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Functions of Models Illustrating the Transitions of Energy and Mobility Systems

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Summary

Models presenting perceived parts of energy and mobility systems, and ideas for transitioning the systems play crucial roles in the communication between stakeholders ranging from government to industry. Sharing the models, which leads to exchanging different perspectives on the systems transitions, can contribute to cooperation among stakeholders. We interviewed stakeholders involved in the transitions to understand the functions that models play for them. We present three use cases in which the models can be supportive to stakeholders. We elicit requirements applicable to designing useful models in practice. Reflecting on the knowledge, we conclude this paper by discussing aspects of integrating the models.

Keywords: communication, information network, mobility system, modeling, policy

1 Introduction

The mobility system is responsible for approximately twenty four percent of total global energy consumption, most of which comes from fossil fuels [1][2]. Transitioning both energy and mobility systems in an integrative manner is therefore crucial in making society more sustainable. On the one hand, changing energy systems requires harmonizing energy affordability, energy security, and environmental sustainability [3]. When it comes to energy affordability, householders earning lower-income and located in suburban and rural areas experience the burden of transportation fuel prices more than others [4]. Mobility subsidy programs or regional transport infrastructure improvement can be designed to support the vulnerable population. Likewise, to ensure energy security, transportation policies such as stimulating the decrease of transport demand in urban areas and investing in a modal shift can be implemented [5]. Furthermore, the environmental sustainability of the energy sector can be tackled by rapidly decarbonizing the mobility system [2]. On the other hand, transitioning the mobility system into a more sustainable state requires modifications to the energy system; advancing accessibility for mobility services necessitates readily responding energy supply infrastructure [6]. Concluding, facilitating cooperation between the energy and mobility sectors is essential to accelerating the transitions of both systems.

Transitioning the two systems in parallel involves cooperation among a variety of stakeholders ranging from politicians, civil servants, businesses, academics, to other citizen groups as well as individual citizens. Two challenges are present in such a cooperation. First, stakeholders have different viewpoints, since they perceive different parts of energy and mobility systems depending on their geographical locations and time, socio-demographic factors, and professional backgrounds. Second, stakeholders hold different views on system transitions by following their beliefs and values, so they interpret the perceived parts of the systems differently and make different decisions [7].

Stakeholders' cooperation can begin with elaborating and disseminating the transitioning systems described according to these views and viewpoints. To communicate their perceived realities and ideas concerning the system transitions (both internally and externally), stakeholders have used developed models [8]. Models are referred to as abstractions that illustrate parts of the systems and ideas for transitioning the parts of the system [8][9]. Stakeholders have utilized models for a long time in developing energy and mobility policy measures, assessing the impact of policymaking, etc. [10][11][12].

Communication among stakeholders can be initiated by sharing models, resulting in cooperation. This model exchange can be mediated by a system that can integrate the models, as presented in Figure 1. Initiating the development process of the model integration system, however, is complicated because first, unless the integration system is developed by specific clients, it is uncertain which stakeholders must be considered as users of the model integration system. Second, stakeholders develop different models depending on time, but also their model developments do not go as planned due to the inherent complexity of energy and mobility systems [13][14][15][16]. For those two reasons, the entire integration process becomes intricate. Additionally, scientific literature has proposed factors that can describe energy and mobility systems more realistically, such as humans' heterogeneity, technological details, interdisciplinarity, path-dependency in institutions, and ethical and philosophical views, like energy justice [17][18][19][20]. If the model integration system aims at providing high-quality communication, the model integration system should be designed in such a way that these aspects can be incorporated, too [21].

