Enhancing Usability of a Design-Decision Support Tool for Municipal Energy Transition Planning

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Preface

Dear reader,

I would love to start this report by saying that the energy transition has always interested me, but honestly, it only really caught my attention about 1.5 years before the start of my thesis. Starting at the TU/e with the Bachelor Sustainable Innovation I had no idea what I wanted to do. The combination of working towards more sustainable practices using technical, social and economic perspective interested me and is the reason I chose to go to Eindhoven. During this I followed the Built Environment track and also followed most of my elective space in this direction. After completing my Bachelor's, I switched to the Master's in Construction Management and Engineering, hoping to explore something closer to the built environment and maybe move away from transition studies. Spoiler alert: that second part did not quite happen as I had expected. A side job transcribing and analyzing endless amounts of interviews about learning and knowledge sharing within the energy transition unexpectedly sparked my curiosity.

Before starting my thesis, I got some warnings: municipalities, which are my main user group, are busy and have limited time to spare. Plus, my supervisors all have quite a busy schedule. So, no stress. Despite that, I am very grateful to my supervisors who helped me find a meaningful topic and their support throughout. Special thanks to Dujuan for her quick responses to my questions and valuable insights, and to Luc for his advice and his critical questions. I also want to thank Naud and his colleagues at Zenmo for their willingness to help with the tool, connecting me to users, and for the good vibes on Wednesdays. Thank you Martijn for giving me the opportunity to work on this topic, getting me started with important context and introductions. I am especially grateful to all the interviewees for their time and enthusiasm, as their energy motivated me to push forward and deliver valuable outcomes.

Additionally, I would also like to thank my family, friends and roommates for their ongoing support throughout my studies, as well as all the people I met during my time studying here for an enjoyable time. A special thanks to the friends (especially Sannah and Daan) who accompanied me at Atlas 8 once in a while and made studying there more fun. Finally, without mentioning the importance of football during my studies, this would not be complete. Playing football has always helped clear my mind and led to some great memories, so I'd like to thank my teammates for that.

To all readers, I hope you enjoy reading this report and find valuable insights within it.

Christine Smits

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Summary

Municipalities play a central role in driving the energy transition at the local level, yet they often face complex decisions that require the support of digital tools. This research therefore investigates how design-decision support tools can be improved to enhance usability for municipalities within the energy transition, grounding these insights in a case study of Zenmo's tool. It examines the purpose of these tools, the usability challenges municipalities face, and how user needs can be translated into more effective solutions, providing insights into how such tools can better align with the practical realities of municipal decision-making.

To address these aims, the research adopted a multi-phase, user-centred methodology. A literature review established the theoretical context for digital tool usage and their challenges in municipal energy transitions. The problem investigation phase involved semi-structured interviews with municipal users and non-users of the tool by Zenmo as well as domain experts, combined with the Kano method to prioritize user needs and feature preferences. In the treatment design and validation phase, user interviews and interactive mock-ups were employed to explore improvements, followed by a heuristic evaluation with Zenmo employees for final feedback.

The findings show that municipalities can use a variety of digital tools for energy transition tasks, ranging from simple dashboards to more advanced tools such as scenario modelling. These various tools are employed for purposes such as problem setting, scenario creation, stakeholder engagement, and monitoring progress, with all different content. User needs were found to be closely connected to both analytical ability and stakeholder involvement. Municipalities require tools that balance complexity and simplicity, enabling both advanced analysis and accessible use for non-experts. However, more complex tools are often underutilized by municipalities in practice due to limited internal capacity, unclear interfaces, or reliance on external consultants. This reflects a mismatch between tool capabilities and the practical workflows of municipal users.

Despite the availability of digital tools, this research identified four key challenges that constrain their effective use in municipal energy planning. First, model content must address the specific questions and planning tasks of municipalities, offering outputs that are directly relevant and actionable. Second, model design and data structures need to balance transparency of model parameters and assumptions, accuracy, interoperability, complexity of the model, while enabling municipalities to integrate local datasets and take ownership of the results. Third, the modelling process itself must be accessible and adaptable, supporting municipalities to update, refine, and experiment with the tool independently, if complexity allows for it. Fourth, modelling outreach must support understanding and engagement by offering clear, interactive visualizations and documentation, enabling both municipalities and external stakeholders to interpret results.

The case study of Zenmo's tool illustrated these points. Users appreciated features like grid congestion visualization and scenario-building, while also expressing the need for more accessible interfaces, clearer scenario comparison, improved onboarding support through documentation and tutorials, and possible integration with other municipal platforms. They noted that advanced functionalities such as spatial analysis and cost estimation, though

valuable, are not essential for core tasks and are better supported through interoperable complementary tools. Rather than focusing solely on new features, the process highlighted the value of aligning design with municipal workflows and analytical ability.

The findings of this research have several practical implications. For developers, involving users early and consistently, supporting both novice and advanced users, and ensuring transparency and clarity are essential for both inputs as results. Interfaces should use familiar terminology, and documentation should be accessible and diverse. For municipalities, selecting tools that align with their planning phase and internal capacity is key. A combination of descriptive, diagnostic, predictive, and prescriptive tools is needed to support robust, iterative decision-making. Scientifically, this research emphasizes the importance of understanding a municipality's workflow and analytical capabilities to enhance the usability of design and decision-support tools effectively.

This research's strengths lie in its mixed-methods approach, combining literature review, interviews, heuristic evaluation, and co-design sessions. However, the study focused primarily on Dutch municipalities and a relatively small sample, which may limit generalizability. Tool improvements were evaluated using mock-ups and existing users, rather than fully functional prototypes and new adopters, which may limit insights into long-term adoption and onboarding. Future research should include broader testing across diverse regions and municipal contexts, involve new users, and further investigate participatory design methods to ensure tools evolve alongside changing policy contexts and user expectations.

In summary, this research highlights that the success of design decision-support tools in municipal energy transitions depends on more than technical functionality. A participatory and iterative design process which focuses on real user needs is essential. Through the case of Zenmo's tool, the research demonstrates how aligning digital tool development with municipal workflows can potentially support more inclusive, effective, and adaptive energy planning.

Samenvatting

Gemeenten hebben een centrale rol in het stimuleren van de energietransitie op lokaal niveau maar worden vaak geconfronteerd met complexe beslissingen waarvoor digitale tools nodig zijn. Dit onderzoek gaat daarom na hoe ontwerp-beslissingsondersteunende tools beter ontworpen kunnen worden om de bruikbaarheid voor gemeenten binnen de energietransitie te vergroten met als uitgangspunt een casestudy van de tool van Zenmo. Hiervoor is onderzocht wat het doel van deze tools is, welke uitdagingen rond de gebruikservaring gemeenten ervaren, en hoe gebruikersbehoeften kunnen worden vertaald naar effectievere oplossingen. Op deze manier biedt het onderzoek inzicht in hoe dergelijke tools beter kunnen aansluiten bij de praktische realiteit van gemeentelijke besluitvorming.

Om deze doelstellingen te bereiken, is in het onderzoek een meerfasige, gebruikergerichte methodologie toegepast. Een literatuurstudie vormde de theoretische basis voor het gebruik van digitale hulpmiddelen en de bijbehorende uitdagingen binnen gemeentelijke energietransities. In de probleemanalysefase werden semigestructureerde interviews gehouden met zowel gemeentelijke gebruikers als niet-gebruikers van de tool van Zenmo, en domeinexperts gecombineerd met de Kano methode om gebruikersbehoeften en voorkeuren voor functies te prioriteren. In de ontwerp- en validatiefase zijn gebruikersinterviews en interactieve mock-ups ingezet om mogelijke verbeteringen te verkennen, gevolgd door een heuristische evaluatie met medewerkers van Zenmo voor de laatste feedback.

Uit de resultaten blijkt dat gemeenten verschillende digitale tools gebruiken voor de energietransitie, variërend van eenvoudige dashboards tot geavanceerde tools gericht op scenario-modellering. Deze verschillende tools worden bijvoorbeeld ingezet voor probleemverkenning, het opstellen van scenario’s, het betrekken van stakeholders en het monitoren van voortgang, elk met verschillende content. Gebruikersbehoeften bleken nauw samen te hangen met zowel analytisch vermogen als betrokkenheid van stakeholders. Gemeenten hebben behoefte aan tools die een balans bieden tussen complexiteit en eenvoud, die zowel geavanceerde scenario's kunnen maken als toegankelijk blijven voor niet-experts. In de praktijk worden door gemeenten complexere tools echter vaak onderbenut vanwege beperkte interne capaciteit, onduidelijke interfaces of afhankelijkheid van externe adviseurs. Dit wijst op een mismatch tussen de mogelijkheden van tools en de praktische werkprocessen van gemeentelijke gebruikers.

Ondanks de beschikbaarheid van digitale tools, zijn er vier hoofd typen uitdagingen geïdentificeerd die het effectieve gebruik ervan binnen gemeentelijke energieplanning. Ten eerste moet de inhoud van het model aansluiten op de specifieke vragen en planningsopgaven van gemeenten, met uitkomsten die direct relevant en toepasbaar zijn. Ten tweede moeten het modelontwerp en de datastructuren een balans vinden tussen transparantie van modelparameters en aannames, nauwkeurigheid, interoperabiliteit en modelcomplexiteit, terwijl gemeenten in staat worden gesteld om lokale datasets te integreren en eigenaarschap te nemen over de resultaten. Ten derde, moet het modelleringsproces toegankelijk en aanpasbaar zijn. zodat gemeenten, indien de complexiteit dit toelaat, het instrument zelfstandig kunnen bijwerken, verfijnen en ermee kunnen experimenteren. Ten vierde moet de communicatie van modelresultaten het begrip en de betrokkenheid ondersteunen, door

het aanbieden van heldere, interactieve visualisaties en toegankelijke documentatie. Dit stelt zowel gemeenten als externe stakeholders in staat om de uitkomsten goed te interpreteren.

De casestudy van de tool van Zenmo bevestigde deze punten. Gebruikers waardeerden functies zoals visualisatie van netcongestie en het opstellen van scenario's, terwijl zij ook de behoefte uitspraken aan toegankelijkere interfaces, duidelijkere scenariovergelijkingen, verbeterde onboarding via documentatie en tutorials, en mogelijke integratie met andere gemeentelijke platforms. Zij gaven aan dat geavanceerde functionaliteiten zoals ruimtelijke analyse en kostenramingen, hoewel waardevol, niet essentieel zijn voor kerntaken en beter ondersteund kunnen worden door aanvullende tools. In plaats van zich uitsluitend te richten op nieuwe functionaliteiten, benadrukte het proces het belang van een ontwerp dat aansluit bij gemeentelijke werkprocessen en analytische capaciteit.

De bevindingen van dit onderzoek hebben verschillende praktische implicaties. Voor ontwikkelaars is het essentieel om gebruikers vanaf het begin en voortdurend te betrekken, ondersteuning te bieden voor zowel beginnende als gevorderde gebruikers, en te zorgen voor transparantie en duidelijkheid te waarborgen met betrekking tot zowel de input als de gegenereerde resultaten. Interfaces moeten gebruikmaken van vertrouwde terminologie, en documentatie moet toegankelijk en gevarieerd zijn. Voor gemeenten is het belangrijk om tools te selecteren die aansluiten bij hun planningsfase en interne capaciteit. Een combinatie van beschrijvende, diagnostische, voorspellende en voorschrijvende tools is nodig om robuuste, iteratieve besluitvorming te ondersteunen. Wetenschappelijk onderstreept dit onderzoek het belang van inzicht in de werkprocessen en analytische vermogens van gemeenten om de bruikbaarheid van ontwerp-beslissingsondersteunende tools effectief te verbeteren.

De sterke punten van dit onderzoek liggen in de mixed-methods aanpak, waarbij literatuuronderzoek, interviews, heuristische evaluatie en co-designsessies werden gecombineerd. De focus lag echter voornamelijk op Nederlandse gemeenten en een relatief kleine steekproef, wat de generaliseerbaarheid kan beperken. Verbeteringen aan de tool zijn geëvalueerd met behulp van mock-ups en bestaande gebruikers, in plaats van volledig functionele prototypes en nieuwe gebruikers, wat inzicht in langetermijnadoptie en onboarding mogelijk beperkt. Toekomstig onderzoek zou bredere tests moeten omvatten in diverse regio's en gemeentelijke contexten, nieuwe gebruikers betrekken en participatieve ontwerpbenaderingen verder verkennen, zodat tools kunnen blijven meegroeien met veranderende beleidscontexten en gebruikersverwachtingen.

Samenvattend laat dit onderzoek zien dat het succes van ontwerp-beslissingsondersteunende tools in gemeentelijke energietransities afhangt van meer dan alleen technische functionaliteit. Een participatief en iteratief ontwerpproces, gericht op de werkelijke behoeften van gebruikers, is essentieel. Aan de hand van de tool van Zenmo toont dit onderzoek hoe digitale toolontwikkeling die aansluit bij gemeentelijke werkprocessen kan bijdragen aan inclusievere, effectievere en een beter aanpasbare energieplanning.

Abstract

Municipalities play a central role in driving the energy transition at the local level, yet they often face complex decisions that require the support of digital tools. This research investigates how design-decision support tools can be better designed to enhance usability for municipalities within the energy transition. A literature study established theoretical context and identified challenges and user needs of digital tools by municipalities. Using a multi-phase, user-centred methodology which included interviews, Kano method, mock-ups, and heuristic evaluation, the research examines Zenmo's decision-support tool as a case study to ground practical insights in real-world municipal contexts.

Findings reveal four key challenges limiting effective tool use: (1) model content must address specific municipal planning questions with directly actionable outputs; (2) model design and data must balance transparency of input data, assumptions, accuracy, interoperability, and complexity while enabling local data integration and result ownership; (3) the modelling process must be accessible and adaptable, allowing municipalities to independently update, refine, and experiment within their capacity; and (4) modelling outreach must provide clear, interactive visualizations and comprehensive documentation to support understanding and engagement among municipal users and external stakeholders.

User feedback on Zenmo's tool indicated that while advanced features such as spatial analysis and cost estimation add value, they are not core functionalities and could be supported through interoperable complementary tools. The feedback also stressed the need for more accessible interfaces, clearer scenario comparison, stronger integration with existing municipal platforms, and improved onboarding support. These findings emphasize participatory, iterative design aligned with municipal workflows and capacities.

Although the mixed-methods approach and participatory design strengthen the study, its focus on Dutch municipalities and limited sample size restrict generalizability. Evaluations based on mock-ups and existing users may also limit insights into long-term adoption by new users.

This research offers insights for practical application and academic understanding by showing that successful municipal energy planning tools require inclusive, context-sensitive design informed by municipal workflows and analytical abilities, rather than just technical features. These insights can guide future tool development and adoption to better support data-driven, inclusive local energy transitions.

Keywords: Municipal energy transition, Decision support tools, User-centred design, Usability, Tool adoption

List of Translations and Abbreviations

Association of Dutch municipalities: Vereniging van Nederlandse gemeenten (VNG)
Distribution system operator (DSO): Regionale netbeheerder
Dutch Environmental Assessment Agency: Planbureau voor de Leefomgeving (PBL)
Dutch government's knowledge centre on the Environment and Planning Act – Informatiepunt Leefomgeving (IPLO)
Electric vehicle (EV)
Energietoets: Energy assessment
Environment act: Omgevingswet
Environmental strategy: Omgevingsvisie
General data protection regulation (GDPR): Algemene verordening gegevensbescherming
Heat Pump (HP)
Heat transition vision: Transitie Visie Warmte (TVW)
Human Risk and Effectiveness (HR&E)
Low carbon technology (LCT)
Ministry of Economic affairs: Ministerie van Economische Zaken (EZK)
Ministry of the Internal affairs and Kingdom relations: Ministerie van Binnenlands Zaken en Koninkrijksrelaties (BZK)
Physical environment plan: Omgevingsplan
Roadmap local energy systems: Stappenplan locale energiesystemen (SLE):
Smart Energy cities (SEC)
Social Innovation energy transition: Sociale Innovatie Energietransitie 2 (SIE-2)
The Dutch Association of Grid Operators: Netbeheer Nederland
Transmission System Operator (TSO): Landelijke netbeheerder
User-centred design (UCD)
User interface (UI)

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1. Introduction

1.1 Problem definition

The Netherlands has positioned itself as a frontrunner on renewable energy deployment as recognized by the IEA (2025). The country has set ambitious targets reduce its greenhouse gas emissions by 49% by 2030 compared to 1990 levels with a further goal of 95% reduction by 2050 (Ministerie van Algemene Zaken, 2021). These objectives are outlined in the National Climate agreement, which emphasizes collaboration across key sectors including electricity, industry, built environment, traffic and transport, and agriculture.

The energy transition results in several significant changes to the country's energy system. The electricity system and its relevant actors face three main challenges: the variability of renewable energy requiring system flexibility, changing electricity demand due to electrification of various sectors, and the need for adequate network capacity to accommodate renewable sources (EZK, 2019). This includes shifting away from natural gas for heating homes, promoting the adoption of electric vehicles, and increasing reliance on renewable energy sources. For example, the agreement states that no new buildings will be heated by natural gas, and that all new passenger cars should be emission-free by 2030 (Ministerie van Algemene Zaken, 2021). Furthermore, the Netherlands aims to have 70% of all electricity coming from wind turbines and solar panels by 2030, which requires a substantial development and modernisation of current infrastructure (Ministerie van Algemene Zaken, 2021).

However, this transition presents complexities that challenge stakeholders at various levels of governance and implementation. To achieve this a holistic, system-wide approach is needed to address the interwoven challenges of the energy transition, requiring coordination across government and sectors. The limited capacity of the energy grid poses a significant barrier when integrating renewable energy sources and the electrification of various sectors (IEA, 2025) particularly in neighbourhoods where the grid is not being sufficiently reinforced (Van Sambeek et al., 2024). The rapid deployment of low-carbon technologies (LCTs), such as electric vehicles (EVs) and heat pumps (HPs) adds a level of complexity to municipal planning efforts. While these technologies are critical for decarbonization goals, they also increase power peaks, reduce grid capacity, and risk overloading cables and transformers (Damianakis et al., 2023; Sengor et al., 2023).

This technical impact is further complicated by social and policy hurdles such as skilled labour shortages, public resistance, poor communication between stakeholders and long approval times for projects hinder and delay necessary power system upgrades (Sengor et al., 2023; PBL 2023). Research by Van Sambeek et al. (2024) indicates that without the adoption of smart devices, more than half of the neighbourhoods in the Netherlands they analysed in their research could experience grid congestion by 2030, particularly during the winter months. To address this challenge, flexible measures such as the usage of smart appliances need to be considered.

To address these issues and minimize power system investments, effective operational management of LCTs has become crucial to enhance grid flexibility, control LCTs and support

sustainable power distribution. However, limitations such as the intermittent nature of renewable energy, potential grid instability and the need for energy storage solutions must be considered. The study by Sengor et al. (2023) suggests that improving LCT management and creating synergies among technologies enhance their integration. Further expansion of LCTs will require infrastructure upgrades and regulating relevant policies accordingly. The findings of Damianakis et al. (2023) reinforce the urgency of these actions, emphasizing the need for targeted solutions to mitigate the challenges occurring by LCT integration.

Within this complex landscape, municipalities are key implementers of the energy transition due to their proximity to local citizens and coordinative role across stakeholders and sectors (Amer et al., 2020). Effective coordination and cooperation across various stakeholders and departments are required to effectively use the flexibility provided by technical solutions (Van Sambeek et al., 2024). This includes coordinating efforts related to heat transition, housing development, renewable energy implementation, and mobility plans. Municipalities must also work closely with grid operators, housing corporations, provinces, and nearby municipalities. Effective communication with residents and other market parties is crucial, with grid operators being particularly important for calculating grid capacity (Scholten et al., 2023).

After the creation of a transition vision for heat (TVW), municipalities are now faced to make heat programs, requiring a more detailed plan for the first selected neighbourhoods which are moving away from gas (NPLW, 2024). The choice of heating strategies presents trade-offs as collective heating has less grid impact but usually has higher costs and more emissions, while individual electrification (e.g. HPs) can lead to lower cost and emissions but overloaded transformers (Loomans & Alkemade, 2024). These choices thus need to be made with care using solutions which work best for their local conditions and considering the effect it could have on owners and users of existing buildings.

Currently, the landscape of decision-making tools built for the energy transition is quite diverse with tools being developed with different goals in mind. This results in various tools being used for different purposes (Höffner et al., 2024; Diran et al., 2020) including aligning local and national energy targets and improving coordination between central and decentralized energy planning efforts (Amer et al., 2020). While research has indicated that there is a general positive attitude towards energy system modelling among decision-makers (Johannsen et al., 2021), the practical application of these tools faces challenges. Diran et al. (2020) have categorized energy transition decision-making knowledge requirements by policymakers into the following key areas: energy supply planning and development, current and future energy demand, infrastructure and resources, multi-actor dynamics and stakeholder engagement, system integration, institutions, policy and instruments, and system state monitoring.

1.2 Research objective and question(s)

With municipalities tasked with facilitating the energy transition, digital tools are a potential way to support their decision-making and execution processes. When looking at usability these tools are often seen as complex to use by municipalities (Johannsen et al., 2024; Henrich et al., 2021). Loomans and Alkemade (2024) describe a tool developed collaboratively with municipalities, yet their findings show that users still struggle to operate the tool without assistance from the developer. This persistent challenge can be explained by the mismatch

between the problem context and artifact design, requiring research approaches that not only analyse existing problems but also develop and rigorously evaluate practical solutions (Wieringa, 2014). The goal of this research is on identifying where usability issues and unaddressed needs arise, and to explore how usability improvements can enable municipalities to use digital tools more effectively in their decision-making.

This leads to the following research question:
How can a design-decision support tool focused on the energy transition be designed to enhance usability for municipalities in decision-making processes?

With the following sub-questions:

1. How do digital tools support municipal decision-making in the energy transition?
    a. What are the main objectives and intended purposes of existing digital tools used for decision-making in the energy transition?
    b. How are digital tools practically used by municipalities in their decision-making processes?
2. How do gaps between the intended purposes of digital tools and the actual needs and experiences of municipal users manifest in the energy transition?
    a. What gaps and usability challenges are identified in the literature regarding digital tools for municipal decision-making?
    b. How are these gaps and challenges reflected in practical examples from municipalities?
3. How do civil servants experience usability challenges and possible unaddressed needs when using Zenmo's tool in practice as a use case?
4. How can Zenmo's tool, as a use case, be improved to better support municipal decision-making processes?

Each sub-question contributes to answering the main research question. The first sub-question explores the main objectives and intended purposes for which municipalities use digital tools, providing essential context. The second identifies gaps between the intended purposes of digital tools and the actual needs and experiences of municipal users, highlighting areas for improvement. The third focuses on Zenmo's tool as a case study to uncover specific usability issues and unmet needs. The fourth sub-question proposes concrete requirements and modifications for Zenmo's tools, ensuring that the final recommendations are grounded in both general insights and practical experience.

1.3 Importance of the Study

As municipalities take on an increasingly central role in the energy transition, the effectiveness of their decision-making is closely tied to the usability of the digital tools at their disposal. By focusing on the tool by Zenmo and involving municipal users and experts in the field in the research process, this research aims to provide practical insights into how such tools can be better aligned to support decision-making processes. The findings aim to inform not only tool developers, but also municipal users seeking to improve the adoption and impact of digital tools in local energy planning. Ultimately, this research contributes to a deeper understanding of how digital tools can be designed around the real needs and experiences of municipal users, empowering them to achieve their energy transition goals more effectively.

1.4 Reading guide

To guide the reader through this thesis, Figure *1* illustrates how each chapter and section addresses the research sub-questions. First, the literature study (Chapter 2) covers sub-questions 1a and 2a by examining the objectives and challenges of digital tools from a theoretical perspective. Afterwards the methodology chapter (Chapter 3) outlines the research approach and methods used to collect and analyse data.

Sections 4.1 and 4.2 of the problem investigation (Chapter 4), respectively, address the practical usage of digital tools in municipalities (sub-question 1b) and provide practical examples of gaps in these tools (sub-question 2b). Immediately after these sections, the answers to sub-questions 1 and 2 are completed by combining insights from both the literature and practical findings. Section 4.3 presents a gap analysis for Zenmo's tool, addressing sub-question 3.

Building on these findings, the treatment design and validation chapter (Chapter 5) details the iterative process of developing, testing, and refining improvements to Zenmo's tool. Finally, the conclusion chapter synthesizes the main findings, reflects on their implications for both practice and future research, and highlights avenues for further development.

