# Supporting Municipal Energy Transition Decision-making

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Authors: Devin Diran, Birgit Henrich, Tara Geerdink (TNO)

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Reviewer: Anne Fleur van Veenstra (TNO)

# Justification

The purpose of this report is to assess the current information supply and utilization for energy transition decision-making by municipalities. This report contributes to the design of a methodology for the regional energy transition, one of the main objectives of the ESTRAC project. The methodology will enable stakeholders to identify and apply the right models, tools and approaches to specific regional energy transitions.

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# 1. Introduction

The 2018 Dutch Climate Agreement aims to reduce $CO_2$ emissions by 49% in 2030 compared to 1990 and reduce greenhouse gases by 95% in 2050 (Government of the Netherlands, 2019). However, its implementation, which should be a collaboration of public and private actors, is challenging. Decisions on how to move this transition forward are subject to great complexity and uncertainty. Municipalities are taking a leading role to envision, plan and implement the energy transition, interacting between the district, municipal and regional level while connecting a wide array of stakeholders, such as energy providers, social housing corporations, grid operators, etc. To successfully execute this role and to develop, implement and monitor municipal energy policy, having access to information, based on correct data, is essential.

This report assesses the current information supply and utilization for energy transition decision-making by municipalities. A better understanding of the current state of the information supply and utilization will contribute to the capacity of municipalities to achieve the objectives of the energy transition.

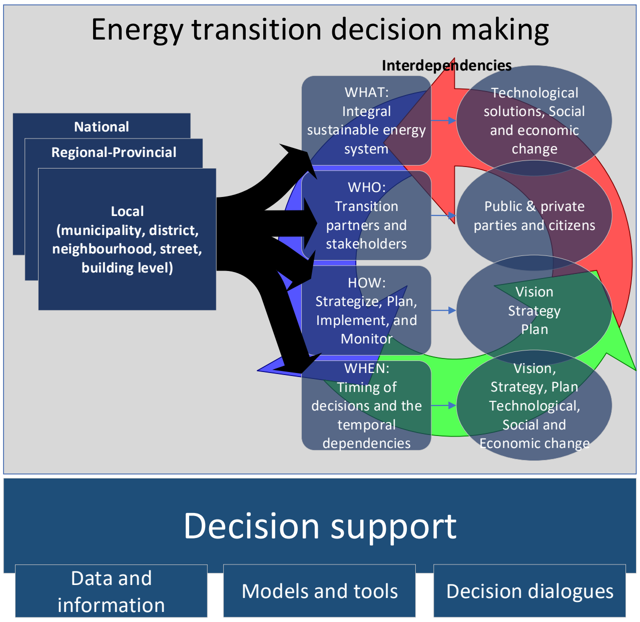


*Figure 1 Municipal energy transition decision-making framework.*

To assess municipalities' current support to decision-making, this research addresses two areas (see Figure 1):

1. ***Energy transition decision-making***, and what this entails for municipalities regarding to 1) WHAT: which decisions have to be made to enable an integral sustainable energy system, 2) WHO: which stakeholders are necessary for making these decisions and which stakeholders are affected by these decisions, 3) HOW these decision should be made and anchored, and 4) WHEN these decisions should be made. Among these aspects there are interdependencies.
2. ***Decision support***, inspired by the theory on decision support systems where three main components are identified by Sprague and Carlson (1982) and Sage (1981), as can be seen in Figure 1: Data and information, Models and tools to analyse the data and generate actionable knowledge, and Decision dialogues to ensure that the right insights are derived from the models and tools.

After this brief introduction, section 2 describes the characteristics of complexity and uncertainty in energy transition decision-making and how municipalities collect information to deal with this complexity and uncertainty. Section 3 addresses the current state of decision support, and discusses information, data, models and tools made available by various parties. Section 4 concludes this report by discussing the findings and presenting recommendations on how to improve municipal decision support with data and information, models and tools and decision dialogues in the energy transition.

# 2. Municipal energy transition decision-making

This section discusses the complexity of municipal decision-making regarding the energy transition, the arena of local policy makers and how decision-making currently takes place at the municipal level.

## 2.1 The complexity of energy transition decision-making

Energy transition decision-making is complex and uncertain. It is not only complex for local policy makers but also for citizens and businesses, whose cooperation and decisions are needed to achieve the energy transition ambitions in the Climate Agreement. What this complexity and uncertainty entails for the local policy makers is discussed in this section. This section is based on Woestenburg et al. (2020) and van Loo (2020).

**Inherent uncertainty**

The energy transition is beset by deep uncertainty; there are uncertainties regarding the development of technologies, energy and raw material markets, energy regulations and financial investments. There are various scenarios for the transition that lead to different energy systems in 2030 and 2050. This uncertainty increases the need for independent and reliable knowledge and expertise for local policymakers. Such knowledge and expertise can help to reduce uncertainties and draft strategies for coping with uncertainties.

**Interdependencies**

Many and various interdependencies exist in the energy transition. There are dependencies between infrastructures, technologies, stakeholders, and in time. Besides the energy transition, other societal developments take place in the spatial-physical domain, such as climate adaptation, transformations in mobility and urban development and the digital transformation. Energy transition decision-making is therefore interrelated with decision-making in other policy domains and more and different stakeholders are getting involved in local decision-making processes regarding the energy transition. Each of these stakeholders acts according to their responsibilities, interests and capabilities, and the decisions made by these stakeholders are interdependent, resulting in multi-actor complexity. As such, there are 1) interdependencies between internal decisions of a government or a stakeholder, 2) interdependencies between governments (across geographic levels) mutually and with stakeholders, 3) interdependencies between infrastructures and with the environment, 4) horizontal (district – district) and vertical (municipality – province) interdependencies across geographic borders. These interdependencies imply that information is needed from different stakeholders, different departments and organisation and different policy levels and that information needs to be shared to provide sufficient information for decision-makers.

**Temporal complexities**

Transitioning the energy sector is a long-term process. Energy transition strategies are made for the long-term and local plans span multiple years. This long-term nature has an impact on decision-making and the development of knowledge and expertise. There must be a certain degree of continuity in the information provision and decision-making over time. However, it is difficult to keep track of the many short-cyclical developments that have consequences for long-cyclical decisions such as energy visions and plans. This brings the risk of path dependency and a situation of lock-in as a result of decisions taken in the short term, but with a long-term impact.

