inputs received during the adoption stage may necessitate revisions in the policy formulation stage, requiring policymakers to revisit and refine their proposed options. Another example is the research conducted by Howlett and Cashore (2009) on policy dynamics. They argued that analyzing policy formulation and adoption together enables a more comprehensive understanding of the factors influencing policy change and its outcomes.

Policy implementation

Policy implementation is the stage where the adopted policies are translated into concrete actions and programs and being executed. It encompasses a wide range of activities, including the development of implementation plans, the allocation of resources, the coordination of various stakeholders and the monitoring of progress. Government organizations may further establish operational procedures and regulations to guide the implementation process, ensuring consistency and clarity in carrying out policy actions (O'Toole Jr & Meier, 2004).

This stage involves addressing technical, administrative, organizational, and behavioral aspects, each with its own intricacies: technical challenges may arise in the deployment of new technologies, the design of infrastructure, or the measurement of outcomes; administrative barriers can emerge from resource constraints, bureaucratic procedures or legal frameworks; organizational issues, such as coordination across different agencies or departments, resistance to change, or capacity limitations, can further complicate the implementation process; finally, the behavior of individuals and groups involved in implementation, influenced by their beliefs, motivations, and incentives, can shape the outcomes and effectiveness of policies (Hill & Hupe, 2002). To untangle such complexities when studying the implementation stage, Jann and Wegrich (2017) recommended that researchers should consider the role of implementation agencies, examine the demands faced by front-line personnel, explore the interplay of different actors and programs and analyze the networks and connections within specific policy domains.

Policy evaluation

Policy evaluation is the is a crucial component of the policy cycle that involves the systematic assessment of policy effectiveness, efficiency, and equity. Although evaluating the effectiveness of implemented policies in achieving their intended goals and desired outcomes has been a common practice, evaluation studies are not confined to a singular phase within the policy cycle; instead, they encompass the entirety of the policy-making process and adopt multiple temporal viewpoints, encompassing both ex-ante and ex-post evaluations (Birkland, 2019).

Evaluation occurs throughout the policy cycle due to its dynamic and iterative nature. At the formulation stage, ex-ante evaluation helps identify the most suitable policy alternatives by examining their potential benefits, costs and unintended consequences (Weimer & Vining, 2017). Evaluation also frequently takes place at implementation stage, where policymakers assess whether the policy is reaching the target population, whether there are any unintended consequences and whether adjustments are necessary to improve the implementation process; additionally, evaluation helps generate knowledge about what works and what doesn't, allowing policymakers to refine their approaches and enhance policy outcomes. This iterative process is vital for evidence-informed policymaking and continuous improvement of policies (Hupe & Hill, 2006).

2.2.2. Charaterization of evidence used at different stages

To operationalize the policy cycle framework within the context of examining the influence of models and other forms of evidence on policymaking, this section provides a summary of evidence selection patterns observed at each stage. These patterns are derived from empirical studies of evidence-based policymaking, Sutcliffe (2005) and Young et al. (2002). The focus here is to establish a correlation between the intended use of evidence and the different stages within a policy cycle, while a comprehensive review of researches on evidence-based policymaking is presented in Section 3.1.

Agenda/target setting

To help policymakers identify and define the issues or challenges that require attention, the evidence used at this stage is often exploratory and aimed at understanding the nature and magnitude of the problem. It includes qualitative and quantitative data, expert opinions, literature reviews, and case studies. The characteristics of evidence used in problem identification are broad coverage, diverse perspectives, and a focus on descriptive analysis.

Policy formulation and adoption
Evidence used at this stage is focused on assessing the effectiveness, feasibility, and potential impact of different policy alternatives. This evidence is characterized by its evaluative nature, including randomized controlled trials , impact evaluations, cost-benefit analyses, and comparative studies. It provides insights into the causal relationships between interventions and outcomes, considers implementation challenges, and considers trade-offs among policy options. Moreover, olicymakers use evidence to communicate the rationale, expected impacts, and benefits of the proposed policies to key decision-makers, legislative bodies, and the public. They rely on evidence to build a persuasive case for policy adoption, presenting research findings, evaluation results, and expert opinions that demonstrate the potential effectiveness and positive outcomes of the proposed policies. Strong evidence-based arguments can help overcome resistance, address skepticism, and increase the likelihood of policy adoption.

Policy implementation
At the implementation stage, evidence plays a crucial role in guiding the actual execution of policies. Policymakers need evidence that helps identify potential barriers, inform the design of implementation strategies, and ensure effective delivery of interventions. The evidence used in this stage includes implementation research, process evaluations, monitoring data, and feedback from stakeholders. It focuses on the practical aspects of policy implementation, such as identifying best practices, adapting interventions to local contexts, and monitoring progress.

Policy evaluation
Evidence used in policy evaluation is designed to measure the outcomes and impacts of policies, providing insights into whether desired objectives have been achieved. Evidence that includes impact evaluations, performance indicators, surveys, and qualitative research methods. It emphasizes outcome-oriented measures, compares actual outcomes with intended goals, and considers unintended consequences and equity implications.

In summary, various types of evidence are chosen for specific stages within the policy cycle to meet their unique needs. Collectively, these forms of evidence possess descriptive, evaluative, implementation-oriented, and outcome-centered attributes, with the overarching goal of informing decision-making, improving policy efficacy, and promoting accountability. This framework is further developed in Section 3.3, within the context of modeling evidence used in energy policymaking.

2.3. Limitations of the framework

It should be noted that the policymaking is rarely a linear process that proceeds smoothly and sequentially from one stage to another. In reality, it frequently entails numerous iterations, feedback loops and adaptations in response to evolving circumstances. The discrete stages outlined in the policy cycle model may overlook the complexities in decision-making and the nonlinear nature of the process.(Birkland, 2019).

Nevertheless, this research is focused on on understanding the influence of models on policymaking, rather than exhaustively depicting the policy development or evaluating policy impacts. Hence, identification of policymaking activities wherein models are used would adequately address the research objective. Previous studies of model-policy interaction have demonstrated that this framework suffices to investigate how models interact with decision-making processes (Henrich et al., 2021; Süsser et al., 2021).

3

Literature Review

This chapter analyzes the policy impact models or model-policy interaction in the energy and sustainable transition field. It intends to provide the context of this research by revealing: (1) common features of models used in energy policies, (2) potential patterns of the purpose, timing and form regarding the model or evidence usage in energy policymaking, (3) challenges and gaps in the application of models.

3.1. Evidence-informed Policymaking

Evidence-informed, or evidence-based policymaking is defined as a method of policymaking that uses optimal evidence to support deliberations and decisions of policy (European Commission, 2021b). The concept came into existence in the 1970s in the movement of switching from opnion-based policymaking to this more systematic and rational approach (Sutcliffe, 2005), and was put under the spotlight by the Blair government in the 1990s (De Marchi et al., 2016). Moving beyond the traditional ways of research (Nutley et al., 2010), governments now resort to portfolio consisting of ”data, information, and knowledge from multiple sources, including quantitative data such as statistics and measurements, qualitative data such as opinions, stakeholder input, conclusions of evaluations, as well as scientific and expert advice” (European Commission, 2021a). Table 3.1 summarizes five types of evidence commonly used in policy development.

Table 3.1: Categorization of evidence used in policymaking

Type	Example	Source
Quantitative evidence	Modelling, cost-benefit analysis, statistics, performance measures, polls	(Sanderson, 2009)
Qualitative evidence	Qualitative research, observational studies	(Mays et al., 2005)
Descriptive evidence	Expert opinion, interview, anecdote	(Mays et al., 2005)
Experimental evidence	Randomized policy trials, quasi-experimental studies	(Oliver et al., 2014)
Re-constructed evidence	Meta-analysis, systematic review, confirmed theories	(Nutley et al., 2010)

No matter what kind of evidence is used, it should satisfy certain requirements to be concerned as legitimate (Cairney & Oliver, 2017; Stoker & Evans, 2016; Sutcliffe, 2005): the evidence should bear hallmarks of scientific research, including rigor, testability, replicability, precision and confidence; the evidence should avoid known pitfalls and pursue a robust methodology; the lifecycle of evidence should be transparent and open to contest. According to Davies 2012, although the format of involving evidence may vary with the government, proper use of evidence would at least entail two aspects: first, evidence about potential trade-offs should be weighed and stated explicitly when political objectives and decisions are made, rejecting unverified assumptions; second, positive evidence does not guarantee the success of policy while negative evidence must trigger an alarm to reconsider the policy being made.

The use of evidence can be conducive to improvement on policies in three ways. Firstly, evidence can mitigate the risk of policy failure including ineffective measures and unintended consequences (Young et al., 2002). The Green Deal, criticized for neglecting the proverbial evidence on what motivated people to opt for higher energy efficiency, could serve as a negative example (McDowall & Britchfield, 2020). The policy was built on an impractical assumption of economical rationality, which ended up with far less reaction to upgrade household energy efficiency than expected. Similarly, little understanding of people's energy consumption pattern also failed to stimulate the replacement of conventional energy suppliers by renewable ones. Secondly, evidence can promote clarity in the increasingly "wicked" policy problems, featuring entangled stakeholders, complicated institutions and technological uncertainty (Head & Alford, 2015). Considering such complexity, Sanderson 2002 observed that policies should be evaluated by a mix of methods and designs to generate instructive insights. Finally, evidence can enhance the accountability of policies and trust in public administration (Head, 2013; Neylan, 2008). Pfenninger et al. 2018 argued that a transparent decision processes corroborated by robust reasoning could facilitate the public acceptance of new polices.

3.2. Models That Inform Energy Policymaking

Energy model outputs have served as as substantiating evidence in making energy policies. Energy models, which capture the energy system in a algorithmic and computational way, have been deployed in the formulation, implementation and assessment of energy policies in the Europe (Gilbert et al., 2018; Kolkman, 2020). Models can make forward projections of the future, extrapolating what the situation could be in thirty years based on current energy policies (Henrich et al., 2021). Models can also be used to inspect scenarios where certain policy targets (e.g. the amount of carbon emission to be reduced) are pursued (Braunreiter et al., 2021), or the potential outcome of policy in development is simulated and benchmarked against a politics-as-usual baseline (Malbon & Parkhurst, 2022). The complexity of energy models also varies, as some can only be executed and explained by professional researchers while some are publicly available to promote wider stakeholder engagement across industry and media (Chiu & Lowe, 2022).

As the energy systems become increasingly convoluted, several types of energy models with distinct focus have emerged. IEA (2022) identified and characterized four groups of energy models with two dimensions: optimisation- or simulation-oriented, with bottom-up (focusing on energy sector) or top-down (covering entire economy) approach (Figure 3.1).

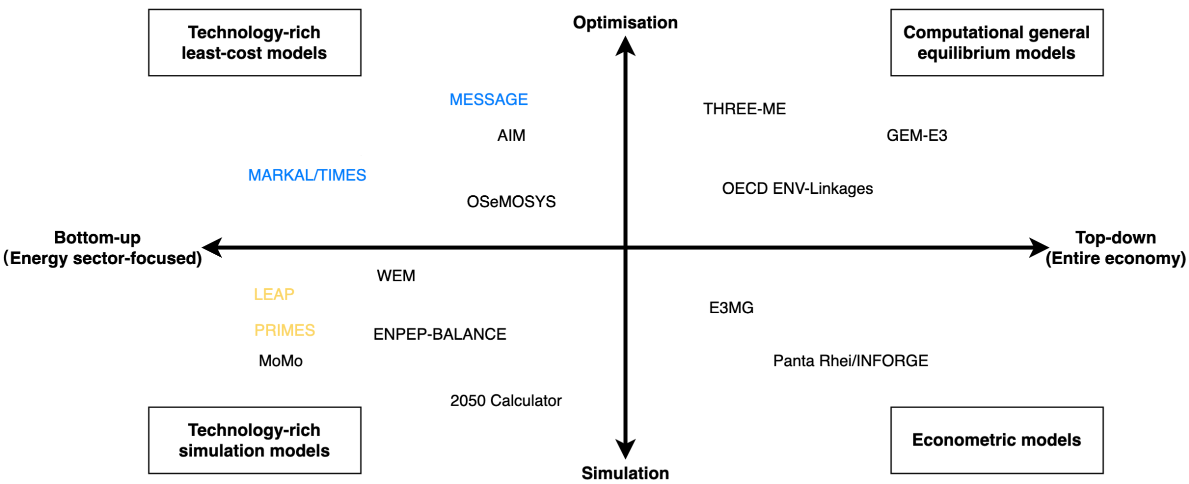

Figure 3.1: Characterization of models commonly used in energy policymaking, adapted from (IEA, 2022)

Pfenninger et al. (2014) provided a detailed delineation of the first dimension, presenting two method and purpose pairings: simulation/forecasts and optimization/scenarios. The primary purpose of the first pair can be classified as predictive, whereas the second pair leans towards normative intentions.

Optimization models have constituted the cornerstone of energy systems modeling for a considerable duration. Bottom-up models entail an intricate depiction of the technical elements comprising the energy system. Nevertheless, their intricacy demands simplifications to retain tractability, involving, for instance, the adoption of nationally aggregated technology deployment and yearly or seasonally averaged supply-demand equilibrium. Two prominent and well-established families of bottom-up models encompass MARKAL/TIMES and MESSAGE. Alongside the bottom-up optimization models, a second pivotal family of large-scale national or regional models adopts simulation methodologies, which prioritize prognosticating the probable evolution of the system rather than generating potential scenarios. In contrast to the frequently rigid mathematical formulations observed in optimization models, these simulation models exhibit modularity and incorporate diverse methods (with certain submodules once again integrating optimization techniques). Notable examples within this category encompass PRIMES and LEAPS.

The second dimension describes to what extent the external environment is considered. According to Huntington (2021), the top-down models integrate the energy system with social-economic landscape so that the potential economic impact (e.g. GDP, social welfare) of energy policies could be predicted. General Equilibrium (GE) models fall into this scope and contribute to analyzing the interaction between energy sector and the greater economy. By contrast, the bottom-up models pivot around energy system with the accentuation of energy flow between suppliers and users. The composition of energy systems is thoroughly studied, including energy generation, infrastructure, technologies and demand-supply dynamics. These models usually run through an array of options based on predetermined target(s) and boundary conditions, ending up with the optimal choice.

It should be noted that there are more dimensions to classify the energy models based on the goal of research (Pfenninger et al., 2014). They proposed two more dichotomous criteria: the first one arises in the form of planning models versus operational models. While energy systems models are traditionally geared towards planning endeavors, the escalating importance of detailed evaluations encompassing fluctuating demand and renewable energy necessitates the convergence of planning and operational perspectives into cohesive models, as expounded within this exposition. In the domain of power systems, this dichotomy materializes in the differentiation between capacity expansion models (for planning) and dispatch models (for operational considerations). The second one is evident in the distinction between snapshots and pathways; that is, whether the model solely presents a static depiction or a desired end state for a system, or whether it outlines a trajectory to reach that specific end state.

3.3. When and How Have Models Been Used in Energy Policymaking

Studies on the empirical evidence of policy process supported by models have been performed from different perspectives. Some researchers attempted to generalize and theorize the roles of models in overall energy policies (Gilbert et al., 2018; Kolkman, 2020). They roughly divide the models into two general groups: ex-ante and ex-post. In the first group, modelling evidence facilitates the exploration of multiple policy alternatives and the selection of the most desirable one. When a energy model is contrived, policymakers could develop a more inclusive understanding of the background in addition to the policy problem itself (Kolkman, 2020). Gilbert et al. 2018 believes that models further enable policymakers to experiment different variables in the energy system to investigate the different results induced by these changes, which is impossible in the reality due to limit of time and resources. Meanwhile, he also acknowledges the imperfection of such forecasting mechanism on account of the uncertainty in practice and the limitation of models. Nevertheless, models can still alert the government to unintended consequences and possible hazards, which helps implement the precautionary principle (Weier & Loke, 2007). In the second group, implemented policies are examined by models, which reveal the divergence between the real energy systems with the policy and a counterfactual situation in the absence of the policy (Gilbert et al., 2018). Compared with alternatives like randomised control trial, models have the advantage of being relatively simple and economic since they do not require the set-up of control groups. For example, Swedish government used DCGE PLANE 2.0 and TIMES to evaluate the implemented climate action plan and provide feedback to the next round of policymaking (Süsser et al., 2021).

Other researchers are more precise about the timing when modeling evidence is introduced into the policy cycle. They usually conducted case studies and focus on the use of models within a specific context, such as certain countries and policies (Henrich et al., 2021; Süsser et al., 2021; Thimet & Mavromatidis, 2022). The empirical findings on how models are used of at each stage are summarize below.

3.3.1. Target/agenda setting

Energy models play a crucial role in informing agenda/target setting in energy policies. They help policymakers better understanding the context, identifying the key challenges, opportunities and priorities within the energy sector (Huntington, 2021). By analyzing different scenarios and modeling the potential impacts of different policy targets, models assist policymakers in setting ambitious yet achievable goals for energy policies. Models can provide insights into the required investments, technological pathways, and policy interventions necessary to achieve desired energy targets.

According to Süsser et al. (2021), models can influence policy targets by providing quantitative estimates and projections. Policymakers often rely on these projections to set ambitious but feasible targets for energy transitions. However, the paper cautions that model outputs should be interpreted with care as they are subject to uncertainties and limitations inherent in the modeling process. Another example is the deep decarbonization models that play a crucial role in target/agenda setting by providing policymakers with insights into the long-term impacts and feasibility of different decarbonization pathways. By utilizing these models, policymakers can evaluate the potential effectiveness of different policy interventions, assess the costs and benefits associated with different pathways, and identify synergies and trade-offs between sectors (Felder & Kumar, 2021).

3.3.2. Policy formulation and adoption

Previous studies reveal a variety of impacts of models on how policies are formulated. To start with, energy models allow policymakers to simulate different scenarios and assess the potential impacts of policy options. By incorporating transport models into the analysis, policymakers can evaluate the consequences of policies on energy demand, emissions, infrastructure requirements and behavioral patterns (Süsser et al., 2021).

What's more, by exploring policy options and conducting ex-ante assessment of them, including Cost Benefit Analysis (CBA), models helped policymakers identify the most effective policy option to achieve their goals. Calvillo (2023) finds that energy efficiency models, such as TIMES, provides policymakers with valuable information to make informed decisions about driving technology adoption through policy. By analyzing the results from different scenarios, policymakers can gain insights into the range of potential solutions, assess the impacts of various policy measures and design effective strategies to achieve their energy efficiency goals. Thimet and Mavromatidis (2022) analyze the use of the 'PLEXOS' model to develop electricity system transition scenarios for Switzerland, Germany, France, and Italy. The model was used to simulate the electricity market and assess the impact of different policy options on the market. Henrich et al. (2021) mention the use of the 'Quickscan Warmtetransitie' model to develop a heat transition strategy for the municipality of Amsterdam, which was meant for evaluating the potential of different heating options and their economic and social implications.

One research of particular interest here is focused on the impact of coupled energy-transport modeling tool on policymaking. Gerboni et al. 2017 find integrated energy and transport models can provide a holistic view of the interdependencies and interactions between energy and transport sectors. This integrated perspective helps inform policy formulation by considering the implications and trade-offs across both domains.

3.3.3. Policy implementation

At this stage, policymakers can assess whether policies are on track to achieve their intended objectives by comparing model-based projections with actual data (Huntington, 2021). Apart from monitoring and evaluating, operational plans are often made at this stage, where models can help policymakers understand how they will perform by incorporating real-world data and considering various factors, including economic conditions, social dynamics and technological constraints. Horschig and Thrän (2017) found that various types of models used in renewable energy policies can simulate and analyze the potential outcomes of different policy interventions, such as feed-in tariffs, renewable portfolio standards, or carbon pricing mechanisms. Thimet and Mavromatidis (2022) study the application of the 'EMLab-Generation' model to evaluate the implementation of the European Union (EU) 2030 climate and energy policy, which was used to simulate the electricity market and assess the impact of the policy on the market. Henrich et al. (2021) discuss the 'Warmtescan' model, a tool to evaluate the feasibility of heat networks in the municipality of Utrecht, which was used to assess the potential impact of the network on energy production, consumption and emissions. This helped policymakers design a policy that was technically feasible and economically viable for the municipality.

3.3.4. Policy evaluation

Models can be instrumental in the ex-post evaluation stage of a policy cycle by providing a systematic and rigorous analysis of policy outcomes. At this stage policymakers assess the effectiveness of policies and make adjustments as needed. Modeling evidence can help policymakers understand the actual impacts of policies and identify areas for improvement. Thimet and Mavromatidis (2022) study the assessment of Swiss electricity system transition policy on energy consumption, greenhouse gas emissions, and economic costs using 'TIMES' model. This helped policymakers identify areas for improvement and adjust the policy as needed. Süsser et al. (2021) describe the use of the TIMES-GR model for Greek energy system. The model was used to assess the impact of the policy on energy consumption, greenhouse gas emissions, and economic costs. This helped policymakers identify areas for improvement and adjust the policy as needed. Henrich et al. (2021) examine how 'Warmte Transitie Atlas' was used to assess the impact of the policy on energy consumption, greenhouse gas emissions, and economic costs in the municipality of Groningen. This helped policymakers identify areas for improvement and adjust the policy as needed.

3.4. Questions and Propositions

Upon reviewing the aforementioned studies, several recurring questions are explored in the analysis of the interplay between models and policies within the domain of energy. These questions can be adapted to the context of charging policies. Meanwhile, by extrapolating the insights garnered from model-driven energy policies, a series of propositions are made for each question, offering a concrete orientation for this research.

1. How can models be used at each stage of policy cycle?
Propositions:

1.1 In target/agenda setting, models can be used to (1) identify priority, (2) conduct impact assessment, (3) facilitate stakeholder engagement and communication.

1.2 In policy formulation and adoption, models can be used to (1) enhance understanding, (2) explore scenarios and policy options, (3) conduct Cost Benefit Analysis (CBA), (4) conduct ex-ante assessment.

1.3 In policy implementation, models can be used to (1) simulate and optimize actions, (2) monitor and evaluate progress, (3) optimize resource allocation, (4) conduct adaptive management, (5) facilitate stakeholder engagement and communication.

1.4 In policy evaluation, models can be used to (1) conduct ex-post assessment, (2) conduct counterfactual analysis, (3) support policy improvement and future policy cycles.

The collective utilization of models mentioned earlier is explained in Section 3.3. It is important to acknowledge that the four assertions do not encompass the entirety of feasible model usages, and their applicability may vary across specific scenarios. Furthermore, the correlation between stages and usages lacks conclusiveness. Ultimately, the deployment of models is highly contingent on individual cases, and these propositions merely serve as an initial stepping stone.