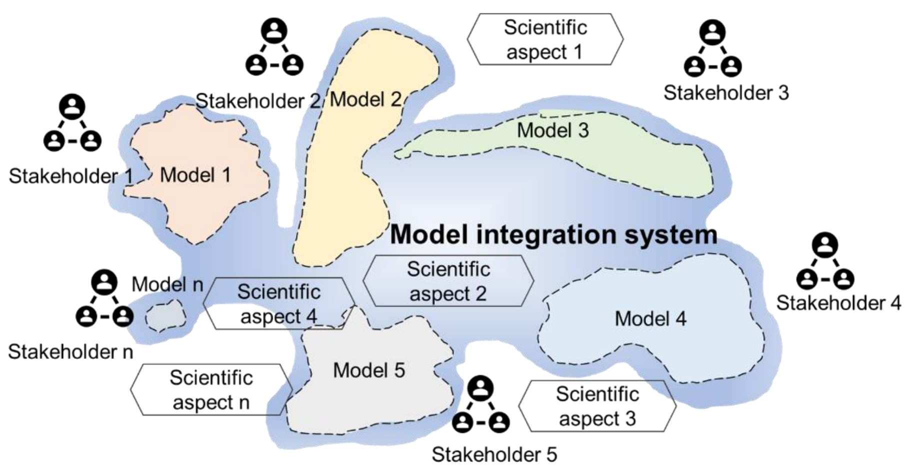

Figure 1. Schematic of the model integration system.

1.1 Context of the research

We researched to design and develop the model integration system. The focus of this paper is to explore users of the model integration system and elicit the functions that models play for them (Figure 1). Recent scientific literature has investigated the use aspect of energy system models in practice. Amer et al. [10] interviewed six practitioners working in Danish municipalities to understand how to better incorporate energy system models and modeling practices into the municipal decision-making process and energy planning process. Süsser et al. [12] interviewed and surveyed model users and modelers of five European countries to grasp suitable model content, model design, modeling process, and model outreach. Considering their recommendation for future research, we focused on analyzing the context of model use in-depth as well as listing the required user interaction and content to be embodied in models.

The research aims are threefold: i) understanding use cases of energy and mobility transition models in practice, ii) eliciting the description of required models by stakeholders, and iii) discussing how the results can contribute to developing the model integration system. This paper is organized as follows. Section 2 explains the purpose of modelling in general and an overview of models presented by scientific literature in the fields of energy and mobility transitions. Section 3 presents methods applied to this research. Section 4 illustrates results including stakeholders' experience in using models and use cases of models in practice. In section 5, we discuss the methods and results, and we conclude the research.

2 Theoretical background

Modelling aims "to answer a question or set of questions better than one can without the model" [9]. Models are formulated into four types, depending on questions to be answered and situations in which either presenting models or creating models: physical (e.g., mock-up), quantitative, qualitative, and mental models [9]. This paper focuses on both quantitative and qualitative models. Because physical models are not fluid to be integrated; mental models exist in people's minds so that mental models are externalized as the other three types of models.

We reviewed academic literature presenting models that involve aspects of energy and mobility transitions. A search string "(model OR simulation OR "decision support system") AND (mobility OR transport OR vehicle) AND ("energy transition" OR decarbonization OR sustainab*)" was employed. Scientific articles were retrieved from two databases, Scopus and Web of Science. We briefly summarize the review results. As for qualitative models, transition-related business models (e.g., sustainable end-of-life vehicle management) and emerging concepts, like sustainable mobility behavior, were defined [22][23]. When it comes to quantitative models, the following four types of models were found: i) optimization models (vehicle routing, decarbonization scheduling strategy, etc.), ii) simulation models (e.g., examining the impacts of delaying decarbonizing the EU transportation sector), iii) models quantifying the performances of energy and mobility systems, and iv) models presenting decision-making (e.g, evaluating public transport systems considering environmental impacts and vehicle technology specifications) [24][25][26][27][28].

Having an overview of academic models providing perspectives on energy and mobility transitions, we explore models required by practitioners working in government and industry, onwards.