**Spatial complexities**

Energy transition decisions have a spatial impact, both on and above the surface, as well as in the sub-surface. This impact may extend beyond the boundaries of a neighbourhood, municipality or region, leading to complexities in the decisions and the mandate of public parties limited to such boundaries. Moreover, the physical space is limited and many other spatial decisions from different sectors impact the energy system. Decisionmakers need information on the impact of location choices and on physical space . As stated before, also other societal transitions claim the spatial-physical domain, which generates the need for multiple solutions and innovative and strategic choices on the optimal use of the physical space (Puts & van der Heijden, 2017).

## 2.2 The decision-making arena of the local policymaker

To evaluate the effect and impact of decisions in this complex and uncertain domain, evidence-based policymaking can be utilized. Evidence-based policymaking is an aspiration rather than an outcome, advocates of evidence-based or evidence-informed policymaking urge policymakers to incorporate research evidence into policy decision-making in order to improve the reliability of the advice regarding effectiveness of policies following from the decision-making process (Head, 2009). Evidence-based (or evidence-informed) policymaking entails the derivation of fact-based knowledge to support the decision-making process of policymakers and can help to predict the effect of policy decisions on the complex socio-economic environment. However, evidence-based policymaking also poses a significant challenge for policymakers as they now have to assemble and manage their knowledge to produce evidence to support decisions and to successfully communicate this evidence to the general public (Androutsopoulou & Charalabidis, 2018).

This challenge of assembling and managing knowledge for decision support is also visible in the energy transition and this is strongly related to the complexity and uncertainty of energy transition decision-making, as discussed in section 2.1. In Figure 2 the decision-making arena of municipal policymakers is depicted schematically. This schematic representation builds on the decision-making framework as presented in Figure 1, zooming into the main type of decisions to be made, and the complexity due to the interaction with a growing stakeholder field. The responsibilities for municipalities, regarding organization and implementation  of the energy transition, are growing. Due to the complexities discussed in 2.1, municipalities do not only have to direct and coordinate their own energy transition decision-making process, but also align with the decision-making processes of other stakeholders such as network operators, citizens, local businesses, energy companies, energy cooperatives and housing corporations. All these stakeholders influence the energy transition and the success of energy transition plans with their interests and their supply of information and knowledge. When to involve and access the knowledge base of these stakeholders, i.e. exchange the relevant knowledge on energy transition decision-making and how to sustain it over time is often not clear for municipalities (Lindkvist et al., 2019).

Next to aligning decisions with ambitions  and information from stakeholders, municipalities also have to operate in line with the ambitions, goals, laws and regulation of the national government, see Figure 2. Decisions from municipal policymakers in this arena range from determining their role in the energy transition (e.g. active, passive, facilitating etc.) to drafting (evidence-based) visions and strategies for the future energy system, to hiring external expertise (or not), to prioritizing activities, and to providing concrete investments in infrastructures or services. On top of that, common roles of stakeholders are currently changing, new roles appear and as do new parties – increasing the complexity for local decision makers.

Figure 2 shows a range of stakeholders, national policy decisions and ambitions and the internal knowledge sharing processes that influence municipal energy transition decisions. The interdependencies between departments within a municipality and the interdependencies between stakeholders increase the complexity for policymakers to realize the energy transition (described in section 2.1).

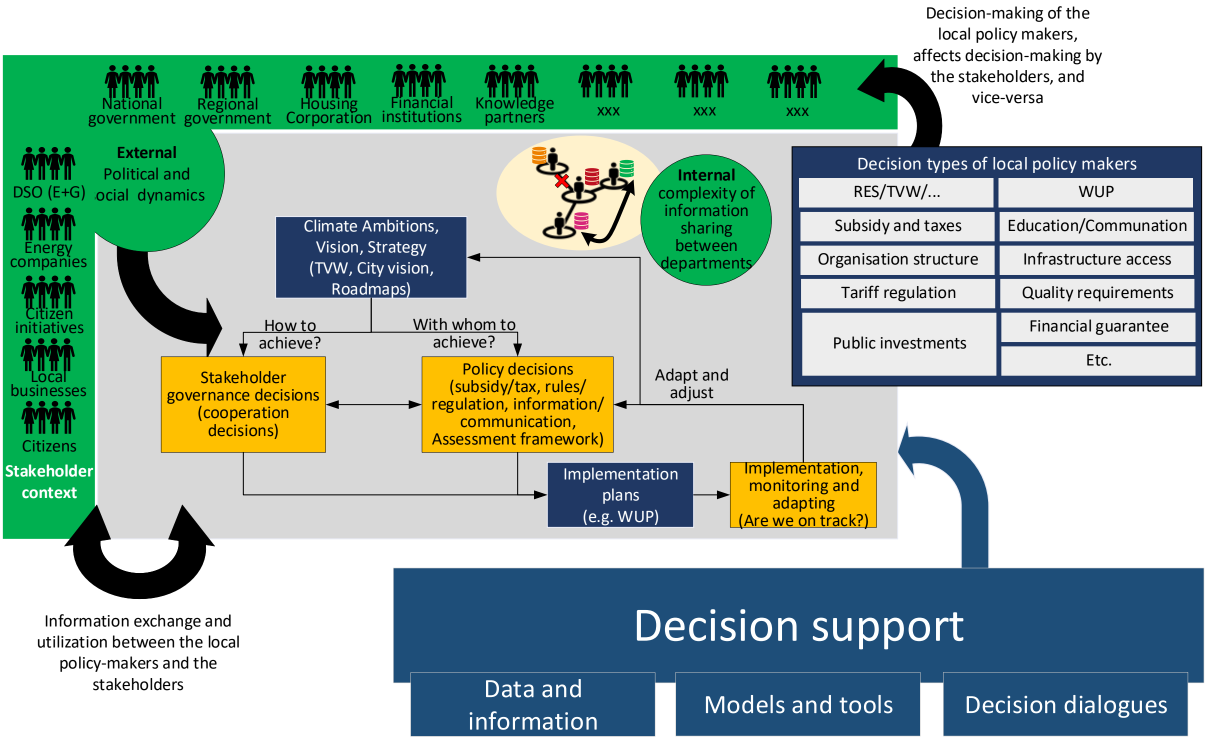


*Figure 2 The energy transition decision-maker arena in which policymakers operate.*