2. What decisions and/or changes could be informed by modeling evidence?
Propositions:

2.1 Modeling evidence can put topics on agenda and initiate a policy process.

2.2 Modeling evidence can trigger policy discussion.

2.3 Modeling evidence can resolve disagreement.

2.4 Modeling evidence can cause the formulation/change of policy component, such as target, strategy and action.

The possible outcomes of applying modeling tool are generalized from the real-life observations in the empirical studies (Henrich et al., 2021; Royston et al., 2023; Süsser et al., 2021). Proposition 2.1 refers to scenarios wherein modeling results effectively demonstrate the significance of a policy topic, thereby necessitating a change of the current policy status. Proposition 2.2 includes both general discussions and policy debates, often witnessing scientific disputes concerning the validity and quality of modeling. Proposition 2.3 refers to situations where models are employed in negotiations to persuade opposing views and align opinions. Proposition 2.4 comprises a broader range of changes that can occur at any stage of the policy process, influenced by modeling evidence. When applying these propositions, extra attention should be paid to the the attribution of these outcomes. According to Süsser et al. (2021), it is quite often the case that modeling results do not serve as the sole determinant of decisions. In such situations, it is essential to describe these decisions and/or changes as being ”informed” by models, thereby recognizing the impact of other contributing factors.

4

Methods

A combination of methods are employed to address the main and sub-questions of this research. Following a literature review, the fundamental design adopts a case study approach, and the key methods utilized include qualitative document analysis and interviews (Figure 4.1). The chapter first explains how can the four research questions be answered by designated methods. The subsequent sections delve into the specific utilization of these methods.

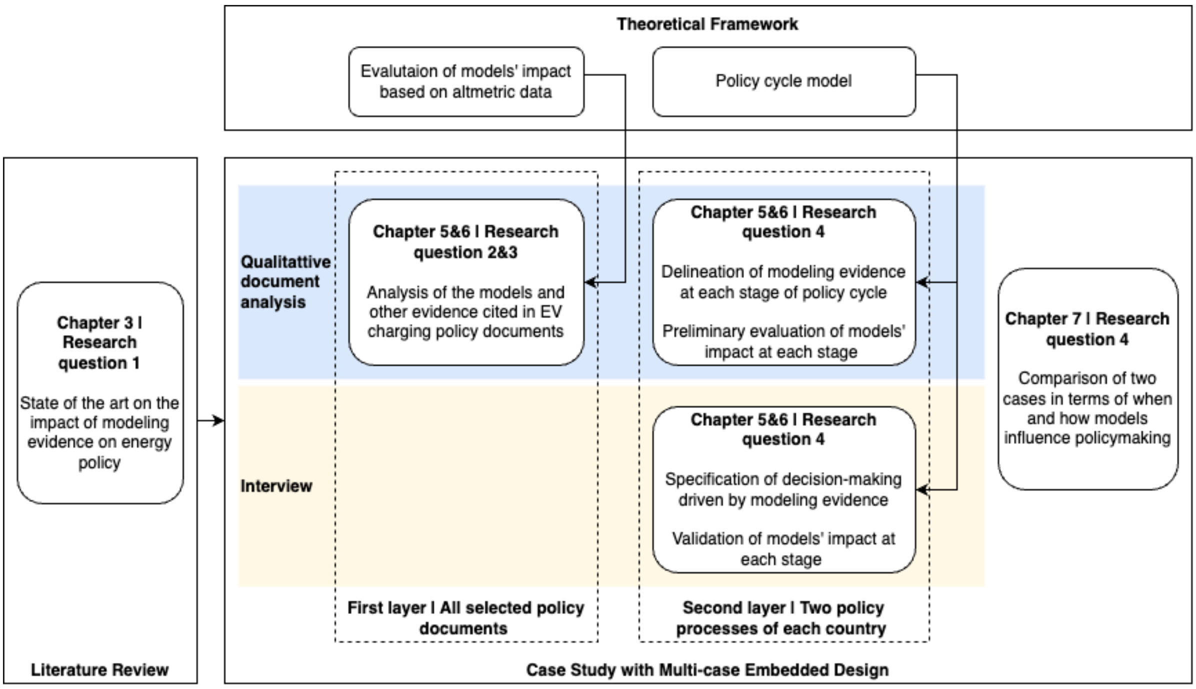

Figure 4.1: Overview of research method

4.1. Methods for Research Questions

Of the four research questions, the first one is answered in a literature review, drawing on existing findings on model-informed energy policies. The remaining three questions are quested using case study as a general method but with different analytic approach and information source, which are specified in this section

1. What is the state of the art on the impact of modeling evidence on energy policy?
By synthesizing the findings from various studies, a literature review can offer a holistic understanding of the state of the art regarding the impact of modeling evidence on energy policy. The review is intended to identify patterns, trends, and potential causal relationships, and it can also highlight divergent perspectives or conflicting results within the existing body of literature. The scope of literature focuses on the energy domain, taking into account the comprehensive nature of the energy system that includes both the transportation and electricity sectors (Savvidis et al., 2019). This leads to a substantial convergence of stakeholders, institutions, and technologies between broader energy policies and policies related to charging (Sæther, 2022).

2.To what extent are models and other types of evidence used for EV charging policy documents in the UK and the Netherlands?
This question is answered by performing a qualitative document analysis on charing policy documents. The charging documents are collected from three levels - local, regional and national - and appraised through qualitative coding. Two sets of codes, one for types of evidence and the other for types of content, are formulated, applied and refined during this step. The document-code, code-code correlation enables the identification of trends, patterns, and discrepancies in the utilization of evidence across diverse policy documents. Details on the selection and analytic process are explained in Section 4.3.

3. What decisions and/or measures in those policy documents are related to modeling evidence?
This question is addressed through the utilization of a qualitative coding approach similar to that of question 2. However, the focus is restricted to documents that have incorporated modeling outcomes, necessitating the adoption of a distinct set of codes to denote decisions or measures influenced by such modeling results. Additional elucidation on this matter is expounded upon in Section 4.3.

How is modeling evidence used at each stage of local charging policy processes and what changes, if any, ensue?
Given the intricate and context-dependent nature of this question, the inclusion of additional sources of information beyond the policy documents is necessary. Consequently, a thorough document analysis is undertaken on informative documentation relevant to these policies. Moreover, interviews with individuals actively involved in the charging policy process are conducted to validate the preliminary findings and offer a comprehensive assessment of the influence of models.

4.2. Case Study

4.2.1. Relavence to this research

The case study method is a research strategy that involves the in-depth investigation of for real-life problems embedded in a complex environment (Yin, 2018). According to Yin (2018), the case study method is particularly useful for exploring complex phenomena that involve multiple actors, processes, and contextual factors. This method involves collecting and analyzing data from multiple sources, such as interviews, observations, documents, and artifacts, to provide a comprehensive and detailed understanding of the case. Case study research typically involves several stages, including selecting the case, defining the research questions, collecting data, analyzing data, and reporting findings.

Case studies are ideal for studying the use of modeling evidence in EV policymaking from two aspects. Firstly, the policymaking process related to EV charging infrastructure is a complex and dynamic process that involves various stakeholders, including policymakers, industry actors and EV drivers. The case study approach can provide an in-depth understanding of this complex process by examining the interactions, power dynamics, and decision-making processes involved. Secondly, case study research is well-suited for exploring the context-dependent nature of policymaking, which is shaped by various contextual factors, including political, economic, social and environmental ones. Such context influences policymakers' decisions and actions and shape the overall trajectory of policy development. A case study approach can provide a detailed analysis of how these contextual factors interact with policymaking processes and outcomes.

4.2.2. Case study design

To address the trade-off between the generalizability and the depth of case studies, this research adopts the multiple-case embedded design that features two layers of analysis:

1. Layer one: two cases - the UK and the Netherlands - are studied comparatively by performing a qualitative document analysis on their national, regional and local policy documents dedicated to EV charging infrastructure development. Based on the content of those documents, the patterns of evidence usage in EV charging policies are concluded country-wise.

2. Layer two: two selected policymaking processes from each country are considered as embedded units for further analysis. On top of perusing the policy documents themselves, this layer also entails the qualitative analysis of documentation relevant to the policy and interviews with professionals involved in the policymaking process.

For each case on the first layer, the common trends in evidence use and the impact of models are derived from the content of sampled documents. These tentative findings will guide the analysis on the second layer, which is described in the next paragraph. Moreover, the similarities and differences across two cases are examined to identify the broader patterns, commonalities and variations. This comparative analysis enhances the potential for extrapolating findings beyond the UK and the Netherlands, thereby increasing the overall generalizability of this research.

On the second layer, the policymaking processes of four charging policies are depicted and analyzed leveraging a diverse array of data sources, including policy documents, interviews, reports and press releases. The tentative findings from the first layers can be validated through the real-life interaction between modeling and policymaking, which complements the altmetric data. It allows for a comprehensive understanding unique context, intricacies, and complexities of each case, to corroborate findings and strengthens the internal validity of this research. It should be noted that such practice is time-consuming and not feasible to conduct on a wider scale. Since the document analysis on the first layer already laid the groundwork of theory building, two deep-dived documents for each country are sufficient to draw a relatively robust conclusion.

In summary, the two layers of study are interconnected and mutually reinforcing. Together they capture the overarching trends and common themes in evidence-informed charging policymaking, while gaining a deep knowledge of when and how models could bring about changes under unique circumstances and contextual nuances.

4.2.3. Case selection

Two countries - the United Kingdom and the Netherlands - are selected as the subjects in this research as they are characterized the following :

1. Both countries are on the front edge of sustainable transition in transport with ambitious targets to reduce carbon emissions. A key action the countries aims to achieve this is by replacing internal combustion engine vehicles (ICEVs) with EVs.

2. Both countries have implemented a comprehensive series of policies aimed at improving the EV charging infrastructure, such as target setting, tax incentives and installation subsidies. These policies have contributed to the rapid expansion of the charging networks in these two countries, as well as a larger sample of policy instruments to be explored.

3. Both countries have a highly engaged and active civil society, with a range of stakeholders, including government agencies, industry associations, and non-governmental organizations, actively involved in shaping the country's sustainable transportation policies. This provides an opportunity to examine the dynamic interaction in policymaking and the importance of building a broad-based coalition to support sustainable transportation policy.

In addition to the justification above, two country-specific considerations further consolidate such choice. The Netherlands is renowned for the most developed public charging infrastructure network in Europe.

In Netherlands, the average public charging points per 10k inhabitants is 699 as of 2022, ranking first in the whole EU and remarkably surpassing the second place Luxemburg, which has 399 public charging points per 10k inhabitants (ChargeUp Europe, 2022). It is interesting to examine how the policies behind such network has been created.

As for the UK, the origin of evidence-informed policymaking, it has established a robust system of data collection and analysis, which provides policymakers with high-quality evidence to inform policy decisions. This includes data on EV charging usage, energy consumption, and greenhouse gas emissions, among others, which is collected and analyzed to inform policymaking. Moreover, the British government has demonstrated a commitment to using evidence to drive innovation in policymaking. This includes the use of new technologies, such as machine learning and artificial intelligence, to analyze large data sets and identify patterns and insights that can inform policymaking (McDowall & Britchfield, 2020).

4.2.4. Case operationalization and case study questions

The case study is operationalized by stipulating how to interpret the observations and build the logical connection between data and propositions (Yin, 2018). The case studies are aimed at identifying patterns of evidence utilization in EV charging policies (epsecially the decisions and/or policy measures related to modeling results), delineating the influence of models by stages in policy process and learning from the similarities and differences between the practice of two countries. To accomplish this objective, the case study encompasses four sequential steps as described below.

Step 1. Each case started with the analysis of selected documents from national, regional and local levels. This step aimes at a general overview of the evidence, especially modeling evidence, used in charging policy documents.

Step 2. A timeline is established for each case based on the policy cycle model explained in Section 2. The activities and policy documents are organized by four stages, namely agenda setting, policy formulation and development, policy implementation and policy evaluation. Meanwhile, the questions and propositions (Table 4.1)derived from literature review (Section 3.4) are used to guide the process tracing and analysis.

Step 3. Interviews with policymakers, modelers and consultants involved in the cases are conducted to verify the findings of step 3. Moreover, new information and professional opinions from the interview can further enrich the timeline. The synthesis of information from documentation and interviews should lead to an in-depth answer to the fourth research question within the context of four local charging policy processes.

Step 4. Within in each case (country), conclusion is drawn on both the overall document analysis results and the findings of two specific policy processes.

After the analysis of each case, a cross-case comparison will be made to study the differences and similarities based on theoretical framework and the propositions from literature review. Conclusions with a reasonable degree of generalizability is expected to be drawn from overview of two countries.

4.3. Qualitative Document Analysis

Qualitative document analysis is a method of scrutinizing written or textual materials in order to identify and construe themes, patterns and trends. It is is commonly employed in qualitative research to extract key information on social phenomena from a diverse array of sources, such as policy documents, academic articles, and media reports (Bowen, 2009). The method is particularly useful when analyzing policy documents, as primary data from participants is hard to collect. More specifically, it can be used to identify the key themes and rationale of an EV charging policy, to analyze the discourse surrounding the use of evidence in it, or to explore the attitudes and perspectives of actors towards such practice.

Bowen (2009) suggests that the process of qualitative document analysis consists of four steps: finding,

Table 4.1: Questions and propositions derived from literature review

Question		Proposition
1. How can models be used at each stage of policy cycle?	1.1	In target/agenda setting, models can be used to (1) identify priority, (2) conduct impact assessment, (3) facilitate stakeholder engagement and communication.
	1.2	In policy formulation and adoption, models can be used to (1) enhance understanding, (2) explore scenarios and policy options, (3) conduct Cost Benefit Analysis (CBA), (4) conduct ex-ante assessment.
	1.3	In policy implementation, models can be used to (1) simulate and optimize actions, (2) monitor and evaluate progress, (3) optimizie resource allocation, (4) conduct adaptive management, (5) facilitate stakeholder engagement and communication.
	1.4	In policy evaluation, models can be used to (1) conduct ex-post assessment, (2) conduct counterfactual analysis, (3) support policy improvement and future policy cycles.
2. What decisions and/or changes could be informed by modeling evidence?	2.1	Modeling evidence can bring topics to agenda and initiate a policy process.
	2.2	Modeling evidence can trigger policy discussion.
	2.3	Modeling evidence can resolve disagreement.
	2.4	Modeling evidence can cause the formulation/change of policy component, such as target, strategy and action.

selecting, appraising, and synthesizing. At the finding stage, a systematic and thorough search for relevant documents is conducted. The results are shortlisted by applying inclusion and exclusion criteria at the selecting stage. The appraising stage involves a careful examination and analysis of the selected documents, based on which common elements across the documents are identified and conclusions are drawn at the synthesizing stage. This section describes how these four steps are implemented in this research.

4.3.1. Finding and selecting

Two types of documentation are needed for the analysis, namely the policy documents and the supplementary documents that provide relevant information on the policy. The former is limited to official publications created by government organizations, while the latter is more inclusive in terms of sources and format. The search flow, different search strategies and selection criteria are applied to each type are described below.

4.3.1.1. Policy documents

For both countries, the national policies was the entry point of document collection. An exhaustive search resulted in a manageable amount of national policy documents pertaining to charging infrastructure. However, the preliminary examination of those documents indicated that local charging policies may offer more insights on the model-policy interaction out of two concerns:

1. Action-oriented content: local governments are frequently delegated to translate national charging policies into tangible plans and actions on the ground, as they possess valuable insights into the charging demand and current state of infrastructure of their administrative areas.

2. Concentrated policy cycle: local policies can be developed and implemented more swiftly due to the smaller scale and simplified decision-making processes compared with national and regional policies, allowing for quicker adjustments and adaptations. The condensed timeline facilitates the study of possible changes caused by models.

Therefore, the majority of the charging policies analyzed and four focused charging policymaking processes are all on the local level, with governments of the counties/cities in the UK and municipalities in the Netherlands being the key actors. Additionally, regional documents are included for completeness of the policy hierarchy. The search processes of the three types of documents are described below.

National documents
The British legislative documents related to charging infrastructure were searched on Legislation.gov.uk. Keyword search using ”Electric Vehicle” and ”Alternative Fuel” yielded 11 and one results respectively. After manually skimming through all of them and excluding documents that do not mention charging infrastructure at all, three legislative documents were selected for analysis. It should be noted that they are the assessment documents instead of the laws or regulations, since the latter only contain legal provisions. The website of the British government (gov.uk) was used to search for national policy documents. A keyword search of ”Electric Vehicle Charging” yielded 1246 results, which reduced to 416 results after limiting the topic to transport. The website filter was used to select content types, namely guidance, regulation, policy papers and consultations, which further shortened the list to 103 results. After reading the snippets of them, only nine charging-oriented documents that are not procedural documents (e.g. how to apply for and install charging infrastructure) and technical specification were kept. Therefore, a total of 12 national documents are selected for analysis.

The Dutch government website (overheid.nl) has aggregated all laws and government documents. In the Laws and regulation segment, a keyword search of ”Laadinfrastructuur” yielded 7 results and none of them were targeted at charging infrastructure. In the Government documents section, a keyword search of ”Laadinfrastructuur” yielded 1137 results, which were filtered by document subtype and themes. Subtypes that obviously do not contain policies are excluded: Kamerstuk (Chamber piece), Kamervraag (Chamber question), Circulaire (Circular letter), Convenant, Jaarverslag (Year calendar) and Toespraak (Speech). Besides, only themes related to charging infrastructure were selected: Economy/Energy, Nature and environment/General and Traffic/Public Transport. Therefore, the number of documents is reduced to 188 and their snippets were scanned to judge the relavence to charging infrastructure. Only nine documents were eventually kept for analysis.

Regional documents
Although the regions in terms of charging infrastructure development are demarcated by different mechanisms in the UK and the Netherlands, they both act as the intermediary covering a broader geographic area than local policies while maintaining a level of specificity and adaptability that may be lacking in national policies. In other words, the regional policies are distinguished by their position in the policy hierarchy instead of policymaking bodies.

In the UK, each of the four major administrative divisions, namely England, Scotland, Wales and Northern Ireland, have developed a regional charging policy document. All of these four documents are obtained from the websites of the corresponding regional department for transport. In the Netherlands, five regional coalitions (samenwerkingsregio) were specified in the National Agenda Charging Infrastructure (NAL, 2019): Northwest/MRA-Elektrisch (Flevoland, Noord-Holland, Utrecht), North (Groningen, Friesland, Drenthe), East/GO-RAL(Overijssel, Gelderland), South (Noord-Brabant, Limburg)and Southwest (Zeeland, Zuid-Holland). Three regional plans of charging infrastructure (Region Northwest, East and South) are obtained on the NAL website, while the rest are not publicly available. After searching for potential replacement, no provincial charging policy documents can be found in Region North either, while the charging policy of Zeeland province is chosen to represent Region Southwest. Therefore, four regional documents are selected in the case of the Netherlands as well.

Local documents
The search of local documents started with the case of the Netherlands, where the ’local government’ is clearly defined. As indicated in the National Agenda Charging Infrastructure (NAL, 2019), the municipalities are responsible for creating the local charging policies in Netherlands. However, there are over 300 municipalities and it is infeasible to go through all of them. Therefore, a few batches of documents were searched and pre-analyzed in an iterative way to figure out what would be the suitable number of documents to identify the trend. The process ended as 29 documents from 25 municipalities (some municipalities have multiple charging policy documents) were collected and analyzed. This size

of sample is sufficient to display the general trend. All these documents were searched by key words ”Laadinfrastructuur” on the Dutch government website (overheid.nl).

Based on the administrative hierarchy, the counties and cities in the UK are somewhat comparable to the municipalities in the Netherlands. Therefore, key word search was used again on the website of Local Government Association (local.gov.uk/publications). The top 26 documents from 25 counties or cities retrieved by key words ”Electric Vehicle Charging” were selected.

Furthermore, two specific policy documents from each case are selected for the second layer of case study to offer higher granularity of the policymaking process. With that in mind, the four documents are chosen based on the two criteria:

1. **The policy document describes the results of model(s) and connect them to the policy content.** As explained in the theoretical framework, the citation or reference of modeling results in a policy document can guarantee that certain model(s) have played a in the policymaking process. Therefore, such document is worthy of further investigation aimed at revealing the details of model usage. Besides, the elaboration of model information, including its name and developers, can lead to more resources in the data collection stage.

2. **There is sufficient information to apply policy cycle analysis to the document.** A major indicator of data availability is the amount of supporting or relevant information provided on the government websites. In order to map the use of evidence to the policy cycle of a document, a clear description of the decision-making and political activities is required apart from identification of the model itself. Moreover, additional information on these policymaking processes can be obtained from the available interviewees, who are directly or indirectly involved in the decision-making. The first-hand experience and professional insights exchanged in such interview can add great value to the findings.

Table 4.2 summarizes all the policy documents selected through the process above. The full list of documents can be found in Appendix **??**.

Table 4.2: Summary of policy documents selected for analysis

Country	Level	Number of documents
The UK	National	12
	Regional	4
	Local	26
	Total	42
The NL	National	9
	Regional	4
	Local	29
	Total	42

4.3.1.2. Supplementary documentation

To track the policymaking process and model-policy interaction on second layer of case study, supplementary documentation such as governmental press releases, meeting/hearing transcripts, news and (government-commissioned) modeling reports are collected using the snowballing method. This method enables a systematic and iterative process of document retrieval, where the four policy documents in focus serve as a foundation for identifying additional relevant sources through a cascading chain of references, citations and recommendations. Both backward snowballing (going through the reference list of the original document) and forward snowballing (seeking citations to the original documents) are used in this process (Jalali & Wohlin, 2012).

The supplementary documentation is mostly available on websites of legislation organizations, governmental organizations, industrial organizations and intelligence suppliers (in this research, mostly the consultancies that develop and run the models). If certain data cannot be found from these primary sources, it will be searched for on Google by keywords. All snowballed documents are evaluated critically for their relevance, reliability and validity. More specifically, documents that answer case-specific questions, come from reputable sources and use sound research methods will be kept for analysis.

4.3.2. Coding and appraising

The third step is to appraise the selected documents to make sense of the data. This involves a close reading and analysis of the text to identify key themes, concepts, and policy measures related to EV charging infrastructure and adoption. Bowen (2009) recommends using a systematic and rigorous approach to the appraisal process, and suggests using tools such as coding frameworks or matrices to help organize and analyze the data. Accordingly, the analysis of EV charging policy documents starts with qualitative coding, which categorizes the excerpts in EV charging policies in a systematic way to identify trends and themes (Elliott, 2018).