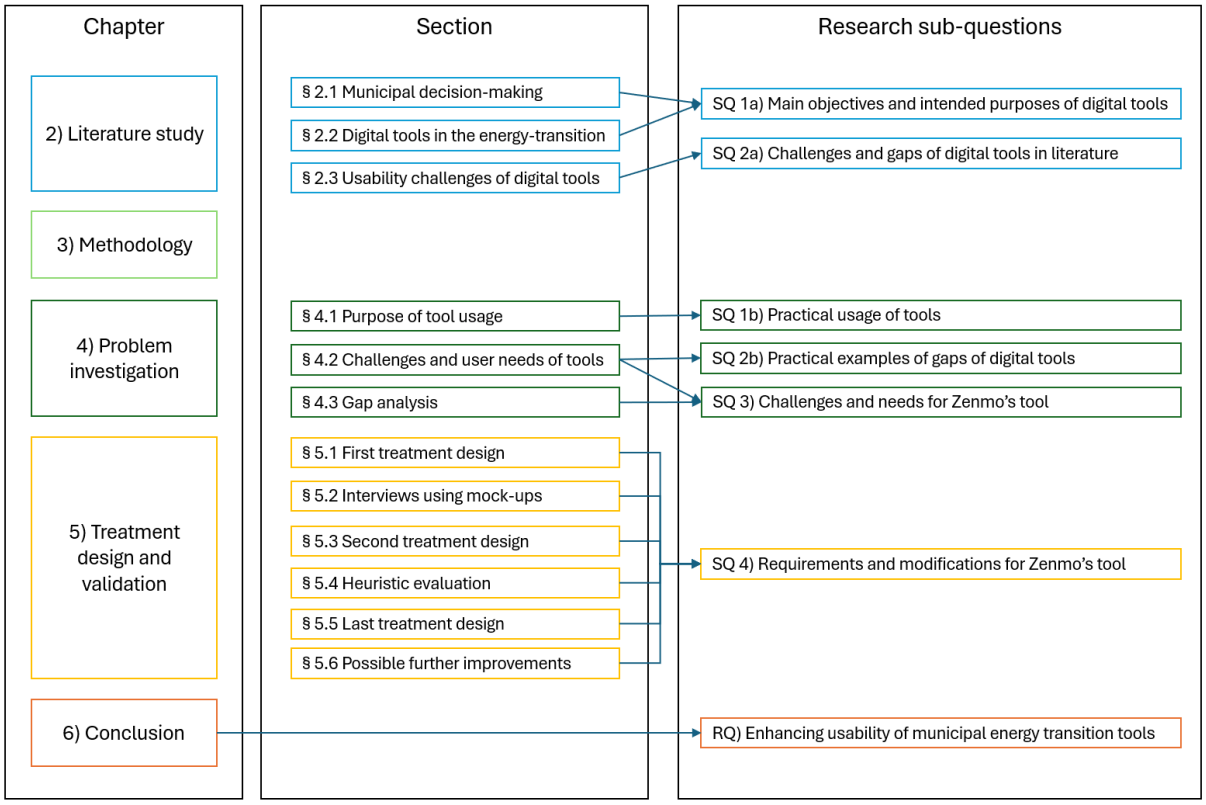

Figure 1: Overview of Research Structure

2. Literature study

Municipal decision-making in the Netherlands is organized within a governmental structure that combines national targets with local autonomy. The 2019 Climate Agreement established a national mitigation quota of 35 TWh of renewable energy by 2030, which has deliberately refrained from specifying local quotas and stimulate bottom-up initiatives (EZK 2019). Municipalities play a leading role in the energy transition, by envisioning, planning and implementing plans, interacting across district, municipal and regional levels (Diran et al., 2021). This approach also requires municipalities to coordinate with various stakeholders including home owners, housing corporation, grid operators and energy companies (Warbroek et al., 2022).

To understand the key challenges and requirements municipalities have in utilizing digital tools for decision-making during the energy transition, this section has been divided into a few part. Section 2.1 provides context on municipal decision-making regarding the energy transition. Then, Section 2.2 dives deeper into why tools could be used by municipalities, what type of tools there are and gives an overview of tools which are already being used by municipalities and for what reason. Then, Section 2.3 addresses the importance of designing digital tools with municipal users in mind and discusses common usability challenges encountered in practice.

The literature was identified using a mix of snowballing, targeted searches, and consultation. Sections 2.1.2, 2.1.4, 2.2.1, 2.2.2, and 2.3.2 primarily used the snowballing technique, starting from key papers such as “Exploring trade-offs: A decision-support tool for local energy system planning” by Loomans and Alkemade (2024), “Energy system planning and analysis software—A comprehensive meta-review with special attention to urban energy systems and district heating” by Höffner et al. (2024) and “Supporting Municipal Energy Transition Decision-making” by Diran et al. (2020). For Section 2.1.1, a targeted search was conducted to identify roadmaps and practical guides supporting municipal energy transition efforts. Section 2.1.3 focused on identifying the instruments currently employed by municipalities. Section 2.2.2 combined literature review, expert consultation, and online verification to identify commonly used digital tools, including those highlighted by Loomans and Alkemade (2024), Coöperatie Versnelling NL (2017). ChatGPT was used to supplement the search for neighbourhood-level tools, and further tools developed by grid operators were identified using informal conversations with experts. The presence and details of the identified tools were then verified through online searches. Section 2.3.1 draws on established design and usability literature to explore best practices for creating user-centred digital tools. Finally, Sections 2.2.4 and 2.3.3 synthesize the main findings and insights from the preceding sections.

2.1 Municipal decision-making

Before exploring how digital tools can support municipalities, it is essential to first understand how municipal decision-making for the energy transition is structured and carried out in practice. This is particularly important because the energy transition spans multiple sectors, requiring municipalities to coordinate efforts across different departments and with a range of external stakeholders (Warbroek et al., 2023). This complexity often leads to overlapping responsibilities, competing policy ambitions, and the need for integrated approaches within

local government. As a result, effective municipal decision-making in the energy transition demands not only technical expertise, but also the ability to manage collaboration and adapt to evolving circumstances.

Municipal decision-making processes can be depicted as a policy cycle (see Figure 2), which consists of three main phases: policy design, policy implementation, and policy evaluation. Each phase includes distinct steps, with stakeholder communication particularly emphasized during the implementation phase to ensure successful translation of plans into action (Verstraete et al., 2021).

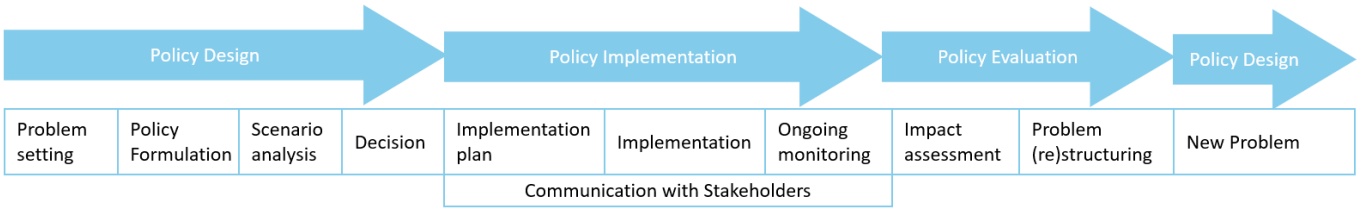

Figure 2: Policy cycle (adapted from Verstraete et al. (2021))

The following subsections explore the key stages of municipal energy transition, with a particular focus on the journey from policy design to implementation. Section 2.1.1 reviews more practical steps which a municipality can take. Section 2.1.2 examines the capacities required for effective decision-making. Section 2.1.3 analyses instruments available to municipalities, while Section 2.1.4 delves into stakeholder involvement. Collectively, these sections offer a comprehensive overview of the essential knowledge, resources, and processes that shape municipal decision-making in the energy transition.

2.1.1 Municipal steps

While the policy cycle in Figure 2 provides a general framework for municipal decision-making, municipalities may also draw on various step-by-step guides to support the implementation of local energy systems. Several such guides exist, including the Over Morgen & Frisse Blikken "Stappenplan lokale energiesystemen" (SLE) (2023), Smart energy cities roadmap (SEC) (n.d.), Fourpoints (Van Der Meijden, 2018), Hier.nu (Klimaatstichting Hier, n.d.) and VNG (2024). While the SLE and SEC guides, which focus on the energy transition as a whole and emphasize a collaborative approach, will be the primary focus here, it is also important to recognize that other frameworks are also available such as the one by Fourpoints and Hier.nu. The framework by Fourpoints is similar to the SLE framework, while the framework by Hier.nu focuses mainly on gas-free and VNG focuses more on public real estate.

SLE emphasizes a collaborative approach, starting with bringing together entrepreneurs and energy users to understand their needs and willingness to collaborate. The guide further stresses the importance of gaining insights into energy consumption and generation patterns, collaborating with grid operators for efficient grid utilization, and creating a system design for an area based on these insights together with various stakeholders.

Complementing this approach, the SEC roadmap integrates socio-economic considerations with technical advancements to ensure effective implementation as can be seen in Figure 3. Developed in collaboration with different municipalities, government bodies such as EZK and

BZK and the Dutch association of grid operators, the roadmap offers a structured framework for implementing energy solutions effectively. It begins with assembling a multidisciplinary team to address both the technical and social dimensions of the energy transition. This team explores potential energy solutions, establishes boundary conditions, and collects data on social and technical factors, engaging stakeholders in all steps. A thorough analysis of these social and technical factors allows municipalities to develop tailored energy solutions that meet the specific needs of different urban areas.

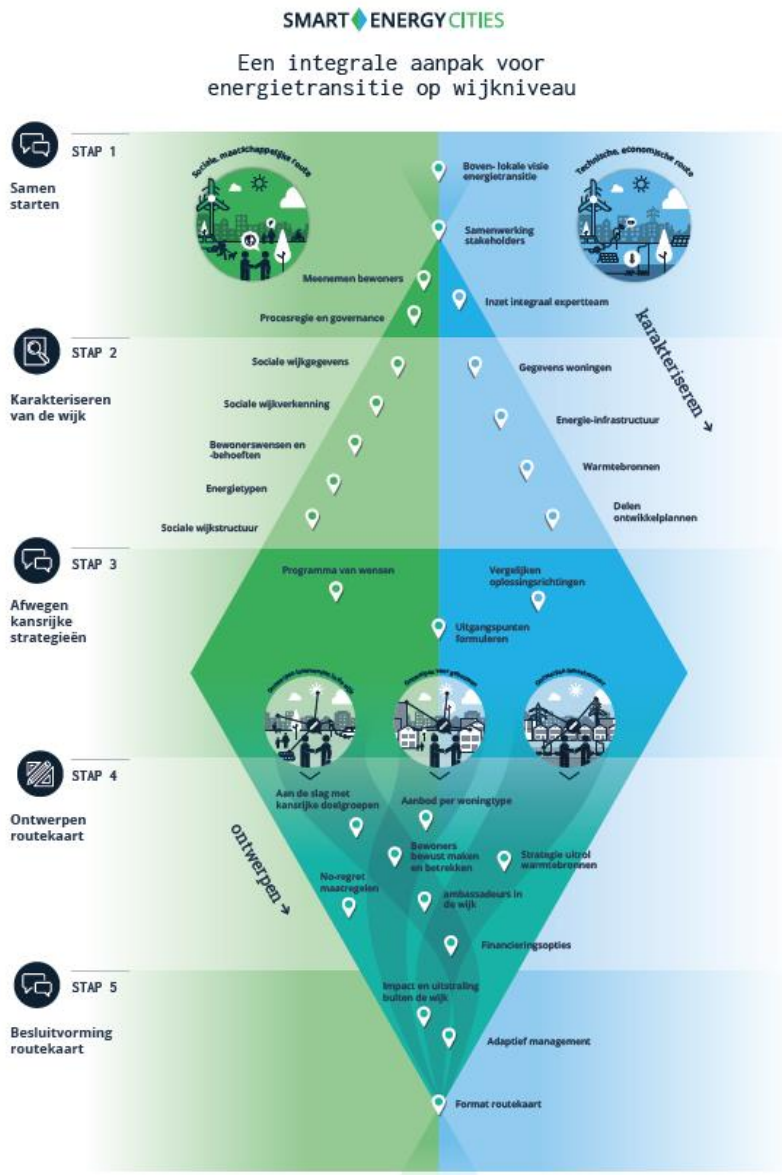

Figure 3: SEC roadmap (Smart Energy Cities, n.d.)

With these insight, municipalities define actions for specific building types, develop new energy systems, create communication strategies, and formulate investment plans for the first one to two years. To maintain flexibility, an agile management approach is advocated, allowing for a start with initial areas and no-regret measures while monitoring trends that may influence final decisions. Moreover, the roadmap stresses the importance of continuous monitoring and adaptation, enabling municipalities to assess the effectiveness of implemented measures and refine strategies based on emerging trends.

In summary, the policy cycle illustrated in Figure 2 highlights the structured yet iterative nature of municipal decision-making, with distinct phases for policy design, implementation, and evaluation. Notably, the policy cycle emphasizes stakeholder communication primarily during implementation, while practical guides such as SLE and SEC demonstrate the added value of involving stakeholders already during policy design.

2.1.2 Municipal capacities

To navigate the above steps successfully, municipalities must possess a range of capacities that enable them to interpret information, coordinate actions, and implement solutions. To understand the capacity of a municipality to use digital tools, it is important to understand both why the municipality would want to use tools and what they need to know to use these insights. According to Borrás et al. (2024) a municipality's capacity is shaped by the three interrelated elements: roles, resources and abilities. Below, each is briefly introduced using the definitions by Borrás et al. (2024) before narrowing the focus to analytical ability, which is central to understanding digital tool usability in municipal contexts.

Roles defines the municipality's involvement (Borrás et al., 2024). This can range from minimal involvement to full control. At the lowest level, municipalities may choose a "letting go" approach, allowing initiatives to be self-governed. They can also facilitate initiatives by providing limited support and boundary-spanning activities. Other times a municipality can stimulate initiatives through structural and financial support (Mees et al., 2019), reducing risk of the initiative during the development and realisation (Over Morgen & Frisse Blikken, 2023). In a more active role the municipality can also use network steering, where they co-initiate and coordinate decision-making processes among stakeholders. At the highest level, municipalities act as regulators, controlling interventions through policymaking and enforcement (Mees et al., 2019). The choice of role influences the municipality's knowledge requirements, risks, and the extent of their involvement in the local energy system (Over Morgen & Frisse Blikken, 2023).

Resources encompass the organizational assets available for the municipality which can be material or immaterial either internally or externally to the organisation. This includes for example skilled labour, financial resources, data and information and political mandates, like those related to urban planning, that legitimize and enable action. These mandates can take the form of formal legal powers or be drawn from broader policy strategies, and include instruments such as land use authority or urban planning competencies, which are discussed in more detail in Section 2.1.3. The availability and quality of resources shape which roles a municipality can assume and how effectively it can develop and apply its abilities. In relation to digital tools this means that without sufficient resources, even the most advanced tools may fail to deliver meaningful results.

Abilities are defined as the set of routines, practices and procedures of the organisation's that enable it to act. Analytical ability refers to exploring, studying, sense-making and interpreting information. This involves not only conducting research and gathering data, but also critically assessing information and developing new insights or visions for the future (Borrás et al., 2024). Digital tools are a means to help a municipality to gain knowledge and analyse information, making this ability an important aspect to understand the usability of a tool. This

research will further use this concept to understand for which phases different tools are used and the usability of the tool.

Due to the complexity of the tasks associated with the energy transition, municipalities often need to hire external consultants to for example conduct data modelling and techno-economic analyses, design citizen participation and communication strategies, and navigate model outputs from for example the Dutch Environmental Assessment Agency, PBL. An issue that municipalities face in this case is that a lot of the expertise and gained knowledge also leaves the municipality (Devenish & Lockwood, 2024). This implies that municipalities often do not have the capacity currently to address the challenges themselves.

2.1.3 Municipal instruments

In addition to these internal capacities, municipalities make use of a range of formal policy instruments that help structure and guide their actions. These instruments form the basis for embedding energy transition objectives within broader municipal planning, but their scope extends beyond energy. Key examples include the environmental strategy, programs, and the physical environment plan, which are identified and explained by IPLO, which is the government's knowledge centre that explains the Environment Act, the Digital System for the Environment Act, and regulations for the physical environment (IPLO, n.d.).

The environmental strategy focuses on long-term ambitions and policy goals for the physical environment. This document integrates energy transition objectives with broader societal challenges. Importantly, the physical environment plan itself serves as the foundation for subsequent plans, as it outlines the necessary preconditions for effective policy development and implementation (IPLO, n.d.). In the physical environment plan, municipalities establish rules regarding the use of the physical environment, such as locations for renewable energy production and conditions for energy infrastructure. This includes both the space underground and above ground. The physical environment plan provides a framework for the implementation of the energy transition on a local level (IPLO, n.d.).

Programs focus on the goals and actions which the municipality or province initiate themselves. They can do this by creating a set of measures to achieve a goal and to monitor the progress of these measures to see if the measures work or need to be adapted (IPLO, n.d.). The heat program is mandatory from 2026 onwards and needs to be renewed every 5 years, operationalizing the TVW into actionable plans. It requires municipalities to provide more detailed data on heat demand, building stock characteristics, infrastructure capacity, and societal costs (NPLW, 2024). The heat program also mandates public participation, ensuring alignment with citizen preferences and local initiatives.

If the TVW was already formulated as a program, it can be used in the transition phase to prevent extra work for municipalities (NPLW, 2024). However, as Devenish and Lockwood (2024) point out these visions are often still vague and need to be revised frequently. This vagueness poses a challenge when coordinating with other actors, such as gas and electricity network operators, who rely on a more stable expectations of demand growth or decline for their plans (Devenish and Lockwood, 2024).

Over time, municipalities have gained access to new policies and tools to support the energy transition. For example, since March 2024, the province of Utrecht has introduced an energy assessment, which requires early evaluation of whether new spatial developments can be accommodated within the energy grid (Provincie Utrecht, 2024). This practical framework helps municipalities and developers address specific challenges and bottlenecks in the energy transition.

To effectively make plans and involve stakeholders, municipalities require a broad range of knowledge, including energy supply planning and development, current and future energy demand, infrastructure and resources, multi-actor dynamics and stakeholder engagement, system integration, institutions, policy and instruments, and system state monitoring (Diran et al., 2020). While guides such as the SLE Guide and SEC roadmap provide valuable context by outlining potential steps municipalities might take in the energy transition, it is the application of concrete policy instruments that enables these steps to be realized in practice. Ultimately, the effectiveness of both the strategic guidance offered by such approaches and the instruments available to municipalities depends not only on their design, but also on how well they are implemented and supported, within the local context.

2.1.4 Challenges in stakeholder involvement

Stakeholder involvement is a crucial and often mandatory aspect of successfully translating ideas into policy and action, whether through new programs, new strategies, adaptations to physical environment plans, or modifications to existing buildings. This includes not only internal collaboration across municipal departments, but also engagement with regional government, local residents, companies, and other key stakeholders within the municipality. By involving stakeholders early on, municipalities can ensure that diverse perspectives are considered, potential barriers are addressed early and solutions are better aligned with local needs and priorities.

One of the internal challenges, is the need for integrated planning and execution of energy and spatial tasks. Not only does energy generation require space, but also distribution, converting and storing energy costs space. Energy generation, distribution, conversion, and storage all demand space, directly competing with other critical sectors such as housing, agriculture, mobility infrastructure, and nature restoration. Balancing these competing spatial demands requires innovative solutions, multifunctional land use, and strategic decision-making (Van Dijk, 2023). However, policymakers often face complexity and uncertainty, which is partly due to information shortages that hinder their ability to accurately assess the impacts of their choices (Diran et al., 2020).

These siloed planning practices, where energy, the built environment and mobility are addressed separately, hinder the development of a cohesive and integrated plans. A truly integrated approach to designing, planning, and executing energy and spatial tasks requires interdisciplinary collaboration (Van Dijk, 2023; Warbroek et al., 2022). This collaboration includes energy and spatial professionals but also includes a broad range of external stakeholders (Van Dijk, 2023). Such collaboration is crucial to align energy plans, policies, and decisions across different sectors to avoid issues such as grid overload (Diran et al., 2020).

The internal challenges faced by municipalities directly impact their ability to collaborate effectively with external stakeholders. Both internal and external actors bring their own sectoral position, choice, boundary, aggregation, payoff, and scope rules to the action situation, resulting in fragmented outcomes (Warbroek et al., 2022). Despite familiarity among actors, existing policy frameworks and regulations often prevent them from jointly addressing interconnected challenges. Currently, the potential for integration remains largely unexplored and unexploited, affecting both internal operations and external collaborations.

Beyond these internal challenges, municipalities also need to collaborate and coordinate with other stakeholders including grid operators, energy cooperatives, landowners, project developers, research institutions, design and consultancy agencies, as well as citizens and businesses (Van Dijk, 2023). Involving these stakeholders in the design and implementation phases is essential to gain support and align decision-making processes of plans as these stakeholders all have their own interests and supply of information and knowledge (Diran et al., 2020).

Engaging residents and housing corporations present their own set of challenges in the energy transition process. Beauchampet and Walsh (2021) note that citizens provide valuable input to municipalities on issues concerning the living quality of their homes and the support needed for necessary changes. Moreover, citizen engagement is essential because individual streets can only be disconnected from the gas grid when each home has voluntarily implemented an alternative, such as an all-electric option or participation in a heating network. To engage citizens municipalities have adopted various approaches, but designing an inclusive process remains challenging. However, designing an inclusive process that reaches the ‘average inhabitant’ instead of the ‘usual suspect’ remains challenging.

The industrial sector is the largest energy-consuming sector in the Netherlands, accounting for almost 40% of the energy usage in 2022 (IEA, 2024). This sector needs to improve their energy efficiency and switch to more renewable fuels (IEA ,2024). Municipalities face challenges in engaging these stakeholders due to the complex industrial processes and the potential economic impacts of energy transition measures (Lammers & Hoppe, 2018). Some industries also have residual heat available, which can be utilized for heat networks (Beauchampet & Walsh, 2021), making their inclusion into energy plans valuable.

The growing grid congestion necessitates the inclusion of grid operators in municipal planning. Grid operators are struggling to keep up with the increase in sustainable energy due to the increase in installations of heat pumps, PV panels and EV chargers (IEA, 2024). The existing infrastructure was not designed to handle the fluctuations in supply from renewable sources or the growing demand from data centres, industries, and residential electrification. Unmanaged autonomous growth in energy consumption within existing connections could lead to long-term power cuts (IEA, 2024). To address this, a neighbourhood-by-neighbourhood approach to strengthen low-voltage grids is proposed (IEA, 2024), as implemented by Enexis groep (2024).

To keep the grid from becoming overloaded, the Dutch Association of Grid Operators has set up a phased approach that scales interventions as needed. Phase 0 represents normal operation with no issues, while Phase 1 signals that grid capacity is insufficient to meet growing

demand, requiring studies and engagement with large users. Phase 2a marks broader impacts on users and necessitates action to manage congestion effectively. Finally, Phase 2b involves market interventions when flexible capacity prices become excessively high (Netbeheer Nederland, 2024). For municipalities, understanding this phased approach is essential for proactive planning and stakeholder engagement throughout the energy transition. This situation demands careful collaboration between grid operators and spatial planners, focusing first on districts with the highest urgency. The renovation will demand significant space both above and below ground, presenting spatial integration challenges that municipalities and grid operators must address together (Enexisgroep, 2024).

In summary, Section 2.1 showed the importance of including various stakeholders to integrate plans across different domains for a successful energy transition. The literature makes clear that municipal energy transition planning is a dynamic, multi-phase process, as depicted in Figure 4. With limited capacity municipalities face a great challenge to tackle the energy transition in a holistic way. They must navigate the complexities of stakeholder engagement, spatial planning, and the technical demands of upgrading energy infrastructure, all to ensure that plans are both feasible and widely supported. Amidst growing grid congestion, rapid technological change, and the need for integrated spatial and energy planning, municipalities are challenged to coordinate efforts, prioritize interventions, and maintain legitimacy in their decision-making processes.