3 Methods

We employed exploratory research, as users of the model integration system are unknown; hence, the profiles of integrated models are also unknown [29]. We approached stakeholders who can be considered future users of the model integration system. With semi-structured interviews, we aimed to elaborate on the contexts in which stakeholders can benefit from using models and on the requirements for useful models. The interviewees in this research were practitioners involved in policymaking, industry, and transition knowledge management. The geographical scope of this research was limited to the Netherlands, where this research was conducted. Thus, the results can also be useful for practitioners who develop models due to such stakeholders' requests or who conduct modeling to provide stakeholders with knowledge concerning the transitions of energy and mobility systems.

3.1 Research method

This research applied a qualitative research method with semi-structured interviews. The semi-structured interviews consisted of four parts, as presented in Table 1. The interviews were designed to understand the following four aspects of the interviewees: i) tasks conducted by the interviewees to realize the transitions and to explore circumstances in which energy and mobility transition models can be supportive, ii) the interviewees' perspectives on energy and transport transitions, iii) the interviewees' experience in the usage of models, and iv) the requirements applicable to the models; to better elicit the model requirements, we developed the transition simulation canvas that could let interviewees imagine model use case scenarios and model functionalities (Figure 2).

Table 1. Semi-structured interview protocol applied to this research.

Interview part	Asked questions/activities per part of the data acquisition process
Understanding tasks conducted by interviewees in their organizations and exploring circumstances wherein energy and mobility transition models can potentially help interviewees' task performance	"What are your usual tasks in your organization?" "Can you explain the projects related to energy and transport transitions that you are responsible for?" "What kinds of decisions do you (have to) make about energy and transport transitions?" "Do you experience any dilemma during such decision-making processes?"
Understanding interviewees' perspectives on energy and transport transitions	"What does accelerating energy and transport transitions mean to you?" "What aspects of energy and transport transitions are you interested in and why?"
Understanding interviewees' experience in the usage of models	"When working in projects related to energy and transport transitions, have you and/or your organization ever used computer software/tools/games?" "What software/tools/games did you use?" "What support did you receive?" "What were the strengths and weaknesses of the software/tools/games?" "How did you get to know the software/tools/games?"
Understanding the required models by interviewees	"How can we make better/useful models?" "What questions could be answered by models?" "What human/non-human objects could be considered in models?" "What analysis period would be suitable from your perspective?" "What geographical locations would be considered?" "What key performance indicators would you employ?"

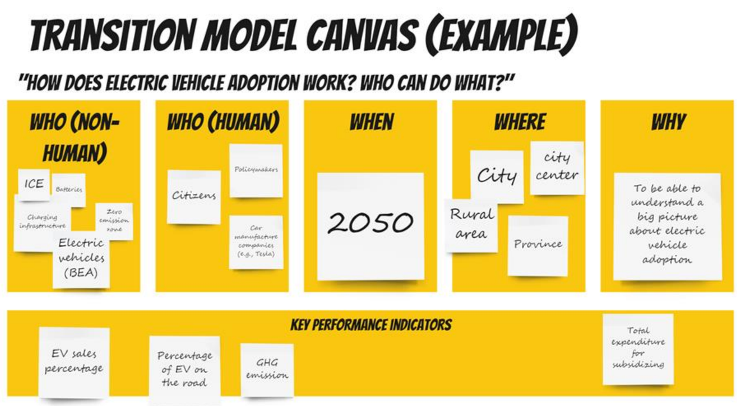

Figure 2. The transition model canvas developed by the authors for this research

3.2 Data collection

We selected interviewees based on quota sampling so that the diverse perspectives of provincial and municipal levels of government, industries, and academics were presented. We invited practitioners who were considered approachable by the authors and willing to participate in the research using convenience sampling, not a randomized group of people [30]. The practitioners offered their experience in using models and outputs of models for policy planning, communication with stakeholders, and gaining a better understanding of the development of products and business models. Moreover, they explained their opinions on developing energy and mobility transition models to make them more useful.