Three groups of codes were developed to describe (1) the types of evidence cited in the policy documents, (2) the types of content related to the evidence and (3) the decisions and changes related to modeling evidence. The full codebook, including the definition and examples of codes, can be found in Appendix **??**. The coding methods for the them are describe below.

The first group of codes is developed using inductive coding. The method involves the systematic examination and interpretation of raw contextual data to engender thematic patterns, conceptual understandings or a procedural model (Williams & Moser, 2019). Starting with the first document, the emergence of a novel evidence type prompts the creation of a new code. The saturation point for this collection of codes was achieved upon analyzing the initial eight documents, ending with a total of nine codes. A code is applied when a piece of evidence is used for a distinct purpose. For example, if three modeling results based on different input are provided to illustrate same one topic, they are coded together and considered as a singular occurrence of modeling evidence.

The second group of codes is developed using a mixed method of deductive and inductive coding. The process starts with a pre-determined set of codes describing how certain evidence is used derived from propositions 1.1-1.4. As the analysis progresses and the document content is examined, certain codes are modified to capture more nuanced characteristics of evidence utilization. Additionally, supplementary codes are introduced to accommodate instances where other types of evidence are identified, considering that the initial code set primarily focuses on modeling evidence. These codes, which are descriptive in nature, are assigned based on the evidence's content. In the end, the group consists of 21 codes.

The third group of codes is developed in a similar way as the second. The initial set of codes is derived from propositions 2.1-2.4. However, the causal relationship between modeling results and decisions and/or changes is often not explicit in the policy document. First, the they might not be mentioned together or within the same part of the documents. Second, it is sometimes difficult to differentiate actual decisions and/or changes from opinions and intentions expressed in the document. To avoid overusing this group of codes, they are assigned only to content that explicitly address the decisions and/or changes, while ignoring the ambiguous content. The contextual content is analyzed in addition to the focused content to substantiate the application of codes. Not all types of proposed decisions and changes are identified in the document, and this group ends up with five codes.

4.3.3. Synthesizing

The final step is to synthesize the results of the analysis to draw conclusions and identify insights. This involves identifying patterns, themes, and trends in the data, and synthesizing the results into a coherent and meaningful analysis. This method can involve different levels of analysis: content analysis involves identifying and categorizing the content of documents based on predefined codes and categories; discourse analysis involves analyzing the language and discourse used in the documents to understand how meaning is constructed and negotiated; critical analysis involves examining the underlying assumptions and values embedded in the documents and the power relations that are reflected in them (Morgan, 2022). This research primarily performs content analysis on EV charging policy documents, while taking the implicit factors into consideration using the critical analysis, when for example, some modeling results are constantly emphasized, or a detailed analysis is performed on the modeling mechanism,

4.4. Semi-structure Interview

To validate and enrich the outcome of document analysis, six semi-structured interviews were conducted. In addition to validating the impact models inferred from policy content in document analysis, interviews with policymakers and modelers offer insights into the decision-making dynamics surrounding the utilization of modeling evidence: Policymakers can provide information on how modeling evidence is received, interpreted and integrated into the policy process. Modelers and consultants can share their experiences in presenting and communicating modeling results to policymakers. Such information is usually not documented and can only be given by participants of those processes. This enables a more comprehensive analysis of the impact of modeling evidence by considering factors such as political considerations, stakeholder interests, and institutional constraints. Moreover, policymakers, modelers and consultants also possess tacit knowledge and practical experience that may not be included previous studies of model-informed policymaking, which is the reason why this interview is semi-structured and allows for spontaneous sharing of information from interviewees.

4.4.1. Recruitment of interviewees

A general principle of choosing interviewees is that they are involved in the development of charging infrastructure in Arnhem, Utrecht, Birmingham or West Sussex County, which is scrutinized on the second layer of case study. These interviewees typically assume one of the three roles: (1) policymakers, who works on the planning and/or delivery of charging infrastructure; (2) modelers, who develop and run the EV charging model(s) that are used in those policies; (3) consultants, who offer expertise to those local governments on charging infrastructure roll-out. An exception would be researchers who study the evidence-informed policymaking on a broader scale, as they have interacted with policymakers before and can provide supplementary insights. Table 4.3 summarizes the information of interviewees and how their experience could enrich the findings of case study.

Another 12 potential interviewees were approached apart from the six listed above, especially the policymakers involved in charging policies in Utrecht and Birmingham. However, interview invitations sent to local governments and report authors were either declined or yielded no response. Nonetheless, the interviewees who consented to participate encompass all three crucial roles in charging policymaking, as well as both countries examined within the case study. As a result, the content gathered from the interviews is anticipated to sufficiently reinforce the findings of this study.

4.4.2. Interview protocol

Before reaching out to potential interviewees, an interview plan was devised and reviewed with the data steward of TPM faculty, and later approved by the Human Resource and Ethics Committee (HREC) at TU Delft. In compliance with General Data Protection Regulation (GDPR), instead of the original transcript, six summaries of interview content have been included in Appendix **??**.

In preparation for the six semi-structured interviews, a set of guiding questions was formulated in advance and shared with the interviewees. The aim was to familiarize them with the key topics to be discussed and acquaint them with the interview procedures. Furthermore, this facilitated the interviewees in recalling their knowledge and experiences relevant to this research, which proved beneficial in capturing unexpected information and cultivating a comprehensive understanding of the interaction between charging policy and models. Throughout the interview, these questions acted as a framework to maintain the focus of the conversation while allowing sufficient flexibility to adapt to the interview's actual progression. As a result, if the interviewee introduces valuable insights that were not previously discovered, ad-hoc questions will be explored and discussed.

The question list (Table 4.4) is structured into five columns. The first and second columns encompass the primary and secondary concepts that elucidate the policymaking process and the interaction be-

Table 4.3: List of interviewees

Interviewee ID	Country	Field of expertise	Relevance to cases
Policymaker A	NL	Charging infrastructure policymaking and implementation	Policymaker A has overseen the development of charging infrastructure in Arnhem municipality; they were responsible for creating the the Electric charging implementation framework.
Policymaker B	UK	Charging infrastructure implementation	Policymaker B has led the delivery of charging infrastructure in West Sussex County based on the strategies put forward in Electric Vehicle Strategy 2019-2030.
Modeler A	NL	EV charging model development	Modeler A has worked in the modeling team that develops and maintains Prognoses (Snel)laden NAL West; they are also familiar with EV Prognose Atlas.
Consultant A	NL	EV charging infrastructure development	Consultant A advised and supervised the proactive roll-out charging infrastructure in two Dutch provinces in 2020.
Consultant B	NL	EV charging infrastructure development	Consultant B has worked as a project manger in MRA-Elektrisch; they calculated the prognosis of charging demand for Dutch municipalities.
Researcher A	UK	Evidence-informed policymaking	Researcher A has extensive research experience in the utilization of evidence (including models) to inform energy policymaking in the UK.

tween policy and models. A third column is included to explicate their correlation with the findings from the literature review and the qualitative document analysis. For each key concept, context-specific detailed questions, tailored to individual interviews, may be incorporated based on the analysis of policy documents at the initial layer of each case. While formulated differently, these questions consistently aim to delve into the corresponding key concept. The fourth column comprises sample questions that are adjusted for each interview. The fifth column specifies which set of questions is assigned to each interviewee, taking into account their distinct roles and perspectives.

Every interview begins with a self-introduction and a concise overview of this research. Subsequently, the interviewee is invited to introduce themselves and provide insights into their field of work. This information aids in determining which predetermined questions will be addressed during the later stages of the interview. The discussion is guided by the key concepts assigned to the interviewee based on their expertise. However, if the interviewee expresses knowledge pertaining to concepts not initially planned for them, those additional concepts will also be explored. Within each concept, the depth and scope of the discussion are shaped by the interviewees' responses.

A summary is generated for each interview transcript. Within the summary, the interview content is restructured and categorized based on the key concept and sub-concept outlined in Table 4.4. As a result, the interview content can be aligned with the case study questions and their initial responses. Ultimately, the interviews aim to yield three outcomes: (1)a thorough understanding of local charging policy processes; (2) the concrete scenarios and activities where models are developed and applied; (3) the causal relationship between modeling evidence and decisions (if any) endorsed by policymakers.

Table 4.4: List of interview questions

Key concept	Sub-concept	Based on	Example questions	Intended interviewees
Policymaking	Agenda/target setting	Policy cycle framework	When and why was the development of charging infrastructure put on agenda? What was the initial goal or target and how was it formulated?	Policymaker A & B
	Policy formulation and adoption		What were the key activities in creating this document and which actors or stakeholders are involved? What are the major considerations and how they are translated into the policy content? Which informational sources were utilized in formulating the content?	
	Policy implementation and evaluation		What are the steps in delivering the charging facilities? Is the development of charging infrastructure monitored and regularly assessed? If so, by what means?	
Modeling	Development of model	Policy document analysis	What is the development trajectory of Prognoses (Snel)laden NAL West? How is it related to the two predecessors, the EV Prognose Atlas and SparkCity model? Was the model commissioned to solve specific questions in charging policy?	Modeler A
	Interpretation of modeling results	Policy document analysis	How were the modeling results communicated to the decision-makers?	
Uses of model	Uses in agenda/ target setting	Proposition 1.1 -1.4	Were target groups and areas in modeling results prioritized in the charging policy? Was the charging target assessed by models?	All interviewees
	Uses in formulation and adoption	Policy document analysis	What has been learnt from the modeling results and did it help with creating the charging policy? Did the model inspire any policy options? Were the policy options evaluated? If so, was the model used in such process?	
	Uses in implementation		Were models used to simulate and improve operations? Were models used to monitor and evaluate the implementation progress?	
	Uses in evaluation		Was the model used to evaluate the policy effect, if so, in what way? Did modeling results indicate how the current policy can be improved?	
	General	Policy document analysis	Under what circumstances do policymakers resort to modeling tools? Does the impact of models vary cross government organizations with different analytical capacity? Does the impact of models vary cross strategic and operational decisions? What negative impact could models have on policymaking if not used properly?	Researcher A
Model-informed decisions/change	New agenda and policy process	Proposition 2.1 -2.4 Policy document analysis	Did modeling evidence bring political attention to the development of charging infrastructure? Was there any charging policy or program initaited based on modeling evidence?	Policymaker A & B Consultant A & B
	Policy discussion		Was there any policy dicussion held on the modeling results?	
	Policy concensus		Was there any disagreement on the planning and delivery of charging facilities? If so, was modeling evidence used to foster a concensus?	
	New target		Was modeling evidence used for setting or updating the target?	
	New strategy		What is the proactive roll-out of charging infrastructure and how modeling evidence is used in such process?	
	New action		What actions, if any, planned the policy document are based on modeling results? Was there any difficulty in translating modeling results into actions?	

5

Case Study of the UK

This chapter presents the case study results of the UK. The findings across all selected charging policy documents in the UK are described in the first section, which corresponds to the first layer of case design. Then the two local charging policy processes are scrutinized in the second and third section, which corresponds to the second layer of case design. The results from both layers are synthesized to draw a conclusion for the UK at the end of this chapter.

5.1. Overview of Evidence Use

A total of 42 British charging policy documents are analyzed, including 16 non-local (national and regional) ones and 26 local ones. As is shown in Figure 5.1, a diverse portfolio of evidence has been used in on all three levels of documents, albeit with varying degrees of frequency (measured by the number of citations, indicated by the area of the circle) and and prevalence (measured by percentage of documents citing the evidence within the non-local, local or total group, indicated by the Y coordinate of the center of the circle). The citation count of a each type of evidence within each document is illustrated in Figure **??** in Appendix **??**.

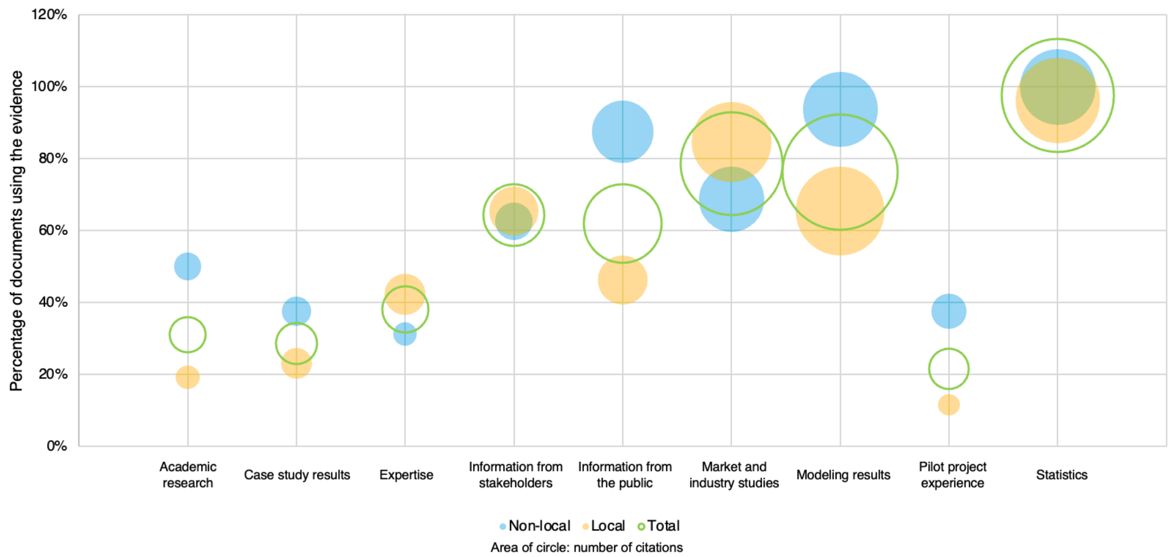

Figure 5.1: The frequency and popularity of evidence cited in British charging policies

Across all British documents, statistics, modeling results and market and industry studies are the three types of evidence most utilized. Statistics exhibit the highest prevalence, as well as being extensively cited. Modeling evidence follows closely in terms of citation count, slightly higher than that of market and industry studies; while the latter type is identified in more documents. Additionally, information obtained from stakeholders and the public is utilized in a considerable percentage of documents, although its individual document references are comparatively less frequent. Between non-local and local documents, four types of evidence exhibit significantly different prevalence: modeling results, information from the public, academic research and pilot project experience. All of them are utilized more widely in non-local documents.

The substantial citation count of modeling results mainly originates from a select few documents, including Electric Vehicle Charging Infrastructure Framework (NE 2022), City-Wide Electric Vehicle Charging Strategy (Birmingham 2021), and New legislative powers for ULEV infrastructure - Impact Assessment (UK 2021 ULEV). This pattern is particularly evident among local documents, with almost half of them not citing modeling evidence.

In all the British documents analyzed, most evidence types primarily contribute to understanding the current state of affairs (Figure 6.2). Among these, statistics evidence is extensively employed to evaluate the ongoing development of charging infrastructure and EV adoption. In contrast, the remaining evidence types exhibit weaker connections to specific content and offer broader applicability. Market and industry studies, as well as information obtained from stakeholders and the public, are particularly versatile and can serve multiple purposes.

In contrast, modeling evidence is predominantly employed for prediction, exploration, and ex-ante assessment, with prediction being the most significant utilization. More specifically, models are extensively used to forecast charging demand, charging facilities, and EV adoption. Furthermore, models facilitate the exploration of charging solutions and the identification of target groups and regions. An additional noteworthy application of models is the analysis of the impact of charging infrastructure on the power grid. While models find application in various other ways, they are not as remarkable as the three aforementioned uses.

	Academic research	Case study results	Expertise	Information from stakeholders	Information from the public	Market and industry studies	Modeling results	Pilot project experience	Statistics
Analyze current charging demand	4	0	2	1	12	19	5	3	6
Analyze financial/business prospect	1	0	1	0	0	3	4	0	2
Analyze future charging demand	0	0	1	0	2	4	24	0	2
Analyze future EV adoption	2	0	1	0	0	8	21	0	2
Analyze future number of charging facilities	0	0	0	0	0	1	36	0	1
Analyze potential charging locations	0	0	2	1	1	1	9	1	3
Analyze the environmental impact	0	0	1	0	0	0	5	0	1
Analyze the grid impact	0	1	1	1	0	2	14	1	3
Analyze vehicle travel patterns	0	0	0	0	1	1	4	0	7
Conduct cost benefit analysis	1	0	0	0	0	3	8	0	3
Design charging network	0	0	0	0	0	0	9	0	0
Evaluate and manage risks	0	0	1	1	0	0	0	0	0
Evaluate current charging infrastructure	0	0	2	1	7	12	2	0	60
Evaluate current EV adoption	2	0	0	0	1	8	0	1	41
Explore charging solutions	0	0	0	0	1	4	18	0	0
Identify barriers to implementation	0	0	1	4	3	2	1	0	1
Identify target groups and areas	0	0	0	0	1	2	18	0	0
Investigate implementation options	1	5	1	3	3	6	2	1	0
Justify the agenda	3	0	0	1	14	10	0	0	0
Operationalize the target	0	0	0	0	0	0	5	0	1
Provide general reference	1	13	9	29	26	27	1	12	10

Figure 5.2: Uses of evidence in British charging policy documents

Citations of modeling evidence do not necessarily lead to a corresponding decision in the same document. Therefore, a policy decision is only considered as model-informed when its connection to modeling outcomes is explicitly mentioned. Under such criteria, the most common type of policy content informed by modeling evidence is the action plan, which is observed in a considerable amount of British charging policies, especially on the local level. 10 out of 17 local policies contains implementation plans related to modeling results, including factors such as the scale of charging facilities and proposed charging solutions. Additionally, modeling evidence can inform target setting and policy agendas, but mostly with low degrees of specificity and enforceability. But under most circumstances, modeling evidence is not considered sufficient to develop the a concrete and binding target for charging infrastructure due to the uncertainty in the development of charging infrastructure. Out of similar concerns, the situation where modeling results are utilized to support policy strategies and the initiation of new policy programs is even less.

Level	Document	Modeling results	Change policy strategy	Initiate new policy/ program	Plan policy action	Set concrete target	Set loose target	Set policy agenda	Set policy strategy
National	UK 2011	1							
	UK 2013 Driving	2			●			●	
	UK 2016 New	4							
	UK 2018	4							
	UK 2020	2		●		●			
	UK 2021	1				●			
	UK 2021 ULEV	11							
	UK 2021 Transitioning	1							
	UK 2022 Improving	3							
	UK 2022 Taking	5			●				●
	UK 2023	4							
Regional	North Ireland 2022	1							
	North England 2022	16	●		●				
	Scotland 2022	1							
	Wales 2021	5			●				
Local	Birmingham 2015	4			●				
	Birmingham 2021	12			●		●		●
	Canterbury 2021	1							
	Carmarthenshire 2022	3			●				
	Ceredigion 2022	8			●				
	CWC 2023	11			●				
	Devon 2022	9			●				
	Hertfordshire 2022	2					●		
	Isle of Wight 2023	5			●				
	Leeds 2022	2							
	Lincolnshire 2022	3							
	London 2019	8			●			●	
	Manchester 2021	2							
	Oxfordshire 2021	1							
	Somerset 2020	6			●				
	Staffordshire 2023	6			●				
	West Sussex 2019	2		●		●		●	●

Figure 5.3: Documented decisions and changes related to modeling evidence

5.2. Birmingham: City-Wide Electric Vehicle Charging Strategy

The establishment of public charging infrastructure in Birmingham commenced in 2012 with the city's involvement in the Plugged in Midlands project. To facilitate its charging network, Birmingham have released two relevant policy documents, with the later one in 2021 dedicated to charging infrastructure in 2021. A noteworthy aspect of this city is its pre-emptive initiation of implementation prior to the formal unveiling of its charging policy. The consultancy, Element Energy, has been steadily and deeply involved in the charging policymaking in Birmingham, acting as both the developer of the EV charging model and the drafter of the documents. This section investigates this evolution of charging policy in Birmingham and the how it was influenced by the model.

5.2.1. Policymaking process

This section focus on the policymaking process of City-Wide Electric Vehicle Charging Strategy, which covers all the stages from target setting to implementation and evaluation (Figure 5.4). The Blueprint for Low Carbon Fuel Infrastructure is included for a short discussion of its formulation informed by modeling evidence.

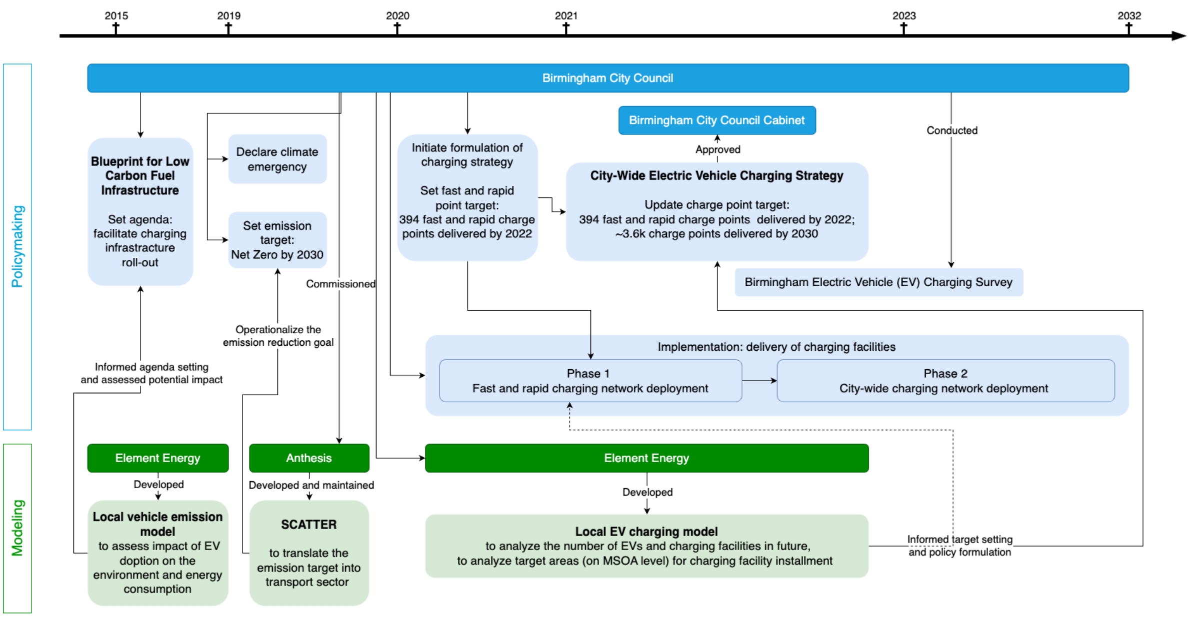

Figure 5.4: Timeline and of policymaking process for EV charging infrastructure in Birmingham

In 2015, the Blueprint for Low Carbon Fuel Infrastructure brought EV adoption and charging infrastructure ramp-up on the agenda. This document provided recommendations for the rollout of infrastructure in Birmingham, providing valuable insights and guiding investments within the sector. Additionally, it advised the Council on the necessary actions to facilitate the implementation of the infrastructure plan. Rather than prescriptive, the document had an exploratory nature, focusing primarily on two key themes: the demand for low carbon vehicles and the local supply of low carbon fuels, including charging facilities. To evaluate the impact of EV adoption on the environment, energy consumption and emission reduction, the consultancy firm Element Energy was commissioned to develop and run a vehicle emission model. This policy also involved extensive consultation with a diverse range of key stakeholders and user groups, which underpinned the modeling results regarding vehicle and infrastructure demand.