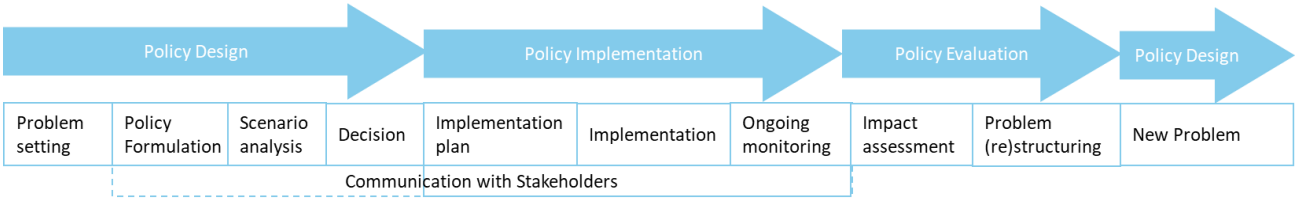

Figure 4: Adjusted Policy Cycle emphasizing stakeholder involvement earlier in the process

2.2 Digital tools and decision-making in the energy transition

Given these decision-making challenges, digital tools can play an important role in supporting municipalities. This section first introduces the purpose of digital tools in municipal decision-making, and then explains the main types of digital tools available and their intended uses. Afterwards, a selection of digital tools currently used by municipalities is presented, organizing them by category and describing their specific purposes. By first mapping why tools are used by municipalities, then the broader landscape and then focusing on tools relevant to municipal practice, this section aims to show the main objectives and intended purposes of digital tool usage.

2.2.1 Usage of tools by municipalities

To aid municipalities in their tasks in the energy transition, there has been an increase in number of design decision support tools to aid stakeholders in this area. For municipalities, expanding their knowledge and using these tools can greatly enhance their ability to communicate, visualize, and evaluate energy transition plans in collaboration with stakeholders. This not only facilitates more transparent and inclusive decision-making but also helps to strengthen the legitimacy and acceptance of the resulting policies (Diran et al., 2020).

Despite the variety of tools available and their potential to support informed decision-making, municipalities still face challenges in selecting and effectively utilizing them. The selection of tools should align with the specific decision-making tasks municipalities face, such as operational management, investment planning, scenario analysis, or power system studies (Höffner et al., 2024). These tools are designed for multiple purposes, including aligning local and national energy targets and improving coordination between central and decentralized energy planning efforts (Amer et al., 2020). While research has indicated that there is a general positive attitude towards energy system modelling among decision-makers (Johannsen et al., 2021), the practical application of these tools faces challenges.

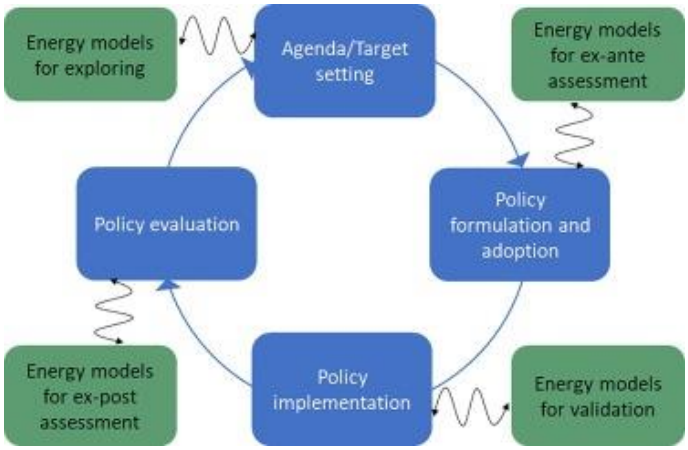

Figure 5: Energy models usage by policymakers (Süsser et al. 2022)

According to Süsser et al. (2022) policymakers mostly use digital tools for strategy development, policy/measure formulation, ex-ante-assessment of policy impact and agenda/target setting of certain policy as seen in Figure 5. To a lesser extent policymakers also use tools for informing/lobbying in politics, ex-post-evaluation/monitoring of implemented policy, policy implementation and other not specified purposes. These models often present outputs through maps, graphics, and tables, which can aid visualization. However, these tools also face several challenges in practical application. Models are often perceived as too abstract, generalized, or oversimplified for local analysis, while simultaneously being complex and user-unfriendly for non-experts. Interactive models could provide practitioners to enhance understanding of the answer and parameter sensitivity.

2.2.2 Digital tool types

To better understand how digital tools can support municipalities in the energy transition, it is useful to examine the main types of tools available and the specific purposes they serve. Looking at current work, there are quite some literature reviews concerning tools and models used in the energy transition such as Diran et al. (2020), Ferrari et al. (2019) and Sola et al. (2018). These reviews highlight the diversity of tools available designed with different goals in mind and tailored to different users, ranging from policymakers to industry stakeholders and researchers. While these reviews are all done with different goals in mind, there is a general consensus that these tools are not optimal yet, and not one tool can address all aspects of the energy transition effectively. In the meta-review paper, Höffner et al. (2024) notes that renewable, affordable and resilient energy system design requires planners to consider conflicting targets and future scenarios.

Urban-scale energy modelling (USEM) tools are receiving attention in literature due to their ability to address more the specific needs of urban energy planning. While USEM tools are valuable for urban planners and policymakers, gaps remain in their ability to model multi-energy systems comprehensively and account for trade-offs between environmental impacts, economic feasibility, and social considerations (Höffner et al., 2024). Sola et al. (2018) highlight

the need to integrate sustainable building design, land use and transportation to identify new opportunities to improve energy efficiency in cities, which might be overlooked otherwise. Ferrari et al. (2019) highlight the role of USEM tools to support local decision-making by evaluating, environmental impacts, economic impacts and energy performance at a city level, further calling for a holistic approach.

Geographical Information Systems (GIS) are a lot less explored in urban energy planning tool literature compared to other tools even though they have potential to enhance decision-making processes (Höffner et al., 2024). Loomans and Alkemade (2024) describe a decision-support tool that relies on GIS to visualize spatial data related to energy demand, infrastructure and renewable energy potential. Further supported by Alhamwi (2017) combing open-source data and models, and GIS systems can help stakeholders understand the structural relation between building, district, energy infrastructure, energy generation and consumption patterns.

Energy system planning and analysis demands a diverse set of tools, which all cater to different its own decision-making needs. As highlighted by Höffner et al. (2024), there is a large range of energy planning tools which can help create simple to complex models for optimizing system operations and system design. These can be broadly categorized into simulation tools, optimization tools, equilibrium tools and scenario tools. (Höffner et al., 2024). Next to this, Matheus et al. (2018) identify dashboards as a tool type for governments to support their decision-making and policy processes or to communicate and interact with the public. These tool types are explained more in-depth in Table *1*.

Table 1: Types of tools

Category	**Explanation**
Simulation tools	Perform dynamic calculations of the energy system's operation based on its characteristics and equations aiding in demand and supply analysis
Optimization tools	Focus on identifying the best solutions to minimize or maximize objectives, often focusing on operational or investment decisions
Equilibrium tools	Evaluate energy systems from a market perspective, analysing the dynamics of supply, demand and prices
Scenario tools	Assess impacts of policy or investment decisions over extended periods
Dashboards	Visualizes a consolidated set of data for a specific purpose, which enables users to see what is happening and initiate actions

According to Bouw et al. (2021), models commonly used in the scientific community are most often optimization models. While these models are useful for identifying optimal solutions, they usually underrepresent end-user characteristics, simplify energy-saving measures by expressing them as annual improvement rates. In contrast, municipalities often rely on simulation models that offer limited technology options and use aggregated, static data.

Diran et al. (2021) also describes a method in which models can be classified according to which form the digital tool is used. They identify tools supporting descriptive, diagnostic, predictive and prescriptive analyses, which offers insights into the maturity of the data-driven applications. Descriptive analysis provides a basic form of data analysis to see what the current situation is and what has occurred. Diagnostic analysis looks at what is causing this, and

predictive analysis focuses on what will happen in the future. Prescriptive analysis looks at how the desired outcome can be achieved, and is seen as more complex, requiring more advanced skills and methods. Municipalities must select tools which best fit their needs and analytical ability. For instance, Verstraete et al. (2021) describes that municipalities often rely on descriptive and monitoring tools during the early stages of problem setting and policy design, while predictive and prescriptive tools are more commonly needed for scenario analysis and decision-making.

Solely based on the scenario planning process, three key dimensions are highlighted by Carvajal et al. (2022) to describe the intended use of the tool by a municipality: forecasting versus back casting, consensus building versus ambition raising, and conservative versus exploratory analysis, as seen is Figure *6*. These dimensions, represent a spectrum of possible approaches that municipalities need to navigate in for the energy transition. Municipalities need to choose the tool which at that point is able to achieve their desired outcome best (Carvajal et al., 2022).

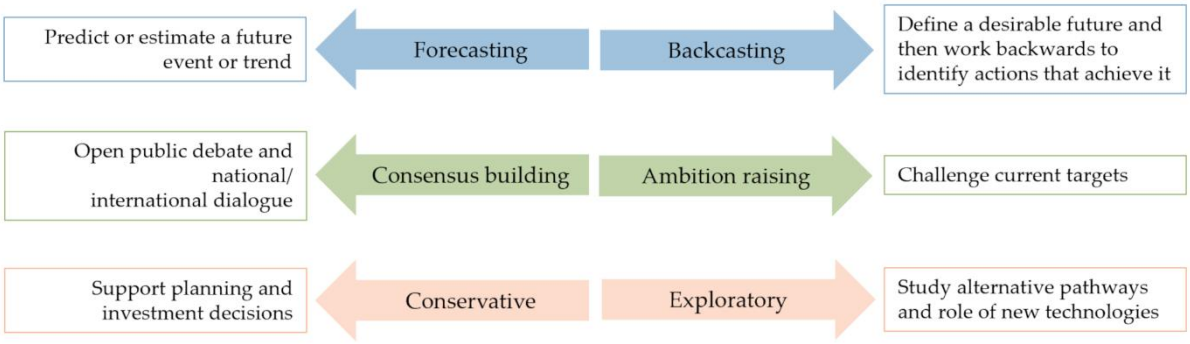

Figure 6: Tool usage for simulation tools (Carvajal et al., 2022)

2.2.3 Currently used tools

Building on the typology introduced in Section 2.2.2, it is important to recognize that the practical value of these tools depends not only on the analytical abilities of a municipality but also on how well they support the iterative and collaborative nature of municipal policy processes. Verstraete et al. (2021) emphasize that tools must present data and analysis in accessible, actionable formats, enabling policymakers to focus on interpreting insights rather than the technical complexities surrounding it. This usability aspect is critical given municipalities' limited capacity.

In the Netherlands decision-making tools are already being used and developed in the energy transition for local energy system planning. As identified by Henrich et al. (2021), tools such as Vesta MAIS, Heat Transition Atlas and CEGOIA are predominantly used for information gathering, spatial planning and energy analysis, and assessing societal costs and benefits. The Heat Transition Atlas could not be found online anymore. This section will look at tools which are available for municipalities in the Netherlands to investigate solutions on a neighbourhood level for the energy transition.

Vesta MAIS is one of the most used tools for heating strategy planning (Loomans & Alkemade, 2024). The tool was developed by PBL, the Dutch environmental agency, and is a techno-economic model that analyses national scenarios for the heating transition in the built

environment at various spatial levels across the Netherlands (Loomans & Alkemade, 2024). While Vesta MAIS serves as a starting point for policymakers, it also receives critique for its limitations in acknowledging local complexity and integral systems perspective (Loomans & Alkemade, 2024).

Table *2* shows a list of tools found early in the process with even more tools also available and being developed. For each identified tool the possible key dimension and tool type, and purpose are summarized. The key dimension (Carvajal et al., 2022) and tool type (Höffner et al., 2024) focus on the dimensions identified before on the classification of tools and how they are used for the simulation and scenario-based tools. The purpose section describes what the tool aims to do and in that way connecting it to the municipal step the insights of the tool could help with.

Table 2: Tools and their key dimensions, tool type and purpose

Tool	**Tool type & key dimensions**	**Purpose**
Vesta MAIS (PBL, n.d.)	**Simulation tool (Mostly Report-based)** (Bouw et al., 2021) Predictive; Forecasting, Conservative	Model heat transition scenarios by estimating heat demand and supply in these scenarios and support heating policy development. Supports gathering and interpreting data on heat demand and supply, assess technical feasibility, costs, and emission reduction across various scenarios (Devenish & Lockwood, 2024). The tool's results are provided to municipalities through the Startanalyse, a standardized report.
CEGOIA (CE Delft, 2024)	**Simulation and optimization tool (Mostly Report-based)** (Bouw et al., 2021) Predictive & Prescriptive; Forecasting & Consensus Building	Provides a basic report offering insights into costs of different heating options, with further exploration available through interactive tools. The tool assists policy design and program formulation by enabling municipalities to optimize and compare sustainable heating scenarios, assess costs, and define feasible measures. Can be used as a starting point for further discussions and decisions on policy or investment choices (Bouw et al., 2021).
Energy Transition Model (Quintel, n.d.)	**Simulation** (Bouw et al., 2021) **and Scenario tool** Descriptive & Diagnostic; Backcasting & Ambition Raising & Exploratory	The tool focuses on calculating CO_2 emissions and costs based on the user-based inputs for residential and commercial heat and electricity, transport and agriculture sectors (Bouw et al., 2021). The model is used to support discussions on energy in the public sector by corporations, NGO's and educators (Wetzels et al., 2020).
Zenmo Tool (Zenmo, n.d.;	**Simulation and Scenario tool;**	Analysing current energy usage and test self-made future scenarios based on possible on

Loomans & Alkemade, 2024)	Descriptive & Diagnostic; Backcasting; Exploratory	parameters based on LCTs that can influence grid congestion. Can also look at the impact of different scenarios on the usage of other energy carriers to see how this mix could change in the future towards more sustainable energy sources.
Tomahawk (Energie Transitie Software B.V., n.d.; Roossien, 2021)	**Simulation tool;** Prescriptive; Consensus building & Conservative to Exploratory	Used in designing and visualizing local heating networks based on municipal strategies also giving an output on total cost of ownership per stakeholder and assists in understanding neighbourhood characteristics.
Smart Twin (Smart Twin, n.d.)	**Simulation tool;** Consensus Building; Diagnostic & Prescriptive	Provides a smart twin of a building or neighbourhood to support collaboration and give insights into energy-saving opportunities. On a neighbourhood level they are developing the tool to a dashboard to provide municipalities with extensive insights and explore energy-saving options of buildings in a neighbourhood.
DEGO (VNG, n.d.-a)	**Dashboard;** Descriptive	Provides municipalities with a map displaying essential data on housing characteristics at the 6-digit postcode level (e.g., 1234 AB), which corresponds to a highly localized spatial unit in the Netherlands, to support energy transition planning.
DEGO Wijkpaspoort (VNG, n.d.-b)	**Dashboard;** Descriptive	Aids policy evaluation/monitoring by providing municipalities with visualizations and infographics on housing and energy data at multiple spatial scales, from the national and city level down to individual neighbourhoods, supporting data gathering and progress tracking.
Energy Strategy Atlas (Sweco, n.d.)	**Dashboard;** Diagnostic	Used in designing local heating networks based on municipal strategies and provides transition costs, type of participation needs and provides quick wins.
Datalab Energy Transition (Datalab Den Haag, n.d.)	**Dashboard;** Descriptive	Provides open data and visualizations on energy transition progress, focusing on neighbourhood-level insights which can be used for monitoring and informing policy development.
Liander Buurtscan (Liander, n.d.)	**Internal Simulation Tool (Report-Based);** Forecasting	Used for visualizing neighbourhood-level energy consumption trends and identifying grid constraints.
Enexis Buurtinzicht	**Internal Scenario Analysis Tool**	Provides municipalities with a report on future neighbourhood-level energy transition impacts

(Enexisgroep, n.d.)	**(Report-Based);** Forecasting	on the grid to identify future grid capacity challenges. Also takes into account the spatial needs of extra charging infrastructure or low or medium voltage stations.
Capacity map Netherlands (Netbeheer Nederland, n.d.)	**Dashboard;** Descriptive	Grid capacity maps show the available grid capacity for demand or generation. It can be used as an indicator to shows visually where their grid has room or is very restricted. This gives municipalities an indication on the availability of grid capacity.

In the Netherlands, as shown in in Table 2, many digital tools currently used are primarily descriptive or focused on monitoring, supporting tasks such as reporting, mapping, and basic analysis of current conditions. Many of these tools are either report-based or dashboard-oriented, requiring little to no modelling effort by municipalities. Report-based tools, such as the Startanalyse built on VestaMAIS, provide results in the form of standardized reports, often relying on assumptions that may not fit local circumstances. Internal tools further limit municipal involvement, as results are delivered by an external party and municipalities have little or no access to the underlying models. Dashboards and map-based visualizations are common, offering clear summaries but mainly serving descriptive or monitoring purposes rather than enabling deeper scenario analysis.

Scenario and simulation tools, such as the ETM and Zenmo, are less widely used but offer a more interactive approach than traditional tools. They are particularly suited for backcasting, as municipalities can work backward from a desired future and input their own assumptions based on either current trends or specific ambitions. These interactive models help visualize complex issues and test how sensitive outcomes are to different parameters. This supports a deeper understanding of possible results and the implications of policy choices, which is especially important in the later steps of scenario analysis when concrete actions must be defined.

Given the diversity of tools, each providing slightly different information and functionalities, municipalities face a fragmented landscape that can complicate both tool selection and data integration. For the analytical ability of a municipality, this can make it difficult for municipalities to gather and interpret data effectively, which in turn hinders the development of clear insights and long-term visions for the future.

2.2.4 Digital tool choice for decision-making

Building on the insights above, this subsection synthesizes the main findings to answer the sub-question regarding the objectives and intended purposes of digital tools used for decision-making in the energy transition. Decision-making in the energy transition involves a series of interconnected steps, each with evolving data needs, analytical demands, and digital tool requirements. Digital tools can provide critical insights into their current situations and potential futures, yet their usefulness depends heavily on the municipality’s capacity to select, understand, and apply these tools appropriately. A municipality's analytical ability is crucial,

ensuring that the right type of tool is used effectively and that its outputs can inform decision-making.

Figure *7* illustrates how municipal goals, such as achieving a gas-free status by 2050, and policy instruments which shape the range of subsequent actions which can be explored using digital tools. These actions revolve around achieving the goals and ambitions of the municipality. The effectiveness of this process is closely linked to municipal capacity, particularly the analytical abilities required to select appropriate tools and interpret tool outputs.

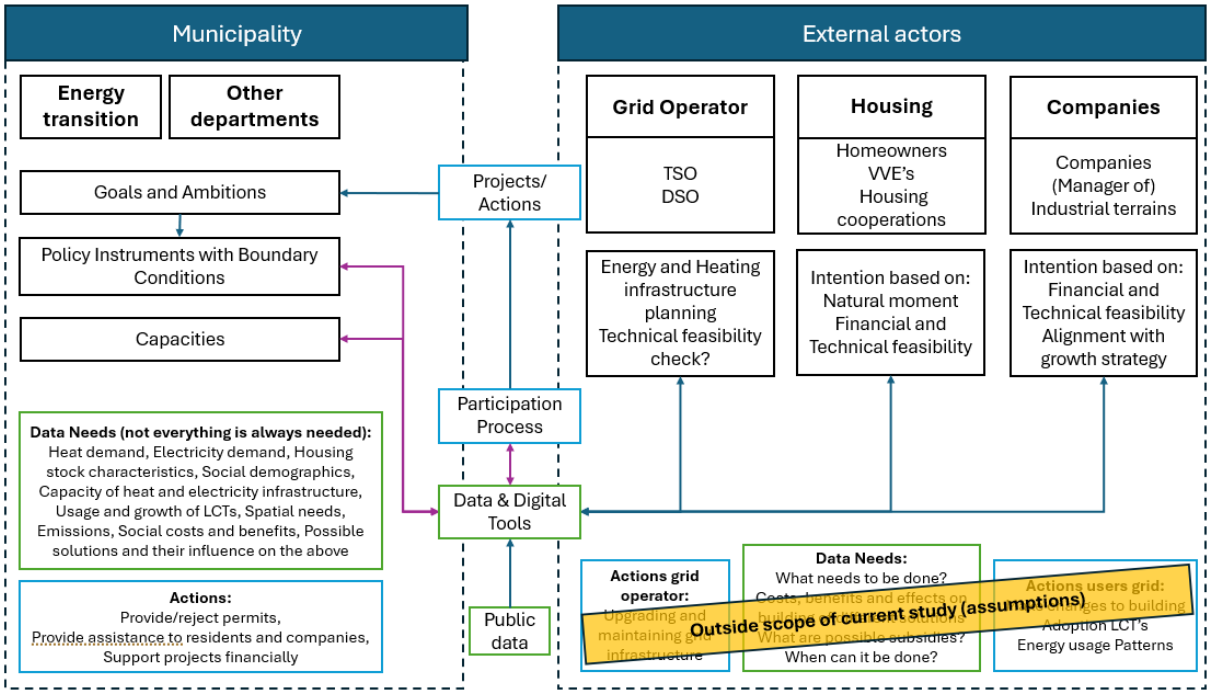

Figure 7: Tool usage in the municipal process

During the early steps of the policy design phase (problem setting and policy formulation) municipalities primarily focus on gathering, organizing, and making sense of diverse datasets. This includes information on heat and electricity demand, housing stock, demographics, and infrastructure capacity. Analytical ability at this stage is crucial as civil servants must interpret raw data, identify key challenges, and set realistic goals and boundary conditions for the energy transition. Descriptive and diagnostic digital tools are particularly valuable here, as they facilitate baseline assessments and help identify underlying challenges within the local context.

As planning progresses from broad visions, such as those articulated in the TVW, to more detailed programs and changes to the physical environment plan, the need for accurate, granular data and a comprehensive understanding of technical and social interdependencies increases. Consequently, their focus shifts toward generating actionable insights and developing concrete plans to guide implementation. Here, more sophisticated digital tools are needed, such as diagnostic, predictive, and prescriptive tools, which allow municipalities to explore possible futures, assess the feasibility of interventions, and make informed choices. Analytical ability remains essential, enabling users to critically evaluate model outputs, understand underlying assumptions, and translate technical findings into visions, plans and insights.

2.3 Overcoming usability challenges of digital tools

Even with tools being specifically developed to aid municipalities, there is some evidence to support there is a gap between model outputs and the practical needs of users. Municipal users encounter difficulties in using and understanding these tools, with information supply often being insufficient for evidence-based energy transition decision-making (Diran et al., 2020). Given these challenges, municipalities often resort to outsourcing as they often do not have the expertise or capacity to utilize these tools and models (Diran et al., 2020). This section will explore how designing for the intended user can be a solution to these issues, followed by a review of challenges affecting the adoption of digital tools by municipal users in decision-making processes for the energy transition.

2.3.1 Designing for the intended user

To address the challenges municipalities face in adopting and using energy transition tools, this section explores two complementary methodologies: user-centred design (UCD) and the design cycle. These methodologies which both are used in software development, have the potential to improve digital tool adoption and effectiveness (Rogers et al., 2019; Wieringa, 2014)

UCD focuses on the real users and their goals, not just technology being the driving force behind product development (Rogers et al., 2019). Three principles are identified: early focus on users and tasks, empirical measurement and iterative design. This means first understanding who the users will be and their cognitive, behavioural, anthropomorphic, and attitudinal characteristics. Usability and user experience goals are then specified, with the design refined based on continuous user feedback.

The design cycle complements this by emphasizing the need to keep improving the tool using different evaluative techniques and making iterative changes to the design. This approach focuses on enhancing both the tool's functionality and its alignment with user requirements (Wieringa, 2014). This iterative process ensures that tools are not only functional but also accessible and practical for municipal decision-makers.

Both UCD and the design cycle use similar techniques to gather user insights and feedback, including interviews, questionnaires, observations, and usability testing. Additionally, other techniques such as walk-throughs, heuristic evaluations and a/b testing can also be utilized (Rogers et al., 2019). These methods can be applied at different stages of the design process to discover requirements, evaluate designs, and refine solutions. Applying these methods can help ensure that digital tools are tailored to the actual needs and overall analytical abilities of civil servants, making them intuitive, accessible, and practical for everyday use.

Ultimately, this user-focused approach addresses adoption and utilization challenges particularly for municipalities with limited resources by empowering staff to interpret results, draw relevant insights, and make informed decisions more independently. Designing digital tools to fit the end-user’s context can strengthen municipal analytical ability over time, reducing dependency on external advisors and supports more sustainable, data-driven decision-making.