Overall, there were eleven interviewees with diverse experience from relevant stakeholder groups in energy and mobility transitions, representing government, the power grid operation, industry providing energy and mobility solutions, and academia. Their fields of experience varied from energy and electric vehicle (EV) charging infrastructure, sustainability and mobility program management, research and development, to communications and policymaking.

Each interview lasted approximately one hour. The sessions took place from February 2022 to April 2022 online due to COVID-19 complications. All interviews were recorded and transcribed, except for one interview; an author noted the interview results.

3.3 Data analysis

We used the ATLAS.ti tool for data analysis. We adapted the QUAGOL qualitative data analysis as follows [31]. First, we tried to gain an overview of the interviews and summarized the main content by using Vivo coding [32]. Then, we collected keywords that appeared most in each interview; we utilized keyword searching to make the results.

4 Results

This section describes models utilized in practice, and strengths and limitations of the models. Then we illustrate three use cases in which models can be supportive to practitioners and elicit requirements applicable to designing useful models in practice.

4.1 Models in practice

Some interviewees directly used models in practice, while others did not. Three out of five regional and local government interviewees mentioned that they only made use of the information given by energy and mobility transition-related models. Government and power grid operation interviewees mentioned a geographical information system, models providing prognoses of the number of demanded EV charging points, models showing grid congestion, models illustrating traffic flow, models predicting EV charging demands, and models presenting grid capacity, as utilized ones in practice. Industry interviewees involved in energy and mobility solution provision said models supporting better mobility technology designs, a carbon footprint calculator, models making practitioners explore the potential opportunity for supplying EV charging points, and models optimizing flexibility solutions.

Those models were developed via diverse channels: internal development by employees, external development by modelling practitioners and consultancy, and collaboration with university students.

4.1.1 Strengths of the models

Our interviewees indicated two strengths of model use from their experience. A government charging infrastructure practitioner mentioned that models that provide the expected demand for EV charging points, their capacity, and locations for the installation facilitated tendering between municipalities and charging point operators. Such models let them estimate the number of EV charging points to be installed. An industry practitioner on EV charging management positively reviewed the functionality of models that forecasts how residents react to a situation when charging points are occupied, as this information can contribute to creating business opportunities.

4.1.2 Limitations of the models

Two types of limitations observed from models utilized in the past were discussed: model content and the methods for creating models. Concerning model content, the following disadvantages were mentioned. First, the issue of limited viewpoints embodied in models was discussed. For instance, the government officers involved in managing sustainability and mobility transition programs mentioned that models only show perspectives considered in the model development; realities such as the relationship between traffic redistribution and passenger behaviors were not fully represented. A realistic presentation of human behaviors was also referred to, like charging behaviors and mobility patterns. In addition, a practitioner coming from an energy solution business mentioned that the concept of mobility considered in a carbon footprint calculator was oversimplified than the interviewee thought because the carbon footprint calculator seemed to consider the values of commuting through personal vehicles and public transport equivalent, just the same human mobility behavior, but in different modes. However, the interviewee was afraid not. Thus, the interviewee suggested that sensemaking on concepts that are the subjects of analyses should be followed by data analyses on the concept. Second, the difficulty of dealing with assumptions involved in models (like selecting parameters) was indicated. A provincial government practitioner, for instance, recalled the lack of credibility from the prognosis on the yearly increase of fast charging station usage.

Four remarks were made regarding the methods for creating models. The first one was having a model that integrates individual models that are separately reviewed in one place. The municipal civil servants mentioned that developing a high-level model integrating models of EV charging demand, grid capacity, and traffic is crucial. A need for models that present the near future (one to three years in the future) where EV charging point operators prepare tenders for EV charging points was expressed. Not so for the far future (decade); long-term projection appeared to be less needed. Third, the extent to which outcomes of models were detailed was discussed. A governmental practitioner in the field of energy infrastructure emphasized keeping a balance between acquiring reliable information and getting entangled in detail. Finally, a business practitioner developing energy flexibility solutions mentioned the importance of having a system that can help energy and mobility systems communicate with European systems (e.g., standardization).