In line with the UK government's objective to achieve net zero greenhouse gas emissions by 2050, Birmingham City Council pledged to attain net zero by 2030 and declared a climate emergency in 2019. The SCATTER model was adopted shortly after to operationalize the target in transport section. The modeling results informed the first and well-defined charging objective in August 2020, aiming to deploy 394 fast and rapid charge points by 2022. It is worth mentioning that this target was set in isolation, lacking any contextual policy, as the city was in the early stages of formulating a comprehensive charging strategy. Essentially, while the City-Wide Electric Vehicle Charging Strategy was being developed, the first implementation phase outlined in the document was already underway.

In November 2021, Birmingham City Council Cabinet has approved the City-Wide Electric Vehicle Charging Strategy. This policy introduced an additional goal of approximately 3,600 charge points, with an emphasis on collaboration with private sector entities for charge point deployment on privately owned land. The second phase of the strategy is scheduled to encompass the expansion of Birmingham's charging network from 2022 to 2032. This phase has a broader scope than the initial phase, catering to all major user groups, including residents lacking off-street parking, car clubs and commercial fleets. The overall demands were modeled by an EV charging model, also developed and ran by Element Energy.

5.2.2. Impact of model(s) delineated by stages of policy cycle

5.2.2.1. Target/agenda setting

Modeling results played a vital role in informing the agenda-setting process for Birmingham's Blueprint for Low Carbon Fuel Infrastructure. By simulating scenarios that involved the implementation of low carbon fuel infrastructure, the models projected the expected reduction in carbon emissions and the corresponding benefits for air quality and public health. Although such evidence highlighted the importance of promoting EV infrastructure development, this document did not put forth any enforceable objectives or policy mechanisms.

As for the specific targets for charge points introduced in 2020 and 2021, only the latter explicitly indicated its direct linkage to the modeling results. When setting this city-wise target, modeling results helped assess the existing and projected future demand for EV charging infrastructure. By analyzing factors such as the current EV market share, anticipated growth in EV adoption and transportation patterns, models provided insights into the expected number of EVs on the road and their charging requirements. This information allowed the city council to understand the scale and magnitude of charging infrastructure needed to meet the growing demand.

5.2.2.2. Policy formulation and adoption

After setting the Net Zero target, Birmingham City Council commissioned using the SCATTER model to explore actions required in transport sector to achieve the target. The model generates a greenhouse gas emissions inventory following the Global Protocol for City-wide Greenhouse Gas emissions for your local authority area Helps the understanding and development of a credible decarbonisation pathway in line with emissions reduction targets. The modeling results were mentioned again in City-Wide Electric Vehicle Charging Strategy to explore the different scenarios of charging demands growth.

When formulating the content of this strategy, the charging model developed by Element Energy played an important role. The modeling results helped anticipate future charging needs and inform policy decisions related to infrastructure scalability. By projecting the growth of EV adoption and associated charging demands, the model allowed policymakers to develop charging policies that considered long-term sustainability and the ability to accommodate a larger EV fleet. Moreover, the modeling results allowed policymakers to identify potential charging hotspots and plan charging infrastructure accordingly. By considering charging activities in residential area, workplace and the public, the model helped prioritize the deployment of charging points in areas where they are most needed. It should be noted the modeled distribution of demand is on MSOA level [1], which does not entail the specific locations of charging facilities.

In addition to being extensively referred to in policy contents, the models results also acted as an ex-ante assessment at this stage. The results of the EV charging model have bolstered the acceptance and implementation of this charging policy, as a cabinet member for Transport and Environment publicly stated:

[1] MSOA is a geographical geographic hierarchy designed to improve the reporting of small area statistics in England and Wales. The minimum population is 5000 and the mean is 7200

> ... I welcome this long-term strategy which has been modelled to future-proof the council's transport and environmental needs.

5.2.2.3. Policy implementation and evaluation

The charging policy did not on whether the modeling results are utilized to determine the specific locations of charge points. Element Energy was reengaged to formulate an implementation strategy for the initial phase of public fast and rapid charge points, with a vague reference that "the locations will be chosen based on a detailed assessment of predicted local demand". Furthermore, the document briefly mentioned the importance of long-term monitoring of EV adoption and charging behavior, but failed to specify the methodology employed for such monitoring. While these descriptions hint at the potential involvement of models, they fall short of providing conclusive evidence regarding their utilization at this stage or their consequential impact.

5.3. West Sussex County: Electric Vehicle Strategy 2019-2030

The introduction of the Electric Vehicle Strategy 2019-2030 in West Sussex County marked the initiation of their endeavor to develop public charging infrastructure. Notably, this strategy adopted a cautious approach to optimize the utilization of limited funding, emphasizing the procurement of a market-based supplier to facilitate strategy implementation. In accordance with this strategic framework, West Sussex embarked on the largest deployment of electric vehicle charging points by a local government in the UK in 2022. County underwent a transition in modeling tools, shifting from the strategy-oriented model developed by Element Energy to the operation-oriented model provided by their collaborative partner, CPO Connected Kerb. This section examines the utilization of different models and how it served different purposes throughout the policy process.

5.3.1. Policymaking process

The Electric Vehicle Strategy 2019-2030 stands as the sole charging policy in West Sussex County, and all stages of the policy cycle can be discerned through its progression (see Figure 5.5). Notably, this case exhibits a distinct line between the formulation and implementation stages, accompanied by an independent decision-making process during the provision of charging infrastructure. Consequently, considerable emphasis is placed on the influence of modeling evidence during this phase.

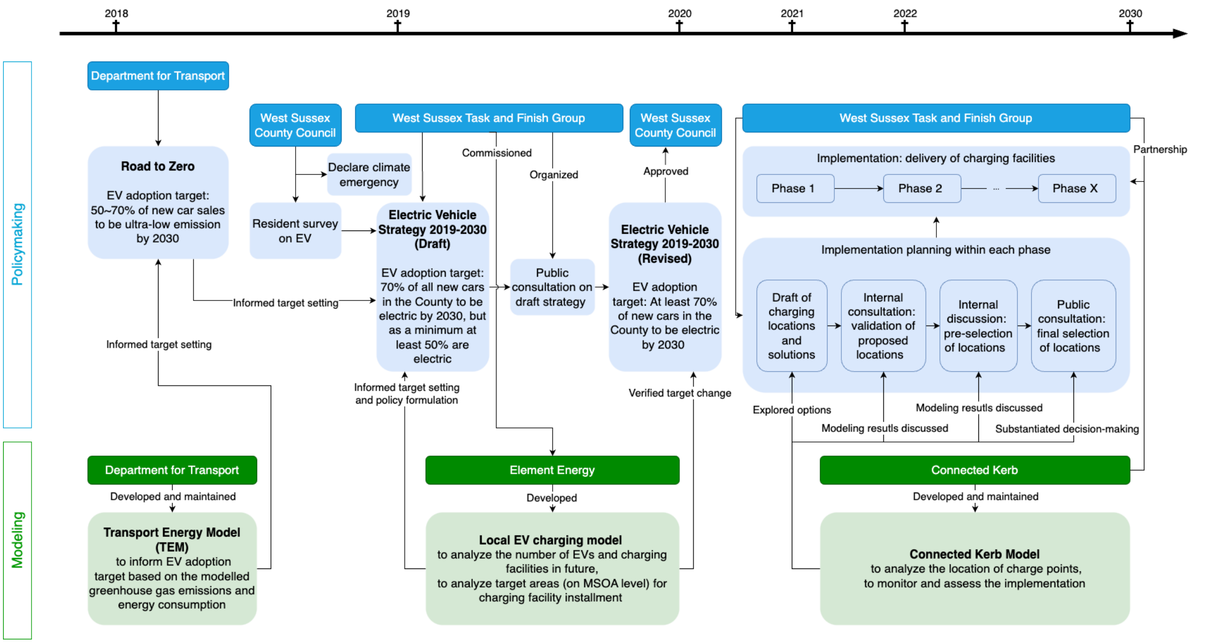

Figure 5.5: Timeline and of policymaking process for EV charging infrastructure in West Sussex County

In 2018, West Sussex declared a climate emergency, signaling a recognition of the urgent need to address environmental challenges. This milestone marked a turning point in the county's approach to sustainability and set the stage for subsequent charging policy development. Later, a Task and Finish Group considered residents' opinions expressed via a resident survey asking what would help people switch to electric vehicles. Building upon the national policy Road to Zero and survey results, West Sussex began formulating its Electric Vehicle Strategy in 2019. With the priority areas for charge point deployment identified by Element Energy's charging model, this draft served as a preliminary roadmap for the transition to electric mobility within West Sussex.

Subsequent to the dissemination of the preliminary draft, an extensive consultation period ensued to elicit feedback and perspectives from a wide array of stakeholders, encompassing residents, businesses, and organizations. This interactive engagement process engendered a holistic comprehension of the distinct needs, concerns, and outlooks of heterogeneous community factions. In light of the survey outcomes and model validation, minor refinements were introduced, comprising a more definitive statement of the EV adoption target.

Regarding the strategy's execution since 2022, West Sussex has entrusted Connected Kerb with the predominant responsibility. The project's complete funding and ongoing chargepoint management and maintenance are assumed by the CPO Connected Kerb. Throughout this process, the company has employed their proprietary modeling tools to select the locations for charge points, which is subject to County Council approval.

5.3.2. Impact of model(s) delineated by stages of policy cycle

5.3.2.1. Target/agenda setting

The initiation of charging policy in West Sussex was initially slow in developing the charging infrastructure until national policies were implemented. At the officer level, there may have been doubts about the need for involvement in every charging decision. The situation is changed by the national charging policy Road to Zero, which set an EV adoption target that 50 70% of new car sales to be ultra-low emission by 2030. This national target was set based on the outcomes of Transport Energy Model (TEM), which was mentioned again in the West Sussex charging policy and used as an input of their own modeling tool. In other words, the TEM model has indirectly informed the agenda setting for EV charging in West Sussex.

The charging model in West Sussex generated the detailed number of prognosis of charging facilities by charging scenario. However, when it comes to the target for charging infrastructure, there was no specific number, only saying to put a "sufficient charging infrastructure in place to support the vehicles predicted to be reliant on public infrastructure". Therefore, the impact of model on specific target setting is relatively limited, merely used to as an enlightening tool.

5.3.2.2. Policy formulation and adoption

The content of Electric Vehicle Strategy 2019-2030 is mostly high-level strategies with limited operational details. Therefore, the only significant impact of modeling evidence is to inform policymakers of the future charging needs and requirements of electric vehicles in West Sussex. By analyzing factors such as population growth, vehicle ownership trends, charging infrastructure availability, and charging patterns, the modeling exercise helps policymakers understand the magnitude and distribution of charging demand across the region.

5.3.2.3. Policy implementation and evaluation

In each phase of implementation, a decision-making process on the charging locations is informed by the results of Connected Kerb's in-house modeling tool. Firstly, the company shares the initial modeling results and the model specifications with the council. Then, a shortlist of potential locations for charging facilities is created and reviewed by the council, followed by internal discussions within the council to assess the feasibility and desirability of the proposed locations. Finally, the council reaches out to residents to gather their feedback and evaluate the public opinion regarding the implementation of the charging facilities.

If questioned about the selection of a particular site, the County Council can refer back to Connected Kerb and request additional modeling data to support their decision-making process. The resolution of disputes or inquiries typically occurs on a case-by-case basis, as the selection process encompasses a considerable number of sites, ranging from 100 to 200 locations per phase. While every site may not undergo triple-checking, the availability of models and data allows for informed responses when challenges or questions arise. By referring to the modeling tool and presenting the data used in the decision-making process, the County Council can provide transparency and evidence-based justifications for their chosen charging locations.

Policymaker B further added that, if the modeling results indicate a clear necessity for equipping a particular location with charging points, it carries substantial weight in the decision-making process. Even if objections arise from the public or other stakeholders, the modeling results hold considerable authority. In the face of objections from the public or other sources, the approach taken by West Sussex is not to dismiss or disregard the objections entirely. Instead, they exercise caution by deferring installation in contentious locations for the time being. These locations are subject to future reassessment, considering factors such as increasing electric vehicle adoption rates and a potential shift in public attitudes. The recognition remains that certain sites, even if met with objections, may still require charge points due to factors like a high density of residences without driveways as indicated by the model. Therefore, it is safe to conclude the modeling results have a decisive impact on the implementation of charging infrastructure in West Sussex.

5.4. Conclusion of the UK

Models plays an important role the charging policy processes in the UK. Modeling evidence has been extensively utilized across all levels of British policy documents, contributing to a comprehensive and diverse evidence framework. Within these policy documents, modeling results are employed for forecasting future scenarios, exploring policy alternatives, and conducting pre-implementation assessments. However, despite informing action planning, British policymakers exhibit a certain degree of skepticism towards models, resulting in limited trust when it comes to higher-level decisions such as policy strategies and binding targets. The imbalanced influence of models on strategic and operational decisions is evident in the two examined local charging policy processes. The case study of West Sussex County further accentuates the greater influence of models during the implementation stage. In this embedded decision-making cycle, models are utilized throughout the decision formulation process and extend to the evaluation of execution results.

6

Case Study of the Netherlands

This chapter presents the case study results of the Netherlands. The findings across all selected charging policy documents in the Netherlands are described in the first section, which corresponds to the first layer of case design. Then the two local charging policy processes are scrutinized in the second and third section, which corresponds to the second layer of case design. The results from both layers are synthesized to draw a conclusion for the Netherlands at the end of this chapter.

6.1. Overview of Evidence Use

A total of 42 Dutch charging policy documents are analyzed, including 13 non-local (national and regional) ones and 29 local ones. As is shown in Figure 6.1, various types of evidence have been identified in all the Dutch documents, but only a few types are used with significant frequency and prevalence. The citation count of a each type of evidence within each document is illustrated in Figure **??** in Appendix **??**.

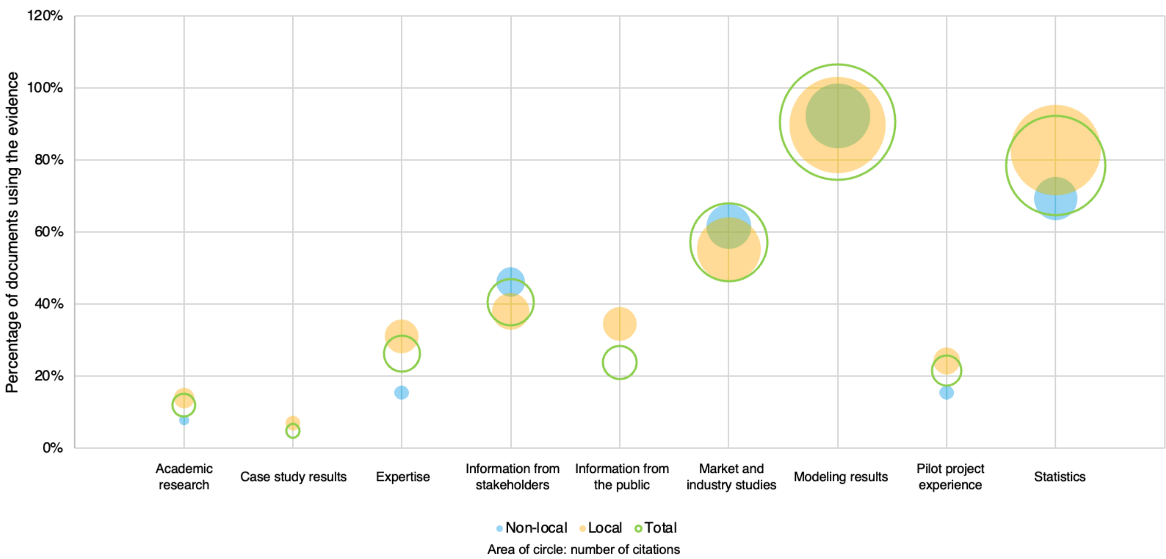

Figure 6.1: The frequency and popularity of evidence cited in Dutch charging policies

Modeling results, statistics and market and industry studies are the three predominant types of evidence in all Dutch documents. Modeling evidence finds broad usage across numerous documents, consistently cited throughout. Notably, the frequency of citations aligns with the prevalence of each evidence type, highlighting their significant contributions. A distinct disparity arises between the top three evidence types and the remainder, as the latter makes notably lesser contributions to the document content. In terms of evidence diversity, local documents tend to reference a broader range of evidence types compared to non-local documents. The prevalence of modeling results and market & industry studies is relatively similar, while most other evidence types are more commonly utilized in local documents. Information from the public and case study results are not used in any of non-local documents. An exception is information from stakeholders, which exhibits a higher percentage of document citations.

Although most Dutch documents analyzed in this case used modeling results, the degree of utilization is different. Plan Charging Infrastructure 2030 (Utrecht 2022), Climate and Energy Outlook 2022 (NL 2022 Climate), Policy Approach to Public Charging Infrastructure (BUCH 2020) are three outstanding examples that extensively apply modeling evidence across a substantial range of aspects. This usage pattern is similarly observed in the utilization of statistics and market & industry studies. Furthermore, when analyzing individual documents, it is evident that local ones tend to encompass a more diverse array of evidence types compared to non-local documents. A prime illustration is the Vision public charging infrastructure Lelystad 2025 (Lelystad 2020), which incorporates as many as eight distinct evidence types.

Within the examined Dutch documents (refer to Figure 6.2), statistics exhibit a close association with specific uses, namely the evaluation of current charging infrastructure and EV adoption. Conversely, most evidence types serve diverse purposes and are generally referenced, with market & industry studies pervading across various content domains. Modeling evidence also serves multiple purposes, primarily centered around prediction, exploration, and ex-ante assessment. Notably, three types of document content heavily rely on model projections, encompassing estimations of required charging facilities, EV adoption rates, and overall charging demand. Moreover, models are frequently employed to explore potential charging locations, which are occasionally combined with charging solutions and overall charging network designs.

	Academic research	Case study results	Expertise	Information from stakeholders	Information from the public	Market and industry studies	Modeling results	Pilot project experience	Statistics
Analyze current charging demand	2	0	0	0	0	10	2	0	6
Analyze financial/business prospect	0	0	0	1	0	3	0	0	1
Analyze future charging demand	1	0	1	2	1	3	18	0	3
Analyze future EV adoption	0	0	0	1	1	5	35	0	3
Analyze future number of charging facilities	0	0	0	0	0	6	59	0	1
Analyze potential charging locations	0	0	1	6	7	0	21	0	0
Analyze the environmental impact	0	0	0	0	0	1	5	0	0
Analyze the grid impact	0	1	0	0	0	6	5	0	0
Analyze vehicle travel patterns	0	0	0	0	1	0	0	0	0
Design charging network	0	0	0	0	0	0	11	0	3
Evaluate and manage risks	0	0	1	1	0	2	0	0	0
Evaluate current charging infrastructure	0	0	0	1	0	5	2	0	56
Evaluate current EV adoption	0	0	0	0	0	1	1	0	28
Explore charging solutions	0	0	0	0	0	2	11	0	0
Identify target groups and areas	0	0	0	0	0	2	7	0	0
Investigate implementation options	0	0	1	2	0	5	5	0	0
Justify the agenda	1	0	1	1	0	3	0	0	0
Operationalize the target	0	0	0	0	0	0	1	0	0
Provide general reference	1	1	7	8	4	8	2	9	2

Figure 6.2: Uses of evidence in Dutch charging policy documents

The inclusion of citations pertaining to modeling evidence does not necessarily imply a corresponding decision within the same document. Hence, a policy decision is deemed to be model-informed only if there is an explicit acknowledgment of its connection to modeling results. Under such criteria, models demonstrate varying influences on different levels of policy decisons (Figure 6.3). At the national level, modeling results play a pivotal role in setting the policy agenda and formulating high-level strategies, both of which are closely tied to the significance of charging infrastructure in the transition to e-mobility, as indicated by the models. In contrast, regional documents exhibit no definitive link between decisions or changes and the utilization of models, despite the presence of a substantial number of citations. Consequently, non-local policy documents do not heavily rely on modeling evidence.

At the local level, modeling evidence predominantly informs policy content related to changing policy strategies and action planning. This correlation between the use of models and policy strategy shifts is exemplified in eight out of the 26 local documents. These documents explicitly mention that municipalities are transitioning from reactive to proactive roll-out of charging infrastructure, facilitated by the insights derived from EV charging models. Furthermore, the same models guide the implementation of these policies, particularly in terms of delivering charging facilities. In two municipalities where modeling results play a significant role across multiple policies, every major component - policy targets, strategies, and actions - is informed by or even based on modeling results.