2.3.2 Usability challenges for digital tools

Following the discussion of UCD and the design cycle, attention now turns to specific usability challenges in energy system models that influence their effectiveness in municipal decision-making. Süsser et al. (2022) distinguish between model users and modellers. Model users are individuals who utilize modelling results for their work, including policymakers, industry representatives, civil society actors, and scientists. These users may commission modelling studies (e.g., a ministry requesting model consultancies) or read findings from academic or consultancy modelling studies. Modellers, in contrast, are the individuals responsible for developing and running the models for these stakeholders.

To improve the usability of energy system models, Gaschnig et al. (2020) identified four categories where improvements are often required: model content, model design and data, modelling process, and modelling outreach. Süsser et al. (2022) further elaborated on these challenges using the same categories. Diran et al. (2020) and Henrich et al. (2020) focus more on usability challenges identified by Dutch municipalities for current tools. The following sections will elaborate on each of these categories, examining their specific challenges and potential improvements for enhancing energy system model usability.

2.3.2.1 Model Content

Model content focuses on what the model investigates and the research question it aims to answer (Gaschnig et al., 2020). In the article by Süsser et al. (2022) there are a few key issues mentioned. Users and modellers recognize insufficient focus on energy security, despite its importance to policy makers. There is also limited focus on environmental impacts of solutions, which limits the ability to assess the overall environmental costs. Furthermore, the integration of behavioural dimensions and the social impact of solutions is inadequate. Economic considerations are also insufficiently addressed with limited attention to cost and broader economic impacts. For municipalities, these gaps are particularly relevant, as local governments need robust models to assess not only technical feasibility but also social acceptance, environmental trade-offs, and economic implications at the community level.

Further gaps which have been identified include the following: modelling of cross-sectoral coverage, flexibility and short-term variability, further electrification, integration of interdependent renewable energy and energy efficiency measures, emergence of new and “disruptive” technologies, technological learning, the role of human behaviour and lock-in effects, incorporating the effect of climate change, modelling of the trade-offs between economic development and environmental protection, modelling a circular economy, and modelling of political goals (Süsser et al., 2022). These gaps are recognized by both modellers and users, though users often emphasize the practical implications of these limitations. For municipalities, such specific gaps can directly affect their ability to design integrated local strategies that reflect the interconnectedness of sectors and evolving policy priorities.

Elaborating on this, Diran et al. (2020) mention that there is a lack of tools that consider the interaction between heating systems and electrical grids as well as tools which focus on the demand side of the energy transition using an integral energy system perspective. Connecting to this issue Sola et al. (2018) mention that the incorporation of transport sectors on energy modelling is often disregarded in USEM tools. Both heating and transport are key examples of

sectors undergoing electrification through the adoption LCTs, and these areas are highly relevant for municipalities, which require integrated modelling approaches to effectively support local planning and the transition to LCTs.

Additionally, Gaschnig et al. (2020) state there is a lack of models which are reliable, detailed and containing impartial information on the entire energy system. There is also a recognized need for tools to become better in supporting strategies, policies and measures, and the ex-ante assessment of policy impacts, and policy formulation (Gaschnig et al., 2020). For municipalities, this means that current models often fall short in providing the actionable insights needed for local decision-making and the tailoring of solutions to specific neighbourhood or community contexts.

In summary, the challenges related to model content highlight critical limitations that directly affect municipalities' ability to plan and implement effective, context-sensitive energy transitions. Addressing these gaps is essential for developing models that can better support local governments in achieving their sustainability and policy objectives.

2.3.2.2 Model Design and Data

Model design and data is defined as how the model content is investigated and how parameters are interlinked (Gaschnig et al., 2020). A key challenge in this is the trade-off between simplicity and complexity for the usability of the model. Users often prefer simpler models as they can be seen as more accessible but might not always capture the full complexity of the energy transition. More complex models can provide more detailed and potentially more accurate results but are often difficult to non-technical end-users. In some cases, complex models require programming skills to use or adapt them, which can act as a technical barrier. This trade-off is particularly relevant for municipalities, as civil servants may not always have the technical expertise or resources to work with highly complex tools, yet they require sufficient detail to inform local decisions. It is therefore important for modellers to define both general and specific modelling purposes to support decision- and policymakers at the municipal level.

Additionally, open-source data and models are supported as the transparency of these models can be crucial in understanding model assumptions and results. Municipal users may also ask for higher spatial and temporal resolution to better understand the local context (Gaschnig et al., 2020). This resonates with the research of Diran et al. (2020), in which fragmentation of data ownership and lack of transparency in data collection are seen as large challenges for evidence-based decision-making. Furthermore, Diran et al. (2020) mention a difficulty to link various outcomes of models due to varying scope, assumptions, techniques and modelling languages used. There is also a lack of sensitivity analysis and result explanations provided, which makes it difficult for non-experts such as municipal users to understand modelling results.

Data quality, recency, specificity and trustworthiness are also ongoing issues, which affect the reliability of the model (Diran et al., 2020). A more practical issue which was mentioned is that there is a mismatch between the neighbourhood division of statistical agencies (like CBS in the Netherlands) and what the municipalities use (Henrich et al., 2021). This potentially limits the applicability of some of the models. There is critical importance for data quality and relevance.

Incorrect or incomplete data at any stage can lead to a wrong or a delay of decisions or investments (Diran, Van Veenstra, et al., 2021).

Addressing these issues, however, can result in even more complex models. A proposed solution by Süsser et al. (2022) is a component- and modular-based system modelling which aims to reduce simulation complexity while maintaining detail. Gaschnig et al. (2020), also recognises these challenges of tool usage and stress the importance of making custom models for user-specific needs to increase tool adoption and effectiveness. For municipalities, these approaches could help balance the need for detailed, context-specific information with usability and accessibility, ultimately supporting more informed and effective local energy planning.

2.3.2.3 Modelling Process

Modelling process refers to the procedures defined and taken by developers to create and refine the model (Gaschnig et al., 2020). Users express a desire to be involved in this process, wanting to know assumptions, how primaries in the model are determined and define scenarios. Openness about the modelling process and the ability to consider conflicting views is thus also a key thing to consider. Especially with the rising complexity of models, stakeholders value involvement and collaboration with modelers. This collaborative approach can also ensure that the different interest of local stakeholders is addressed, advancing the relevance and applicability of the model to real-world decision-making contexts. Involving municipal stakeholders in the modelling process can help reflect diverse local interests and improve the practical value of model outputs for policy and planning.

As mentioned by Diran et al. (2020), transparency in the modelling process can also be important to increase the support for decisions which are made based on its outcomes. An option to do this is to enhance collaboration among policymakers, local stakeholders and citizens to gather validated data and derive collective knowledge to support decisions utilizing models and tools. This approach is especially valuable as municipalities shift from technocratic decision-support systems toward more participatory processes, where stakeholder involvement in decision-making is central.

2.3.2.4 Modelling Outreach

Modelling outreach focuses on the efforts to communicate the model and its results in an accessible manner (Gaschnig et al., 2020). Users require easy-to understand visualisations, such as graphs, figures, model presentations or factsheets to convey complex issues in a simple and understandable way (Gaschnig et al., 2020). Interactive elements can be used to foster a better understanding of how different parameters and assumptions affect results and thus the model's mechanics. The modelling results should be presented in a visually appealing way to clearly illustrate possible futures and policy effects. These communication formats should provide easy access to model functionalities and result to cater to users with varying levels of expertise. Educational materials like FAQs and information packages can also be of help to navigate more complex models (Süsser et al., 2022). Communicating what the model assumptions, uncertainties and what model results can say and what not is essential here as well (Gaschnig et al., 2020).

Another challenge in modelling outreach is the disconnect between modellers' and users' needs. While, modellers prioritize data-rich outputs, municipal users typically require actionable insights (Johannsen et al., 2021). This disconnect can hinder decision-makers to use tools for real-world scenarios. Diran et al. (2020) connect the need for transparency on the models used and the underlying assumptions to trust and support for the decision-making which proceeds using model. This reinforces the importance of clear and accessible communication to build trust and confidence in model outputs and their application in decision-making.

The usability challenges for energy system models, categorized into model content, design and data, process, and outreach, stress the complexity of creating tools that are both comprehensive and user-friendly for municipal decision-makers. Addressing these challenges aligns closely with the principles of UCD and the design cycle. Focusing on users and their tasks can help address content gaps and ensure models meet real-world decision-making needs. The collaborative approaches between modelers and users can enhance transparency, relevance and improve communication of results, making the outputs more accessible and actionable for municipal decision makers.

In summary, effective modelling outreach is useful to ensure that digital tools are accessible, understandable, and actionable for municipal decision-makers. By prioritizing clear visualizations, transparent presentation of assumptions and uncertainties, and tailored communication formats, modelers can bridge the gap between technical complexity and practical usability. Addressing these modelling outreach challenges not only builds trust and engagement among local stakeholders but also enhances the impact of models in supporting municipal energy transitions.

2.3.3 Usability determinants for digital tools

Drawing from the above literature, this section synthesizes the usability gaps of digital tools. Many tools do not cover important topics such as energy security, environmental impacts, and social or economic factors, which limits municipalities' ability to develop comprehensive and locally relevant strategies. Tools like the Startanalyse offer useful starting points but often lack the flexibility and adaptability needed by municipalities. For other tools, the complexity can exceed the current analytical abilities of civil servants, restricting practical use. This highlights the need for tools that not only provide understandable and actionable outputs, but also help build internal analytical capacity, as emphasized by Johannsen et al. (2021).

Stakeholder involvement remains crucial throughout the process, particularly as municipalities move from design to implementation. Visualizing scenarios and outcomes helps civil servants better grasp complex issues and supports the clear communication of plans and trade-offs to stakeholders. This transparency fosters more meaningful engagement and trust. However, challenges persist in communicating results clearly and providing accessible visualizations and educational support, making it difficult for both municipalities and stakeholders to fully understand and apply the information. The participatory process is inherently iterative, with stakeholder feedback prompting ongoing refinements in both analysis and planning. Ultimately, this leads to policy outcomes that are better aligned with municipal goals and stakeholder needs.

Overall, the effective use of digital decision support tools in municipal energy transitions is shaped by challenges related to model content, model design and data, modelling process, and modelling outreach, as discussed in the previous sections. These categories collectively influence both the analytical ability of municipalities and the extent of meaningful stakeholder involvement. Addressing these barriers is crucial for maximizing the value of such tools. Applying UCD principles and an iterative development cycle can help ensure that digital decision support tools are aligned with actual needs and abilities of municipal users, making these tools more effective in practice.

3. Methodology

In response to the usability challenges and requirements identified, this research adopts a design science approach to develop and validate improvements in municipal digital tools. Design science focuses on studying the interactions between an artifact, in this case the tool by Zenmo, and its context (Wieringa, 2014). The research process follows the iterative design cycle, which is structured into three main phases: problem investigation, treatment design and treatment validation. Each phase is guided by specific research methods tailored to address the unique objectives of that stage.

The Human Risk and Effectiveness (HR&E) evaluation framework (Venable et al., 2014) guides the evaluation throughout the development process. HR&E is particularly suited for socio-technical artifacts with significant user interaction, where the major risks lie in adoption, use, and real-world applicability. It emphasizes early formative evaluation to reduce these more human-centred risks by possibly beginning with artificial settings but moving quickly into naturalistic environments. These naturalistic formative evaluations capture the complexity of real organizational settings. Toward the end of the process, the strategy includes summative evaluations to rigorously assess whether the tool's utility and benefits are likely to persist in long-term, real-world use despite adoption challenges.

Following this approach, the evaluation activities in this research align with the HR&E strategy's progression from early formative to later summative evaluations, and from more artificial to increasingly naturalistic settings, as illustrated in Figure *8*. The process starts with the literature study, which informs the problem investigation phase. Semi-structured interviews (Step 2) provide early formative input by identifying user needs and challenges, with some participants already referencing the Zenmo tool for context without direct tool or mock-up interaction. Insights from both the literature and interviews are analysed using the Kano method (Step 3), which prioritizes user requirements and guides necessary adjustments. Importantly, the Kano analysis also references the Zenmo tool to ensure that all user feedback and requirements are grounded in the specific context and features of the tool.

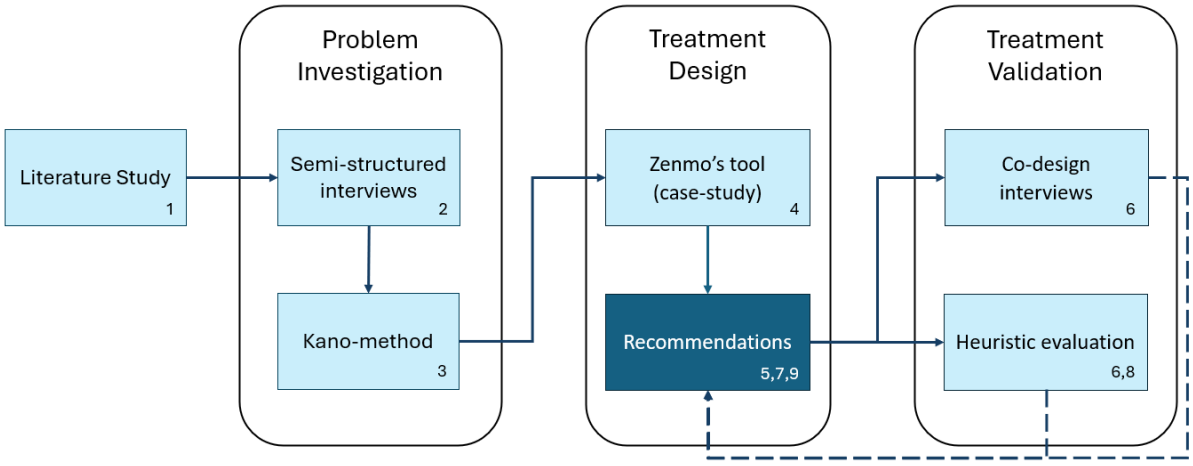

Figure 8: Overview of methodology

In the treatment design phase, the Zenmo tool serves as a case study (Step 4), enabling initial testing and refinement through mock-ups. This phase also includes the development of recommendations (Steps 5, 7, 9) that support iterative improvements. Moving into the

treatment validation phase, co-design interviews (Step 6) engage users with mock-ups Zenmo's refined tool in more naturalistic settings, facilitating formative evaluation by capturing authentic user feedback. Finally, a heuristic evaluation (Steps 6, 8) provides a summative assessment of the tool's usability and its fit within real-world municipal contexts.

This structured, iterative process ensures that evaluation methods evolve progressively from conceptual exploration to practical validation, strengthening the tool's relevance and effectiveness for supporting municipalities in the energy transition. Detailed descriptions of each method and phase follow in the subsequent sections.

3.1 Case-study Zenmo tool

For this research a case-study was conducted using the tool by Zenmo. This is a digital tool which is currently being further developed and used in a couple of municipalities. Especially the neighbourhood model (see Figure 9) has been a particular focus, as many municipalities are actively seeking solutions to reduce grid congestion and implement new heat programs. Insights on the tool's intended use and capabilities were gathered through informal conversations with Zenmo.

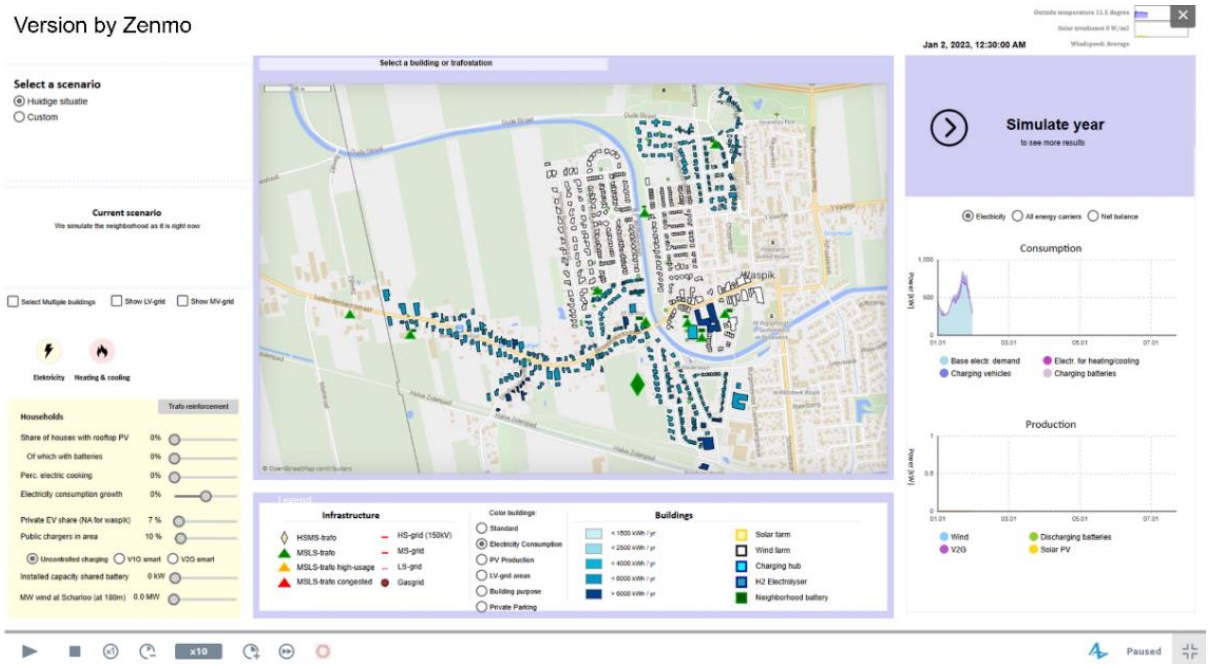

Figure 9: Screenshot of a version of Zenmo's current tool

Zenmo's neighbourhood model is being developed with the idea to help municipalities identify where grid congestion occurs and explore possible mitigation strategies by simulating different future scenarios. Using data specific to an area, such as local energy usage and infrastructure, the tool improves the context dependency of its answers, ensuring that scenarios are tailored to local context. By interacting with sliders and adjusting parameters, users can visualize the impact of various choices on the energy grid, making the tool an exploratory platform for testing options to achieve a future without grid congestion. This approach enables municipalities to assess the consequences of both intervention and non-intervention, fostering a deeper understanding of the implications of LCT implementation. It allows municipalities to explore the grid impact of initiatives such as PV and wind parks, as well as

the transition to all-electric heating systems. Particularly in areas with increasing numbers of LCTs and limited grid expansion, the tool's scenario analysis can be of value. Additionally, Zenmo's tool visualizes different energy carriers, providing a comprehensive overview of energy usage and how various scenarios alter consumption patterns.

3.2 Problem investigation

Problem investigation focuses on understanding what phenomena needs to be improved and why (Wieringa, 2014). The problem investigation phase extends on the literature study chapter to explore how digital tools are used by municipalities (capacities) and which challenges they face using the Zenmo tool. To explore how and why digital tools are used, the link between tools and the municipal users' capacities, stakeholder involvement and policy instruments are further explored. The challenges identified are categorized into model content, model design and data, modelling process and modelling outreach. To gain user insights on general tool usage and a more in-depth understanding of the Zenmo tool, this phase used semi-structured interviews. This reflects the early formative stage of the HR&E strategy, where user insights are gathered in a relatively artificial setting to inform subsequent design.

Semi-structured interviews allow for the interviewer to be more flexible with the order of questions and explore unforeseen issues more in-depth (Adams, 2015). Data from the interviews were analysed using thematic analysis. Thematic analysis is a method to systematically identify, organize and offer insight into patterns across the collected information (Braun & Clarke, 2012). By examining these recurring themes, the method allowed for a deeper understanding of shared or collective meanings and experiences among the interviewees. This systematic analysis of the interviews aimed to create a better overview of municipalities' needs, challenges and insights regarding decision-making tool usage in the energy transition.

The interviews all took approximately one hour. All the interviews were audio-recorded and transcribed with participant consent for analysis, using only anonymized data in the thesis. The people who were interviewed are people working in the energy transition department at municipalities as well as a few experts helping municipalities in the energy transition. One UI expert was interviewed to understand the possible challenges users might have in this. A short overview is presented in Table 3, including interviewee numbers for further reference to them. The goal of these interviews is to understand what the users of the tool need from a tool to aid them in decision-making and how the tool could be made more usable or understandable for its potential users.

Table 3: Problem investigation interviewees

Interviewees	**Description**
Experts	3 experts (Interviewees 2,3 have worked with the Zenmo tool, 4 is looking at different tools)
Municipal users	2 Zenmo users (Interviewees 1 & 9) 3 Other tool users (Interviewees 5, 6, 7)
User Interface expert	1 (Interviewee 8)

The set-up of the interview uses problem and solution interviews as described by Nijssen (2022) as a guide. The interview guide can be found in Appendix A. The first part of the

interview is to gain insight into the problem and why alternatives might not be able to answer the same set of questions and how tools are used currently in municipal processes. The second part of the interview focuses more on what the solution can be to the problem identified and see if this could aid municipalities more.

As a version of the digital tool is already available for certain municipalities to use, questions more focused on evaluating the tool by Zenmo was asked to those who know the tool. For the other municipal users, the insights were more focused on identifying characteristics/features of tools they use which could potentially be incorporated or should not be incorporated into the tool by Zenmo. As identified before, tools have different purposes which means that the benefits and challenges of using other tools might differ.

A key component of the problem investigation was the application of the Kano method to prioritize user requirements. The Kano method systematically classifies user requirements into five categories based on their impact on satisfaction: Must-be, One-dimensional, Attractive, Indifferent, and Reverse. As shown in Figure 10, the Kano model plots requirement fulfilment (x-axis: unfulfilled → fulfilled) against user satisfaction (y-axis: dissatisfaction → satisfaction) (Shahin et al., 2013). Each category forms a distinct curve, reflecting how users respond to feature implementation.

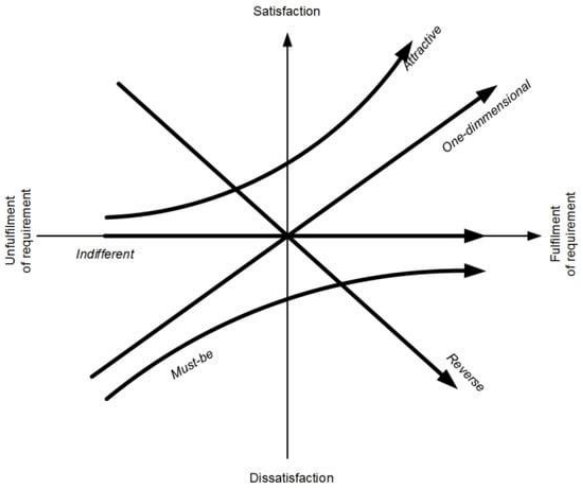

Figure 10: Kano-model (Shahin et al., 2013)

During the interviews, participants were asked to identify features they would like or dislike in digital tools they use. By combining these responses with findings from the literature, an analysis was conducted to classify the functions of the Zenmo tool according to the Kano methodology. This approach helped clarify which features are essential, which drive satisfaction, and which may be less relevant or even undesirable.

3.3 Treatment design and validation phase

From the problem investigation, the research progresses to the treatment design phase which focused on a case study of the Zenmo tool. The treatment design phase focuses on designing possible interventions to treat the most important problems identified earlier (Wieringa, 2014). The improvements were informed by insights from both the literature review and the interviews, ensuring that the proposed solutions were grounded in real user needs and practical challenges encountered by municipalities.

The treatment validation phase focusses on assessing the tool's effectiveness and applicability in a real-world setting (Wieringa, 2014). This approach aligns with the human risk and effectiveness strategy described by Venable et al. (2014) which involves moving toward more naturalistic and summative evaluation methods throughout the design process progresses. These included naturalistic formative evaluation through co-design interviews and a

summative heuristic evaluation assessing the tool's overall usability and fit, aiming to determine whether the implemented changes addressed the previously identified problems, particularly regarding usability and alignment with user expectations.

The design process began with the development of preliminary mock-ups, created using both findings from the problem investigation and a set of established usability heuristics. Using mock-ups allowed for rapid prototyping and iterative adjustments, enabling users to visually assess proposed changes and provide concrete feedback. Three semi-structured interviews were then conducted with (former) users representing the intended audience of the tool by Zenmo. This number allowed for multiple viewpoints, while also reflecting the limited time left for the study and the limited time of municipal users to help. Each interview lasted about an hour and was video and screen-recorded, with participant consent, and transcribed for analysis using anonymized data.