To understand and cope with these interdependencies, accessing the knowledge and expertise of various municipal departments and exchanging information between these departments is essential. Which information is needed, and thus which information needs to be shared and in what format is an important question for local decision-makers. However, exchange of information within municipalities is limited by organisational challenges. Often, there is suboptimal communication between the departments, and data and information within various departments is collected, stored and processed in different formats (Diran et al. 2020a), information and data is strongly scattered over departments and there is a general lack of transparency in the available and used data and information within departments. In addition, knowledge sharing by and with other stakeholders outside of the municipal organization is met with challenges as well (de Vries et al. 2019). To tackle challenges for information development and exchange between municipal departments mutually and with stakeholders the decision dialogue, as introduced in section 1, is essential for decision support (Sprague and Carlson 1982). The decision dialogue is traditionally described as the dialogue between human and machine/computer to derive the appropriate insights (Sprague & Carlson, 1982). However, effective decision support encompasses more than human and computer dialogues. It entails a process of interaction and collaboration between policymakers, local stakeholders and third parties involved in the knowledge development, to ensure that the right insights are derived from the models and tools, and that appropriate data is gathered for the utilization of models and tools. Creating and maintaining familiarity, understanding, and trust among policymakers to support information sharing is an important addition to a human-computer dialogue.

## 2.3 The informed decision-making process at municipal level

An important step in the decision-making process of drafting local energy strategies and plans, is the establishment of an assessment framework. Such frameworks are introduced by Woestenburg et al. (2020), ECW (2020) and Huygen and Diran (2020) for Dutch heat transition cases. An assessment framework can be utilized for scenario analysis (assessing the scenario's on efficacy and likelihood), but also for the pre-feasibility phase (e.g. studying the potential energy sources in an area and its associated costs and environmental impact) and for the implementation of energy plans (assessing detailed policy and technology solutions). According to Huygen and Diran (2020) an assessment framework guides the information needs of local policy makers via the criteria to be included in the assessment framework. A large variety can be observed when comparing the assessment framework of the various municipalities. Table 1 provides an overview, as presented by Huygen and Diran (2020).

*Table 1: An overview of criteria included in the assessment framework for the heat transition on the municipal and district scale by various municipalities, derived from (Huygen & Diran, 2020).*

| **Ex. 1**<br>**Criteria for district energy plan The Hague** | **Ex. 2**<br>**Criteria for natural gas free Geuzenveld-Slotermeer** | **Ex. 3**<br>**Criteria for roadmap energy transition Groningen** | **Ex. 4**<br>**Criteria for heating strategy Haarlem** | **Ex. 5**<br>**Criteria for heat infrastructure Rotterdam** |
|---|---|---|---|---|
| Energy Availability | Affordability | $CO_2$ reduction | Costs end-user | Total Cost of Ownership |
| Responsible technology | Technical feasibility | Impact living environment | System wide investment | $CO_2$ reductions |
| $CO_2$ reduction | Liveability impact | Job creation | Opportunities for synergies | Robustness |
| Impact on electricity infra | City accessibility | Total investments | Nuisance | |
| Robustness | Freedom of choice | Spatial impact | Social organization neighbourhood | |
| Planning complexity | Flexibility | | Energy efficiency gains | |
| Fit in city plan | Social support | | | |
| Investments costs dwellings | | | | |
| Total investments | | | | |
| Sub-surface impact | | | | |
| Spatial impact | | | | |
| End-user tariffs | | | | |
| Social support | | | | |

Taking into account these assessment frameworks and what is reported on knowledge requirements by Woestenburg et al. (2020) and Huygen and Diran (2020), energy transition decision-making knowledge requirements by policymakers can be categorized as follows:

- *Energy supply planning and development*: for example information on the uncertainty, potential, social acceptability and flexibility of renewable energy supplies.
- *Current and future energy demand*: for example information on current energy use, demand development over time and dwelling (energetic) characteristics.
- *Infrastructure and resources*: for example information on grid constraints, effects on underground infrastructure and the available human resources.
- *Multi-actor dynamics and stakeholder engagement*: for example information on drivers behind citizen participation and information on investment capacity and cycles.
- *System integration*: for example information on the effect of a changing heat supply on the electrical grid, and the interaction with industry and mobility.
- *Institutions, policy and Instruments*: for example information on cross-domain impact of policies, cost-effectiveness of support schemes and effects of new legislation.
- *System state monitoring*: for example information on the impact of specific energy transition projects to monitor transition progress and the need to intervene.

By reviewing various research projects that have investigated energy transition information demand and requirements (Bodem+, 2018; Geels et al., 2016; Hanna et al., 2019; Henrich, 2020; Katz, 2017; Matthijsen et al., 2020; NWO, 2019; Pont Berghauser & TwynstraGudde, 2019; Van der Linden & Akkerboom, 2018; Woestenburg et al., 2020) it became clear that the current information supply of municipalities is not sufficient for evidence-based energy transition decision-making. Some examples of current information gaps, formulated as knowledge questions, are shown in Appendix A.

One reason for these information gaps is that policymakers have issues with accessing information that is fragmented and spread out over a large and diverse group of stakeholders. In general, two scenarios can be distinguished that show how local policymakers acquire the knowledge and information to support their decisions (see Figure 3). These scenarios were developed by analyzing municipal heating transition projects and can be generalized to the broader energy transition (Diran et al., 2020b). In one scenario municipalities develop local capacity and skills to generate knowledge independently (in-house), while in the other external parties are contracted for the knowledge provision (outsourcing). In-between these two extremes, varieties of in-house development and outsourcing can be found. Research among 163 Dutch policymakers (de Vries et al., 2019) showed that 62% of energy transition policymakers claim to be dependent on external parties, such as consultancies, for the (technical) expertise in energy transition decision-making and planning.