Level	Document	Modeling results	Decisions and changes related to modeling results							
			Change policy strategy	Change target	Initiate new policy/ program	Plan policy action	Set concrete target	Set loose target	Set policy agenda	Set policy strategy
National	NL 2016 Vision	2								●
	NL 2019 National	5								
	NL 2019 Climate Agreement	1	●						●	●
	NL 2022 Regret	3								
	NL 2021 Climate	5				●				
	NL 2022 Climate	9				●				
	NL 2016 Electric	2							●	
	NL 2020	3			●					
Regional	Noordwest 2021	4								
	Oost 2020	1								
	Zeeland 2019	3								
	Zuid 2020	2								
Local	Arnhem 2021	4	●		●	●	●			
	Arnhem 2019	2							●	
	Rotterdam 2021	3								
	Utrecht 2022	10	●	●		●				
	Utrecht 2018	4	●		●	●	●			
	Utrecht 2019	3	●							
	Utrecht 2015	2							●	
	Utrecht 2010	2							●	
	Albrandswaard 2021	4								
	Almere 2020	6	●			●				
	Bloemendaal 2022	1								
	BUCH 2020	7								
	Geldrop-Mierlo 2021	4	●							
	Groningen 2019	4				●				
	Haaksbergen 2022	3	●							
	Heemskerk 2022	4								
	Huizen 2021	1								
	HvTwente 2021	1								
	Lelystad 2020	3				●				
	Nijmegen 2021	2	●			●				
	Veere 2023	3								
	Wierden 2021	3								
	Zoetermeer 2021	3				●				
	Bernheze 2021	3								
	Amsterdam 2020 Appendix	2								
	Amsterdam 2020	4			●	●				

Figure 6.3: Documented decisions and changes related to modeling evidence

6.2. Arnhem: Electric Charging Implementation Framework

The municipality of Arnhem is at the forefront of the energy and mobility transition, with an ambition to be energy-neutral by 2050. The inception of the municipality-led development of EV charging infrastructure in Arnhem dates back to 2013, when the charging market was at its infancy. Shortly after, the municipality began to experiment with the strategic and future-proof selection of charging locations. It also partnered up with TU Eindhoven and two consultancies in the development of the SparkCity model. The model served as the fundamental prototype for EV Prognose Atlas, the predominant EV charging model in the Netherlands. Therefore, Arnhem has been pioneer of using EV charging model to inform policymaking. In 2021, the municipality finalized its first policy document dedicated to charging infrastructure, the Electric Charging Implementation Framework, which was undoubtedly informed by the results of EV Prognose Atlas (also known as EVMaps). This section looks into the process of policymaking and the intricate interplay between the model and policy.

6.2.1. Policymaking process

The EV charging policymaking in Arnhem went through two periods: demand-driven roll-out and proactive roll-out, and the turning point is the launch of the SparkCity model around 2018 (Figure 6.4). Prior to 2018, there was no official policy document pertaining to charging infrastructure in Arnhem. Still, this period can be viewed as an extensive prelude to the charging policy cycle. The New Energy made in Arnhem 2020-2030, which addressed charging infrastructure at a strategic level, is studied for target setting stage. Since the Electric Charging Implementation Framework inherited such target, it is examined for the subsequent four stages.

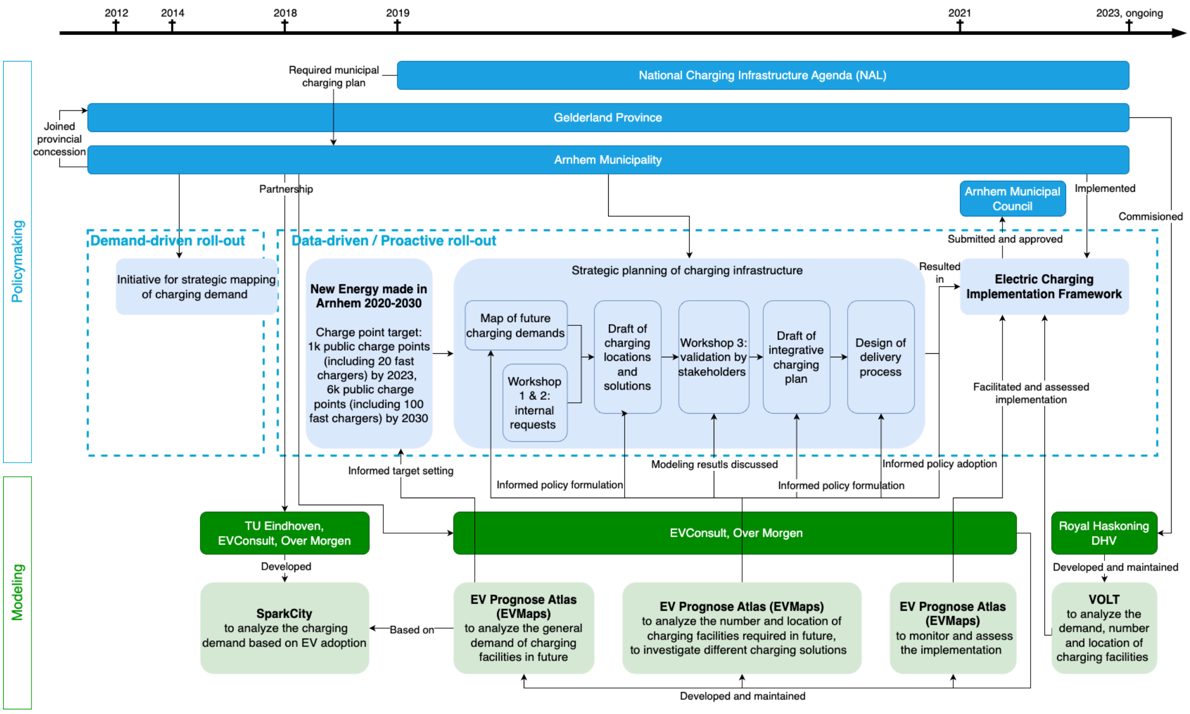

Figure 6.4: Timeline and of policymaking process for EV charging infrastructure in Arnhem

Demand-driven roll-out: 2010-2017

The development of charging infrastructure in Arnhem dated back to 2012, when the municipality got request for installing charging facilities but did not have enough resource or capacity. To tackle this problem, Arnhem was the first municipality to outsource the tender for charging stations to Allego, a charge point operator (CPO). In the concession, where cities purchased the charging stations separately and outsourced their management. Meanwhile, the city was also looking for a way to look ahead into the future and it had the consultancy EVConsult draw up the first strategic planning maps in 2014. It was the first attempt to understand the future need for charging infrastructure at district level, which help the municipality actively identify proper the charging locations. This exercise later evolved into the development of the SparkCity model, as the municipality officially partnered up with modelers from TU Eindhoven and EVConsult. The model was launched at the end of 2017, which was immediately applied to setting the target for proactive charging infrastructure roll-out in Arnhem.

Data-driven/Proactive roll-out: from 2018 and onwards
In response to the Climate Agreement (Klimaatakkoord, a climate policy document of the Netherlands) and the Gelders Energy Agreement (Gelders Energieakkoord, a policy document of Gelderland province), Arnhem initiated the program New Energy made in Arnhem 2020-2030 (NemiA 2030), with the principal target of 61% CO2 reduction compared to 2017. Within the scope of NemiA 2030, 42 kt of CO2 reduction would be achieved in sustainable mobility. The municipality was aware that adequate charging infrastructure was a prerequisite for attaining the targeted reduction. Besides, the National Agenda Charging Infrastructure also delegated local goverments to create their own charging policies. Therefore, they set a concrete goal for charging infrastructure based on the modeling results of EV Prognose Atlas, an EV charging model developed by Over Morgen and EVConsult based on the SparkCity model. The goal required 1,000 charge points (including 20 fast chargers) to be installed in 2023 and 6,000 charge points (including 100 fast chargers) to be installed in 2030.

The NemiA 2030 program, was submitted to the municipal council in November 2018 and adopted in January 2020. Three meetings were held on it during this period and the publicly accessible meeting materials revealed no opposition to the charging infrastructure target. In March 2019, the municipality already commissioned EVConsult to produce a report on strategic planning for charging infrastructure, especially exploring potential policy options to proactively ensure that there is a sufficient supply of charging facilities that align with overall city planning. This report was intended for internal reference only, but the process of creating it laid the foundation for the municipal charging policy Electric Charging Implementation Framework.

In the beginning, EVConsult generated the forecasting map of the future charging demand at district level using the EV Prognose Atlas. Later, two internal workshops were held to discuss the modeling results. Municipal staff from Public Space (Programming and Management), Real Estate, Parking Management and Environmental Teams departments provided insights into preferences, exceptions, and opportunities concerning charging solutions within existing and prospective neighborhoods. The consultation led to the general principle that advocated for the placement of a minimal number of individual charging stations and emphasized the utilization of clustered, integrated and multi-modal solutions. Through the synthesis of modeling findings and the collective deliberations of multiple stakeholders, a proposal that contains suitable locations and the recommended charging solutions was created.

Then the municipality organized the third and final workshop to discuss the proposal with both internal and external stakeholders: municipal staff from major maintenance department, parking officials, project leaders of new districts, grid operator Alliander and CPO Allego. In this meeting, the modeling results were used to address the objections on the shortlisted locations as well as the approach to deploying those charge points (Policymaker A). Eventually all parties reached an agreement and the municipality started working on the delivery framework by specifying three lines of action: policy & organization, communication & support and projects.

The framework was approved by the Board of Mayor and Aldermen (College Burgemeester en Wethouders) in October 2021. Under this framework, the municipality is currently working on tender for the new charge points. Prior to the installation of proactively selected charge points, the municipality also need to go through the traffic order (Verkeersbesluit) procedure to obtain community approval. Besides, the municipality has also been actively informing the public of their new charging strategy. During this process they were often asked to justify the charging solutions, and the modeling evidence has proven to be quite convincing. By 2025, the municipality will evaluate the how the first batch of 1,000 public charge points are exploited before scaling up and deploy the remaining 5,000 in the objective.

6.2.2. Impact of model(s) delineated by stages of policy cycle

6.2.2.1. Target/agenda setting

Since being first created in the NemiA, the target for charging facilities in Arnhem has been adhered to in all subsequent planning and policymaking without undergoing any modifications. This target was established utilizing a top-down approach, predicated upon the forecasted overall charging demand by the EV Prognose Atlas. The numerical value embodied within the goal represents a rounded-up approximation of the actualized modeling results[1], as demonstrated in Table 6.1. Therefore, it is almost certain that modeling results exerted a decisive influence on target setting.

Table 6.1: The modeling results and the final target of charge points in Arnhem

Year	Modeling results		Policy target
	Number of charging stations	Number of charge points	
2018	335	470	
2021	435	875	1000 (in 2023)
2030	3078	6156	6000

6.2.2.2. Policy formulation and adoption

The charging plan map generated by EV Prognose Atlas has significantly contribute to the formulation of charging policy in Arnhem. By integrating various variables such as statistical data and assumptions on EV uptake, this map yields a robust projection of the future demand for charge points by different user groups. Guided by the municipality's predefined principles for charging facility implementation, prospective sites are identified and located using hexagons with a 100-meter radius.

The charging plan map has been a guideline for the expansion of the network. It should be noted that this did not mean the targeted areas and potential locations are selected and finalized at once. Rather, it provided a gradual deployment strategy aligned with the overarching objectives set forth by the municipality. The municipality would constantly use the model at later stages to guide the actual implementation. By then, they would apply the model in a different way, with more focus on certain areas and more operational criteria included. At the policy formulation stage, the map created an overview of the overview of charging demands that has empowered policymakers to identify the districts that will exhibit the highest charging demands by using a color-coded system within the hexagonal units to represent the projected charging demand for a specific year. The municipality of Arnhem found this function quite intuitive and helpful when formulating the policy, as they could prioritize those locations and strategically place charging facilities at locations for which no application for charging facilities had yet been made.

According to Policymaker A, the modeling results of EV Prognose Atlas helped to address the concerns raised by both the municipality and the public subsequent to the proposition of potential charging locations. An example of the first type was from the municipal staff who oversee the maintenance of the public space. They expressed their reservations regarding the potential repercussions of charging facilities on the aesthetic appeal of urban landscapes and the seamless functioning of pre-existing public infrastructure. Cognizant of these concerns, they contested specific charging point locations and advocated for their placement in less conspicuous areas. In response, the map illustrating charging demands was presented to persuade them that the chargers should be installed where they can optimally meet charging needs while minimizing the inconvenience of users having to walk long distances.

The second type of disputes arises from residents who express concerns regarding parking space availability within their community. They frequently question the selection of charging point locations and the necessity of installing them in those specific areas. It should be noted that the proactive roll-out approach entails the deployment of EV facilities in anticipation of future EV ownership, which may not be prevalent at present. To address these concerns, the charging plan map was utilized to provide a visual representation of the projected increase in EV adoption within the neighborhood, thereby

[1] One charging station can have multiple charge points, this number is more flexible based on how the municipality plans to aggregate charging facilities

illustrating the corresponding charging demand. The visually appealing and easily comprehensible charging plan map proved to be highly persuasive during community engagement efforts. Additionally, the forecasted growth of EVs, another modeling output from EV Prognose Atlas, was employed to bolster residents' confidence in the inevitable transition to e-mobility. In essence, the utilization of modeling results has played a pivotal role in garnering support for the policy from both internal stakeholders within the municipality and the public, thereby facilitating its successful adoption.

6.2.2.3. Policy implementation and evaluation

Once the municipality started putting the proactive strategy into action in a specific district, they would re-run the model with increased geographical granularity to ascertain the charging demand within the district based on the forecasted data. The modeling outcomes would be initially deliberated internally in a meeting involving the Living Environment Team, followed by consultations with the district committee. Further engagement with the community would ensue, including informative briefings in the neighborhood newspaper and on the neighborhood website, as well as an information session for all interested residents of the district. Additionally, the municipality would compare the modeled charging locations with the opinions and alternative locations proposed by residents, which would be gathered through a neighborhood survey. The suggested locations would also undergo consultations with the CPO Allego regarding implementation and financial aspects. Finally, the municipality would issue a traffic order, and upon its approval, construction could commence. Apart from the proactive deployment of charging facilities, the map could also accelerate the processing of requests for charge points, which remained a valid approach in Arnhem. Prepared with the suitable locations identified by the model, the municipality could efficiently assess and make decision on such applications.

The newly installed charging facilities are continually monitored and integrated into the EV Prognose Atlas in real-time, enabling dynamic tracking. The model also keeps updating the on the prognosis of charging demand, as well as and the utilization patterns of existing charge points. The model synthesize these data sources and visualize interrelation between the supply and demand of charging facilities. As a result, the municipality can keep track of the roll-out process and evaluate the charging network in Arnhem. As set out in NemiA 2030, the year 2025 represents a milestone for assessing the performance of the first 1,000 public charge points that have been deployed. The outcomes of this evaluation hold significant implications, potentially necessitating policy adjustments to actualize the implementation of the remaining 5,000 charge points in the next period.

Apart from EV Prognose Atlas, the municipality of Arnhem also uses another model called VOLT when choosing the locations of charging facility. This modeling tool developed by Royal Haskoning DHV and adopted by the province of Gelderland. It is also a geospatial charging model that analyzes the demand, number and location of charging facilities. In order to participate in the provincial concession of Gelderland, the municipality was required to employ this tool for mapping out charging locations. However, the simultaneous application of both the EV Prognose Atlas and VOLT has presented certain inconveniences to the municipality (Policymaker A), which will be discussed later in this section.

6.2.2.4. Systematic impact

The utilization of EV charging models also influences the entire policymaking process in a holistic way, encompassing strategic contemplation at the highest echelons to on-the-ground implementation activities. These newly devised processes, made possible by the adoption of models, display a close interrelation between their constituent stages, necessitating a comprehensive analysis to elucidate the role played by models. In the context of Arnhem, the utilization of models unveils two systematic impacts, which are described below.

Enable the shift from reactive to proactive deployment

Both policy documents and interviews have underscored the critical transition from demand-driven to supply-driven/proactive roll-out of charging infrastructure in Arnhem. Previously, the municipality had limited insights into the overall charging needs and their geographical distribution in Arnhem. The major source of information was the requests on charging facilities made by individuals or organizations. EV Prognose Atlas facilitated the consolidation of diverse variables, statistical data, and growth projections concerning electric vehicles, enabling the prediction of district-level charging demands in the municipality. In other words, this model transformed the reactive process into a proactive approach, empowering the municipality to strategically plan charging locations with enhanced control and a bigger picture. Guided by the proactive charging policy, Arnhem can foster the development of a future-proof charging network with the supply staying ahead of the demand. This not only mitigates potential obstacles for existing EV drivers caused by insufficient charging facilities, but also encourages non-EV drivers to switch to EVs, thus accelerating the overall shift toward e-mobility.

The modeling outcomes also optimize the process of decision-making and operation, with the pilot project of Arnhem-Noord neighborhood being an example. Previously, activities such as traffic order issuance, objection procedures, communication, grid connection and installation are conducted on the basis of each single request. Going through these considerable array of steps could take three to six months, and all of them require significant resources and efforts. Now that the municipality can pre-select a batch of charging locations using EV Prognose Atlas, the procedural steps are restructured to streamline the bulk processing of locations recommended by the modeling, thereby reducing the lead time and enhancing operational efficiency.

As is shown in Figure 6.5, the potential locations generated by models have already been included in the municipal charging policy, while the traffic orders has already been taken. When it comes to the actual placement of new charging locations based on the modeling results or (ideally a minimal number of) requests, the locations are already known and coordinated, and the decision-making process has already taken place. Consequently, the remaining tasks solely involve the final selection of location and the installation of charge points. Consequently, the implementation period can be significantly reduced from 130 days to 50 days, representing a notable enhancement in operational efficiency.

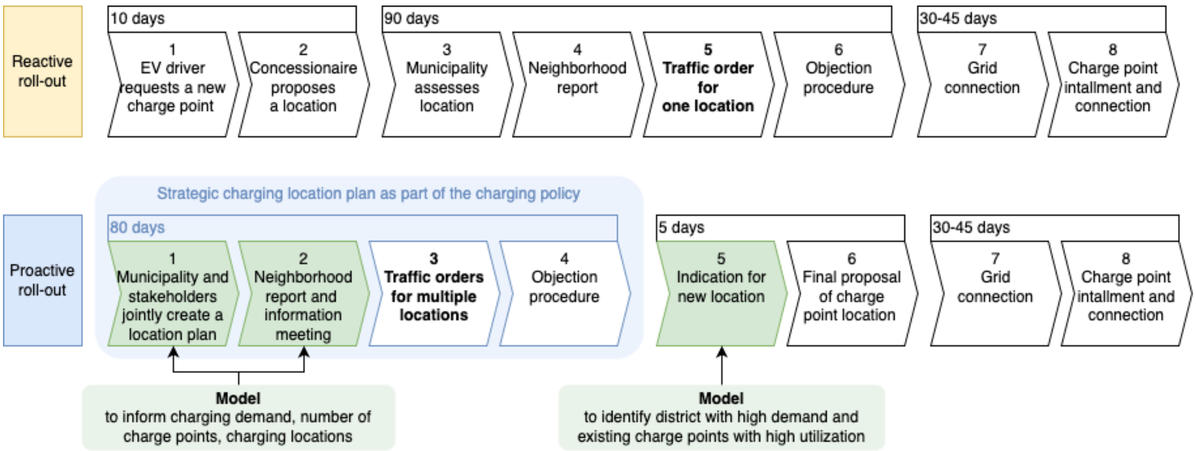

Figure 6.5: Comparison of reactive and proactive development of charging infrastructure

Integrate charging network with city planning

The identification of potential charge points must consider many other criteria and restrictions in addition to charging demands, to name a few, the spatial criteria, the grid condition, the load impact, the parking space and the accessibility. In the case of Arnhem, the spatial consideration has already be incorporated into the modeling process in Arnhem since the spatial suitability for public charging is also included as a layer in the EV Prognose Atlas in addition to the predictions for charging needs. This has been determined on the basis of spatial characteristics and the available public parking area in the hexagon. The EV Forecast Atlas is based on data from various reliable national sources, but a different local situation cannot be ruled out. It is therefore important to also gather local knowledge when interpreting and designed the EV Prognosis Atlas. In this way, the charging facilities are destined fitting into the spatial design and does not cause (excessive) hindrance to other functions of the public space. The model also helped the municipality to balance the clustering of charge points and the convenience of users, which is represented by the distance they need to walk to get their EVs charged.

EV Prognose Atlas also facilitated incorporating grid considerations into the planning of the charging network. When creating the charging policy, the municipality validated the potential charging locations with the grid operator Alliander. By leveraging the modeling results, power demand, load balancing and distribution network aspects could be further explored to ensure that the charging facilities could be adequately powered.

6.3. Utrecht: Plan Charging Infrastructure 2030

The the municipality of Utrecht set its first target for EV charge points in 2010 as part of its broader sustainability goals. The municipality recognized the potential of electric vehicles to contribute to reducing carbon emissions and improving air quality within the city. Ever since then, Utrecht has demonstrated a strong commitment to e-mobility transition and has created a series of progressive charging policies to facilitate the uptake of EVs. There have been five interconnected policy documents and each iteration builds upon the previous ones, with the latest Plan Charging Infrastructure 2030 (Utrecht, 2022) represents a culmination of these efforts. A variety of models driving adjustments and changes have been identified throughout the charging policy evolution, which are described and analyzed below.

6.3.1. Policymaking process

The trajectory of EV charging policies in Utrecht also consists of the same two periods and watershed moment is around 2018 as well (Figure 6.6). The two policies in demand-driven period mainly provides insights into the target setting as they lack fully developed policy measures. For the three policies in data-driven period, the stages of target setting and policy formulation are studied together as these stages are accomplished in parallel or in rapid succession; the stages of implementation and evaluation are also studied jointly as these policies undergo regular assessments when being implemented.