The main objective of the semi-structured interviews was to gather in-depth feedback on the adapted Zenmo tool by exploring users' perceptions, workflows, and preferences. During these interviews, participants interacted with the mock-ups, assessed proposed changes, and provided detailed suggestions for refinement. The interviews followed a structured guide, with an overview of mock-ups and current possible features from other models of Zenmo (see Appendix B for both) and addressed key themes such as initial impressions, overall usability, comparisons between simplified and full-complexity user interfaces, and preferences for educational materials to support both new and advanced users. Although the mock-ups were not functional, this hands-on approach enabled users to directly influence the design and offer concrete suggestions for improvement. Feedback from these interviews was quickly incorporated into subsequent iterations, ensuring that user input was actively integrated into the ongoing development of the tool.

Heuristic evaluation was used as an extra validation method to reduce the demand for civil servants and to evaluate the new and older recommendations. A group of designers and researchers, in this case eight Zenmo employees familiar with the tool, systematically assessed the user interface using a set of usability principles. The evaluation process involved a briefing session, an evaluation period, and a debriefing session, following the approach described by Rogers et al. (2019). The briefing session included ten minutes to present initial findings and improvements, followed by five minutes for questions and discussion. Each evaluator then had ten minutes to assess the tool, which was feasible given their familiarity with the tool. Finally, there was a ten-minute debrief and discussion of the output. The heuristics used were adapted from Nielsen and Molich (1990), with one additional heuristic introduced to address the unique challenges of digital tools in the energy transition domain. The following seven heuristics were prioritized:

- **Match Between System and the Real World:** The system should use language, concepts, and phrases that are familiar to users, following real-world conventions so that information appears in a natural and logical order.
- **User Control and Freedom:** Users should be able to easily undo or exit unwanted actions, giving them clear ways to recover from mistakes or leave an unwanted state.

- **Recognition Rather Than Recall:** The interface should minimise the need for users to remember information by making options, actions, and instructions visible or easily accessible.
- **Flexibility and Efficiency of Use:** The system should support both novice and experienced users, allowing frequent actions to be performed more efficiently and enabling users to tailor the interface to their needs.
- **Aesthetic and Minimalist Design Dialogs:** The interface should only display relevant information, avoiding unnecessary elements that could distract or overwhelm users.
- **Help and Documentation:** Even though it is preferable if the system can be used without documentation, it may be necessary to provide help and documentation Support materials should be easy to find, concise and focused on helping users complete their tasks.
- **Model's Information Content (own):** Users should be able to quickly understand what actions are possible within the tool and how these actions relate to their specific context and desired outcomes.

These heuristics were used as guiding principles throughout the treatment design phase and served as evaluation criteria during the formal heuristic evaluation. They were selected and adapted to address the specific challenges identified in the literature review and interviews, ensuring the design process remained focused on usability and user needs.

Both the semi-structured interviews and the heuristic evaluation served as key co-creation methods, directly involving end-users and experts in the assessment and iterative refinement of Zenmo's tool. This participatory approach ensured that the tool's improvements were not only evaluated but also co-created with its intended users. While other co-creation techniques such as workshops or participatory prototyping, as also identified by Rogers et al. (2019), can be valuable in early design phases, the iterative involvement of users and experts through interviews and evaluation provided the most direct and actionable input for this project's context.

In summary, the methodology combines literature analysis, initial semi-structured interviews, heuristic evaluation, and a round of semi-structured interviews involving mock-ups to iteratively refine the tool by Zenmo. This approach addresses the most important challenges faced by users of the tool using a user-centred and co-creative design process. The following chapters provide an overview of the main challenges identified, detail the improvements made to the tool by Zenmo, and consider their significance for both practical application and further research.

4. Problem investigation results

Using interviews, this section elaborates on the literature study section to examine how digital tools are used in practice and to identify practical challenges. As previously discussed, digital tools are increasingly central to municipal efforts in the energy transition, supporting everything from data gathering and sense-making to vision development and stakeholder engagement. Municipalities use digital tools to integrate multiple data sources, analyse current and future scenarios where the time frame depends on the specific context, and communicate with diverse stakeholders. The challenges and user requirements are categorized into model content, model design and data, modelling approach, and modelling outreach. Naturally, challenges in using models and interpreting data can differ per person.

4.1 Purpose of Tool Usage

Building on the literature study, which highlights how digital tools support decision-making processes, this section shifts focus to their practical application in municipal settings. The literature highlighted two key requirements: municipalities need strong analytical ability and should involve stakeholders when using digital tools for decision-making in the energy transition. By integrating theoretical insights with practical application, this section offers a real-world perspective on both the challenges and opportunities that municipalities face when employing digital tools in the energy transition. Figure *11* illustrates the interconnectedness of these three elements and briefly introduces these challenges, which are discussed in detail below.

This section draws primarily on interview findings to explore how municipalities address these requirements in practice. The following subsections first discuss the two core aspects of analytical ability: (1) gathering, sense-making, and assessing data, and (2) developing insights and visions. Section 4.1.3 then discusses stakeholder involvement. Finally, Section 4.1.4 first synthesizes the main interview findings of these sections and then integrates relevant literature to conclude on the overall purpose and value of digital tools in municipal contexts.

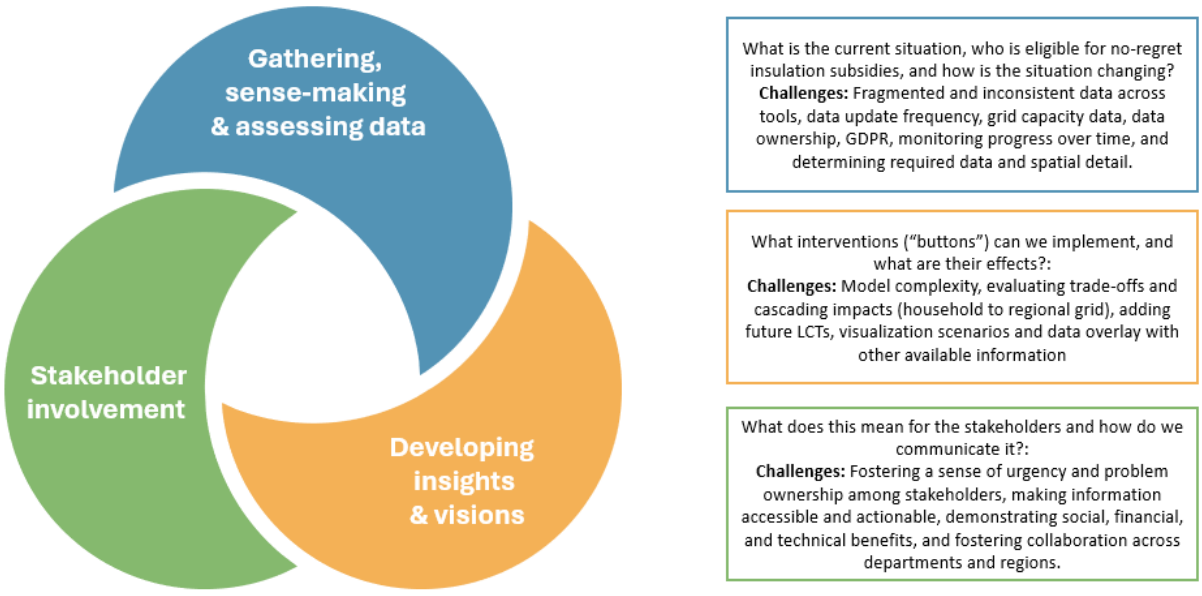

Figure 11: Cyclical and intertwined processes in municipal decision-making.

4.1.1 Gathering, sense-making and assessing of data

A municipality's understanding of its challenges and potential solutions begins with clearly defining the problem, grounded in systematic data collection and assessment. Problem analysis is a central activity, assessing both existing issues and future challenges. Selecting the right digital tools is crucial and should be guided by the specific questions municipalities need to answer and the type of analysis required.

In practice, municipalities frequently utilize a range of digital tools to guide their efforts. This often starts by investigating which households are eligible for subsidies for no-regret measures such as insulation improvements. As their understanding of the energy transition grows, they recognize the need for tools that support a more holistic approach, enabling them to assess the broader impacts of their plans on neighbourhood and regional energy systems. However, combining the different information sources and understanding the assumptions behind them is quite complex and sometimes quite technical. As Interviewee 7 mentioned it sometimes feels like piecing together a puzzle from various sources, which could make it more difficult for a future employee to understand what has been done. This fragmentation and lack of integration of information also complicates efforts to develop a holistic view of the energy transition.

As municipalities progress in their planning and understanding of their challenge and objectives, their data needs and tool needs evolve. Current tool usage tends to focus primarily on immediate needs such as the implementation of insulation, with less emphasis on forecasting future scenarios. As Interviewee 4 mentioned, understanding which tool or features are needed should be guided by the specific question to be answered. This includes, for example, anticipating where future problems may arise in the energy system, which is often overlooked due to limited available information because municipalities have typically operated under the assumption that energy is readily available.

Ideally, progress should be monitored which requires collecting data. For certain interventions, such as insulation, there is often a gap between the desire to know exactly what has been implemented, which is restricted by GDPR, and the current practice of only knowing that some action has occurred. This makes it important to identify reliable indicators that can provide meaningful feedback on progress and signal when adjustments are needed. Overall, monitoring developments over time is crucial for steering and adjusting municipal energy transition strategies by tracking success factors, assessing the impact of measures and guiding future actions with more effectively.

Municipalities often face limited capacity to manage and synthesize the complex data needed for effective planning, especially while also implementing efficiency measures. However, it is acknowledged that building own analytical ability to analyse data instead of relying solely on advisory companies for certain tasks is preferred. o overcome the challenges of managing and synthesizing data, municipalities are developing their own GIS systems to integrate various data sources. This allows them to overlay different types of information and better understand the interlinkages between data, facilitating more informed decision-making. An example by As Interviewee 6 explained, municipalities ultimately want to connect different opportunities and improvements within a neighbourhood to create changes that benefit the area as a whole.

However, it is important to understand what information is needed and at what spatial level, regarding both privacy and usability.

A key challenge for municipalities using the tool by Zenmo is the initial process of gathering data from the grid operator, which is often difficult and can delay the start of the analysis. Once the data is loaded, working with it and building scenarios within the tool can also be time-consuming, as the wide range of available options and settings, while powerful, may make it difficult to maintain focus on the main planning objectives. Interviewee 9 noted that this abundance of features can lead to confusion or a loss of direction. Compared to simpler, less visual tools like Power BI, Zenmo offers more possibilities but also requires more effort to navigate and interpret results. To support users in making better sense of the tool's capabilities and outputs, the addition of clear tutorials or instructional videos was suggested as a valuable improvement.

4.1.2 Developing insight and visions

Following data collection, municipalities develop deeper insights and long-term visions by analysing choices and trade-offs necessary to meet their objectives. By understanding the problem and gaining insights, boundary conditions and plans meeting these conditions can be made. Decisions related to heat networks may involve considerations such as the extent of insulation required or the availability of space for additional low-voltage stations. Approaches for subsidized insulation measures are made by combining various information sources, such as year of construction, energy labels, solar energy production and gas demand, which are not all available on building level.

Scenario analysis further supports the development of insights and visions by helping identify actionable interventions and evaluate their feasibility within local constraints. The benefit of scenario analysis is understanding which "buttons to turn" as a municipality, meaning what interventions they can implement (e.g. neighbourhood batteries, heat networks) and how external factors or future developments may affect which scenario is most effective. It is also important to consider the cascading impacts of these interventions, such as how household-level actions affect broader regional networks, including low, medium, and high-voltage grids. This systems perspective is particularly important when assessing how the plans of one area may influence the solution pathways in other areas, requiring strategies that are both effective and coherent across different scales.

A practical example of this approach comes from Interviewee 1, who upon analysing grid congestion data, discovered the main problem was not in the neighbourhood but on the industrial terrain. This insight prompted a strategic shift to prioritize congestion relief in the industrial area. This is an example which shows that the insights developed from digital tools can help develop visions for the future better.

Looking forward, several interviewees identified energy assessments as a valuable criterion for future developments. Integrating such assessments early in the planning process ensures that the capacity and limitations of the energy grid are considered from the start of the project, rather than as an afterthought. Since regulations and requirements for energy assessments vary between municipalities, Interviewee 2 noted that a scenario tool like Zenmo could help

build the case locally for their inclusion by visualizing local energy system challenges. By incorporating energy assessments into the initial stages of project development, municipalities can better align their growth and sustainability goals with the realities of the local energy infrastructure.

4.1.3 Stakeholder involvement

Effective stakeholder involvement remains a key component in both theory and practice. Municipalities face the challenge of not only recognizing the urgency themselves but also ensuring that other stakeholders truly feel this urgency and understand the need for timely action. Problem ownership and acknowledging the seriousness of the challenge are crucial in this context. Municipalities must communicate the problem and the rationale behind proposed solutions clearly to diverse stakeholders. This need for a shared sense of urgency and problem ownership is highlighted in the interviews but is less emphasized in literature.

This challenge becomes especially critical when households are directly impacted and expected to implement changes. Residents require information in various forms to address their different needs and motivations. Participation can be difficult, as municipalities often struggle with when and how to involve residents, balancing the freedom to explore different solutions with the need to provide clear information about the problems and possible interventions. Demonstrating to residents how their actions influence the broader issue can foster a sense of problem ownership by helping them see that their contributions matter and that they are part of the solution.

A similar dynamic applies to companies, such as those located on industrial sites, where it is important to illustrate how grid congestion can affect their potential for business growth. In the short-term individual solutions are sought after, but on the long-term this is not sustainable and combining energy solutions with their neighbouring companies might be better. Showing these dynamics could potentially push for change. The overarching challenge is to persuade people to make the changes voluntarily as municipalities cannot obligate them.

For municipal users, demonstrating the social, financial and technical benefits of proposed solutions, such as lower societal costs or improved feasibility, was identified in the interviews as crucial for fostering acceptance and collaboration. These insights align with the literature, such as Süsser et al. (2022), who also note the lack of supporting tools in this area. Transparency enables stakeholders to understand, accept, and implement plans or to propose adjustments that better address their specific needs. An example provided by Interviewee 7 showed that stakeholder willingness to take measures, such as insulation, can be influenced by visualizing how their actions enable broader solutions, like connecting a school to the grid.

Internally, municipalities also benefit from transparent communication, as it supports the adaptation of plans, justifies budgetary requirements, and facilitates collaboration across departments (e.g. due to spatial needs or impact of mobility on the energy transition). Recognizing the interconnectedness of problems and the urgency of integrating various perspectives remains challenging due to siloed thinking. An example by Interviewee 9 shows the importance of tools crossing boundaries of these siloes to enable improved communication between departments. For example, the impact different aspects on the

trade-offs in the energy grid and spatial needs of the municipality are critical to take into account on the long-term. Regional communication is also essential to address issues like grid congestion at high-voltage stations

4.1.4 Digital tool support for municipal decision-making

This section synthesizes the key insights from the preceding interview findings, highlighting how municipalities currently use digital tools to support the energy transition. It then integrates relevant literature to contextualize these practical experiences within broader theoretical frameworks. By combining literature and interview findings, this synthesis clarifies the overall purpose and value of digital tools in municipal contexts.

Municipalities use a variety of digital tools tailored to their specific needs, with many relying on simpler dashboards and reports for quick insights into local issues. While valuable for initial problem identification and monitoring, these tools have limited capacity to support more strategic or long-term planning. Collecting and integrating information from multiple digital tools, and understanding the assumptions behind them, remains complex and makes it difficult for municipalities to build a holistic view of the energy transition.

There is a growing recognition among municipal staff of the potential benefits that more advanced digital tools can offer, such as integrating multiple data sources and modelling future scenarios. However, many municipalities are still in the process of exploring these advanced tools and have not yet incorporated them into their workflows due to various challenges. As a result, the use of advanced digital solutions remains limited. To address data fragmentation, some municipalities are combining data using their own GIS platforms provided they have the necessary internal capacity to develop and maintain them. Although most digital tools are currently used internally for data gathering and analysis, municipalities recognize the importance of engaging stakeholders and fostering transparency, but find it challenging to do so effectively with existing tools.

This practical overview aligns with literature describing digital tools as enablers of integrated and participatory decision-making, yet municipalities often underuse their full potential. One reason for this gap is that effective selection and use of digital tools depend not only on technical features of the tool but also on the analytical abilities, knowledge needs, and workflows of civil servants.

The use of more advanced tools like simulation, optimization, and scenario analysis remains limited. Scenario tools such as Zenmo can help visualize possible futures and support strategic discussions, but overall adoption of these advanced tools is still in its early stages. This gap between potential and practice is influenced by challenges such as fragmented data, limited analytical ability, and difficulties in combining information from multiple tools. Consequently, digital tools are mainly used internally for data gathering, identifying local challenges and short term problem solving, while broader uses such as stakeholder engagement and long-term scenario planning are still emerging.

Looking ahead, digital tools hold significant potential to further support municipalities by improving scenario analysis, data integration, and visualization. These advancements could

help address both short- and long-term challenges, foster transparent communication, and enable more meaningful stakeholder involvement. As municipalities continue to build their capacity, digital tools are expected to play an increasingly central role in making robust and widely supported decisions throughout the energy transition.

4.2 Challenges and User needs of Tools

This section analyses challenges in existing tool, using the four identified categories identified in literature: model content, model design and data, modelling process, and modelling outreach. Moreover, tool-specific limitations have been identified during the evaluation of the tool by Zenmo. Finally, 4.2.5 synthesizes usability challenges from interviewees and then reflects on them using findings from literature.

4.2.1 Model Content

Municipalities often struggle to define their core energy transition questions, leading to questions regarding data and tool requirements. This ambiguity complicates holistic planning, particularly when solutions must address both local and regional infrastructure or balance cross-sectoral impacts, such as coordinating energy efficiency upgrades with mobility hub development. As Interviewee 3 noted, translating these broad insights into concrete, actionable strategies is even more challenging. This uncertainty that municipalities experience about what a model should contain is consistent with Gaschnig et al. (2020), who note that model content must be clearly aligned with the research question and the decision-making context.

An important aspect mentioned here is tool adaptability, so being able to add and update data. Municipalities value being able to integrate their own collected data, which is important for ongoing monitoring and responding to evolving local conditions. For example, Interviewee 5 described how tracking insulation subsidies uptake required integrating new data over time to target households that had not yet participated. Similarly, the ability to incorporate new information about, for example, grid congestion or upcoming projects was seen as vital for keeping scenario analyses relevant and actionable. This aligns with Süsser et al. (2022), who highlight the need for modular and responsive models, but interviewees placed even greater emphasis on ongoing responsiveness to evolving local conditions.

The ability to intuitively explore the relationships between energy sources, infrastructure, and consumption patterns is essential. GIS mapping and scenario graphs allow users to examine how interventions such as energy efficiency upgrades or the introduction of mobility hubs influence the local energy system. By working with different map layers, municipalities can identify opportunities for integrated solutions to societal challenges and gain a clearer understanding of the spatial and technical consequences of their decisions. The literature similarly emphasizes the importance of visualization and scenario analysis for actionable insights (Gaschnig et al., 2020).

Scenario analysis tools are sought after to evaluate trade-offs in local contexts, such as balancing insulation requirements against grid capacity upgrades. To use these tools effectively, they require municipality's ability to first contextualize its unique priorities. The

benefits of using a scenario tool like that of Zenmo, is understanding what “buttons a municipality can turn” and being able to add the idea of autonomous growth of energy consumption. In Zenmo’s tool visualization of the interconnected impacts of living, working, and traveling on the grid was seen as a major strength.

However, several limitations were consistently identified. Users noted that Zenmo currently misses the spatial aspect of solutions, limiting its ability to connect technical interventions to the actual physical space required for their implementation. For example, installing a new low-voltage station is not just a technical decision, but it also requires reserving a specific plot of land. Once this space is allocated for electrical infrastructure, it cannot be used for other developments such as housing or green areas. This means that every decision to place a substation directly reduces the available space for other valuable community functions.

Moreover, the tool struggles to model cascading effects across interconnected grid levels. It is a critical gap given the need to evaluate how localized decisions such as insulation policies or EV charging infrastructure affect broader regional energy capacity. This partly coincided with the findings by Diran et al. (2020) and Sola et al. (2018), who point out the lack of tools that integrate heating, electricity, and transport sectors from an integral energy system perspective.

Further limitations included Zenmo’s static design, which does not easily incorporate evolving conditions like new renewable projects or policy shifts. This reduces the tool’s long-term relevance and highlights the need for more dynamic scenario updating, echoing Süsser et al. (2022)’s call for tools that can support ongoing policy adaptation their emphasis on supporting ex-ante policy assessment. Finally, while interviewees recognized the value of including financial and social aspects in scenario analysis. Interviews also emphasized that this aspect might not necessarily need to be added to this tool, provided that the tool can work together with other tools and processes used by municipalities.

4.2.2 Model Design and Data

Effective tools must balance technical rigor with usability, ensuring compliance with general data protection regulations (GDPR) while enabling data interoperability and ownership. A tool should also enable modularity to add area-specific data. GDPR concerns are especially relevant for building-level data, as privacy must be considered. Interviewees stressed the need for layered data accessibility to protect privacy yet maintain rich local datasets for internal planning. This practical concern complements the literature’s emphasis on transparency and open data (Gaschnig et al., 2020), adding the important dimension of legal compliance and operational data management.

Municipal users also highlighted the difficulty of integrating quantitative data with qualitative goals and boundary conditions. Municipal users also highlighted the difficulty of integrating quantitative data with qualitative goals and boundary conditions. The ability to update models with more recent or precise information as it becomes available is essential to maintain relevance and accuracy in a rapidly evolving energy landscape. These points align with calls for adaptable, modular modelling approaches (Süsser et al., 2022) and the literature’s recognition

of challenges linking diverse model outcomes (Diran et al., 2020) but add a stronger focus on operational needs and policy integration.

Overlaying different information sources, such as spatial data layers on maps, was seen as essential for municipal users. Interviewees suggested that easy-to-use filters and interactive map features would allow users to visualize the effects of interventions, such as adding insulation or heat networks to selected houses, and immediately see the impact. The ability to customize the user interface, including logical placement of selection buttons and map layers, was identified as a valuable feature for improving usability and supporting different user needs. This customizability is also mentioned shortly by Gaschnig et al. (2020) to customize models more to user-specific needs.

Next to open access tools like the Startanalyse and DEGO's tools, municipalities can pay to access tools made by other companies. A notable challenge with paid or subscription-based tools is that when access ends, municipalities may lose both the tool and the associated data, resulting in a loss of valuable knowledge and insights. While municipalities typically retain ownership of their original data, losing access to the tool and its outputs can result in a significant loss of valuable knowledge and insights. This highlights the importance of ensuring long-term access not only to raw data but also to the results and analyses generated, enabling municipalities to retain lessons learned and build internal capacity over time, which is a topic that is less frequently discussed in the literature.

The Zenmo model is seen as quite technical, with many possibilities, but its design can be complex for users with less knowledge of the energy grid. Also, the model requires the user to understand the reasoning behind sliders better. Potential improvements include combining multiple data sources within Zenmo to enhance user understanding and ensuring the model remains adaptable as new data or requirements arise. For example, distinctions between technologies, for example, charging an EV at home versus using a home battery, should be made explicit to avoid confusion. The way EV charging is modelled (assuming street charging only) may need adjustment to reflect home charging scenarios. Interviews noted this can be a barrier to broader adoption, especially among users who may not have a technical background but are nonetheless responsible for making or communicating key decisions. These usability barriers echo literature concerns about the trade-off between complexity and accessibility (Gaschnig et al., 2020), and the need for clearer explanations to support non-expert users (Diran et al., 2020).

Users also reported that when they received outputs from Zenmo, they needed to check the data carefully and found some small mistakes. Additionally, some buttons in the interface did not produce any visible change in the output, leading to confusion by the user. Given that the model is still under development and municipalities are aware of this, such issues are acceptable for now. However, for future versions, more attention should be paid to data accuracy and quality control to build user trust and reduce the time spent verifying results. Addressing these smaller bugs and improving data reliability will be important steps as the tool matures and is used more widely. This reinforces the literature's emphasis on data quality, recency, and trustworthiness for effective decision support (Henrich et al., 2021; Diran et al., 2020).