4.2 Use cases and requirements of energy and mobility transition models

4.2.1 Use cases

The interviewees provided three use cases in which energy and mobility transition models can be utilized well by them in practice: i) models facilitating discussions on energy system planning among parties, ii) models helping the creation of knowledge within organizations for better planning, and iii) models assessing the technical and societal impacts of organizational strategies tackling the transitions. We briefly look into them in this section.

Facilitating discussions on energy systems planning among parties

The civil servants with experience in energy infrastructure planning provided a use case wherein models can be properly used. A challenge in planning the change of current energy systems to renewable energy systems by the government was indicated as having a lack of communication between government and industry. From the government's perspective, the mismatch between energy planned to be supplied according to governmental plans and the actual energy demanded by industry is a concern. In addition, the government can provide a better option for energy supply strategies, such as suggesting different energy sources for an industry's heat generation plan. From the perspective of industry, however, it is complicated to openly discuss their energy supply plans with the government due to the confidentiality of the information.

In such situations, both parties may continue making decisions with incomplete information, as neither has a complete understanding of the other, which is not the optimal win-win situation. To tackle the situation, a provincial civil servant presented the idea of running a collaboration task force to include both of them as well as other parties, like citizens and heavy vehicle industries. The task force can use a model wherein parties test out their energy plans and get feedback from others. It can allow the task force parties to acquire complete information. In such cases, energy and mobility transition models are used as a medium to facilitate the discussion among parties and assist parties in generating transition ideas, testing their ideas, and getting feedback. In this respect, energy and mobility transition models do not necessarily serve as monologuing narrators but are closer to facilitators and mediators.

Creating knowledge within organizations about energy and mobility systems in the future

The second use context of energy and mobility transition models was provided by government officials and industry practitioners. It was that practitioners interact with models by exploring the effects of varying inputs and parameters. This concept was formulated based on the following three cases brought by the interviewees: i) a model that indicates the state of progress in energy and mobility transitions, ii) models that support governmental practitioners in designing and planning regional energy and mobility infrastructure adaption, and iii) models that present future business environments and opportunities. Models capable of infrastructure design support can help governmental practitioners better understand the consequences of industries' decisions for regional energy systems, according to the interviewees experienced in provincial energy network planning. Models that illustrate consumer and market behaviors in the future, such as emerging technology adoption and vehicle technology development, like increasing EV battery capacity, were considered useful, according to practitioners in energy and mobility solution businesses.

Assessing the impacts of business practices and solutions striving for the transitions

The third use context was that practitioners in industry and grid operation acquire evaluations of their business practices and solutions based on purpose-specific key performance indicators. The practitioners in EV charging innovation and marketing communications mentioned evaluating the extent to which flexibility solutions can prevent grid congestion and the sustainability of product delivery and employees' mobility patterns. The consultant experienced in flexibility solutions emphasized identifying societal values of flexibility solutions, like energy independency.

4.2.2 Representations of useful models

Regardless of the use cases described in the previous section, the interviewees mentioned questions that can be answered by using models; they also provided objects, ideas, and key performance indicators that can be considered in models (Table 2). The questions that interviewees wanted to examine with the models differed. However, the objects, ideas and key performance indicators were not largely distinct. The status of the power grid connection and power grid capacity was often mentioned. Charging infrastructure and mobility patterns were also considered. Checking labor availability for upgrading the grid was regarded crucial. Concerning key performance indicators, indicators that evaluate system performance, like system resilience and labor availability, were most addressed, followed by environmental impact indicators, like GHG emissions.