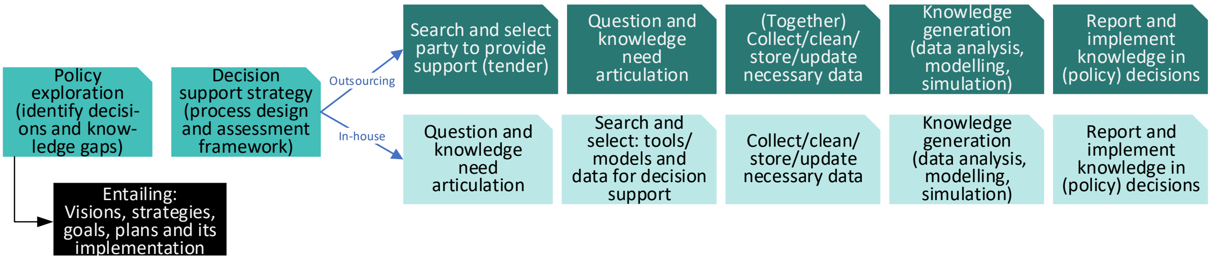


*Figure 3 Two scenarios for policymakers to acquire energy transition decision support. Derived from (Diran et al. 2020).*

Recent studies by TNO (Diran, 2019; Henrich, 2020) dive deeper into these interactions between local policymakers and third parties. These studies show that within the Dutch heat transition, municipalities have different outsourcing strategies, but that nearly all municipalities outsource (parts of) the so-called decision support process, in which third parties retrieve knowledge and information for the decision-making process. Appendix D provides an overview of the knowledge acquiring strategies of eight Dutch municipalities in the development of their heat transition vision.

Outsourcing often happens because municipalities want, or are obliged too, utilize data-driven support tools and models such as data viewers, data platforms or energy models for their evidence-based decision-making. Because municipalities often do not have the expertise or capacity to use these tools and models (Henrich 2020) and because many of these tools and models are not open access (see Appendix B), municipalities collaborate with or hire third-party expertise. An advantage of outsourcing (parts of) the decision-support process is that the municipality has access to more resources such as knowledge, information, skills and tools.

However, hiring an external party also has some risks, especially in receiving biased or inadequate decision-support. The capabilities of certain tools or models that are offered by third parties, such as consultancies, may influence early stages of evidence-based policymaking (such as research question formulation), and the commercial interests of these parties may result in biased advice favouring products or services of allied market parties. Moreover, there is the risk of policymakers not being able to critically reflect on information or knowledge offered by consultancies (such as modelling results or data sets) or that they are not able to articulate suitable research questions (Henrich 2020), which may lead to decision-making based on incorrect or insufficient information. Considering these risks, there seems to be a need for a more structural and transparent approach to gather information and knowledge from third parties and to assess the quality of this information. One strategy that some municipalities apply to decrease the risks discussed, is to hire contra-expertise on the advice and or decision support the municipality has received from third parties (Woestenburg et al. 2020).

# 3. Decision support for Energy Transition decision-making

Following the elaboration of the need for decision-support by municipalities, this section discusses which data and decision support tools & models are available for this decision-support. Moreover, light is shed on the challenges which arise in utilizing data, tools and models, and which guidelines are available to deal with these challenges.

## 3.1 Availability and utilization of decision support tools and models

Over time, an extensive ecosystem of data, tools and models has been developed to support local policymakers and stakeholders in their decision-making processes. Table 4 in Appendix B presents the main decision support tools and models currently used in the energy transition decision-making processes of policymakers and gives insight into their goals, types of access, developers, etc. A total of fifty tools and models were identified[1] as being most commonly used by municipalities and the stakeholders. A distinction can be made between Data viewers, (Quantitative) Energy models, and Data and Model Platforms. Most data platforms and viewers are open access, but many other tools and models, such as energy models and visualization tools, are privately owned and can only be utilized by policymakers when hiring a consultancy that owns the tools or models, or by paying a license fee. The three most commonly used tools and models are discussed below.

**Data viewers (7/50)**

Data viewers entail the collection, preparation and visualization of raw data in digital dashboards, often GIS enabled. Through these data viewers, policymakers and other stakeholders are enabled to view and explore data, in order to gain insights on the themes captured by the data viewer. Seven out of the fifty tools and models that were identified, can be categorized as data viewers. This visual format facilitates more effective decision-making since it is easier for people to comprehend information through visuals than through raw data. Energy transition data (but also energy modelling results) are often presented on (multi-layered) GIS-maps (Geographical Information Systems). Such GIS-maps show, for example, characteristics of neighbourhoods and citizens, information on spatial development, and on the potential of sustainable energy sources. Many viewers include data from CBS[2], PBL[3], the national program RES[4], Kadaster and some offer the opportunity to add data (for example from the municipality or from energy models). Six out of the seven data viewers found are available in open access.

***Energy models (42/50)***

Quantitative energy models are powerful instruments for generating new knowledge, for example on the costs of future technology pathways and the economic and environmental impact of policies. A total of 42 energy models, in a non-exhaustive set, are addressed in this study. The majority of the models found can be classified as optimization models, common equilibrium models, macro-economic models and/or simulation models. Using quantitative models can be beneficial as they can capture new data and information and facilitate stakeholder collaboration (van Veenstra & Kotterink, 2017). Quantitative modelling can link policy goals to their required physical changes and vice versa while offering a robust and formalized research method (Geels et al., 2016). They can be applied as tools to support decision-making processes, as they can reveal the impact of decisions on e.g. policies, governance, and investments via a forward looking perspective on transitions (Turnheim et al. 2015).

[1] This overview does not represent all tools available, but is merely meant to provide insight into the amount and sort of available decision support tools.

[2] CBS: Statistics Netherlands

[3] PBL: Netherlands Environmental Assessment Agency

[4] RES: Regional Energy Strategy

In Figure 4, an overview is provided of various methods, including the category of quantitative energy models, which can be utilized to develop end evaluate energy policy. Quantitative models have limitations when it comes to the behavior of stakeholders, the role of inertia and innovation and explaining the spatial dimensions of the energy transition (Bolwig et al., 2019). Moreover, each quantitative model is a lens which focusses on a certain aspect of the transition (Turnheim et al. 2015). Future developments that are expected to make their way towards the policy practice are hybrid methods, combining qualitative and quantitative methods. On this subject, research has been developing at a fast pace among modeling and simulation scholars, however, these methods are addressed to a lesser extent in the governance literature.