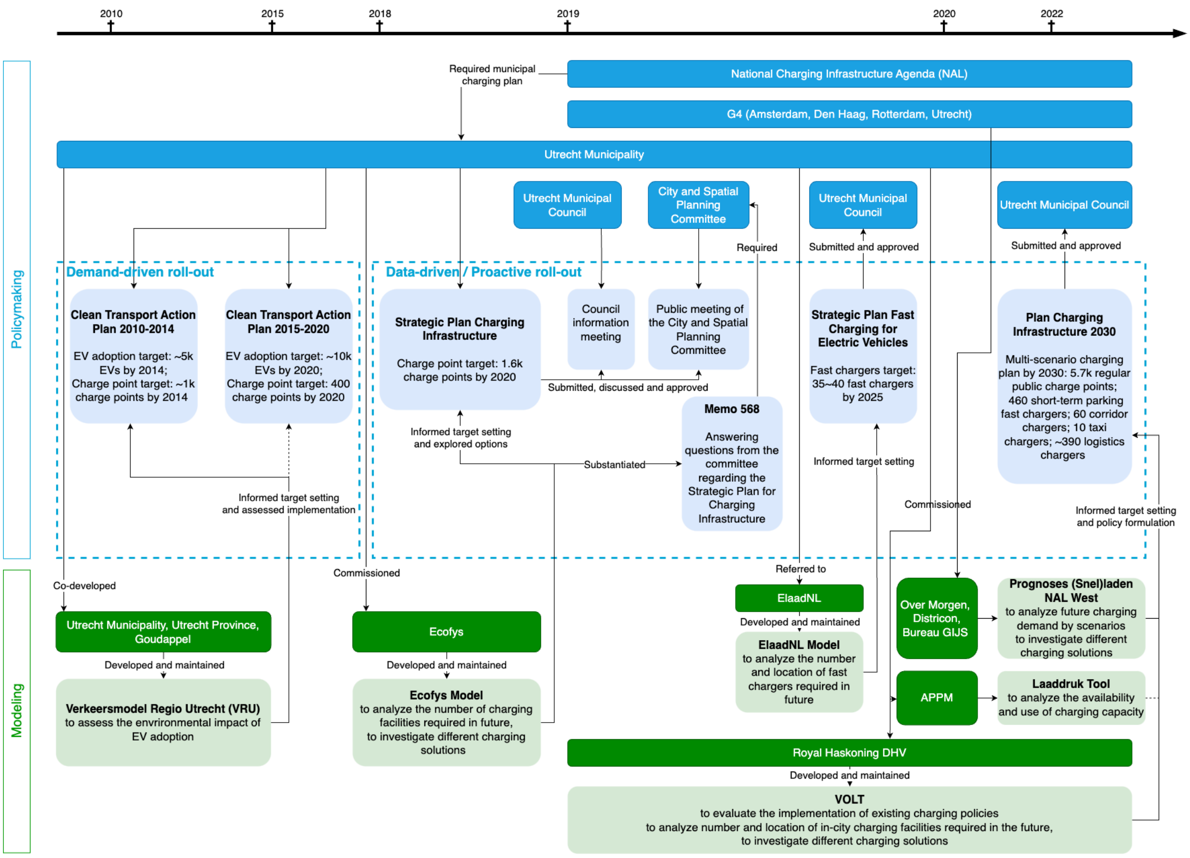

Figure 6.6: Timeline and of policymaking process for EV charging infrastructure in Utrecht

Demand-driven roll-out: 2010-2017

In 2010, the municipality of Utrecht declared their goals of fostering EV adoption in Clean Transport Action Plan (2010-2014). The program aimed to have 5,000 EVs in Utrecht by 2014, along with approximately 1,000 charge points deployed in incremental phases throughout four years. These are subordinate goals to the broader environment and climate ambition, which requires eliminating or minimizing emissions of harmful substances such as CO2 and nitrogen oxides (NOx) in transport. The Verkeersmodel Regio Utrecht (VRU) model was applied to translate such ambition into the concrete number of EVs to be utilized. It was also mentioned in the document that the VRU model would be used in an interim evaluation to assess how the air quality would be affected by EVs in-use by then, and adjust the proposed measures for 2013 and 2014 if necessary. In fact, no adjustment was announced later in the time span this plan.

Although the number of charge points was specified on a timeline, there was no explanation on how the number of charge points was calculated. Other than stating that locations of public charge points will be determined based on applications from individuals and companies, the content regarding where and how to install those charge points was rather vague. Looking back, the target fell seriously short of expectation as less than 300 charge points were installed by 2014. In the successive policy, Clean Transport Action Plan (2015-2020), the target of charge points would last till 2017 and the number was scaled back to 400, while the EV target was updated to 10000 by 2020. It was unclear on what basis were the changes made, but the policy document included a substantial volume of facts and numbers to appraise the level of electric transport then.

Data-driven/Proactive roll-out: from 2018 and onwards
In October 2018, the municipality of Utrecht completed the draft of its first charging-centric policy: Utrecht is charging for 2030 - Strategic Plan Charging Infrastructure. In this policy, they made a definitive commitment to establishing a network comprising 1,600 points before the year 2020. This target was formulated based on the outcomes of the commissioned modeling exercise conducted by Ecofys, which was part of an extensive examination of future charging demands. Concurrently, the municipal acknowledged the imperative of having a minimum of 5,000 public charge points by 2025 and a minimum of 10,000 by 2030, although no obligatory objectives were set for these more distant timeframes. The Ecofys Model also inspired an exploration of various policy alternatives by grouping the predicated into different charging scenarios.

The draft was submitted to the municipal council in October 2018, and was reviewed in the Council information meeting (Raadsinformatiebijeenkomst) held in January 2019. During the meeting, the council received technical explanations and further in-depth knowledge from experts, stakeholders and other municipalities. Various types of organizations were involved: charging industry organization ElaadNL, municipality of the Hague, automotive industry organization RAI Vereniging, energy companies Nuon and Pitpoint, charge point operators Allego and FasNed. The plan was then discussed by the committee for potential improvement. The modeling results were presented to support the strategy and withstood the discussion of participants.

Shortly after the information meeting, the draft was submitted to the City and Spatial Planning Committee and discussed in a meeting in March 2019. The key topics included baselines and preconditions used in the draft, approach and upcoming tender for the roll-out of charging infrastructure for electric transport. This meeting outlined the decision-making items on this draft and prompted debate among all parties about the plan and approach of the municipality. A memo answering questions from the committee was published later, which mentioned that the modeled charging demands were used to inform the scope of task and would be further translated into actionable indicators.

Still, the committee deemed it necessary to develop more detailed plan addressing the fast charging demand. Subsequently, the Strategic Plan for Fast Charging of Electric Vehicles was submitted in July 2019 as a follow-up. The formulation of this document did not involve the application of a customized model; it simply drew upon a national study conducted by ElaadNL on fast charging infrastructure. The municipality derived their targets for fast chargers from the projected nationwide demand, which had been modeled by ElaadNL.

Another modeling practice also started in 2019, which enabled the transitioning from demand-driven to proactive approach as highlighted in Strategic Plan Charging Infrastructure. The municipality used the VOLT, a GIS-based charging model developed by Royal HaskoningDHV to inform the proactive implementation. This model monitored the utilization of existing charge points and integrated such data with demographic and travel information to anticipate the necessary number of charging points in each neighborhood. It then helped determine what the best location for these charging points is in the city, based on the pre-determined municipal guidelines. Since the municipality began to use the model, it has been empowered to engage in active planning for charging infrastructure rather than simply being reactive to demands for charge points.

With the proliferation of EVs, certain user groups that were previously overlooked in charging policies have gained heightened prominence. Notably, the logistics sector (delivery and freight traffic), taxis and target group transport have emerged as increasingly crucial stakeholders. The G4 group, a regional coalition Utrecht participates in, commissioned a more inclusive and comprehensive regional charging model known as Prognoses (Snel)laden NAL West. The primary objective of this model was to analyze the charging demand across various scenarios and target groups. The modeling results have engendered a series of strategic adjustments concerning the locations and deployment of (fast) chargers throughout the city. A consortium of consulting firms was commissioned in September 2020 to conduct an analysis of the future charging demand, utilizing models as a vital analytical tool.

The Plan Charging Infrastructure 2030 created in 2022 was substantially informed by the utilization of these models. A paramount alteration that sets it apart from preceding policies is the detailed illustration of charging sites predicated on distinct target groups and charging scenarios. The numbers in target were also revised based on the modeling results. This policy also exhibited a higher level of granularity regarding actionable measures, grounded in the disparity between the prevailing circumstances and the imperatives derived from the models to achieve the designated targets.

6.3.2. Impact of model(s) delineated by stages of policy cycle

6.3.2.1. Target/agenda setting

The targets in policies since 2018 have been shaped by the insights derived from modeling endeavors. However, it should be emphasized that the modeling results do not possess definitive authority and are not treated as absolute objectives. Rather, they serve as a compass and a foundation, with the municipality incorporating them alongside other pertinent factors, such as the existing installed charging infrastructure and the prevailing dynamics of the EV market. In essence, the final target figures stipulated in the three documents align with the modeling results, but their determination encompasses a broader spectrum of factors and references, extending beyond a simple replication of the model outcomes.

The municipality's use of more sophisticated models since 2019 has compelled them to reassess the prevailing situation and refine their targets accordingly. As exemplified in the 2022 plan, the modeled future demand shows a decrease, particularly noticeable for the year 2030. The plan assumes approximately 4,600 regular public charging points by 2025 and 5,700 by 2030, deviating from the municipality's previous projections of 5,000 charging points by 2025 and 10,000 by 2030. Nevertheless, the municipality did not blindly embrace the new modeling results and alter their targets solely based on them. They conducted further research to validate these differences, which were attributed to the expectation that EVs in 2030 will require less frequent charging due to larger batteries and charging stations achieve greater efficacy at higher densities.

6.3.2.2. Policy formulation and adoption

The models are employed as a navigational tool by the municipality to create and undertake measures in order to fulfill the projected charging demands.The degree of intricacy and the chosen modeling approach will determine the extent and granularity of their capacity to inspire policy resolutions.

The Ecofys model solely focused on numerical forecasting, providing a strategic-level perspective with an overall overview of the projected distribution among these solutions. The prognosis concerning the ratio of charging solutions suggested at a gradual shift towards a larger proportion of public charging in the upcoming years, and the municipality decided to expand the charging network beyond traditional public spaces. However, this model did not address the precise methods and locations for deploying fast chargers, which were missing in the 2018 charging plan. Similarly, the 2019 plan only presented potential strategic options and lays out plans to foster closer collaboration with stakeholders in order to explore the potential for implementing the fast charging infrastructure.

The other three geospatial and charging-oriented models, namely VOLT, Prognoses (Snel)laden NAL West and Laaddruk Tool, have all made notable contributions to policy formulation, operating at both the strategic and operational levels. These models undertook comprehensive analyses of the future quantity and placement of charging facilities within the city, examining diverse charging solutions. Specifically, the VOLT model meticulously identifies optimal charging point locations by meticulously considering an array of factors, encompassing available space, street infrastructure, accessibility, and proximity to the electricity grid. In contrast, the NAL West model transcends local boundaries by incorporating a regional perspective, exploring future charging demands across three spatial scales: corridor charging along highways, community charging areas, and logistics depot charging. Moreover, this model maps user target groups and charging solutions (public or private, slow or fast charging) within these scales, facilitating an exploration of various charging scenarios. The Laaddruk Tool compares the availability and utilization of charging capacity. Based on ideal charging pressure, a planning map is created for the required charging infrastructure in Utrecht, considering technical considerations and opportunities for optimal spatial integration. The results obtained from this model have also influenced the selection of CPOs in the municipality's public tenders.

The modeling results proved instrumental in garnering support from decision-makers at two pivotal assemblies organized by the municipal council and the City and Spatial Planning Committee. Notably, based on publicly available information, all charging policies in Utrecht did not receive any strong objection. At most, there were questions seeking clarification on specific policy aspects, and the modeling outcomes were utilized to address such concerns. Hence, the models indeed played a role in facilitating policy adoption in this case of Utrecht, although the precise magnitude of their influence remains uncertain given the absence of any significant disagreements they resolved.

6.3.2.3. Policy implementation and evaluation

The policy document and the description of three geospatial charging models indicated that the municipality constantly monitor the deployment and usage of charging points in Utrecht with these tools.

In the 2022 charging plan, the municipality conducted a comprehensive evaluation of their implementation efforts and made necessary adjustments to their subsequent actions, guided by the prognosis generated by models. Recognizing the need to meet the latest projected demand, they acknowledged that the pace of charging station installation would soon escalate from 20 to approximately 30 stations per month. Additionally, they conducted an assessment of the development of their inner-city network of short-parking fast chargers and concluded that the prognosis for these chargers aligned with the municipal concession, which allows for the inclusion of 60 fast chargers at designated locations. They were also aware of a considerable task ahead of facilitating fast charging in the city and planned for additional locations based on modeling results.

During the interview with consultant A, they verified that Utrecht upheld "opladen veiligheid (charging security)" by examining the occupation rate of charging points for a specific number of hours each day, which converged with the function of Laaddruk Tool. This model calculates a corresponding value, and should it exceed a predetermined threshold, proactive measures are taken to expand the charging network within the designated area. Besides, Royal Haskoning DHV, which developed the VOLT model, stated that the planned number of charging facilities in Utrecht would be gradually implemented and grow in tandem with the increase in electric cars in the city. In other words, the implementation is guided by the modeling results and the usage patterns of existing charge points served as a crucial input of such model.

6.3.2.4. Systematic impact

The systematic impacts of models are also observed in the context of Utrecht with some variances. They are described and explained as follows.

Enable the shift from reactive to proactive deployment
Similar to Arnhem, the old approach to charging facility roll-out in Utrecht followed a demand-driven and time-consuming process. The situation has been changed with the use of model: the ability to

anticipate the need for new charging points based on utilization data and other relevant factors from existing charging infrastructure has become feasible. Ideally, the modeling results aim to bridge the gap between charging demand and the availability of charging facilities. It should be noted that the municipality still handles the individual request for additional charge point, which gives them extra control information about the charging demand in Utrecht.

Based on the modeled demand, the municipality expected as many as 20 charging points may have to be installed every week between 2020 and 2025. The expansion will be strategically bundled in spatial and temporal groups derived from modeling results, allowing a greater number of charging points to enter the procedure. This approach not only benefits various stakeholders within the charging infrastructure ecosystem, including grid operators, energy suppliers, and charging station operators, but also optimizes tasks such as licensing, public space allocation, and communication by considering the predictable workload during the planning phase. Additionally, synchronized implementation of all traffic regulations can be conducted simultaneously for each district, thereby significantly enhancing the overall efficiency of the process through the utilization of models.

Integrate charging network with city planning

All models used by Utrecht indicated that the charging needs of electric vehicles can be addressed through diverse means. Public charge points are not the only nor the most desirable solution. The modeling results demonstrate a comprehensive assortment of charging solutions, with a slight inclination towards augmented public charging in the foreseeable future. As a result, the municipality would plan for more charging outside the public space and where charging takes place in the public space, which should take place in clusters where possible. They also intended to decrease the intruding objects in public space in order to tackle the tension with spatial quality.

Advanced models like VOLT can incorporate the criteria above into simulation, thereby offering potential solutions that minimize the addition of objects to public spaces and ensure their careful integration where deemed necessary. Meanwhile, the model also explores other alternatives in addition to charging infrastructure in public space, such as charging plazas in parking garages and parking facilities at companies that we make publicly accessible. The selection of these strategic and pivotal charging locations necessitates a comprehensive consideration of various factors, which is the forte of modeling tools. Furthermore, the model is utilized to investigate the feasibility of substituting certain charging requirements in public spaces with fast charging at central locations, thereby encompassing a portion of the demand. In short, the models essential for designing a charging network that conforms with the general city planning and consists of balanced solutions.

6.4. Conclusion of the Netherlands

The impact of models on charging policy processes within Dutch municipalities has been of utmost significance, while their influence on non-local charging policies remains relatively limited. This observation is derived from the extensive utilization of modeling evidence in all Dutch charging policy documents and is further substantiated by in-depth investigations of charging policymaking in Arnhem and Utrecht. Within these policy documents, modeling results play a crucial role in predicting future scenarios, exploring policy alternatives, and conducting pre-implementation assessments. Local policymakers have greatly relied on models throughout every stage of policymaking, encompassing target formulation and evaluation. Beyond the individual stages, models have fundamentally reshaped the overall charging policymaking process in Dutch municipalities by facilitating proactive charging infrastructure deployment and integrated charging network planning.

7

Comparison of Cases

This chapter presents a comparative analysis of the influence of modeling evidence on charging policymaking in the UK and the Netherlands. The comparison is conducted at two levels within the case study: (1) the utilization of evidence across all charging policy documents, and (2) the impact of modeling evidence on local charging policy processes. Subsequently, similarities and differences between the two cases are summarized and analyzed.

7.1. Overall Evidence Use

The evidence-informed charging policymaking in the two countries is compared how different types of evidence are cited in documents across three governmental levels, which serves as a concrete metric to assess the recognition and impact of evidence in the policymaking process. The analysis is conducted along two dimensions: the extent of citations to indicate the degree of utilization, and the contextualization of citations to uncover their specific usage .

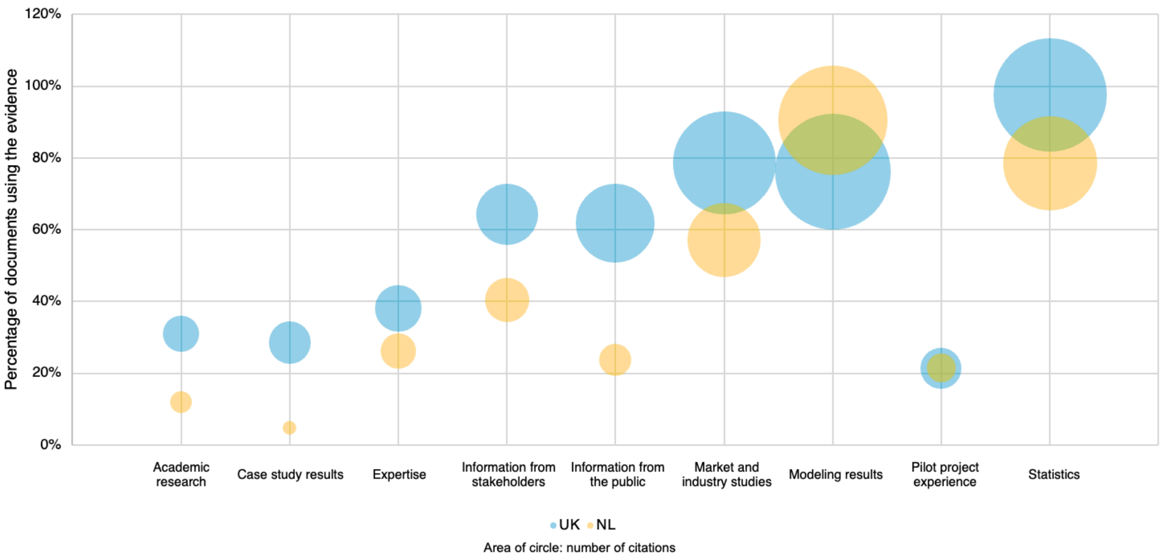

Figure 7.1: Comparison of evidence citation in charging policy documents by country

The country-wise cumulative citations in charging policy documents are illustrated in Figure 7.1. Market and industry studies, modeling results, and statistics emerge as the three predominant types of evidence employed in both countries. These three types of evidence receive a substantially higher number of citations compared to others and have been used in at least two thirds of the documents analyzed. In both countries, policymakers actively engage stakeholders and give due consideration to their input. British documents exhibit a more widespread utilization of most types of evidence, as evidenced by both citation frequency and the number of documents. Such disparity is particularly notable regarding information from the public, as 62% percent of British documents refer to results from public survey or consultation, while 24 % of Dutch documents do so. Modeling results are the only type of evidence that is used more widely in the Netherlands than in the UK, with utilization rates of 90% and 72% respectively.

Similar patterns in policy content related to three major evidence types are identified in both countries (Figure 7.2). Statistics are consistently utilized to assess the existing state of charging infrastructure and EV adoption, while also serving as input for comprehensive data-driven analyses. Modeling evidence is prominently associated with two content themes in both countries, namely prognosis of future charging needs and exploration implementation options. Still, it is employed for a wider array of purposes in British documents and assumes a more significant role in ex-ante assessments, particularly concerning cost-benefit analysis and grid impact. Market and industry studies also have diverse applications ; however, their influence is comparatively lower than the previous two types of evidence, as they inform a significantly lesser amount of the content.

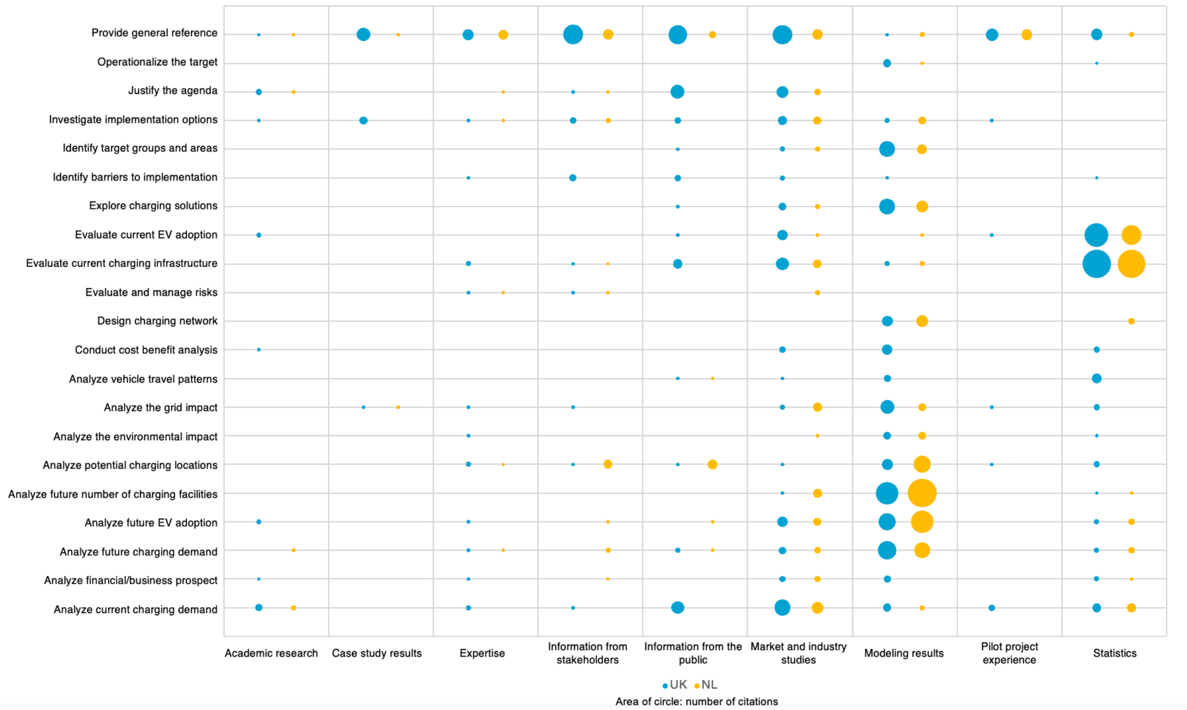

Figure 7.2: Comparison of how modeling evidence is used in charging policy documents by country

In both countries, modeling evidence indeed led to certain tangible policy decisions, with the level of impact varying noticeably based on administrative scope and decision themes. As is explained in case-wise results, a policy decision is only considered as model-informed when its connection to modeling outcomes is explicitly mentioned in the same document. Figure 7.3 compares the percentage of documents contains such model-informed decisions in two countries, categorized into non-local (national and regional) and local groups.