4.2.3 Modelling Process

A recurring theme in the interviews was the strong desire for tools that are flexible and easy to update, allowing municipalities to independently incorporate new data-such as renewable energy projects, mobility hubs, or policy changes-without frequent assistance from external modelers. This independence is crucial for maintaining data recency and ensuring the ongoing relevance of model outputs. However, many municipalities lack the technical capacity to program these updates themselves, so there is a clear need for user-friendly interfaces or other support that make such adjustments straightforward and accessible. These findings directly support Gaschnig et al. (2020), who highlight the importance of user involvement and adaptability in model development, especially as models become more complex and context specific.

Interviewees also emphasized that the ability to update and compare results from different tools is important for long-term use and strategic planning. The process of keeping models up to date should be streamlined, minimizing the need for external support and reducing administrative burdens. Cost was cited by interviewees as a significant factor in model selection, with municipalities noting that processing invoices and relying on external developers for updates can be both time-consuming and expensive. Ideally, the value of purchasing and maintaining a tool should be justified by the impact and actionable insights it provides. Tool and result ownership were also highlighted as essential for building internal capacity and retaining institutional knowledge over time.

While the Zenmo model allows some user-driven adjustments, its current closed architecture forces the users to depend on developers for major changes and adaptations. This can be time-consuming and costly if this needs to be done recurringly. Creating a more modular system could be an option to fix this, but interviewees also recognize that this could be quite complex, which reduces model usability. This partially aligns with the literature recommendations for modular models as mentioned by Süsser et al. (2022).

4.2.4 Modelling Outreach

Digital tools are gaining in complexity due to the need to be able to overlay various collected information. This can themselves there was a clear call for features that help filter relevant information, provide concise support materials, such as concise FAQs, webinars, and clear documentation of assumptions to support broader understanding and adoption. A point of attention here is to make the basic idea as clear as possible from the start as long documentation with assumptions might only be read by people with a real interest in it, but municipal users often do not have the time to do this. This need is also emphasized for the tool by Zenmo. This practical need for filtering and accessibility reflects the literature's emphasis on user-centred communication and the importance of making model outputs and assumptions transparent and easy to grasp (Gaschnig et al., 2020; Süsser et al., 2022).

Visuals and terminology are also critical for usability. For the tool by Zenmo the usage of icons on the map and its graphs to visualize different aspect are seen as positive features. However, there are a few aspects which should be investigated further to improve usability. The use of ambiguous terms, such as "electrification," can hinder understanding, as users may not know exactly what is being changed when selecting certain options. Similarly, terms like "high

temperature nets" or "heat pumps" can be interpreted in multiple ways unless further specified, such as indicating the exact temperature or type of heat pump. This is a point also raised in literature which highlights the need for clear, standardized terminology to support effective communication (Gaschnig et al., 2020).

Given the complexity of the challenges addressed by the tool, Interviewees 2 and 9 suggested a tiered approach: an easy version to introduce municipal users to core functionalities and aid in stakeholder communication, and an advanced version for more detailed scenario-building and flexible analysis. This tiered approach could help accommodate both new and experienced users, fostering transparency and enabling more meaningful engagement.

Additionally, interviewees noted minor usability issues, such as unclear feedback when interacting with certain elements. For instance, red voltage stations appearing after clicking on them in the year view, making it seem like the station is experiencing grid congestion. These smaller bugs, while not critical, can disrupt the user experience and should be addressed in future updates. Suggestions were also provided by Interviewee 8 to improve the adjustability of the user interface, such as providing a logical location for multi-building selection buttons and repositioning map layers function for more intuitive process. Interviewee 9, built on this by suggesting a customizable UI. By refining these interface elements and ensuring logical, UCD, Zenmo can become more intuitive and effective for municipalities navigating the energy transition.

Cross-departmental collaboration and stakeholder engagement remain significant barriers to effective energy transition planning. Municipalities often face challenges in persuading other departments to acknowledge and incorporate energy network constraints into their plans. Tools should try to map this sense of urgency, trade-offs and assumptions behind it to convey the message to other stakeholders. Using visuals and known terminology can help convey this message. Furthermore, for stakeholder involvement, the tool by Zenmo requires some computing power from your laptop and can crash while showing it with Teams for example. This could make it difficult to use currently with other stakeholders.

4.2.5 Usability gaps and challenges in practice

The interview findings reveal that, while digital tools are increasingly central to municipal energy transition efforts, their value is shaped as much by practical usability and communication needs as by technical rigor. These challenges are reflected in concrete, everyday barriers across all four main categories.

In model content, municipalities would want to integrate and update some local data, like insulation subsidy uptake, but they find it much harder to include more complex information such as grid congestion doe to limited data availability and technical barriers. Many tools also lack spatial detail, like taking into account the land needed for substations, which makes realistic planning more difficult and can lead to overlooking important trade-offs with other land uses. Being able to update data independently and customize analyses is especially important for long-term planning and monitoring, given how local conditions and policy goals keep changing.

When it comes to model design and data, municipalities have to balance privacy concerns with the need for detailed local information. However, practical usability suffers because interfaces are often complicated and controls are unclear, making it hard for users to fully use the tools. There is also a risk that losing access to paid tools means losing valuable knowledge and insights, which shows the need for solutions that are transparent and easy to access or save outputs of.

In the modelling process, municipalities want to be able to update models and data on their own, but many still rely on external developers because the tools are not designed to be easy to change or update internally. This dependence slows down their ability to react to changing conditions and limits the flexibility they need for effective planning.

Finally, in modelling outreach, unclear terminology and minor interface problems make it harder to communicate clearly and engage stakeholders. Interviewees stressed the importance of tools that work for users with different levels of expertise, for example by offering simple and advanced versions or customizable interfaces. These examples show that municipalities need tools that are not only technically strong but also flexible, transparent, and easy to adapt so they stay useful as policies and data evolve.

A further insight from the interviews is that many current tools are primarily descriptive, focusing on presenting the current state rather than enabling users to explore future scenarios or test the impact of new policies and technologies. This gap limits the usefulness of such tools for proactive planning and scenario analysis, which municipal users increasingly require. Together, these findings highlight that improvements must address both technical and practical needs to ensure ongoing relevance and value in municipal contexts. Ensuring clarity in the user interface, providing accessible guidance, and supporting scenario exploration are all crucial for empowering civil servants to make informed, timely decisions.

The combined insights from both the literature and interviews demonstrate a clear and persistent gap between user needs and tool outputs. While the literature provided a broad overview of usability challenges, the interviews offered more concrete, practical examples such as fragmented data, limited flexibility, and the need for clear ownership of results. For example, municipalities often address data fragmentation by creating their own GIS solutions to combine disparate sources, a challenge less emphasized in academic discussions. While digital tools are often designed with an emphasis on technical rigor and comprehensive data analysis, their true value for municipalities depends equally on practical usability, adaptability, and the ability to support local decision-making processes.

The interviews and literature highlighted that municipal users expect the tool to be clear, transparent, and adaptable to their local context. Essential requirements include user-friendly interfaces, transparency in data and assumptions, comprehensive documentation, and strong visualizations. Additionally, tools should use familiar terminology, provide accessible educational resources, and facilitate communication with stakeholders. The ability to easily compare scenarios was emphasized, reflecting the growing need for tools that support both internal decision-making and stakeholder involvement. As municipalities increasingly move toward participatory and future-oriented planning, addressing these practical needs will be key to ensuring digital tools truly enable informed and effective energy transition strategies.

4.3 Gap Analysis

Building on the methodology outlined in Section 3.1, this section explores civil servants' experiences with usability challenges and unmet needs while using Zenmo's tool in municipal settings. Table 4 categorizes identified features according to the Kano model, distinguishing essential functions from those that enhance satisfaction, should be deprioritized or avoided in further development of the tool by Zenmo. By linking each feature to its relevant challenge category, the analysis reveals how usability issues affect civil servants' engagement with the tool and their capacity to support effective municipal planning and decision-making.

Table 4: Kano categorization of features and functionalities

Kano Category	Feature / Functionality	Category	Kano Category	Feature / Functionality	Category
Must-be	Visualisations	Modelling Outreach	**Attractive**	Adding features	Modelling Process
	Buttons and sliders	Model Design and Data		Connections with other departments	Modelling Outreach
	Energy grid data	Model Content		Interface adaptability	Modelling Outreach
	Data updateability	Model Design and Data		Results ownership	Model Process
	Data accuracy and quality control	Model Design and Data		Monitoring	Modelling Process
One-dimensional	Building-level data	Model Content		Layered data access and permissions	Model Design and Data
	Understandable controls for EVs and batteries	Model Design and Data		Transparent assumptions and results	Modelling Outreach
	Educational material	Modelling Outreach		Interoperability of data	Model Design and Data
	Matching terminology	Modelling Outreach	**Indifferent**	Only forward-moving simulation	Model Design and Data
	Clear legend	Model Outreach	**Reverse**	Showing only numbers as output	Model Content
	Map layers of other data	Model Design and Data		Buttons that do not change any output	Model Design and Data
	Manageable costs for buying and using tool	Modelling Process		Mistakes in data and design	Model Design and Data
Attractive/ One-dimensional	Cascading grid levels (could differ per user)	Model Content			

At the core of user expectations are must-be features which represent the essential baseline for the tool by Zenmo. These features are things which interviewees mentioned as key features for a tool used by a municipality and things which are key in terms of the goal of this tool. For example, clear visualisations are essential for making complex data understandable to both civil servants and external stakeholders. Interactive scenario control, using buttons and sliders in this case, allow users to explore scenarios and see the impact of different interventions. As a scenario tool this is essential to create added value for the tool. Also, reliable, up-to-date energy grid data is necessary for accurate problem analysis, while updateability ensures the tool will remain relevant as local conditions and policies evolve. Data accuracy and quality control underpin trust in the tool's outputs, which is crucial for decision-making and stakeholder engagement.

One-dimensional features further enhance user satisfaction as they improve. Interviewees mentioned these features quite often and came up in literature as things which would increase or decrease satisfaction if it was better or worse. Building-level data enables precise planning and targeted interventions, especially when municipalities have collected detailed information themselves. Controls for electric vehicles and batteries must be understandable, as unclear interface elements can frustrate users and hinder adoption. Educational materials are particularly valued for more technical tools, allowing users to build understanding without always relying on external support. Consistent, municipality-aligned terminology and clear legends further reduce confusion, making the tool easier to use from the outset. The ability to overlay map layers with other spatial data helps users contextualize energy information. Equally important are the costs associated with the tool. Municipalities often operate within tight budget constraints, so it is essential that the tool remains affordable not only in terms of initial purchase or licensing fees, but also with respect to ongoing maintenance, updates, and user support.

Further enhancing the tool's appeal are attractive features. Interviewees mentioned these features as possible improvements, which could improve satisfaction if it were added but for now is does not decrease satisfaction if it is not there. The flexibility to add new features or adapt the tool as needs change is highly valued, particularly if municipalities can do so themselves, although this must be balanced with usability and cost considerations. Integration with other departments, such as spatial planning or mobility, is increasingly important for comprehensive energy transition strategies, and interface adaptability allows users to tailor the tool to their preferences, improving both efficiency and satisfaction. Results ownership is a growing concern, as municipalities want to ensure continued access to their own results, especially if they wish to integrate outputs into their own GIS platforms. Monitoring functions support ongoing progress tracking, while layered data access and permissions help balance privacy with the need for collaboration. Transparent assumptions and results build trust and enable meaningful comparisons between tools, and data interoperability ensures municipalities can use the tool by Zenmo alongside other preferred platforms.

A feature which occupies the space between one-dimensional and attractive is cascading grid levels as it depends on the user needs and expectations. For some, this enables holistic analysis across multiple network layers and is essential for comprehensive planning, while for others, it is a desirable enhancement that adds value as their use of the tool matures.

Also, there is a feature for which users are indifferent. In this case simulations only moving forward in time was mentioned. Users understand this is a natural part of the model and do not see it as adding or detracting value, so these features do not influence satisfaction or dissatisfaction. Recognizing which features are indifferent helps focus development resources on aspects that truly matter to users.

Finally, certain features actively detract from the user experience and should be avoided. Interviewees mentioned these features explicitly in a way they that showed they dislike the aspect in a tool. Users are dissatisfied when presented with only raw data, as actionable insights are needed for planning and stakeholder engagement. Non-functional buttons or mistakes in data and design not only confuse users but also damage trust and waste valuable time.

To fully realize its potential, Zenmo should continue to focus on its strengths in technical modelling and already strong visualization capabilities, while also considering how it can best complement other tools and processes within the municipality. Rather than aiming to be a comprehensive solution that thoroughly calculates every detail, the strength of Zenmo's tool lies at visualizing the energy demand of a neighbourhood. By facilitating exploration and supporting early-stage scenario analysis, the tool by Zenmo can play a crucial role in helping municipalities navigate the complexities of the energy transition and move toward actionable solutions.

Focusing on usability on the long-term and for a larger number of users, the first improvements should focus on the must-be, one-dimensional and reverse features. Later, a focus on attractive features could improve user satisfaction further. These improvements, which is something Interviewee 9 emphasized as well, are essential for usability across a larger user-base. This perspective sets the stage for the next section, which will focus on potential improvements to the Zenmo tool to better support municipalities in developing robust, integrated energy plans.

To conclude, civil servants' experiences with Zenmo's tool reveal that while it focuses on energy transition scenario making and offers actionable insights beyond simple problem identification, usability challenges remain. It's interactive features help municipalities understand the effects of certain interventions on the energy grid, while also potentially facilitating stakeholder involvement by visualizing the energy system dynamics in a more understandable and accessible way. However, its comprehensive scope may overwhelm new users, highlighting the possible need for simplified interfaces and effective onboarding. This reflects a common trade-off between complexity and usability of digital tools. Enhancing integration with emerging data sources and better alignment with municipal workflows could further enhance its relevance and adoption.

5. Treatment Design and Validation

Building on the findings from the Kano method, this chapter focuses on improving Zenmo's tool to better support municipal decision-making processes. It details the iterative design and validation process undertaken to address the prioritized usability needs identified before. Figure 12 shows the version of the tool by Zenmo that serves as the basis for subsequent adjustments. The treatment design phase integrates heuristic evaluation and user feedback, focusing first on the more essential features and functions mentioned in the Kano method before considering enhancements that could further increase user satisfaction. This chapter outlines the steps taken, from initial redesign to user testing and subsequent refinement. The chapter then concludes with a discussion of potential larger-scale changes in Section 5.6 and finally synthesizes the findings in Section 5.7.

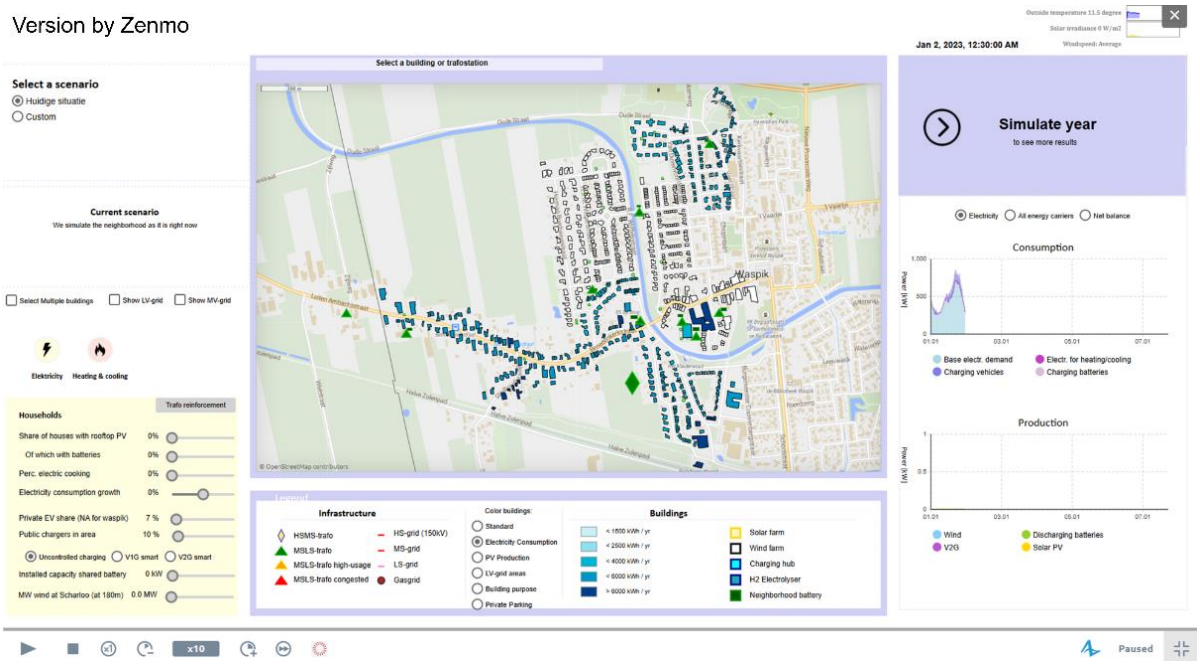

Figure 12: Screenshot of a version of Zenmo's current tool

5.1 First Treatment Design

The initial improvements prioritized enhancing the overall usability of the UI of Zenmo's tool, guided by the prioritized needs identified through the Kano analysis and the application of usability heuristics. Rather than addressing technical issues such as data quality or loading speed, this phase concentrated on practical and actionable changes to the UI that could meaningfully improve the user experience for both new and existing users. The improvements were first implemented in the standard version of the UI, which serves as the foundation for all users. Building on this, a simplified version was developed to further lower the entry barrier for new or less experienced users.

5.1.1 Improved standard user interface

The improved standard UI, seen in Figure 13, incorporates a range of enhancements designed to address the most pressing usability challenges and better align the tool with the needs of municipal users. These are focused on the terminology, organisation of the elements in the UI

and additional support for the users. A positive aspect of the tool was mentioned to be the quick feedback of the scenario sliders to the simulation, which means that this should be kept in the tool.

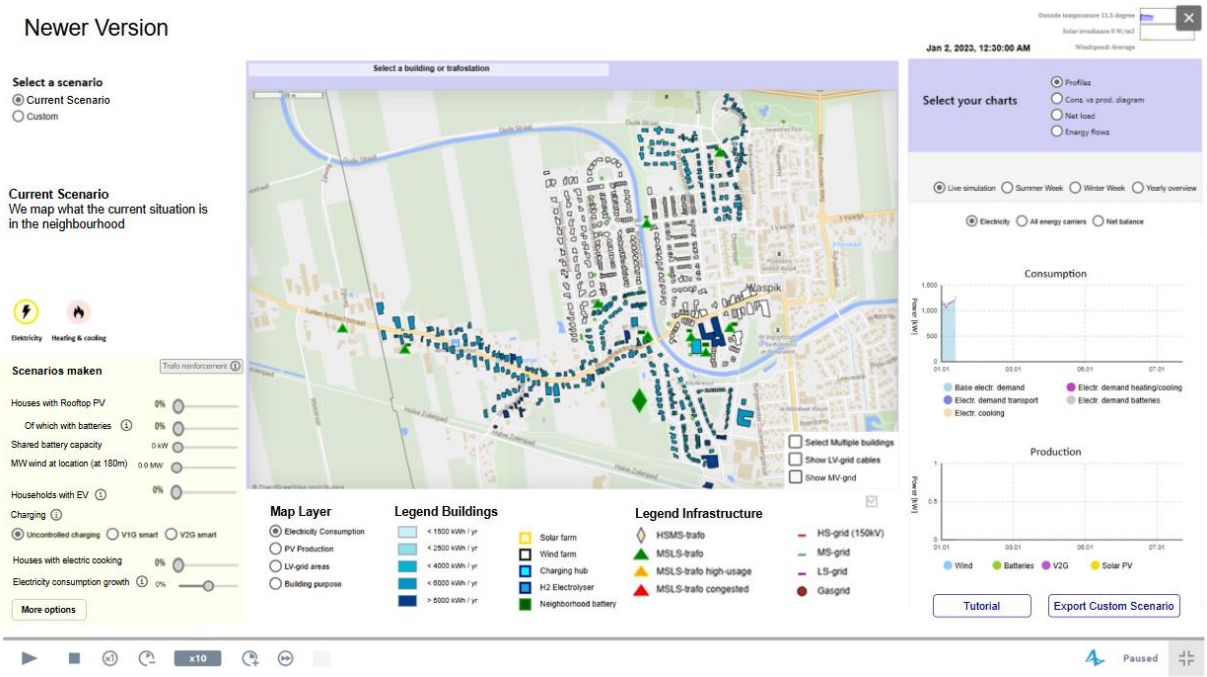

Figure 13: First new version of the tool

First, the terminology used throughout the interface was carefully reviewed and adjusted where needed. Feedback from both municipal users and domain experts highlighted that unclear or overly technical language, such as ambiguous battery-related functions, can create confusion and hinder their ability to effectively use the tool. To further support users, the interface now includes information icons next to scenario options that may require further explanation and a tutorial button that provides supporting material to improve understanding of the tool. By aligning labels and instructions with the users' everyday language and context, the tool now better matches the system to the real world, making its functions more transparent and intuitive.

In addition to terminology, significant attention was given to the organization and accessibility of core UI elements. The legend and map selection components were reorganized so that the layer selection option appears first, providing a more logical flow. Controls for selecting low- and medium-voltage grids, as well as the option to select multiple buildings, were integrated directly into the map interface. This not only supports intuitive, map-based navigation but also minimizes the user's memory load, as actions and options are easily found rather than requiring users to recall information from other parts of the interface.

Further, all graph-related options are now visible without requiring the user to initiate a simulation, and features like the voltage station reinforcement are presented upfront. This streamlines the workflow and further reduces cognitive load, again supporting the principle of recognition over recall. To provide users with immediate feedback and reinforce their sense of control, a clear selection indicator, such as a highlighted circle, was added to show when

electricity is selected. This not only improves visual feedback but also enhances users' ability to quickly recognize the current state of the tool.

A dedicated export function was added to the interface, allowing users to easily download data of the scenario for further analysis or reporting. This improvement is related to the heuristic of flexibility and efficiency of use, as it streamlines a common workflow for users and reduces the number of steps required to access the data. This aligns with the need for municipalities to make decisions and being to compare and reason for certain choices. By making this function readily accessible, the tool supports users to save their scenarios in an easy way to compare them better. In this way, the export feature enhances overall usability by enabling users to quickly obtain and utilize the information generated by the tool, without unnecessary extra steps. These enhancements collectively aim to create a more logical, accessible, and user-friendly experience, empowering municipal users to effectively utilize the tool in their energy planning activities.

5.1.2 Simplified user interface

Building on the improvements made to the standard interface, the simplified user interface was developed to specifically support first-time or less experienced users. This version, seen in Figure 14, retains the key usability enhancements described in Section 5.2.1, including reorganization of the core UI elements, direct visibility of essential options, the export data function and contextual help through tutorial and information icons. Using mostly the same UI builds on the recognition and recall heuristic to ensure features can still be found in mostly the same spot.