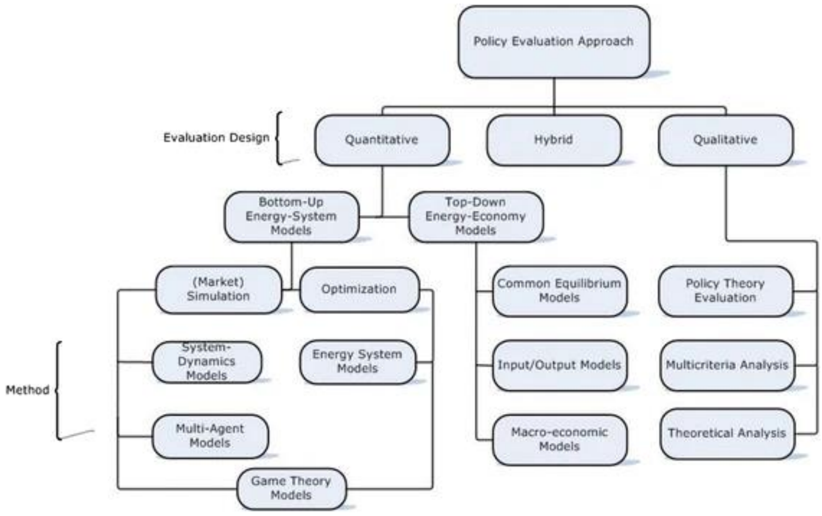


*Figure 4 Methods of policy evaluation in the support of energy transition policymaking, adapted from (Horsgich and Thrän, 2017)*

In the Netherlands, many energy models have been developed to reduce complexity and provide insight into the dependencies of the local energy system, thereby supporting informed decision-making. The expert group on energy transition models, initiated by Netbeheer Nederland and including the front-runner stakeholders in energy modeling and simulation (Expertgroep Energietransitie Rekenmodellen, 2019), established a toolkit called 'Energy transition models' to support municipalities, housing corporations and energy cooperatives in finding models which fit their needs. This toolkit includes an inventory of 31 models, of which the following can be noticed:

1. Energy carrier: 5/31 models focus on heat, 7/31 models focus on electricity, while 19/31 models include both electricity and heat, with the possible addition of alternative energy carriers such as biogas or $H_2$.
2. Geographic scope: the majority of the models (17/31) cover the regional to the local (district or street) level within the model. Of those 17 models, 5 models extend the scope to individual dwellings.
3. Type of decisions: 22/31 models address the strategic level of decision-making, which entails the vision and master plan, 15/31 models address urban spatial planning, while no model addresses the implementation of energy transition plans.
4. Functional scope: 28/31 models can be specified as energetic models (focus on the generation, flow, storage and use of energy), 6/31 models boost the functionality of simulating energy markets, 3/31 include policy measures, and 15/31 models have a spatial functionality.
5. Model owner/developer: for the 31 models in this inventory a total of 28 parties were found involved in the development and delivery of the models.

There are 14 Models not included in the Toolkit of Netbeheer Nederland, that are included in the overview in Appendix B. These models include models of CE Delft focused on the Dutch electricity market, various other commercial models focused on the heat transition, various commercial models that integrate both electricity and heat and several models developed in an international context on electricity and heat with potential for use in the Netherlands. Next to the models discussed by Netbeheer Nederland and those discussed in Appendix B, there are also more technical and specific models that can be used to support energy transition decision-making such as Building Information and HVAC[5] models. However, the use of these models by policymakers in energy transition decision-making is limited (Henrich 2020). The potential lies in the integration of these building level models, or the insights from these models, in the models and tools applicable for policymakers.

**Data or model platforms (3/50)**
Three data and model platforms were found in this study, the PICO platform, Het Duurzaam Data Platform (the Sustainable Data Platform) and the Mondaine suite.

- PICO is currently open access, but restrictions may be imposed in the near future. PICO provides a platform for spatial, social, economic and financial models and data. For instance PICO enables calculation with PBL's Vesta MAIS model, and the visualization of those results on maps.
- Het Duurzaam Data Platform is owned by Backhoom. It is a platform for data of residential house characteristics created with 3D-models.
- Mondaine suite offers a platform which enables the coupling of for different energy transition models, namely Quintel's Energy Transition Model and PBL's Vesta MAIS. Moreover, the coupling with the PICO platform is made (e.g. on sustainable energy potential).

Considering the information needs presented in section 1 and this overview of available tools and models, the following types of tools and models seem to be missing in the current energy transition ecosystem:

- An integrated data platform for the energy transition that unburdens involved stakeholders in finding, accessing and sharing data and that allows all parties to execute and monitor the energy transition (VIVET 2019). Currently a large amount of data platforms can be found, each with a different, often partially overlapping, purpose and specialization (Diran, 2019). Making a choice on a suitable platform, and subsequently deriving the desired insights from these platform is difficult (Nijsink, Heisink and Van der Veen, 2020).
- Tools or models that focus on execution, operation and maintenance phases. Most tools, and especially energy models, are high-level strategic tools and models that can support vision creation and pathway definition. Only a few tools and models address urban spatial planning and no tools were found that focus on the execution and operational phases of the energy transition. More specialized and specific tools (such as building information models) may offer some opportunities for this, however these are currently often considered unsuitable for energy transition policymaking.
- Tools or models focused on the demand side of the energy transition. The majority of the tools available focus on the energy generation side of the energy system. Demand-side management and energy efficiency is insufficiently included (Expertgroep Energietransitie Rekenmodellen, 2019).
- Tools or models that consider the interaction between heating systems and electrical grids (Henrich 2020). Even though the overview of section 4.2 shows some models that include both

[5] HVAC: Heating, ventilation, and air conditioning

the heat and electricity sector, policymakers in the study of Henrich (2020) indicate that they lack models that consider the interaction between heating systems and electrical grids. This indicates that policymakers can either not find or access these energy models, or that these do not offer the desired knowledge yet.

## 3.2 Challenges in model utilization by policymakers

Effective energy transition decision-making is currently hindered by some specific challenges regarding energy model utilization. Table 2 shows an overview of the challenges of using energy models for decision-support in energy transition decision-making and their relation to the information needs of policymakers. These challenges mostly relate to missing, inaccurate or aggregated data sets, the complexity of models, and the lack of transparency and social factors in energy models. Transparency of the underlying assumptions, sensitivities and input-data of a model is necessary since the quality and usability of energy modelling is highly dependent on the input data and assumptions made. Transparency may also increase the trustworthiness of models (and therefore the legitimacy of policy choices), as energy models sometimes provide contrasting results for the same research questions (Brouwer, 2019).