On national and regional level, modeling evidence has a limited impact on decision-making in both countries. Only a few documents clearly cite modeling evidence in the rationale behind any policy decisions. In British non-local policies, a somewhat noteworthy trend is the occasional utilization of modeling evidence in shaping operational plans within the document. In contrast, Dutch non-local policies primarily rely on modeling evidence for strategic decisions, with minimal to no inclusion of operational plans.

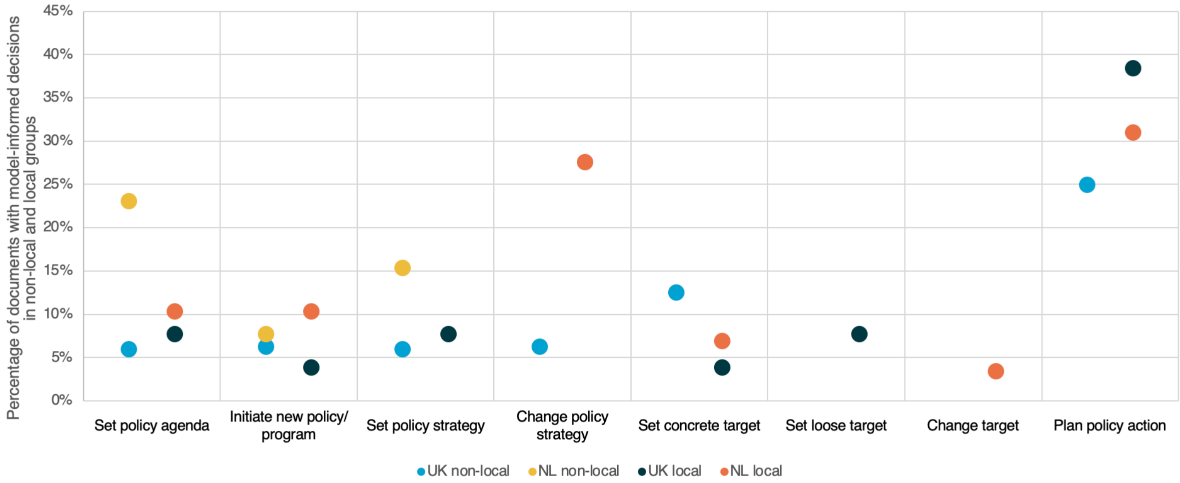

Figure 7.3: Comparison of non-local and local documents with model-informed decisions in the UK and the Netherlands

On local level, modeling evidence exhibits a significantly higher level of influence on action planning, as observed in local charging policies from both countries. In comparison to non-local documents, local policies tend to demonstrate a more detailed approach to measures and actions related to the development of charging infrastructure, accompanied by explicit citations of modeling evidence. Moreover, models play a particularly strong role in driving policy strategy changes in Dutch municipalities, with more than a quarter of these documents explicitly mentioning the transition from reactive roll-out to proactive roll-out based on modeling results.

7.2. Modeling Evidence in Local Policy Processes

This section compares the four local charging policy processes and verify if the model-policy interaction observed in previous researches apply to these cases, organized by two questions raised in Section 3.4. For each question, an overview is provided regarding the confirmation or rejection of the propositions, followed by the description of the rationale behind each determination.

7.2.1. How are models used at each stage of policy cycle

7.2.1.1. Target/agenda setting

The targets were stated with different levels of concreteness in four local policies. Birmingham, Arnhem and Utrecht all had a solid number of charge points to be implemented under the policy, while West Sussex County only said ”sufficient” charging facilities to support another target regarding the adoption of EVs. Table 7.1 shows how models were used to set these goals.

Table 7.1: Comparison of how models are used for target/agenda setting in four local charging policy processes

Proposition	Findings			
	Birmingham	West Sussex County	Arnhem	Utrecht
To identify priority	Confirmed. City areas were stratified on three levels of priority.	Confirmed. 10 MSOA areas were prioritized for charge point installation.	Confirmed. Two districts with greatest charging demand were identified.	Confirmed. Six target groups and two target areas were identified.
To assess impact	Rejected.	Rejected.	Rejected.	Rejected.
To facilitate stakeholder engagement	Rejected.	Rejected.	Confirmed. Model-informed targets were discussed in workshops.	Rejected.

All four local policies utilized models to prioritize specific areas and/or user groups, which were subsequently integrated into the targets for the development of charging infrastructure. The determination of priority was solely based on the geospatial distribution of charging demands derived from the models. None of these policies assessed the impact of these targets using the models, as it was not a viable option according to the model descriptions provided. Furthermore, target setting in these policies was largely uncontroversial, as they did not entail operational specifics. It was also uncommon to involve stakeholders at this early stage, as no concrete policy content was formulated yet. Arnhem was the only municipality that utilized the modeling results to facilitate discussions on the feasibility of their target through workshops involving both internal and external stakeholders.

7.2.1.2. Policy formulation and adoption

As summarized in Table 7.2, despite the utilization of models to enhance understanding of charging infrastructure and examine charging solutions across all four policies, variations are observed in the structure and magnitude of their impact on policy content, notably concerning the explication of modeling findings and the granularity of measures formulated based on said findings.

Table 7.2: Comparison of how models are used for policy formulation and adoption in four local charging policy processes

Proposition	Findings			
	Birmingham	West Sussex County	Arnhem	Utrecht
To enhance understanding	Confirmed. The city was informed of the modeling approach and results.	Confirmed. The county council discussed and compared the modeling approach with other modeling practice to highlight local characteristics and behaviours.	Confirmed. The municipality was involved in the development of the model.	Confirmed. The municipality was informed of the modeling approach and results.
To explore scenarios and options	Confirmed. Multiple charging solutions characterized by charger type and speed were modeled.	Confirmed. Three types of charging solutions were modeled.	Confirmed. Potential charging locations and charging types were modeled.	Confirmed. Potential charging locations were modeled and categorized by target group and technical speficifications.
To conduct CBA	Rejected.	Rejected.	Rejected.	Rejected.
To conduct ex-ante assessment	Confirmed. The environmental impact of the charging policy is evaluated.	Rejected.	Rejected.	Rejected.

In the four policies, the utilization of modeling outcomes contributed to an enhanced awareness among policymakers regarding the charging infrastructure. The incorporation of various factors into the models, encompassing attributes of vehicles, charging technologies, and charging behaviors, facilitated a more comprehensive comprehension of the sector by policymakers. The level of this comprehension was further influenced by the interpretation and application of the modeling outcomes. Birmingham and Utrecht primarily received the modeling results and demonstrated a satisfactory grasp of the underlying mechanisms. In contrast, West Sussex County and Arnhem actively engaged in the modeling process, thereby acquiring deeper insights into both the models themselves and the charging sector.

In terms of exploring policy options, the Dutch policies are much more detail-oriented than their British counterparts. Both Arnhem and Utrecht have already identified potential locations for the installation of charging facilities, thereby defining the layout of the municipal charging network, albeit subject to further adjustments. This divergence is closely associated with the capabilities of the charging models employed in these policies. The charging models utilized in the Dutch policies, namely EV Prognose Atlas, VOLT, Prognoses (Snel)laden NAL West, and Laaddruk Tool, operate at a smaller geographical unit than the Element Energy charging model utilized in the British policies. As a result, the Dutch models provide a higher level of accuracy in determining charging locations. Consequently, the modeling results have a more tangible impact on charging planning in Dutch municipalities.

Except for the Birmingham charging policy, where the environmental impact was modeled, the rest of The four policies exhibit a notable alignment in their exclusion of Cost Benefit Analysis and ex-ante assessment, not to mention the utilization of models for these purposes. As explicitly mentioned in the aforementioned documents, these policies enjoy a greater degree of flexibility in implementing charging policies and often embrace a trial-and-error approach. They possess the capability to experiment with various measures, observe the resulting outcomes, and make adjustments based on local conditions and feedback from residents. This flexibility allows them to assess the effectiveness of the policies in real-world situations, thereby mitigating the requirement for complex and time-consuming ex-ante assessments. Moreover, considering the relatively localized impact of these policies compared to broader national or regional policies, the potential policy outcomes are frequently confined to specific areas and can be assessed without an extensive analysis.

7.2.1.3. Policy implementation

The implementation of charging facilities in Birmingham was was undertaken by their contracted CPO ESB Energy, and there was limited information publicly available regarding this endeavor. For the implementation of the remaining three policies summarized in Table 7.3, models typically assume an important role in formulating comprehensive delivery plans, assessing the implementation process, and facilitating stakeholder engagement.

Table 7.3: Comparison of how models are used for policy implementation in four local charging policy processes

Proposition	Findings			
	Birmingham	West Sussex County	Arnhem	Utrecht
To simulate and optimize actions	Unclear.	Confirmed. Potential charging locations were generated by another charging model developed by CPO.	Confirmed. Potential charging locations were optimized with space planning criteria taken into consideration.	Confirmed. Potential charging locations were optimized with space planning criteria taken into consideration.
To monitor and evaluate progress	Unclear.	Confirmed. The charging network is evaluated by CPO.	Confirmed. Newly implemented charging facilities were synced up in the model for evaluation on charging supply and demand.	Confirmed. The availability and use of charging capacity were constantly monitored and evaluated by model.
To optimize resource allocation	Unclear.	Unclear.	Confirmed. The placement of charging facilities started in target districts with highest charging demand.	Unclear.
To conduct adaptive management	Unclear.	Confirmed. The delivery plan at each phase would be adjusted based on modeling results.	Confirmed. The placement criteria used in specific programs would be adjusted based on modeling results.	Confirmed. The delivery plans were iterated in different versions of polices with increasing operability.
To facilitate stakeholder engagement	Unclear.	Confirmed. Stakeholders and the public were involved in finalizing the potential list of charging locations.	Confirmed. Stakeholders and the public were involved in finalizing the potential list of charging locations.	Confirmed. Stakeholders and the public were involved in finalizing the potential list of charging locations.

The identification of charging sites constitutes the most crucial stage in the implementation of local charging policies, and this process heavily relies on modeling outcomes in the three local policies. Furthermore, in two Dutch municipalities, advanced geospatial charging models have incorporated the aforementioned criteria into simulations, thus offering potential solutions that minimize the addition of structures to public spaces and ensure their careful integration where deemed necessary. Additionally, the model also explores alternative options apart from charging infrastructure in public areas, such as charging plazas within parking garages and providing public access to parking facilities at companies. The selection of these strategic and pivotal charging locations necessitates a comprehensive assessment of various factors, which is the strength of modeling tools.

The implementation progress of the three policies is also monitored and evaluated by models, which serves as the input for adaptive management of charging facility delivery. The charging models continuously track and analyze various aspects related to charging capacity, such as the number and distribution of charging stations, their capacity, and the charging load placed on them. This data allows policymakers and CPOs to assess the adequacy of the charging infrastructure and identify any potential gaps or areas of improvement. Furthermore, the models used by two Dutch municipalities also analyze the frequency and duration of charging sessions, peak usage times, and the overall demand patterns. This information helps in understanding the charging behavior, updating areas with emerging demand and optimizing the overall charging network with increasingly actionable insights.

The stakeholders and the public are seriously engaged in the final decision on locations, where modeling results have been used as the foundation for discussion. More specifically, modeling results help to provide a common understanding of the charging needs and demand patterns within the community. This enables stakeholders to have informed discussions and contribute their expertise and insights to the decision-making process. Modeling results also provide a transparent and data-driven basis for these discussions, allowing the public to understand the rationale behind the proposed charging locations. This fosters trust, encourages participation and ensures that the final decisions are acceptable to the community.

Regarding resource allocation, the charging policy in Arnhem stands out as the sole policy explicitly indicating a rollout strategy that commences with high-demand target regions. The interview with policymaker A underscored the necessity of this decision in light of the municipality's constrained resources. As for the remaining three local policies, while not explicitly stated, it is highly probable that they too allocate resources to priority areas based on modeling outcomes, as initially considered at the target setting stage.

7.2.1.4. Policy evaluation

Table 7.4 presents a comprehensive overview of the utilization of models in the holistic assessment of charging policies, encompassing a broader range of factors beyond the implementation-focused evaluation. The approaches employed vary across the four policies: Birmingham vaguely mentions policy review and updates; Utrecht has already undergone two policy updates; West Sussex County and Arnhem have planned policy reviews, which have not yet been executed. Therefore, it is confirmed that Utrecht utilized the outcomes of the existing policy as inputs for models to evaluate the feasibility of meeting future demands as intended. Informed by such modeling practices, they revised targets for charging facilities and refined the roll-out approaches in subsequent policy iterations. Regarding West Sussex County and Arnhem, it is highly probable that modeling results will be employed for similar purposes, as it primarily involves fine-tuning the modeling inputs in comparison to what has been done during the implementation phase. Besides, none of the four policies considered apply counterfactual analysis, which is understandable in the context of local charging policies. As evidenced in the case of Utrecht, evaluating the policy's impact can be effectively achieved by incorporating the implemented charging infrastructure into models to assess if the intended objectives were met.

Table 7.4: Comparison of how models are used for policy evaluation in four local charging policy processes

Proposition	Findings			
	Birmingham	West Sussex County	Arnhem	Utrecht
To conduct ex-post assessment	Unclear.	Unclear.	Unclear.	Confirmed. The implemented charging facilities from existing policy was used as input of models to evaluate if demands were fulfilled as planned.
To conduct counterfactual analysis	Rejected	Rejected.	Rejected.	Rejected.
To support policy improvement	Unclear.	Unclear.	Unclear.	Confirmed. Three versions of charging policies have been created since 2018, with updated targets and actions informed by models.

7.2.2. What decisions and changes are informed by modeling evidence

To complement the process-oriented comparison outlined in the previous section, this section presents a result-focused comparison of effective decisions and alterations that are guided by modeling evidence in four specific local charging policy processes. Table 7.5 summarizes the extent to which the patterns observed in the energy sector hold true within the context of these four local charging policies.

Table 7.5: Comparison of model-informed decisions and changes in four local charging policy processes

Proposition	Findings			
	Birmingham	West Sussex County	Arnhem	Utrecht
To set agenda	Unclear.	Confirmed. Models were used to set the agenda while initiating the policymaking for local charging infrastructure.	Confirmed. Modeling results were used in NemiA to demonstrate the necessity of improving charging infrastructure before the charging policy was created.	Confirmed. Modeling results were used in Clean Transport Action Plan to demonstrate the necessity of improving charging infrastructure before the first charging policy was created.
To trigger policy discussion	Rejected.	Rejected.	Rejected.	Rejected.
To resolve disagreement	Unclear.	Confirmed. Modeling evidence was used in the delivery phase to justify the selection of charging locations if objections were raised.	Confirmed. Modeling evidence was extensively used to mitigate objections from both stakeholders and public on the charging locations.	Unclear.
To formulate/change policy content:				
(1) Target	Confirmed. A loose target for charging infrastructure to be developed by 2030 were informed by modeling results, with room for adjustment.	Confirmed. A concrete target for EV adoption was set based on modeling results, while no concrete target was set for charging facilities.	Confirmed. A concrete target for number of charge points was set based on modeling results.	Confirmed. Concrete targets for charging facilities were formulated and updated based on modeling results.
(2) Strategy	Confirmed. A two-phase strategy was created to tackle the priority charging demands indicated by the model.	Confirmed. A cautious strategy was adopted due to the uncertainty identified in modeling process.	Confirmed. The charging model enabled the transition from reactive to proactive rollout of charging infrastructure, synergized with city planning.	Confirmed. The charging model enabled the transition from reactive to proactive rollout of charging infrastructure, synergized with city planning.
(3) Action	Confirmed. A delivery roadmap was created based on the foretasted number of charging facilities and simulated charging solutions.	Confirmed. Measures were proposed for three types of charging solutions modeled.	Confirmed. General actions were planed based on the charging map generated by the model; concrete actions were proposed for specific roll-out programs in priority districts unidentified by the model.	Confirmed. General actions were first planed based on modeled charging demand; concrete actions specified by target groups and areas were updated in subsequent versions based on more comprehensive modeling results.

EV charging models have a more substantial impact on agenda setting in Dutch localities compared to British counterparts. In Arnhem and Utrecht, charging models were implemented for agenda setting purposes well before modeling policies were established. Initially, the modeling practice served as a subordinate element within the broader energy or transport planning framework, underscoring the need for a systematic policy to foster the advancement of charging infrastructure. Such difference may be attributed to the Netherlands' early adoption of research on EV adoption and charging demands, exemplified by the development of the SparkCity model. Subsequently, more sophisticated models such as the EV Prognose Atlas and Prognoses (Snel)laden NAL West emerged and gained widespread recognition among municipalities. No EV charging model with a comparable level of functionality and acceptance has been identified in the UK thus far.

Models did not cause scientific or political debate in any of these four local policies. This is primarily due to the alignment of these charging policies with previously established local energy of climate agenda, or broader regional or national charging strategies, leaving little room for debate. When policies are in line with higher-level directives, it reduces the scope for contention and foster certain consensus among policymakers and stakeholders regarding the importance and benefits of EV charging infrastructure. Moreover, in all four cases the chosen EV charging models were considered technically efficient, reliable, and well-suited to the local context, which minimized the need for scientific or political debate.

Modeling evidence facilitate the consensus on the selection of charging locations in West Sussex County and Arnhem, with the other two localities lacking sufficient evidence to verify the same use. Still, it is reasonable to presume that this phenomenon is more widespread across various local charging policies. Modeling evidence provides an objective and data-driven approach to decision-making, effectively reducing subjective biases and preferences, thus fostering an objective consensus-building process. Furthermore, the utilization of models allows stakeholders and the public to comprehend the rationale behind the specific charging location choices. This promotes informed discussions and actively involves stakeholders through a transparent and openly discussed process. The transparency fosters trust and encourages participation, ultimately expediting the resolution of disagreements.

Models' influence on policy formulation in the four local policies is reinforced by the essential components of policy content, namely targets, strategies and actions, all of which are informed by modeling evidence. However, the extent to which models can shape policy targets and strategies notably depends on the perception of uncertainty associated with modeling methods.The two British policies prioritize the accuracy of forecasting in the dynamic EV sector, thereby refraining from translating the modeling outcomes into binding and rigid targets for charging infrastructure. In contrast, the two Dutch policies exhibit a higher level of confidence in the modeling outcomes, with Arnhem directly basing its targets on these results. Nevertheless, the acknowledgment of uncertainty and the inclusion of regular target reviews and updates are part of their plans. Concerns of a similar nature have led to the more abstract and high-level nature of the model-informed strategy and action in the two British policies, allowing for significant room for specification during implementation. Conversely, the proactive roll-out strategy adopted along with the action planned accordingly in the two Dutch municipalities incorporates operational details that are fundamentally enabled by the charging model.

8

Discussion and Conclusion

8.1. Discussion

In this section, the results of two case studies and how they contribute to answering the research questions are discussed. The utilization of modeling evidence, along with the consequential impact on policy decisions and changes, are highlighted in the context of charging policies and compared with findings in the energy policymaking.

8.1.1. Impact of models and other evidence on charging policy documents

Base on the theories of Bornmann et al. (2016), the impact of models and other evidence on charging policies are evaluated based on the number of policy citations and the context of these citations. Both countries demonstrate strong capability of obtaining evidence from various sources and synthesize various types of evidence to substantiate the policy contents. In such practice, the following patterns are identified.

8.1.1.1. Preference on three types of evidence in all charging policy documents

The results of highlight the extensive use of a diverse portfolio of evidence in charging policies in both the UK and the Netherlands. Market and industry studies, modeling results, and statistics emerge as the most prevalent types of evidence utilized in these policy documents. These three types of evidence are consistently cited at a substantially higher rate compared to other types, indicating their significant role in shaping charging policies. Moreover, the policymakers in both countries actively engage stakeholders and consider their input, reflecting a participatory approach to policy-making. However, a notable disparity is observed between the two countries in terms of the utilization of various types of evidence. British charging policy documents exhibit a more widespread incorporation of evidence, as evidenced by both the frequency of citations and the number of documents analyzed. This suggests a more comprehensive approach to evidence-based decision-making in the UK charging policies.

In terms of the utilization of a specific evidence type, a significant disparity regarding the utilization of public input was identified. While public survey or consultation results are referenced in a substantial portion of British documents (62%), their incorporation is relatively limited in Dutch documents (24%). This suggests that the UK places greater emphasis on engaging the public and considering their perspectives when formulating charging policies. Furthermore, the modeling results are used more extensively in the Netherlands compared to the UK. The higher utilization rate of modeling evidence in the NL (90%) indicates its significance in shaping charging policies in this country. In contrast, the UK utilizes modeling evidence to a slightly lesser extent (72%). This difference may be attributed to variations in policy priorities, methodologies, or available resources between the two countries.

Despite these differences, there has been a consistent correlation between the content of charging policies and the three major types of evidence. Statistics play a crucial role in assessing the existing state of charging infrastructure and electric vehicle adoption, serving as input for data-driven analyses. Modeling evidence is notably connected to two key areas of interest in both countries: forecasting future charging demands and investigating various implementation strategies. However, in British documents, it finds broader applications in ex-ante evaluations, particularly in relation to financial/business prospect, cost-benefit analysis and grid implications. Market and industry analyses, though comprising a smaller portion of the content, remain relevant in assessing present EV adoption, charging demand, and charging infrastructure development in both countries. Furthermore, they are often used as input in the projection of the future state of these three aspects.

8.1.1.2. Models' varying degree of influence over policy content

Modeling evidence has varying levels of impact on policy decisions in both countries, depending on the administrative scope and decision themes. On a national and regional level, the influence of modeling evidence is limited, with only a small number of documents explicitly citing modeling outcomes as a basis for policy decisions. In British non-local policies, there is a notable trend of utilizing modeling evidence to shape both strategic and operational plans within the documents. The former approach involves the establishment of a comprehensive charging infrastructure objective, whether quantitative or qualitative, and presents a systematic plan of action with specific areas of focus for each phase. These strategic components are typically formulated within the broader context of climate action, including commitments to achieve zero emissions and declarations of a climate emergency. In this context, models serve as valuable tools for translating these climate objectives into requirement on EV usage and charging infrastructure. The latter is concerned with devising a developmental trajectory for charging infrastructure that aligns with the identified requirements, offering precise numerical targets for charging facilities and furnishing detailed guidelines regarding their deployment, encompassing considerations of timing, spatial allocation, and implementation methodologies. In contrast, Dutch non-local policies primarily rely on modeling evidence for strategic decisions, with little to no inclusion of operational plans.