Table 2 Useful models' functions

Questions that can be answered by using models	Key performance indicators (Considerations for decision-making)
How can we make a cost-effective energy system in collaboration with parties claiming the use of public space?	Highest possible (energy) efficiency
	Lowest cost for building the system (during 30 years)
	Lowest cost for exploration (after 30 years)
	Highest understandability by citizens (acceptance)
	Highest level of interoperability (user friendly)
	Highest level of reliability (resilient)
	The extent to which enough energy is delivered
Designing a cost-effective electricity network	The amount of space used per square meter
	The general cost of the infrastructure
	The cost of energy paid per citizen

How would the power grid handle different types of transitions?	Grid capacity
	GHG emissions
	Economic development of the region (socio-demographic development, lower unemployment)
How do we adapt a local infrastructure to emission-free mobility systems?	CO_2 emissions
	Costs
	Staff/labor availability
	Time to build infrastructure
	Air quality
	The circularity of materials (raw material efficiency)
	Climate adaptation
	Space use
How fast can the transitions move forward?	How logistic companies consider concerning the transitions
	GHG emissions
	Grid capacity
	Manpower capacity for grid
The impacts of different flexibility solutions on the power grid	The degree to which congestion can be prevented by applying a certain form of flexibility
The number of people going to drive cars of different sizes, fuel, and technology	Accessibility to purchasing vehicles
EV charging point business opportunity	Grid connection
	Patterns of EV usage (when plugging in?)
	How many chargers are needed?
The values of flexibility solutions	The complete value (hidden cost, social value etc.)
How to make the organization sustainable considering products' delivery systems and employees' travel mode?	GHG emissions
	Sustainability indicators
	Efficiency in energy use

4.2.3 Designing useful models

The interviewees of transportation policy research and the mobility solution industry provided suggestions for designing models useful in practice. First, the importance of visualizing information was stressed, especially when racial policies are dealt with. Policymaking does not always involve risk-taking. It was discussed that people would be afraid of changes before they see the changes; once they see the changes, they would be less stressed. Thus, visualizing the expected citizens' responses to racial policy implementation might help the policymaking process. Next, the ideas of applying Maslow's hierarchy of needs and Bloom's taxonomy were provided too. These two concepts can be useful when modelers face situations in which the messages conveyed by models seem less approachable from the user's perspective. For example, as humans could pursue esteem when lower needs like physiological needs are met, model-users would need basic information first, followed by new ideas and innovative simulations. Thirdly, targeting users sharply was emphasized; if models are aimed to be used in government, making a distinction between politicians and civil servants is critical. Last, it was discussed that documenting crucial assumptions is as important as creating fine user interfaces for models.

5 Discussion and conclusion

We discuss how the knowledge gained through the interviews can be used for creating a system that integrates models that illustrate the transitions of energy and mobility systems (Section 5.1). In section 5.2, we explain the research limitations and recommend future research topics. We conclude this research in section 5.3.

5.1 Reflection on the results

We explored use cases of energy and mobility transition models in practice and identified the requirements applied to the models by interviewing practitioners working in the transition field in regional and local governments, industry, and academics in the Netherlands. From the research results, we observed two aspects that can be considered for developing a system integrating model.

One is related to a requirement applicable to the model integration system. The model integration system should be designed in a way that the perceived confidence of stakeholders in the amount of contained information can be balanced. Stakeholders have different capacities for creating and utilizing models in practice. Some have more resources, like modeling practitioners in organizations and budgets, while others have less. Moreover, some may even have limited access to required data due to the limited right to ask for the data from other parties. An example was mentioned by governmental interviewees about the lack of information on the industry sector's energy demand and supply plans. In such a situation, neither of the stakeholders gains benefits. Stakeholders with less complete information may generate less competent data; other stakeholders with more complete information might, ironically, get to interact with low-quality data. The overall quality of the shared information may decrease, which is not the desired outcome of deploying a system integrating models.