Sensitivity analysis[6], comparative modelling[7] studies and multi-model ecologies[8] could improve the robustness of modelling results. However, all have their respective challenges which mostly relate to the added complexity of the modelling process, which is already challenging as it is. Multiple studies state that energy models are currently (too) difficult to use for policymakers (Ben Amer et al., 2020; Erker et al., 2019; Koussouris et al., 2015; Nikolic et al., 2020a; Sakellaris et al., 2018). At the same time, various studies state that energy models tend to simplify their depiction of societal and political factors, which can make it difficult to use them for policy design and decision-making. Social aspects, such as behaviour and attitude of the public, influence proposed or implemented policies and should therefore not be ignored (Androutsopoulou & Charalabidis, 2018).

*Table 2: An overview of challenges related to utilizing energy models for energy transition decision-making.*

| Model utilization challenge | Mentioned by | Relation to type of information requirements |
|---|---|---|
| Models provide different and sometimes contrasting results for the same research question | (Brouwer, 2019); (Diran et al. 2020); (Henrich 2020) | Demand-side<br>Supply-side<br>Infrastructure and resources<br>Institutions, policy and instruments<br>Multi-actor and stakeholder engagement<br>System integration |
| Energy models are (too) difficult to use for policymakers | (Ben Amer et al., 2020); (Erker et al., 2019); (Koussouris et al., 2015); Nikolic et al., 2019); (Sakellaris et al., 2018) | Demand-side<br>Supply-side<br>Infrastructure and resources<br>Institutions, Policy and instruments<br>Multi-actor and stakeholder engagement<br>System integration |
| Missing, inaccurate or aggregated data sets affect the usability of modelling results | (Henrich, 2020) | Demand-side<br>Supply-side<br>Infrastructure and resources<br>Institutions, policy and instruments<br>Multi-actor and stakeholder engagement<br>System integration |

[6] Sensitivity analysis: determines how target variables are affected by changes in other (input) variables.
[7] Comparative modelling: comparing the results of different tools for the same research question.
[8] Multi-model ecologies: system of interacting models.

| | | |
|---|---|---|
| Current energy transition models lack transparency. Much is unclear about the underlying assumptions, sensitivities and input-data of models that support energy transition decision-making | (Diran et al., 2020b); (Henrich 2020); (Geerdink et al., 2020); (Hupkens 2019) | Demand-side<br>Supply-side<br>Infrastructure and resource<br>Institutions, Policy and instruments<br>System integration |
| The social aspects of the energy transition are poorly represented in energy transition models. Especially optimization models tend to simplify their depiction of societal and political factors which can make it difficult to use them for inclusive and supported policy design | (Wiese et al., 2018); (Henrich 2020);<br>(Li et al., 2015); (Zvingilaite & Klinge Jacobsen, 2015);<br>(Busch et al., 2017) | Multi-actor and stakeholder engagement<br>System integration |

## 3.3 Limited quality of data for decision support models and tools

Without a solid data supply, the tools and models discussed in section 3.1 will remain sub-optimal to poor in supporting energy transition decision-making. All three types of decision support tools discussed in section 3.1 are data-driven, meaning they need correct and sufficient data to provide useful information. In addition, raw data sets can also provide useful input for energy transition decision-making, for example, to provide insight into neighborhood characteristics, installation efficiencies, or demand development. Table 3 shows an overview of the data sets that are considered in need of improvement for energy transition decision-making by various studies, and their relation to the information requirements of policymakers (as described in Appendix A). Reasons for this lack or inadequacies of data can be summarized as privacy legislation, a time-consuming and expensive data collection process, complexity of formats and standards, a lack of supporting tools for data analysis, difficulty of finding and accessing data and a lack of openness and data sharing (Diran et al., 2020[ab]). An overview of all factors that hinder effective use of data in energy transition decision-making is shown in Appendix C.

To give an example, multiple studies that focused on data in the Dutch heating transition VIVET (2019) Diran (2019), Diran et al. (2020[ab]) and Henrich (2020) found that dwelling characteristics, such as current insulation level, are poorly represented in current data sets and that energy use data of dwellings is only available for policymakers on an aggregated level, and with a delay of a year, due to privacy legislation. This makes it difficult to calculate the costs and benefits of transitioning to natural-gas free heating and to compare different technological options for these dwellings or for specific neighborhoods.

*Table 3: An overview of missing or inaccurate data relevant for energy transition decision-making.*

| Missing or inaccurate data | Mentioned by | Relation to information requirement |
|---|---|---|
| Network data | (VIVET, 2019) (Tillema, 2020) (Henrich, 2020) (Diran et al., 2020b) | System integration<br>Infrastructure and resources |
| Installations data | (VIVET, 2019) (Van Putten et al., 2020) | Supply-side<br>Infrastructure and resources |
| Dwelling data | (VIVET, 2019) (Geertjes & Keller, 2020) (Diran, 2019) (Diran et al., 2020[ab]) (Henrich, 2020) | Demand-side<br>Institution, policy and instruments |
| Energy usage data | (VIVET, 2019) (Diran, 2019) (Diran et al., 2020[ab])(Henrich, 2020) | Demand-side<br>Institution, policy and instrument |
| Energy potential data | (VIVET, 2019) (Henrich, 2020) | Supply-side<br>Institution, policy and instruments |
| Planning data | (VIVET, 2019) | Infrastructure and resource<br>Multi-actor and stakeholder engagement |

| | | |
|---|---|---|
| Contextual data | (VIVET, 2019) (Diran, 2019) (Diran et al., 2020[ab])<br>(Henrich, 2020) | Institution, policy and instrument<br>Multi-actor and stakeholder engagement |

## 3.4 Reflecting on the informed decision process

Data, tools and energy models are often developed separately, but in practice, they are strongly interrelated. Furthermore, they serve a specific purpose in the policy context. Therefore, they require a process to help articulate the correct knowledge question, to acquire the right data and information as input, and to interpret the output as knowledge to support the decision-making process. This not only internally within the municipality, but also with stakeholders and knowledge parties (e.g. commercial advisory firms or consultants). In the traditional definition of the decision dialogue, namely focusing on the human-computer dialogue as presented by Sprague and Carlson (1982), this interaction with the stakeholders and third parties is not included. The findings in this study point towards the importance of a collaboration strategy to create and maintain familiarity, understanding, and trust among policymakers, among others, to support information sharing. This can be considered part of the transition from technocratic decision-support systems, towards participatory decision support systems as addressed by Pereira and Quintana (2002) in a response to contemporary governance styles in water management. Then the question arises how these collaboration strategies can be designed and implemented for the local energy transition?