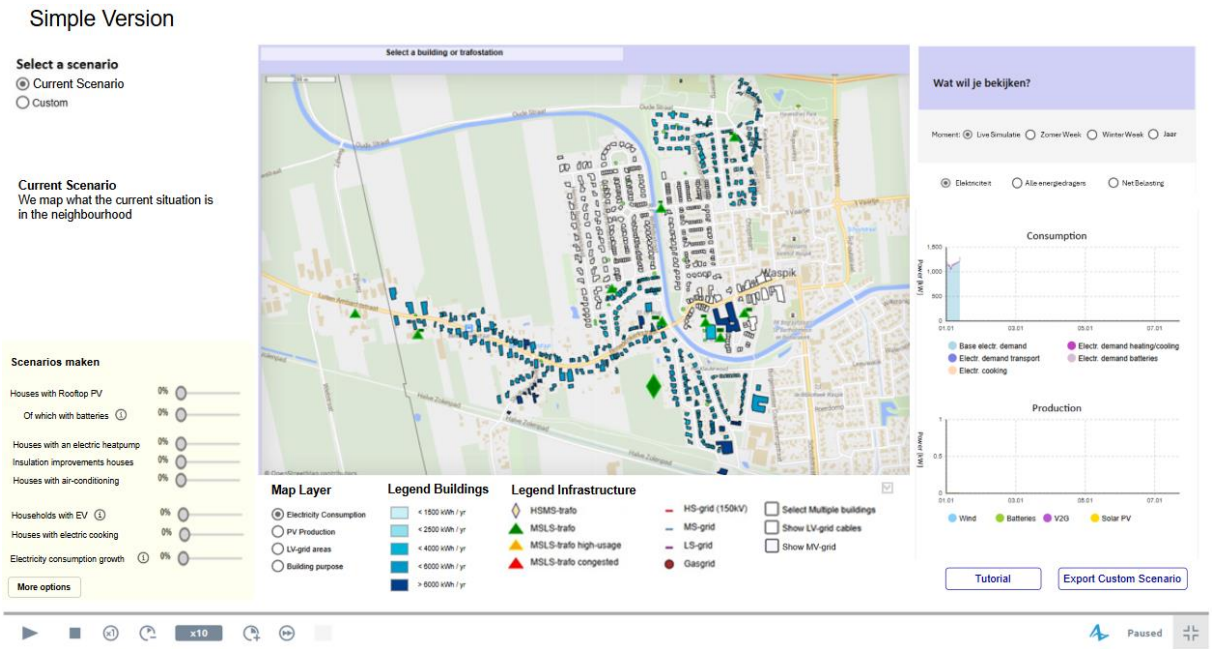

Figure 14: First simple version of the tool

The primary distinction of the simplified interface lies in its focus on essential features and the reduction of visual complexity trying to create a minimalistic design with only the most-used functions. Only the most critical scenario options are presented, including energy grid load graphs, consumption and production graphs, and a map with transformer locations. The scope

is intentionally limited to autonomous growth scenarios-such as photovoltaic (PV) adoption, electric vehicles (EV), and heat pumps-while more advanced solution modelling is omitted. This approach is guided by principles of simplicity and minimalism, to ensure that every element has a clear purpose and thus reducing cognitive load and making it easier for new users to understand and engage with the tool.

By maintaining all options directly visible and providing contextual help at key decision points, the simplified UI enables users to build confidence and familiarity before transitioning to the more feature-rich standard interface. At the bottom there is an option to add more options to the tool, which users can click to add more possibilities to the tool. This progressive disclosure strategy ensures that the tool remains accessible and effective for a diverse user base, while upholding the same standards of clarity, consistency, and usability established in the standard interface.

5.1.3 Improved support materials

To further enhance user experience and ensure both new and experienced users can effectively utilize the Zenmo tool, a range of support materials was made available and integrated into the interface. These resources are intended to provide guidance, reduce the learning curve, and enable users to resolve questions independently, without requiring direct assistance from the model developer

Information buttons are strategically placed next to sliders and scenario options throughout the interface, offering concise explanations or links to more detailed documentation. This supports users in understanding specific functionalities without interrupting their workflow. An example of this can be found in Figure 15, where specific functionalities which might be confusing for the user were chosen to have an information button to directly understand what it does. Hovering or clicking on the information button would give a small pop-up with extra information about the variable.

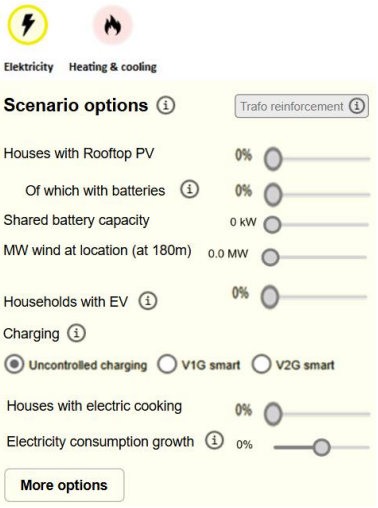

Figure 15: Scenarios with information icons

Interactive tutorials, guides users step-by-step through the different features. First by going through the main features and then into more in-depth possibilities. This tutorial is designed to be self-paced and practical, allowing users to revisit instructions as needed and explore the tool's capabilities in a hands-on manner. An example of the tutorial is presented in Figure 16 and Figure 17, with a longer example found in Appendix C.

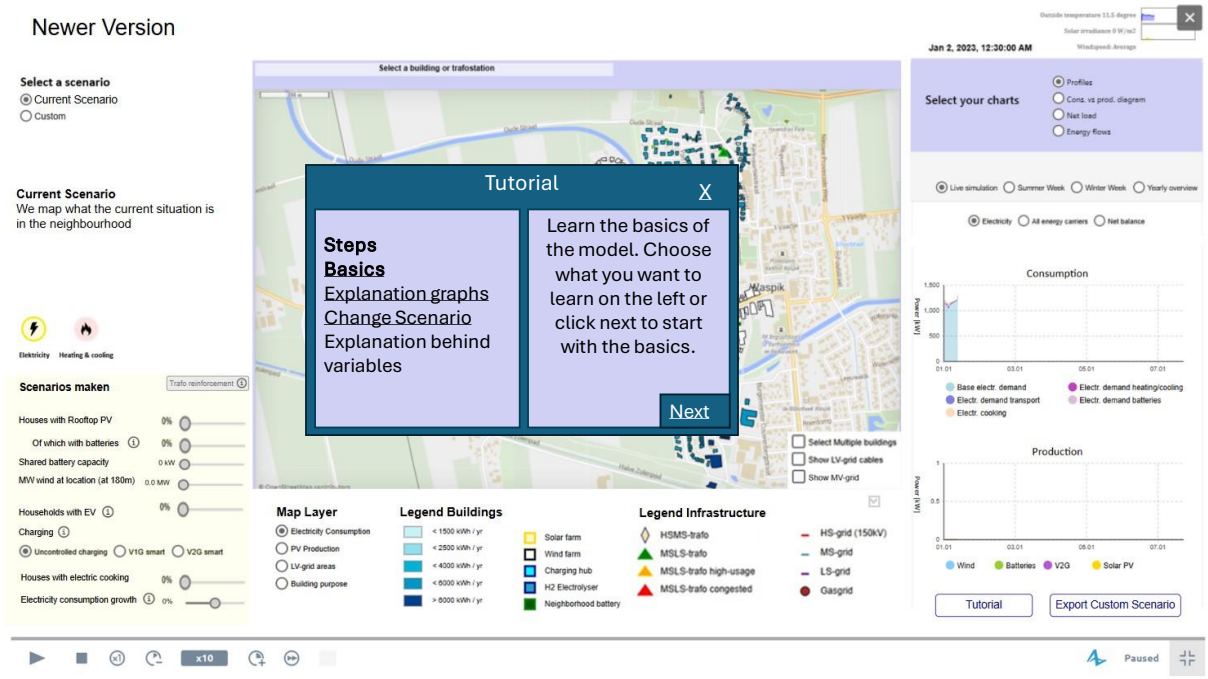

Figure 16: Short example of basic tutorial screen

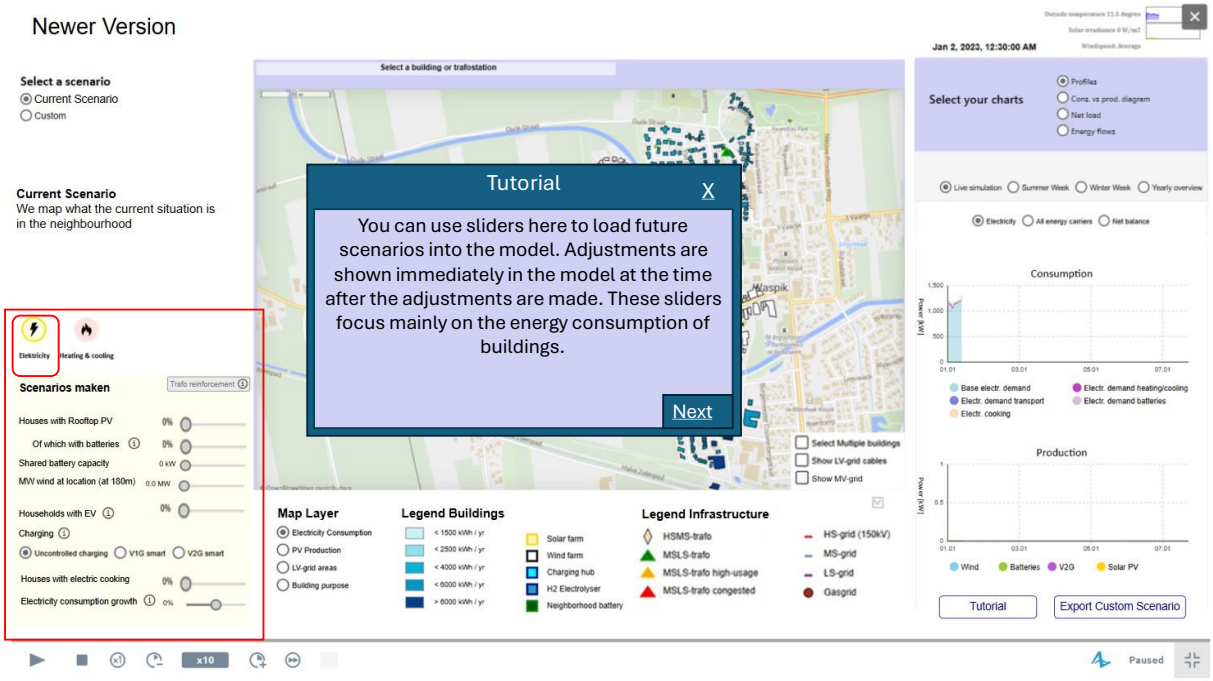

Figure 17: Example of a possible explanation in the tutorial

In addition, although dedicated instructional videos were not produced as part of this project, the value of such materials is well recognized and was also highlighted by users during the interviews in the problem investigation phase. Many users are already familiar with this format and can easily imagine how such videos would complement the existing support materials. Where relevant, links to external videos could be provided in the tool for example in the tutorial.

5.2 Interviews using mock-ups

The first round of treatment design was evaluated through interviews with users who are already familiar with Zenmo's tool. First questions were aimed to gather feedback on the two user interface versions developed in the treatment design phase. Participants were presented with prototypes of both interfaces and asked to evaluate their approachability, clarity, feature completeness, and ease of navigation. In addition, the interviews explored user preferences regarding support materials, including contextual information buttons, interactive tutorials, and instructional videos. This helped identify which types of help users find most valuable and how these resources could best be integrated to support both novice and experienced users.

5.2.1 Interview outcomes UIs

Building on the user feedback gathered from mock-ups, integrating these insights into the design process can significantly enhance both usability and user satisfaction. The ability to add features, as recognized by interviewees, allows for a high degree of customization, which is especially valuable for municipalities dealing with context dependent variables and solutions. However, this flexibility also introduces the risk of overwhelming users with too many options, making it crucial to strike a balance between customization and simplicity. Notably, the importance of offering a variety of heating options stands out, as municipalities often require detailed and diverse heating variables to accurately plan for local needs.

To address this, offering both a comprehensive and a simplified version of the tool could be recommended. The simple version should focus on the essential features and offer a clear, intuitive experience, concentrating on the initial questions relevant to a neighbourhood, such as adding PVs, EVs, and batteries, which is an approach that aligns well with the mock-up. A step-by-step introduction for new users could be useful in this simple version, guiding them through the tool's core functionalities. At the same time, maintaining two different interfaces might introduce complexity in development and support, so this trade-off should be considered in future iterations.

The mock-up incorporated exporting scenarios button which received very positive feedback from all interviewees. Users emphasized that exporting should include both the scenario variables and the outcomes, as this is currently a manual process for many and would greatly improve efficiency if automated within the tool. In addition, the ability to save and compare scenarios was highlighted as highly valuable. Saving scenarios enables users to revisit and reuse their configurations without having to manually re-enter slider values, making the workflow much smoother. Comparing scenarios was also seen as important, though there were mixed opinions on whether this should be handled within the tool itself or via external applications like Excel.

Understanding and interpreting graphs is another area where users expressed a need for improvement. It is important to present graphs in a logical and transparent way, clearly documenting the underlying assumptions. One specific suggestion was to include a graph that displays both energy demand and production in a single view, which could be interpret self-sufficiency of an area. There was also a suggestion to better explain what is shown in each graph and perhaps to split some variables (e.g., separating different types of heating production) to make the effects of each variable more visible. Users also wanted to see the

graphs bigger and be able to zoom in on certain time periods, which points to the need for greater modularity in the interface. This modularity could possibly support a more detailed analysis.

Furthermore, as the quality of data input into the model improves, the relevance and accuracy of the model's outputs can also increase. At present, the model runs partially on assumptions and partially on real data, which makes interpretation challenging for users. Improving data integration will be important for the tool's continued development.

The organization and logic of tabs and features should be carefully considered, as feedback from individual interviewees revealed a range of perspectives regarding the distribution of parameters under different tabs. While none of the interviewees expressed clear dissatisfaction with the current structure, there was some uncertainty about whether an alternative organization might be more effective. Several interviewees reflected on whether grouping features differently could improve usability, but no clear preference or consensus emerged. As such, the structure of tabs and parameters remains an open point for further exploration and user testing, ensuring that any adjustments are genuinely beneficial to the user experience.

The addition of a conversation guide could further support users by addressing common questions, initially focusing on municipal users and later expanding to residents or companies. Such a guide would allow users to click on questions they might have and receive clear, relevant answers, helping them quickly identify what is most important for their specific situation. This could be especially valuable for topics central to the energy transition, such as the impact of heating programs or electric vehicles on the energy grid, including the potential of V2G (vehicle-to-grid) technology to alleviate grid challenges. By thoughtfully integrating these user-driven insights, the tool can become more intuitive, adaptable, and effective for a wide range of users. A conversation guide would thus not only supports self-directed learning but also makes complex data more approachable, particularly for users who may be less familiar with technical details.

Other issues raised by users included the importance of visualizing cascading grid effects, the annoyance of having to restart the program if left idle, the value of a summary or automatic analysis button, and the desire to add area-specific technologies. Users also mentioned confusion caused by buttons with no output, the usefulness of scenarios that show differences per year (to monitor change), and the ongoing challenge of getting data into the model.

5.2.2 Interview outcomes support materials

There was a very positive reaction to the inclusion of a tutorial within the tool itself, as users found it easily accessible and appreciated not having to leave the tool to find explanations. This approach lowers barriers to learning and supports both beginner and experienced users. Also, information icons were seen as a useful extra; although some users felt that a comprehensive tutorial could partially replace their function, keeping these icons as supplementary aids is likely beneficial since they do not take up much space. They could provide quick clarifications or direct users to further information, helping ensure transparency

about where data comes from or how certain variables are defined, and making it easier for users to find assumptions or background information whenever it is relevant.

Both the tutorial and the information icons can serve as central places within the tool where users can find explanations and links to further documentation, for example on the assumptions behind the tool's calculation methods. While a first-time user might not immediately need this level of detail, such documentation is particularly valuable for municipalities, enabling them to build a stronger narrative for stakeholders and conduct more thorough analyses. Including all detailed documentation directly within the tutorial or information icons could make them too long and overwhelming, so providing clear links to external resources, such as what types of solar panels or heat pumps are used, or what is included in specific graphs, allows users to access comprehensive explanations when needed, while still having a space within the tool where these assumptions can always be found.

The tutorial also raised the question by an interviewee whether a separate simple version of the tool is necessary. However, considering the viewpoint of a different interviewee which notes the importance of not overwhelming users with too many functions when they start, it seems like both options do not necessarily cancel out one another. Especially for people who are less knowledgeable on the energy transition when starting to use the tool both aspects could then still be valued. The tutorial should primarily guide beginning users through the different fields and their functionalities, while more experienced users can access deeper explanations and links to documentation as needed.

Videos were suggested as particularly helpful for walking users through real-world scenarios. One user described the value of a video that demonstrates how a municipality might approach a specific problem and adapt a scenario to their own needs, making the tool's practical application clearer. While there was a general preference for the tutorial for guiding users through the tool, videos could serve as a valuable supplement for those who prefer visual and auditory instruction.

By iterating on features and keeping feedback channels open, the tool can better meet user needs. One interviewee noted that simplifying the interface could enable a mobile app, making neighbourhood energy planning more accessible for civil servants first and later to residents and companies. This user-centred, iterative approach ensures the Zenmo tool stays relevant and aligned with its audience. Actively involving users helped validate some of the design changes, identify usability issues, and guide improvements, ensuring the tool evolves to meet practical needs effectively.

5.3 Second treatment design

From the above feedback it was clear that a save scenario could also be useful to add. Additionally, adding a more elaborate scenario description to explain the scenario could also be useful. The conversation guide was also added as an option underneath the graphs as this can help guide users through relevant information and the questions they have. How these changes have been incorporated into the tool mock-up can be seen in Figure 18.Figure 18: Adjustments round 2

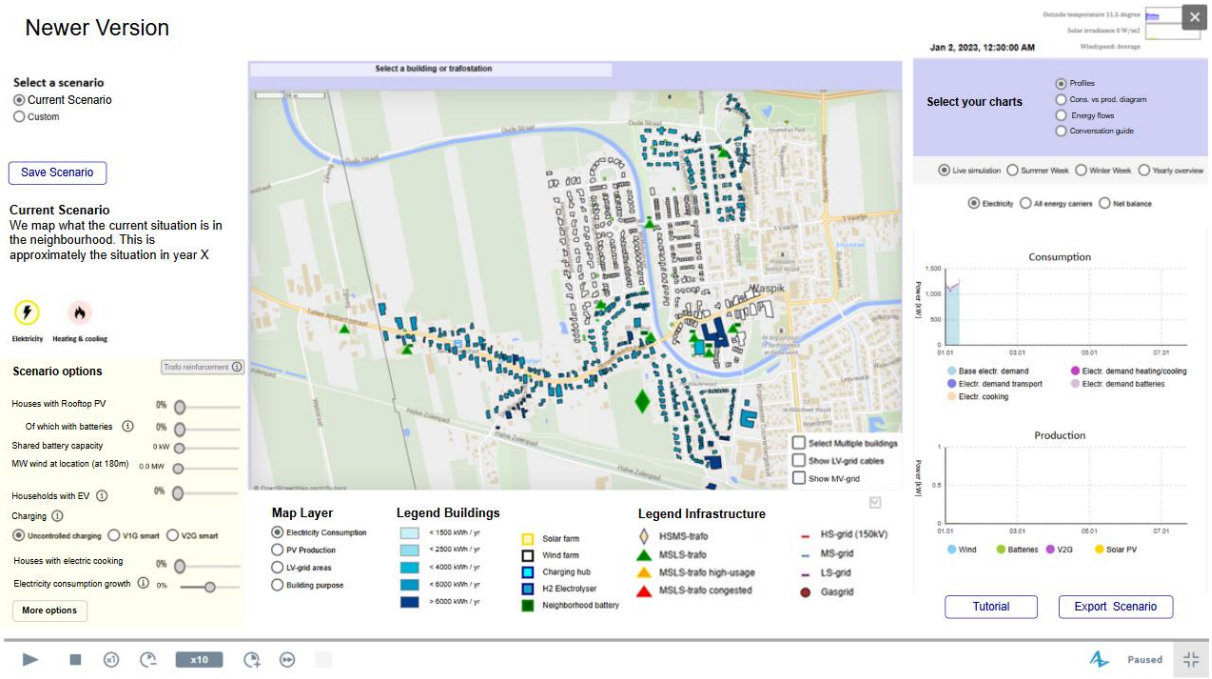

Figure 18: Adjustments round 2

5.4 Second round of treatment design: Heuristic evaluation

Afterwards, the tool was evaluated across selected heuristics which were explained in Section 3.3. From this several strengths and areas for improvement became apparent. Regarding the match between system and the real world, the interface already makes an effort to use terminology users know. However, there might be a few instances where the terminology does not match for which further user feedback might be needed or should be clarified (e.g. using an information icon). Especially when adding and changing features this needs to be considered to reduce confusion.

With respect to user control and freedom, there was feedback regarding limited options for the user to go back to previous states or scenarios. Using a back button and “Ctrl Z” option would then allow users to quickly go back to the old scenario they ran. Additionally, saving and being able to compare the scenarios, like in the mock-up, has the potential to enhance users’ ability to faster experiment and make informed decisions. Also, a dedicated restart button for the simulation could streamline the process of going back to the start of the live simulation.

For recognition rather than recall, there is still some room to improve the consistency and visibility of key elements. Standardizing the colour scheme across the website, scenario creation, and graphs would help users more easily recognize and interpret information. In some areas, adding a “see more” option could reveal additional settings without overwhelming the main interface. Next to that, it is also very important to provide clear visual cues or tooltips explaining why options are unavailable, thus preventing confusion. An example which was given was that the simulate year part has a good reason that it is there to start with as there would otherwise be a lot of unclickable buttons.

In terms of flexibility and efficiency of use, the ability to use saved scenarios is an important feature to quickly show certain scenarios. For experienced users, the tool becomes much faster

to navigate once they are familiar with the model, and these options like exporting, comparing and saving scenarios are implemented.

The tool has already received positive feedback for its aesthetic and design, but there is still potential for refinement to make it look less complex. Careful consideration should be given to the placement of new buttons and features to avoid clutter. Where possible, lengthy explanatory text can be replaced with concise info icons. A suggestion was also to reorganize the screen completely to various tabs which all have a logical idea behind what they show. For example, one tab could look more into making a scenario and another might focus more on the map to show the possible flickering of the voltage stations.

When it comes to help and documentation, there is a clear need for more comprehensive and accessible resources. Also, the link to documentation and the documentation by itself need improvements to show up-to-date and detailed information, especially regarding the assumptions used in the model. As these are things which can increase users' understanding and trust in the model. Also, the videos were mentioned as a possibility to help users as explained in Section 5.2.

Finally, addressing the model information content heuristic, it is evident that users would benefit from additional documentation, videos, and tutorials that explain the model's logic, assumptions, and limitations. Enhancing the visual distinction between clickable and non-clickable buttons, for example by adding shadows or hover effects, would also improve usability. The map used to visualize the area, is a positive aspect and should be kept as seen in the above sections as well.

Some more general comments regarding the improvements made in Section 5.1 are that there are now still two different actions in the legend at two different locations. On the left you can choose the map layer, and on the right, there are actions regarding what you see on the map and selection of multiple buildings. Furthermore, also for the complex version the legend can be reduced to the functions which are being used.

5.5 Final adjustments

To further enhance usability, an information button will be added at the top of the scenario creation section, providing users with quick access to relevant documentation and guidance. An undo button with a "Ctrl + Z" shortcut now would allow users to easily revert to the previous scenario state, improving workflow efficiency and reducing the risk of accidental changes. Additionally, a restart button has been introduced at the bottom, enabling users to quickly return to the start of the simulation. The map legend has been refined to display only the elements currently visible on the map, ensuring clarity and relevance for users. Moreover, the map actions have been repositioned to the left side, alongside the existing map layers, creating a more organized and intuitive layout. These adjustments, visible in Figure 19, aim to streamline the user experience and make the tool more intuitive for both new and experienced users.

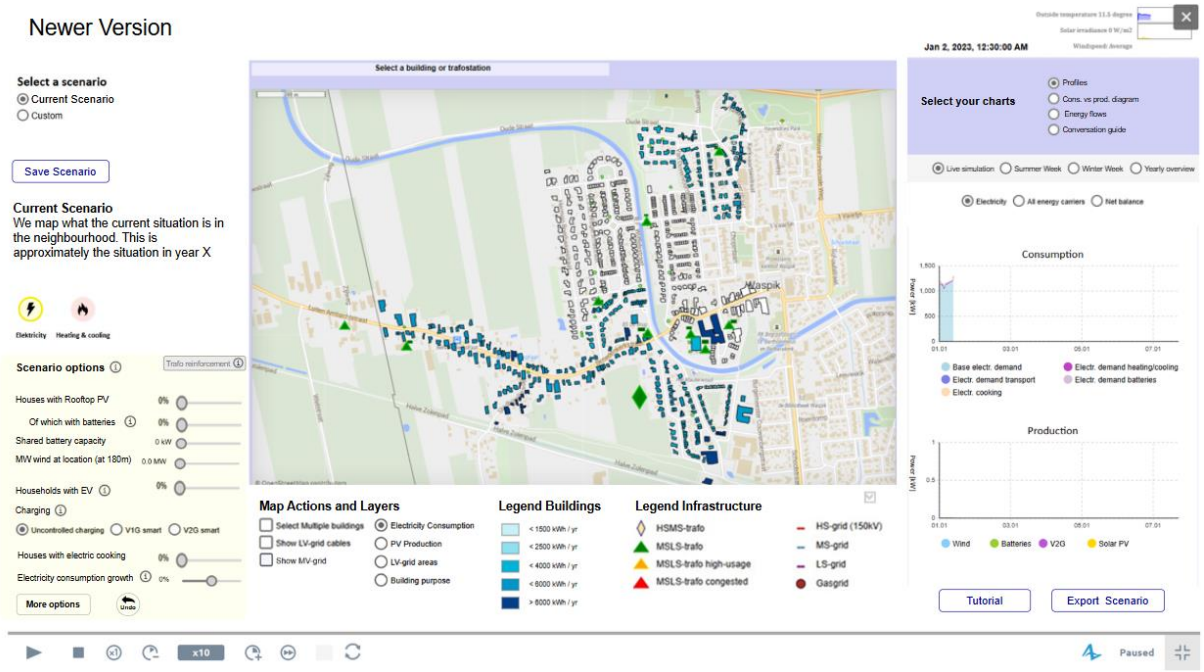

Figure 19: Last improvements in tool

5.6 Possible further improvement directions

Table 5, initially developed earlier in this research, has now been refined to reflect a more nuanced understanding of user needs and expectations based on recent evaluation phases. The updated table (Table 5) highlights, in orange, those aspects that received direct user feedback, while new suggestions and priorities identified in the latest round of interviews are shown in green.