On the local level, modeling evidence has a significantly higher level of influence on action planning, particularly evident in the local charging policies of both countries. Local policies demonstrate a more tangible approach to measures and actions related to the development of charging infrastructure, accompanied by explicit citations of modeling evidence. Furthermore, models play a strong role in driving policy strategy changes in Dutch municipalities, as over a quarter of the selected documents explicitly mention transitioning from reactive roll-out to proactive roll-out based on modeling results.

8.1.1.3. Fit between policy needs and model functionalities

The different degree of models' impact on policy content can boil down to the mapping between the orientation of the policy and the functionality of the model. Strategic policies are typically long-term and overarching, aimed at setting broad objectives, targets, and guidelines. These policies often consider factors such as sustainability goals, market dynamic and technology trends. On the other hand, operational policies are more immediate and detailed, aimed at the on-the-ground implementation and management of specific initiatives or projects. The orientation of the policy, whether strategic or operational, shapes the requirements for the modeling approach.

Strategic policies often require models that can assess the potential impacts and outcomes of different scenarios, evaluate the effectiveness of various policy interventions, and provide insights into the long-term implications of different policy choices. These models need to capture a wide range of variables and incorporate complex dynamics to inform strategic decision-making. Most charging policies on national level and the two British local policies falls into this category. Instead of precisely pinpointing the locations of charge points, these models emphasize the regions where the charging infrastructure either currently falls short of meeting the charging demand or may potentially face deficiencies. Furthermore, they accentuate the integration of diverse charging technologies and network layouts to address the cumulative charging requirements. This information unveils priority groups and guides the formulation of operational plans.

Operational policies, on the other hand, typically require models that can provide real-time or near-real-time information for immediate action. These models may focus on forecasting short-term demand, optimizing resource allocation, or monitoring the performance of specific projects. They need to be responsive, adaptable and capable of providing actionable insights to support operational decision-making, exemplified by most Dutch local charging policies. Models used by these municipalities display a higher level of geographical detail, which provides the ready-to-implement information on where and when to put the charge points. As a result, these models call for more precise and localized inputs, encompassing data on local demographics, mobility trends, urban environment attributes, and energy infrastructure configuration.

8.1.2. Impact of models on local charging policy processes

Modeling evidence has been applied throughout the entire policy cycle in the context of four local charging policies. The effects associated with each stage are summarized in Section 7.2.1, forming the basis for the discussion of three overarching themes in this section.

8.1.2.1. One model for all stages or multiple models for different stages

Modeling evidence serves various purposes across different stages. However, if a particular model has limited functionality or scope, it becomes necessary to employ different models sequentially to address the particular requirement at each stage.

In the two focused British charging policies, a clear distinction exists between the utilization of models in the formulation of strategies and their implementation. When devising the charging plan, the models provide policymakers with information regarding the anticipated quantity and spatial distribution of future charging demand at a higher level of abstraction. These modeling outcomes do not specify the precise arrangement of the charging network or the exact positions of charge points; rather, they indicate the appropriateness of deploying charging infrastructure at the level of Middle Layer Super Output Areas (MSOA) (MSOAs). Apparently this precision is not sufficient to determine the exact locations of charging facilities in the delivery phase. Therefore, other modeling exercises are required and the often commissioned to the providers of charging facilities. For example, West Sussex County based its decision of charge point locations on the modeling results of their contracted CPO, Connected Kerb. It is unclear if the charging facility supplier for Birmingham applied modeling tool to inform the delivery process, but the high-level modeling results from the Element Energy model are apparently not applicable under such circumstance.

A clearer contrast can be made between the practice of the two Dutch municipalities in terms of how they different levels of needs at different stages, the municipality has the option to either adhere to a single model while making adjustments to its functionalities or utilize a series of models with distinct specializations. The former approach is exemplified by Arnhem, where they harnessed the diverse capabilities of the EV Prognose Atlas and its modeling outcomes at varying levels of granularity. At the target setting stage, they refered to the numerical forecast of demand of charge points generated by the model; at the policy formulation stage, they formulated strategies and identified priorities based on the overview of charging demands and solutions of the entire municipality, which is illustrated in a charging plan map generated by the model; at implementation stage, they fine-tuned the models for specific districts and initiated the deployment process based on the modeling outcomes.

The latter approach is exemplified by Utrecht, which applied a series of models with distinct focuses as their charging policies evolved. At target setting and early formulation stage in 2018, they applied the numerical results of the Ecofys model since the municipality focused on understanding the overall charging demands and general directions of solutions; later when they adjusted the target for charging facilities and added more operational details into the policy conent in 2022, they synthesized results of multiple geospatial charging model and create a detailed plan map that specify the layout of charging network by target group and charging type, which was necessary to guide the actual implementation; at implementation stage, they also zoomed in on the location or district level of models and finalized placement decisions based on modeling results.

However, a worrying observation is that multiple models could cause perplexity in planning if they are not well aligned. In the case of Arnhem, EV Prognose Atlas has been the primary model used to inform charging policy. However, the policymaker was also required to take the results of another model VOLT into consideration while being not familiar with the mechanism of that model. The integration of divergent outcomes from both models into the formulation of a charging plan has proven to be a challenging task (Policymaker A). Misaligned results can arise due to variations in EV charging model architecture, training data or assumptions embedded within the models (Modeler A). These differences may lead to discrepancies in the predicted outcomes, making it difficult for policymakers to determine which results to prioritize. This phenomenon has not been identified in previous studies in the energy field, however it corresponds to the concerns raised by Saltelli and Giampietro (2017) on misalignment of evidence in general policymaking. Hence, it is reasonable to expect that policymakers faced with contradictory information stemming from disparate models may have difficulty in comprehending, analyzing, and integrating the multifaceted perspectives. In other words, the possible overload of information caused by unaligned modeling practice could undermine the decision-making process and hamper the efficiency of planning.

8.1.2.2. Applying models with healthy skepticism

The impact of charging models on policy decisions is often diminished by the inherent uncertainty associated with these models. This is evident in the case of four local policies analyzed in this study. While all four policies acknowledged the uncertainty intrinsic to the modeling results, their approach to incorporating these models into their decision-making process differed significantly.

Two British policies opted to completely avoid setting concrete targets in the longer term, despite the availability of charging demand forecasts generated by the models. This indicates a level of skepticism towards the reliability and accuracy of the modeling results. By refraining from establishing specific targets, these policies demonstrate a cautious approach, potentially driven by concerns about making commitments based on uncertain projections. More specifically, the West Sussex County policy omitted numerical targets for charge points in their charging strategy. Instead, they opted to address this aspect during a specific delivery phase. By deferring the consideration of numerical targets, the policy suggests a hesitancy to rely heavily on modeling results when setting charging infrastructure goals.

In the two Dutch policies, there exists a measure of skepticism as well. The policy content frequently underscores the significant uncertainty surrounding the modeling results. For example, all Utrecht policies acknowledge that prognoses are subject to the various factors not incorporated into the model and there is considerable variation of charging solutions caused by technological advancement. To effectively respond to evolving developments, their implementation approach is oriented toward adaptability. During the interview, Modeler A also commends Utrecht's practice, which involves initiating construction based on the recommended model while allowing for future flexibility. It is recognized that the model is an imperfect representation of reality and does not provide an absolute truth but serves as a tool to guide decision-making. Consequently, Utrecht proceeds with construction based on the model's findings and closely monitors progress. As they advance through subsequent stages of the planning policy cycle, they retain the capacity to adapt their plans. This approach enables Utrecht to effectively prioritize and allocate resources, particularly when identifying locations that exhibit exceptional performance and require immediate attention.

Overall, the skepticism surrounding the modeling results reduces the influence of these models on the target-setting process in EV charging policies. The policies analyzed demonstrate a preference for flexibility and adaptability, opting for a more cautious and measured approach to avoid making commitments based on uncertain projections. The diminished impact of EV charging models on policy decisions highlights the need for ongoing improvements in modeling methodologies and enhanced transparency regarding the underlying assumptions and limitations of these models. This will enable policymakers to make more informed decisions while managing and accounting for the inherent uncertainties associated with EV charging modeling.

8.1.2.3. Paradigm shift in policymaking enabled by models in Dutch municipalities

A holistic change on the entire policy process has been identified in many Dutch municipalities. More than a quarter of Dutch local documents stated that models are the indispensable enabler of proactive charging policy. In some municipalities, such as Utrecht, the modeling outcomes have served not only as a means but also as an impetus for the such change. In their 2018 charging plan, the municipality the inadequacy of the reactive roll-out to accommodate a huge disparity between their currently installed infrastructure and modeled future demand. Therefore, the municipality was motivated to take initiative and actively expand its charging network. Whether viewed as the causal factor or not, EV charging models have undeniably reshaped the procedures of policymaking by moving the major decision-making ahead of the rise of demand. Such change would be impossible without models that anticipate charging needs and identify optimal charge point locations in order to address these needs. The decision-making has also been streamlined through the consolidation of multiple potential charging locations generated by the model. As a result, the occurrence of neighborhood reports, traffic orders and objections can be aggregated into a singular event within a specific timeframe. In contrast, the reactive approach proved to be a time-consuming procedure that necessitated repetition for each new charge point.

EV charging models have also changed the public engagement process in formulating and implementing the policies, where residents need to fully understand the prospective charging infrastructure in their municipality. Communication is key to creating and executing a strategic approach, and stimulating the utilization of the forthcoming charging network. As is the case of Arnhem and Utrecht, the charging plan map is both a supporting tool for decision-making and a facilitator of communication. The modeled charging network has been transformed to a illustrative map disseminated via an online platform or discussed during neighborhood or district meetings. Sharing such information has proven to be conducive to garnering support for both the charging policy and the placement of charging facilities, as is suggested by Policymaker A.

8.1.3. Comparison to previous studies

Regarding the specific applications of energy models in different stages of the policy process, 12 out of 15 proposed uses are observed in at least one of the four local policy processes. These findings underscore the potential of EV charging models to serve comparable purposes as energy models, at a minimum level. When it comes to the general changes and decisions informed by modeling evidence, three out of four patterns in energy policymaking are also observed in the context of charging policies as explained in Section 7.2.1. This section focuses on the discrepancy between model utilization observed in the two policy realms and seeks for potential explanation.

8.1.3.1. Shorter target setting process with less controversy

In the realm of local charging policies, the establishment of targets is less contentious compared to energy or environmental policies. The utilization of modeling data also follows a relatively seamless process, devoid of any scientific or policy disagreement (Süsser et al., 2021), as evidenced by the four local processes. This disparity can be explained through three key factors. Firstly, local charging policies primarily focus on fostering the EVadoption and establishing the requisite infrastructure. The narrower scope of these policies facilitates stakeholder consensus on target establishment, as they share a collective objective of supporting EV adoption and curbing local emissions. Secondly, the rationale behind local charging policies is often straightforward and directly aligned with local priorities. For instance, the two British charging policies are underpinned by their commitment to Net Zero and their declaration of a climate emergency, while the two Dutch policies stem from preceding energy or transport policy frameworks. The clarity of the rationale contributes to a smoother process of target setting, as stakeholders can readily comprehend and align with the objectives. Lastly, as observed notably in Utrecht, local charging policies possess greater flexibility and adaptability in comparison to energy policies. This suggests that local charging policies can be more readily revised and adjusted in response to changing circumstances, emerging technologies, and stakeholder feedback. The ease of revision empowers policymakers to promptly address evolving needs and optimize the efficacy of local charging policies over time.

Given the context of a narrow focus, clear rationale, and ease of revision, the influence of modeling evidence in local charging policies is diminished in terms of stimulating policy discourse. This is because stakeholders already possess a shared understanding and agreement regarding the necessity of such policies, thus reducing the requirement for extensive deliberation and dissent. Should policymakers exhibit sufficient confidence in the robustness of the modeling results, the impact of modeling evidence is further amplified in informing target setting due to the reduced controversy.

8.1.3.2. Fewer ex-ante assessment in local policy formulation

Only one ex-ante assessment was performed for the four examined local charging policies; for the other three documents, models were not utilized to evaluate their impact during the policy formulation stage. The model utilization for ex-ante assessment in local charging policies is mainly limited to the impact on grid and environment, and is performed relatively less compared to the extensive practice observed in broader energy policies (Calvillo, 2023; Henrich et al., 2021; Thimet & Mavromatidis, 2022) for the following reasons. Several factors contribute to this divergence. Firstly, local charging policies have a narrower scope and impact a smaller population compared to energy policies, resulting in relatively lower risks and impacts. Consequently, ex-ante assessments are less critical in this context. Secondly, local charging policies offer opportunities for experimentation and innovation, facilitating faster development, implementation, and adaptability based on local circumstances, feedback and emerging technologies. The limited scale of these policies allows for greater flexibility in formulation and implementation, reducing the need for extensive ex-ante assessments. Finally, collaborative decision-making processes already fulfill the evaluation purpose through workshops and consultations organized for the four local policies. These processes enable policymakers to gather input, expertise, and insights from diverse stakeholders, contributing to informed policy formulation.

However, it is important to recognize that the model-based ex-ante evaluation is still a valuable tool when it comes to understanding the environmental and grid impact of charging policies. Besides, ongoing monitoring, evaluation and adjustments remain crucial for local charging policies. While ex-ante assessments may not be as indispensable as in energy policies, models continue to play a significant role when multiple data inputs needs to be integrated and cross-checked.

8.1.4. Potential of charging models in the e-mobility transition

Hamming (1962) contended that the essence of computing lies in insights, surpassing mere numerical calculations. The evolution of energy systems models has been inherently driven by the imperative for enlightening comprehension. Additionally, ongoing discussions explore the diverse utility of these models, extending beyond their conventional numerical roles (Pfenninger et al., 2014). Similarly, EV charging models can support the bigger picture of clean transport, energy transition and climate action beyond merely providing information about the number and location of charging points, which are their major applications observed in this research.

A promising advancement of using EV charging models can be the cross-sectoral integration in transport, energy, and environmental planning. EV charging models can assess the potential impact of large-scale EV adoption on the electricity grid and identify areas that may require grid upgrades or reinforcements. This proactive approach ensures that the grid can handle the increased demand from electric vehicles without compromising reliability. Meanwhile, by considering factors such as energy source mix, emissions, and energy consumption patterns, policymakers can make informed decisions to minimize the overall carbon footprint of the transportation sector. They can then implement emission reduction strategies based on this data, such as promoting renewable energy or incentivizing off-peak charging.

Besides, the ex-post function of EV charging models should receive more attention to optimize policy and incentive planning. These models can be used to assess the effectiveness of various policies and incentives aimed at promoting EV adoption and clean transportation. Policymakers can simulate different scenarios and evaluate the potential outcomes of specific interventions before implementation. Integrating EV charging models with policy-making processes allows for evidence-based decision-making. Policymakers can use the data to design effective incentives, subsidies or regulations that encourage electric vehicle adoption and align with environmental and energy goals. Communicating the rationale behind decision-making, in this case the results EV charging models, to the public can increase awareness and support for clean transport and energy transition initiatives. It helps build public trust and ensures that the transition to EVs aligns with the environmental goals of the community.

8.2. Limitations and Recommendations for Future Research

8.2.1. Dependence on document selection

One primary limitation of this research lies in the limited number of local EV charging documents selected randomly for analysis. Due to resource constraints and time limitations, only a relatively small sample size was selected for analysis. As a result, the findings derived from this limited sample may not fully represent the broader spectrum of EV charging practices and patterns in the entire population. It is possible that the selected documents may have inadvertently biased the outcomes and failed to capture the full range of variability that exists in the target population. The randomness of the selection process itself may diminish the extent to which our selected documents accurately reflect the overall use of modeling evidence. While random selection is commonly used to mitigate sampling bias and increase the chances of representative results, it does not guarantee the absence of selection bias altogether. There is a possibility that certain types of EV charging documents were overrepresented or underrepresented in the sample due to chance.

Therefore, the potential biases introduced by the selection process and the limited sample size could restrict the accurate reflection of the overall use of modeling evidence in the EV charging domain. A potential direction for future researches is to conduct a meta-analysis that a greater range of documents that can lead to statistically meaningful results. As is found in this research, EV charging policymaking can vary significantly based on local context. By incorporating diverse documents, the applicability of modeling evidence can be examined in various settings and identify potential variations and trends. Hence, a broader range of documents could provide more comprehensive insights, enhance the generalizability of findings and improve the statistical strength of conclusions.

8.2.2. Keyword oriented document analysis

The analysis of each charging policy document started with skimming the content and and only concentrating on excerpts containing specific target words. This method aimed to identify sections that were most likely to contain information relevant to our research questions. However, this method inherently carries the risk of missing important details and overlooking relevant content. Skimming and focusing on specific target words may not capture the full context or complexity of the charging policy documents. Moreover, the documents written in Dutch were machine translated into English versions, which added to the chances that valuable insights, nuances and key information were overlooked with limited amount of target words, leading to an incomplete understanding of the charging policy landscape. Another potential limitation of this approach is the reliance on the quality and consistency of document formatting. The effectiveness of skimming and identifying relevant excerpts heavily depends on the structure, organization and labeling of the documents. Inconsistencies in formatting or variations in document structures, which is rather common in local charging policies, could impact the accuracy and reliability of our analysis, as relevant content may be missed or misinterpreted due to variations in the presentation of information.

To mitigate these limitations, future research should consider employing more comprehensive and systematic methods for document analysis. Instead of relying solely on skimming and target word identification, researchers could adopt more rigorous techniques such as thorough reading, or using language processing algorithm to analyze the entire documents. This would involve analyzing the complete documents and systematically categorizing relevant information based on a more comprehensive criteria.

8.2.3. Context specific findings in local policy processes

When studying the how modeling evidence is incorporated into local charging policy processes, this research only provides a snapshot of the complicated model-policy interaction by deep diving into four specific cases. Hence, there is a risk of overlooking the nuances and variations that may exist in different contexts. As indicated in the results, charging models and local policies may differ significantly across different localities. The four cases selected for this research may not adequately represent the full spectrum of charging models and local policy interactions. Furthermore, the deep dive into these specific cases may introduce biases and idiosyncrasies that are unique to those particular contexts. Factors such as local infrastructure, government priorities and historical developments could heavily influence the dynamics of charging models and local policies. Another potential limitation stems from the complexity and evolving nature of charging models and local policies. The charging landscape is constantly evolving, with new technologies, business models, and policy interventions being introduced regularly. By conducting our research at a specific point in time, we may not capture the full breadth of charging model variations and local policy developments. The findings obtained may not be applicable to future contexts or may become outdated as the charging ecosystem evolves.

To improve the generalizability, future research should consider expanding the scope of analysis by including a larger and more diverse set of cases. This could involve examining charging models and local policies across different regions, countries, and market conditions to capture a broader range of variables and factors that influence their interactions. Additionally, longitudinal studies could be conducted to track the evolution of charging models and local policies over time, providing a more comprehensive understanding of their dynamics and potential changes in outcomes.

8.3. Conclusion

In this section, the findings in this research is concluded based on the four research questions, which serves to answer the main research question:
How does modeling evidence influence EV charging infrastructure policymaking in the UK and the Netherlands?

1. What is the state of the art on the impact of modeling evidence on energy policy?

The state of the art on the impact of modeling evidence on energy policy is characterized by the increasing integration of energy models into various stages of the policy cycle. They impact energy policies by informing agenda/target setting, aiding policy formulation, supporting implementation, and facilitating policy evaluation. Case studies focus on specific contexts, revealing their multifaceted role. Models help policymakers understand the energy sector's challenges, identify priorities, and set ambitious yet achievable goals. They simulate scenarios, assess policy impacts, and conduct ex-ante assessments like Cost-Benefit Analysis to identify effective policy options. During implementation, models track progress by comparing projections with actual data, refining operational plans. In the ex-post evaluation stage, models enable rigorous analysis of policy outcomes, helping policymakers understand impacts and areas for improvement. Overall, energy models are crucial decision-support tools, contributing to data-driven, sustainable energy policies.

2. To what extent are models and other types of evidence used for EV charging policy documents in the UK and the Netherlands?

Based on the analysis of charging policy documents in the UK and the Netherlands, market and industry studies, modeling results, and statistics are the three primary types of evidence used in these policy documents. These three types of evidence are cited more frequently compared to academic research, case study results, expertise, information from stakeholders & public and pilot project experience. They are also employed in at least two-thirds of the analyzed documents. British documents demonstrate a more widespread use of various types of evidence, as indicated by higher citation frequencies and the number of documents utilizing them. The only exception is modeling evidence, which is widely used in the Netherlands than in the UK. Overall, modeling evidence is employed for a wider array of purposes in British documents, including forecasting future charging needs, exploring implementation options and evaluating grid, environmental and business impact.

3. What decisions and/or measures in those policy documents are related to modeling evidence?

Modeling evidence is prominently associated with two content themes: prognosis of future charging needs and exploration of implementation options. In British documents, it assumes a more significant role in ex-ante assessments, particularly in cost-benefit analysis and grid impact. On the national and regional level, modeling evidence has a limited impact on decision-making in both countries. While a few documents explicitly cite modeling evidence as a rationale behind policy decisions, the overall influence remains minimal. In British non-local policies, modeling evidence is used to shape both strategic and operational plans, whereas Dutch non-local policies primarily rely on it for strategic decisions. Overall, modeling evidence has led to tangible policy decisions, but the level of impact varies based on administrative scope and decision themes, with British documents showing a more diverse range of applications.

4.How is modeling evidence used at each stage of local charging policy processes and what changes, if any, are brought by models?

Some prominent uses of modeling evidence at each stage observed in the four local policy processes are (1) to identify priority, (2) to enhance understanding and explore policy options, (3) to simulate, monitor and optimize operations, along with engaging stakeholders, (4) to evaluate and improve policy respectively. EV charging models have significantly influenced policy consensus and policy content - including target, strategy and action - in local policies from both countries. Moreover, EV charging models are the key enabler of the change from reactive roll-out to proactive roll-out in Dutch municipalities. Modifications on agenda setting in Dutch localities are also substantially informed by modeling evidence compared to their British counterparts, which can be attributed to the Netherlands' early research into charging models.

In summary, this study enhances the understanding of the influence of models on the process of EV charging policy formulation in the UK and the Netherlands. It provides a comprehensive overview of evidence utilization patterns across policies at different levels and offers a detailed insight into the specific role of models in the local context. By identifying the conditions and mechanisms that dictate the usage of modeling evidence in decision-making, policymakers can effectively prioritize diverse evidence sources based on specific circumstances, taking into account constraints of limited time and resources. Additionally, by comparing the divergent patterns of evidence utilization in these two countries, policymakers can implement targeted improvements and promote closer collaboration with modelers to optimize evidence utilization.

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