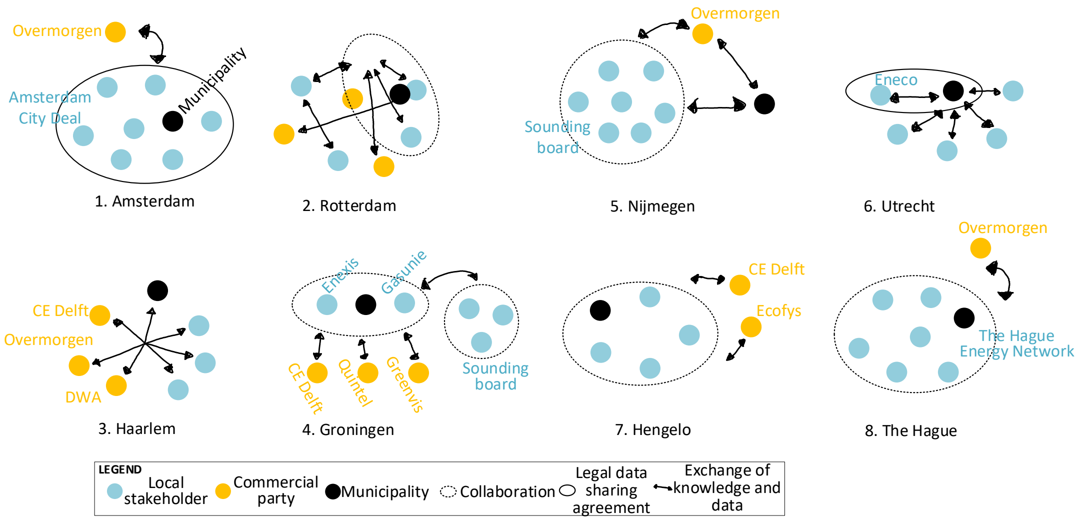


*Figure 5: The variety in shapes among decision support processes, adapted from (Diran et al., 2020b).*

A study by Diran et al. (2020b) assessed the various implementations of information sharing and utilization for the heat transition among the municipality and stakeholders for eight Dutch municipalities. In figure 5 the findings from this study are visualized. Seven of the eight municipalities are found to involve an external party in the collection and / or analysis of data for the Transitievisie Warmte or TVW (translates to Transition Vision Heat). Advisory firm Overmorgen is identified as an importance knowledge partner, involved in no fewer than 4 of the 8 municipalities. When analysing the registered advisory, engineering and consultancy firms registered at the ECW, it can be observed that the options for decision support are ample. In figure 6 this overview is provided.

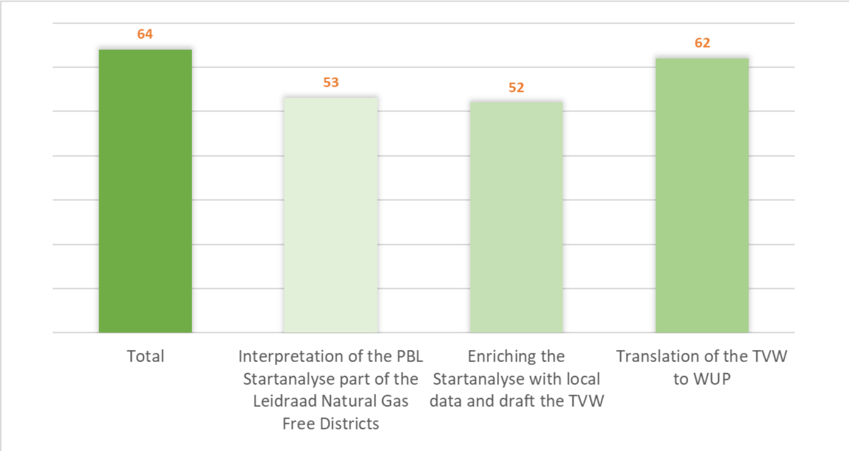


*Figure 6: An overview of commercial parties active in heat transition policy and decision support, own graph with data from (ECW, 2020)*

Of the eight Dutch cities studied by Diran et al. (2020b) Utrecht is the only one with its own data team that works on data issues in various domains for the entire municipality. Rotterdam, Haarlem and Utrecht mainly work on an ad hoc basis and one-on-one with local parties on the data requirements for the TVW. This often happens through existing contacts. Nijmegen and Groningen form a sounding board consisting of local stakeholders to develop the TVW. Parties with which almost all municipalities cooperate are the network operators, housing corporations, energy suppliers and heat companies. In some municipalities, there is also collaboration with residents' associations. More information on the information collaboration is presented in Appendix D.

Amsterdam, Hengelo and The Hague have an existing partnership with local parties. These are now being used to work together on the TVW. Only in Amsterdam have agreements been made regarding the sharing of data, by means of a non-disclosure agreement between the parties in the City Deal. Utrecht has made legal agreements with one locally active energy provider for data sharing, and is working on a City Deal.

How actors engage with each other in the exchange of information and other resources is subject to the local political and social context, respectively the relationship between local policy makers, stakeholders, citizens and other parties involved in decision support, and the experience and capacity of the process organiser (Diran et al., 2020[b]; van Est et al., 2016).

In seven out of eight cases the decision dialogue is formalized by means of collaboration agreements, in some cases with a legal ground, and backed financially. However, even though they have formalized agreements, these municipalities still experience many barriers in the information provisioning. While they are considered front-runners in the Netherlands in terms of the advancements in data and information sharing, analysis and eventually informed decision-making, the transition of this information towards actionable knowledge for decisions, is, thus, still work in progress. Relating the lessons from these eight Dutch cities with the work by Pereira and Quintana (2002) on participatory decision support systems, it can be stated that modern decision support needs to entail not only a decision dialogue, but also decision deliberations.