The second concerns a different approach to creating the model integration system. The aim of creating the model integration system does not need to be fixated on integrating all models or all stakeholders; rather, it should focus on the fundamental motivation behind the creation, facilitating communication between stakeholders, and cooperation. In this sense, not all stakeholders and their models have to be coupled to communicate. It was seen that governments do not necessarily have to communicate with companies developing software solutions unless the companies demand a massive amount of energy. In addition, three use cases (section 4.2.1) imply formats of communication. Instead, we can start creating the configurations of stakeholders' communication networks that can lead to their cooperation. Then, we can figure out models that can better operate the communication networks, followed by contouring system(s) for integrating the models.

5.2 Research limitations and future research recommendations

We foremost stress that this research outcome must not be generalized, as our interviewees did not sufficiently represent all relevant stakeholders involved in the energy and mobility transitions in the Netherlands. We suggest future research to expand the population of research so that various perspectives of citizen groups, non-governmental organizations, media, etc. can be considered. Moreover, future research can also increase the number of research participants. By doing so, more diverse and robust use cases can be formulated. Second, the fidelity and scopes of models that were directly or indirectly used by the interviewees probably varied, but we did not take that into account; we suggest future research to do so.

Looking at the transition model canvas (section 3.1), it was useful for finding out commonalities and distinctions between canvases. Moreover, we see the canvas can be supportive for modeling practitioners developing models for users. However, we acknowledge that it was complicated to learn how to use it when trying to acquire an overarching view and solutions for the integration of canvases. Therefore, we suggest conducting future research on improving or modifying the boundary object for obtaining model-user requirements.

Models reviewed in the theoretical background were partially discussed in the interviews. We recognized that models presented in scientific literature could support realizing two of the three use cases, creating knowledge within organizations about energy and mobility systems in the future, and assessing the impacts of business practices and solutions striving for the transitions. Yet, the last use case (models that facilitate discussions on energy systems planning among parties) requires future research both on better understanding energy and mobility systems and on the software perspectives, such as usability, data visualization, collaboration and conversation in a virtual environment. With this regard, we consider future research in which energy and mobility transition modelling researchers and computer science researchers (virtual reality, digital twin, artificial intelligence, etc.) collaborate. Cross-disciplinary modelling research can be useful for fulfilling user requirements and fully realizing use cases.

Meanwhile, we struggled with a terminology issue which was about "mobility system" and "transportation/transport system". We often saw two terms were interchangeably used. However, we suggest a future research idea of comparing relevant concepts and providing clear definitions.

5.3 Conclusion

Transitioning both energy and mobility systems can be realized with stakeholders' cooperation. The cooperation can be realized by communication between stakeholders concerning their ideas, plans, and technical solutions. To better communicate, stakeholders develop models. The models can be exchanged through a system, and the system therefore must be able to integrate the models. Our research involved the creation of a model integration system that aimed at facilitating communication and cooperation between stakeholders. Understanding how to create model integration systems can be done by understanding stakeholders who are the potential users of the system. We explored users and use cases and elicited requirements applicable to the models. We reflected on how the model integration system can be developed based on user observation results.

With an exploratory research approach, we interviewed eleven practitioners with experience in energy and mobility transitions and experience in working in government, industry, and academics in the Netherlands. We noted that energy and mobility transition models can provide the functions of: i) facilitating discussions on energy system planning among parties, ii) creating knowledge within organizations about energy and mobility systems in the future, and iii) assessing the impacts of business practices and solutions striving for the transitions. The interviewees found that considering the power grid capacity is critical. Furthermore, charging infrastructure and mobility patterns, such as which vehicle will be driven by person A as well as manpower for power grid operations and management, were often indicated. Based on the research results and process, we gained two insights that may apply to the model integration system. First, no matter which models are integrated, the model integration system can be designed in a way that stakeholders with less complete information can get support so that the overarching quality of shared information does not decrease. The second point was concerning methods for creating the model integration system, which was to create communication networks of stakeholders and find models that can operate the networks well—not trying to integrate models first.

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