Table 5: Adjusted Kano method table after last round of feedback

Kano Category	Feature / Functionality	Kano Category	Feature / Functionality
Must-be	Visualisations	**Attractive**	Adding features yourself
	Buttons and sliders		Connections with other departments
	Energy grid data		Interface adaptability
	Data updateability		Results ownership
	Data accuracy and quality control		Monitoring
One-dimensional	Building-level data		Layered data access and permissions
	Understandable controls for EVs and batteries		Transparent assumptions and results
	Educational material		Interoperability of data
	Matching terminology		Modularity (possibility to see graph larger)
	Clear legend		Scenario comparison in tool

	Map layers of other data		Adding new neighbourhood
	Manageable costs for buying and using tool	**Reverse**	Showing only numbers as output
	Saving scenarios yourself		Buttons that do not change any output
Attractive/ One-dimensional	Cascading grid levels		Mistakes in data and design
Indifferent	Only forward-moving simulation		Needing to restart the model after it being idle

While needs such as scenario saving, comparison, and enhanced learning resources have already been addressed in the latest improvements, other suggestions remain as valuable opportunities for future work. For example, the integration of cascading effects and additional map layers was highlighted as particularly important for enabling more granular and context-specific planning, but these features have not yet been incorporated into the mock-up. Similarly, although data interoperability was frequently mentioned, it remains an area for further exploration and development. Users also expressed a strong interest in greater modularity and customization, such as adjusting visual elements or tailoring the interface to different user expertise levels. Finally, to improve overall user experience, addressing issues like model restarts and providing intuitive feedback remains a priority.

In addition to the previously discussed priorities, user feedback also highlighted a further opportunity for enhancing the tool's usability and effectiveness. There was interest in restructuring the tool's interface into a set of clearly defined tabs, each dedicated to a specific aspect of the energy transition or planning process. This modular organization would enable users to more easily navigate between different types of information, such as scenario analysis, data inputs, or monitoring results, and focus on the content most relevant to their current task. By segmenting the tool in this way, it becomes possible to reduce cognitive load and streamline the user experience, making the tool more accessible and efficient for a diverse range of municipal users.

It is important to recognize that while these potential improvements would answer more detailed questions and support advanced use cases, not all features should be implemented at once or even at all. Overloading the tool with complexity could undermine its usability. Rather than implementing all possible functionalities at once, prioritizing those features that align closely with core municipal workflows and ensuring seamless interoperability with other platforms will maximize the tool's value without compromising usability.

5.7 Synthesis of requirements and modifications for Zenmo's tool

In conclusion, Zenmo's tool can more effectively support municipal decision-making by focusing on a clear, accessible interface and features that directly address user needs. Prioritizing familiar terminology, logical grouping of core elements, such as the map legend, layer selection, and scenario controls, and adding functions like scenario export (including both inputs and outcomes), undo, and restart buttons would streamline workflows and reduce cognitive load. Integrating in-tool scenario comparison and simplifying the interface would

make the tool more approachable for both civil servants and residents, directly supporting the scenario analysis phase of a municipality. An interesting finding from the interviews was that a simple interface could potentially empower residents to explore energy challenges and potential solutions themselves, supporting more inclusive decision-making processes. Gradually revealing advanced options and educational materials would further support users with varying levels of expertise.

To ensure the tool remains adaptable and future proof, enhancing data integration and interoperability, for example by enabling connection with municipal GIS systems, could be interesting feature to consider. Also, focusing on interoperability could mean that Zenmo would not need to develop all advanced functions internally, but can instead allow users to combine its outputs with other tools for more detailed analysis. This approach helps maintain usability while expanding the tool's overall functionality.

Next to interoperability, Zenmo's tool has several other areas with potential for improvement that could add value for municipal planning. Future developments could include enhanced spatial analysis, cost estimation modules, or cascading grid levels for multi-level analysis, as well as features like a conversation guide to address common municipal questions. Refining tab organization, making the interface more modular, and expanding support materials like interactive tutorials and instructional videos would further increase the adaptability, transparency, and effectiveness of Zenmo's tool for municipal planning.

Continuing these improvements requires ongoing dialogue with users and iterative refinement, guided by structured feedback methods like the Kano method. By consistently incorporating user insights and responding to evolving user needs the tool can potentially become more relevant, effective, and adaptable as municipal energy transition planning evolves. Together, these strategies highlight the importance of user driven development in maintaining the practical value and long-term impact of digital tools.

6. Conclusion and discussion

This research set out to understand how design decision support can be designed to enhance usability by civil servants. By combining literature, user interviews, and a case study of Zenmo's tool, the study identified key usability challenges and practical opportunities for improvement. The following sections summarize the main findings, discuss their implications, and offer recommendations to help ensure these digital tools become more accessible, actionable, and effective for municipal decision-makers.

6.1 Conclusion

The Dutch energy transition places municipalities at the centre of complex decision-making processes that require balancing technical, social, and policy challenges. Design-decision support tools are intended to help municipalities navigate these complexities by providing data-driven insights and scenario analyses. In practice, however, these tools are often underutilized. Rather than supporting integrated, participatory, and long-term planning, they are mostly used for internal data gathering and short term problem solving. Municipalities tend to rely on simpler dashboards and reports, while the adoption of more advanced tools, such as scenario tools, remains limited. This underutilization is not just a technical issue but a practical one. When tools are not accessible or intuitive for civil servants, it constrains their potential to inform and improve decision-making.

The main usability challenges identified fall into four categories. For model content, tools often lack alignment with local knowledge needs, do not provide the data granularity required for municipal questions or lack options for scenario comparison. In terms of model design and data, tools need to be transparent, accurate, and interoperable, while enabling municipalities to integrate local datasets and take ownership of the results. However, tools are often too complex making it too difficult to understand how outcomes are produced and how their own inputs influence them. Regarding the modelling process, municipalities are often dependent on external developers for updates, which limits adaptability as local needs evolve. Finally, for model outreach, results are sometimes communicated in technical language or without clear visualizations, reducing both internal usability and stakeholder involvement.

To address these challenges, solutions could focus on making it easier to integrate local data and tailor analyses, simplifying interfaces and clarifying parameter relationships, and enabling users to update or adapt models themselves where possible. Improving communication through clear language and strong visualizations can also make outputs more actionable and easier to share. At the same time, it is important to avoid increasing complexity when introducing new features. For features which could make the tool more complicated, such as adding spatial or cost estimations features, it is important to understand whether the feature is needed within the tool or if a complementary tool could also support this. Crucially, an iterative, user-centred approach, with early and ongoing involvement of civil servants, will help ensure that tools remain relevant, usable, and trusted. By addressing these challenges and applying practical solutions, municipalities can better integrate digital decision support tools into their workflows, fostering more robust, inclusive, and long-term planning throughout the energy transition.

6.2 Discussion

Successful adoption of digital tools depends not only on their design, but also municipal capacity and their workflows. When internal expertise or capacity is limited, municipalities may rely more on external experts or consultants operate complex tools or conduct analyses. In such cases, these experts may prioritize advanced features or detailed outputs, potentially shifting design priorities away from user-friendly interfaces aimed at municipal staff. In these cases, it becomes especially valuable for the tool to provide outputs that are easy to communicate, such as clear visuals or reports, so that decision makers can understand and share findings regardless of who operates the tool. Recognizing the diversity of users, from technical experts to policy officials, is essential for designing tools that remain relevant and effective across different municipal contexts.

Next to user needs, it is also important to consider the technical and financial feasibility of digital tool improvements. While this research used the Kano method to better understand and prioritize user needs, it did not explore the tension between development costs and practical benefits. Developers face the challenge of investing resources in both interface improvements and complex features like advanced data integration, which must be weighed against potential tool adoption and long-term sustainability. Municipalities also need to assess whether these enhancements justify their limited budgets and capacities. Clear assessment criteria and ongoing dialogue can help align tool development with real needs and available resources.

Additionally, user testing should not be limited to experienced users. Including civil servants who are new to the tool can reveal onboarding challenges and highlight improvements that make it easier for all users to gain confidence and integrate the tool into their daily work. This approach ensures that usability improvements address the needs of both novice and advanced users, supporting broader adoption and more effective use in practice.

Another important aspect is help and documentation. While this research touched on initial ideas for improving support materials, further research is needed to identify best practices for help systems and user guidance. Comprehensive onboarding and accessible documentation are especially valuable for new and advanced users to build confidence among staff. Optimizing these materials, informed by broader literature and user feedback, can further lower barriers to effective tool use for all user groups.

6.3 Practical implications

For practitioners and tool developers, the findings highlight the importance of UCD, intuitive interfaces, and clear educational materials. Early and ongoing involvement of end-users, support for both starting and advanced users, and transparency in assumptions and outputs are all critical for fostering adoption and effective use. Developers should ensure that documentation is accessible, interfaces use familiar terminology, and onboarding is supported by various educational materials. As tools and data become more integrated, flexibility and adaptability to both municipal needs and user expertise will become increasingly important.

For municipalities, the findings suggest the importance of selecting tools that align closely with existing workflows and analytical ability. Descriptive dashboards can help define and frame

problems, while scenario analysis tools become more valuable as municipalities move toward evaluating solutions. Monitoring tools are essential for tracking progress and making adjustments. This research shows that effective planning requires a combination of descriptive, diagnostic, predictive, and prescriptive tools, each tailored to a different phase of decision-making.

From a scientific perspective, this research advances the understanding of municipal analytical ability and workflow influences the usability of design-decision support tools in municipal settings. By actively considering these factors, the study contributes to improving tool usability tailored to real-world municipal practices. The findings reinforce the importance of visualization and interactivity in making complex outcomes accessible and actionable. Providing both simplified and advanced versions, along with clear support materials, could reduce barriers for a range of users. The participatory, iterative approach may inspire further research on tool design for energy transition planning.

Societally, improved usability in tools like Zenmo can help municipalities better anticipate energy network loads, contributing to more resilient planning and reducing the risk of blackouts or costly infrastructural failures. Even though stakeholder involvement was not the main focus of this research, the findings suggest that accessible tools can also support participation processes, helping municipalities communicate more effectively with residents, companies, and other stakeholders, and increasing the likelihood of successful implementation.

6.4 Strengths and Limitations of the Approach

The strengths of this research lie in its mixed-methods approach, which combined a literature review, interviews, heuristic evaluation and co-design interviews. This provided both a broad overview of digital tool use in municipal energy transitions and deep, practical insights into user needs and challenges. The systematic use of the Kano method enabled prioritization of features based on actual user preferences. The iterative feedback process with municipal users enabled the identification and rapid implementation of targeted improvements, demonstrating the value of continuous user engagement.

Nevertheless, several limitations should be acknowledged. The study focused primarily on Dutch municipalities and relied on a relatively small sample size, which may affect the generalizability of the findings to other contexts or countries. In addition, the tool itself is not yet in wide-scale use, which limits the diversity of user experiences that could be evaluated. The evaluation of tool improvements was conducted using mock-ups and input from existing users, rather than through fully functional prototypes or first-time adopters, which may have constrained insights into long-term adoption and onboarding challenges.

Another limitation is that the method mainly captures user needs as they are expressed at a particular stage in the municipal planning process. Since municipalities move iteratively through phases, needs may evolve beyond those identified here, which should be considered when interpreting results.

6.5 Recommendations and future research

Looking ahead, improving digital decision-support tools for municipal energy transitions requires both targeted development and continued research. Developers should broaden user testing to include civil servants unfamiliar with these tools, which will help to identify onboarding challenges and build user confidence. At the same time, expanding research to a wider range of municipal contexts will test the generalizability of current findings and reveal new user needs. Integrating these tools with existing municipal systems, such as GIS platforms, can streamline workflows and enhance spatial analysis. Further research should examine how such integration affects tool usage, particularly in municipalities with varying technical abilities.

A key finding of this study is that tools must be adaptable and transparent, allowing municipalities to bring in local data and adjust analyses to their specific needs. However, this flexibility can add complexity, so future research should explore how to best balance usability and advanced features. Comparative studies of user experiences across different interface designs could identify ways to simplify tools without sacrificing essential functions. Future research could also explore how regular feedback loops and real-world testing can keep tools aligned with evolving municipal workflows, policy contexts and user expectations. Additionally, research could examine how municipalities and developers assess the technical and financial feasibility of new tool features, ensuring development aligns with both needs and resource constraints.

Finally, as municipalities increasingly involve residents and other stakeholders, digital tools should facilitate meaningful dialogue and transparent communication. Features like simplified interfaces and scenario visualization can make outputs more accessible. Future research could also investigate how these features support public participation and consensus-building in energy planning.

In closing, this thesis offers practical recommendations for the design and adoption of design-decision support tools, drawing on insights from the case study of Zenmo. By focusing on UCD and continuous user involvement, these insights aim to ensure that such tools are accessible, intuitive, and better aligned with the real-world needs of municipalities as they navigate the energy transition. Meeting these broader challenges will help ensure that digital tools remain responsive to the evolving needs of municipalities and play a meaningful role in shaping a sustainable future.

AI Usage Disclaimer

Artificial Intelligence tools were used during the writing process of this thesis for limited purposes, including rewriting sentences or paragraphs for improved clarity and coherence, and assisting in brainstorming ideas. All final content and critical analysis reflect the author's own understanding and judgment.

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Appendix A: Interview Guide Problem Investigation

Introduction

- Short introduction and consent
- What is your current role, and how are you involved in the energy transition?
- How would you assess your expertise in the energy transition?

Current Tool Usage

- Can you walk me through the process of tackling an energy transition challenge where you used insights from a tool/data? (For example, from identifying a problem to finding and implementing a solution?)
- What were the biggest challenges in that process? (E.g., time, data availability, stakeholder alignment?)
- At which stages do you rely most on digital tools or data? (e.g. execution, monitoring, making plans)

- Which tools do you currently use for the energy transition, and what do you find most useful about them? (link to must-be, one-dimensional and attractive)
  - What are the biggest challenges you encounter when using these tools?
  - Have you ever wished these tools could do something they currently don't?

Zenmo Tool

- Based on these challenges, do you see a role for a tool like Zenmo? If so, where would it be most helpful?
  - Is this more to facilitate discussions, to better understand neighbourhoods, or to base decisions on future scenarios?
  - Could the tool improve collaboration with other stakeholders? If so, how?

- What are the reasons you would use this tool instead of another tool?
  - What specific insights should this tool provide to support your decisions?
- How easy is the tool to use (think of GUI, prior knowledge needs, technical skills)
  - Do you feel you fully understand what the Zenmo tool can do, or would you need additional guidance? How do you think this can be improved?

- What obstacles do you foresee in using the Zenmo tool compared to other tools?
  - What features or improvements would you like to see in a newer tool based on your experience with the current tool?
  - For example: adjusting time/spatial scale, saving scenarios, summarizing key aspects, or gaining better insights into the current situation (like energy labels, year of construction etc.), FAQs. Do you find this a must have or nice to have feature?
  - Are there any redundant features or features you would rather not have?
- How would this tool be used in the long-term?
  - Can it be used only for the energy transition domain?
  - Would you use these tools for every neighbourhood or only for specific areas?
- What knowledge have you gained from using this tool?
  - Would this additional knowledge be sufficient to use this tool, or does it need to be further verified by experts like grid operators?

Appendix B: Interview Guide mock-up-based feedback

Introduction

- Short introduction and consent
- What is your current role, and how are you involved in the energy transition?
- What is your knowledge level on using the tool or a different form of the tool?
- How easy is the tool to use (think of GUI, prior knowledge needs, technical skills)
    - Do you feel you fully understand what the Zenmo tool can do, or would you need additional guidance? How do you think this can be improved?

UI comparison

For UI 1 (Simplified version)

- How approachable does this interface feel for someone new to the tool?
- Are there any parts you still find confusing or intimidating?
- Do you feel you could complete a basic scenario without prior training?
- What, if anything, do you miss from more advanced tools?
    - What are key features?
    - How would you sort them best?
- Are there any redundant features or features you would rather not have?
- Is there anything else you would like to change?

For UI 2 (Full complexity, Improved)

- How logical and organized does this version feel?
- Is it easy to find the options you need, even with more complexity?
- Does the step-by-step or grouped approach help you navigate the tool?
- Would you feel comfortable using this for more advanced or detailed scenarios?
- Are there areas where you still feel lost or overwhelmed?
- Is there anything else you would like to change?
    - Would you find it helpful to start with the simplified UI and later transition to the standard UI?

Educational Materials Preferences

- Show short examples of Info icons/tooltips, Short explanatory videos & Interactive tutorial

Questions educational materials:

- Which of these help options would you actually use, and why?
- For a new user, which format would make you feel most confident starting out?
- For more advanced users, what kind of help or documentation is most useful?
- Are there any types of help you dislike or would ignore?
- Would you prefer to have all help available in the tool, or some as external resources (e.g., videos on a website)?
- How valuable would you find each of these educational materials, if available?
- How important is it that help is available anywhere you would like vs. as a separate onboarding experience?

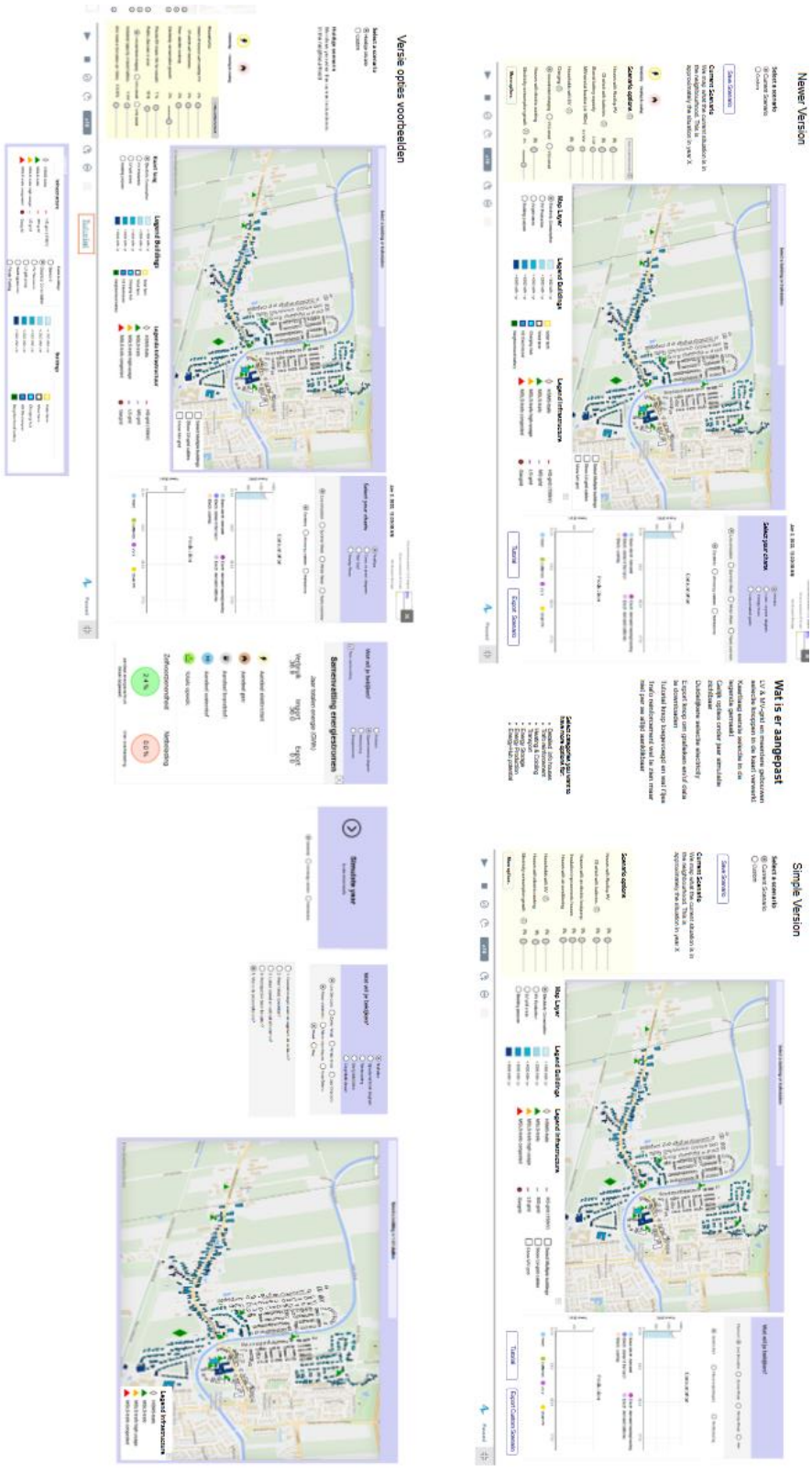
Finishing questions

- Is there a way to combine the best aspects of both?

- How would this tool be used in the long-term?
    - Can it be used only for the energy transition domain?
- Do you have any further comments or tips?

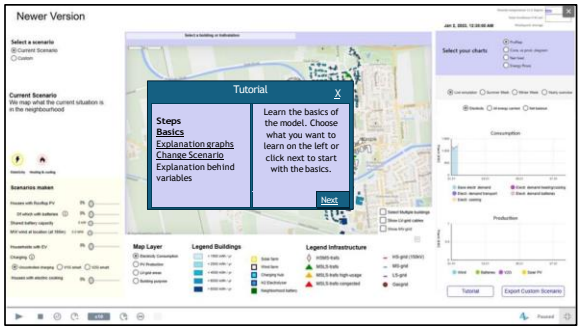
Part 1 of picture

Part 2 of picture



Appendix C: Tutorial slides

1



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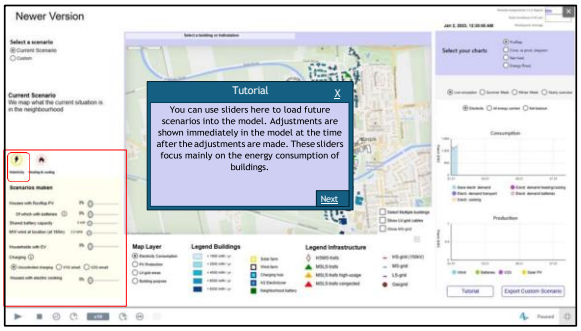

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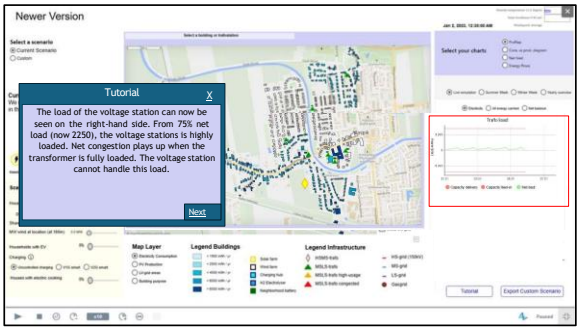

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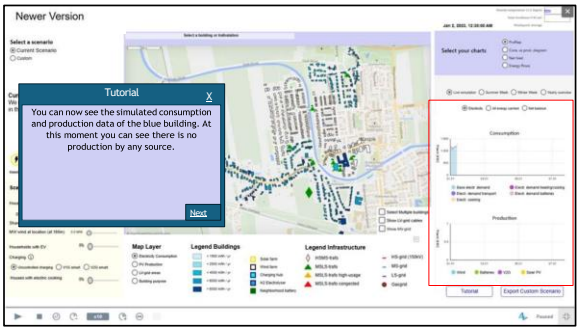

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