Van Est and van Waes (2016) study the participation processes of national and regional Dutch energy programs from 1980 till 2016 and draw the conclusion that over time the debate has made way for a more constructive dialogue and process of participation in efforts to improve the relation between society and politics, and gain joint political and social support. Nevertheless, the assessed procedures in place to arrange the relation between politics and society are deemed ineffective and strongly criticised. For the heat transition, the Climate Agreement proposes the district approach (Wijkaanpak in Dutch) as an improved strategy of energy transition decision making for municipalities which takes sheds light on the specific characteristics of the district and brings decision making closer to the citizens and stakeholders. Also this approach faces many challenges, e.g. regarding the achievement of municipal wide transition from the district level (the sum of the parts), and is currently under scrutiny (van Poelgeest, 2020). Diran et al. (2020b) support this on the municipal level and observe that with an increasing amount of stakeholders which influence municipal decision making, it is observed that dialogues are taking place where actors confront each other with various knowledge in efforts to gain a common understanding of the challenges and decisions to be made. This dialogue yields possible gaps in the knowledge and possible conflicting knowledge, setting the stage to jointly develop new knowledge where that is missing, and to validate conflicting knowledge. For instance, when energy models are used, the dialogue between the municipality and the externa knowledge partners may entail the assumptions made in the models, and the quality of the data in the models. Transparency in the decision support is enabled by including the stakeholders in this dialogue. This transparency on the models used (and the underlying assumptions and data) result in an increased likelihood of support for the proceeding decisions. Moreover, the transparency also uncovers which data is still lacking or unavailable for decision support models and tools, and what the purpose is of this data utilization. With this knowledge on the data gaps and the purpose and benefit of having this data available for the municipal decision making process, the stakeholders can be motivated to share their data where this may contribute to the municipal decision making process.

Following a dialogue, and often intertwined with the dialogue, is the process of deliberation towards evidence-based decisions. Deliberation takes the dialogue to the next step. By channelling knowledge generated and addressed in the dialogue, from data and by utilizing models and tools, toward the exploration and selection of the right course of energy transition decisions. The actions include individual decisions by an actor, both public and private, and joint decisions by the actors involved in the decision dialogue and deliberations. In figure 2 the various types of decisions for the municipal policymakers were introduced. For this process of dialogue and deliberation, the tools and models i.e. presented in sub-section 3.3, function in a supporting role, e.g. to provide insights on the right course of action given its costs and impact. On this phase of the collective decision deliberation, not much empirical research exists for the energy transition in the Netherlands. The programme on Natural Gas Free Districts is funding the initiation and planning of the heat transition in 27 districts nation-wide, with a second round of pilot districts following now. In these districts experiments are established to decide on the natural gas free transition of the district, in close cooperation with the local stakeholders and citizens. Hence, this is a significant step toward decision deliberation and dialogue among stakeholders. To the knowledge of the authors this set of pilot districts is not yet researched on how decision deliberation works in these districts and what the challenges and success factors are. The need for this research is underpinned in this report.

## 3.5 Guidelines for data, model and tool utilization in decision-support

Multiple guidelines have been developed to decrease the challenges regarding unavailable or inadequate data, model and tool usage to support evidence-based decision-making at the local and regional levels. Appendix E presents an overview of such national and international guidelines. A distinction is made between guidelines for data and data platforms, guidelines for energy models, and more comprehensive guidelines for energy transition decision-making. For data and data platforms, these guidelines relate to standardizing data, providing findable, accessible, interoperable and reusable (FAIR) data and to adjusting laws and regulations regarding the registration of networks, energy use and available residual heat. For energy models these guidelines relate to providing transparent models, using the right models that fit the context and scope, providing sensitivity analysis, involving stakeholders, creating interoperability between models, and providing sufficient explanation to make the modelling results comprehensible to non-experts. Within these guidelines, transparency is often seen as the most important requirement for good modelling practice and most recommended practices in these guidelines are related to increasing this transparency.

Some initiatives develop ‘modelling steps’ that parties can follow within their energy transition decision-making processes,  for examples www.energiemodelleren.nl. In this online interface, information is provided for the various types of models that exist including steps for both policy makers and energy modellers for effective utilization of models. Energiemodelleren.nl addresses various good modelling practices as proposed by Nikolic et al. (2019a), such as the recommendation of ensuring transparency of assumptions and limitations to modellers, and the recommendation to policymakers to ask modellers for sensitivity analysis.

Moreover, comprehensive guidelines have been developed on decision support for the heat transition in particular. The Expertise Centre on Heat (Energie Centrum Warmte, ECW) developed a package called ‘de Leidraad’ on how to establish a Transition Vision Heat (TVW) and the district implementation plan (WUP) in that process utilize the Vesta MAIS model (ECW, 2020). This package includes a guide on the collection of local data for improved insights from Vesta MAIS at the local level. This guide includes an assessment framework consisting of techno-economic, and social and organizational criteria. For these criteria, and along the proposition of a decision dialogue process discussed in sub-section 3.4, the guide addresses which stakeholders to involve for the delivery of the data necessary to assess the criteria.

Furthermore, the SHIFFT research project with Middelburg as a use case (Van de Vijver et al., 2020) proposes a common approach for heat transition strategy development and implementation. This approach stresses the importance of involving citizens in strategy development and implementation, and elaborates on how such involvement can be organised. In this approach the dialogue and participation process is also specifically related to the activities pertaining to the collective collection and sharing of local data and information, and to utilize this data and information in the available tools and models.

# 4. Discussion and recommendations

Evidence-based policy making has great potential for local policymakers to develop and implement robust and legitimate energy transition policy that copes with the ample unknowns, uncertainties, and multi-dimensional complexities of the journey towards a climate neutral energy system. However, the effective and efficient implementation of evidence-based policymaking is challenging. Evidence-based policymaking requires a trusted, high quality and reliable information supply. Currently, the information that local decision-makers require is not always available or of sufficient quality for energy transition decision-making. Moreover, the data and information, and the tools and models to collect and combine this information towards actionable insights for policymakers, are owned by a multitude of stakeholders. Incomplete information, fragmentation of ownership, lack of transparency and openness in the current information landscape are some of the biggest challenges for evidence-based energy transition decision-making in municipalities. To deal with the current challenges, there is a need for a reliable, detailed and impartial information on the whole energy system. Within decision support efforts, a more integrated information supply would enable the analyses, assessment, and discussion of information for policymaking and policy evaluation, which transcends multiple actors, time dependency, and spatial complexity.

This report, explored the challenges faced in the three components of decision support systems, i.e. Data and information, Models and tools, and the Decision dialogue. It shows which data and information for energy transition decision-making is lacking, and which other hurdles hinder effective use of the available energy transition decision support-tools. In addition, it provides an overview of concepts discussed in guidelines and best practices to improve the current decision-support. The sections below discuss these findings. Figure 7 presents a graphical overview of the findings of this research.

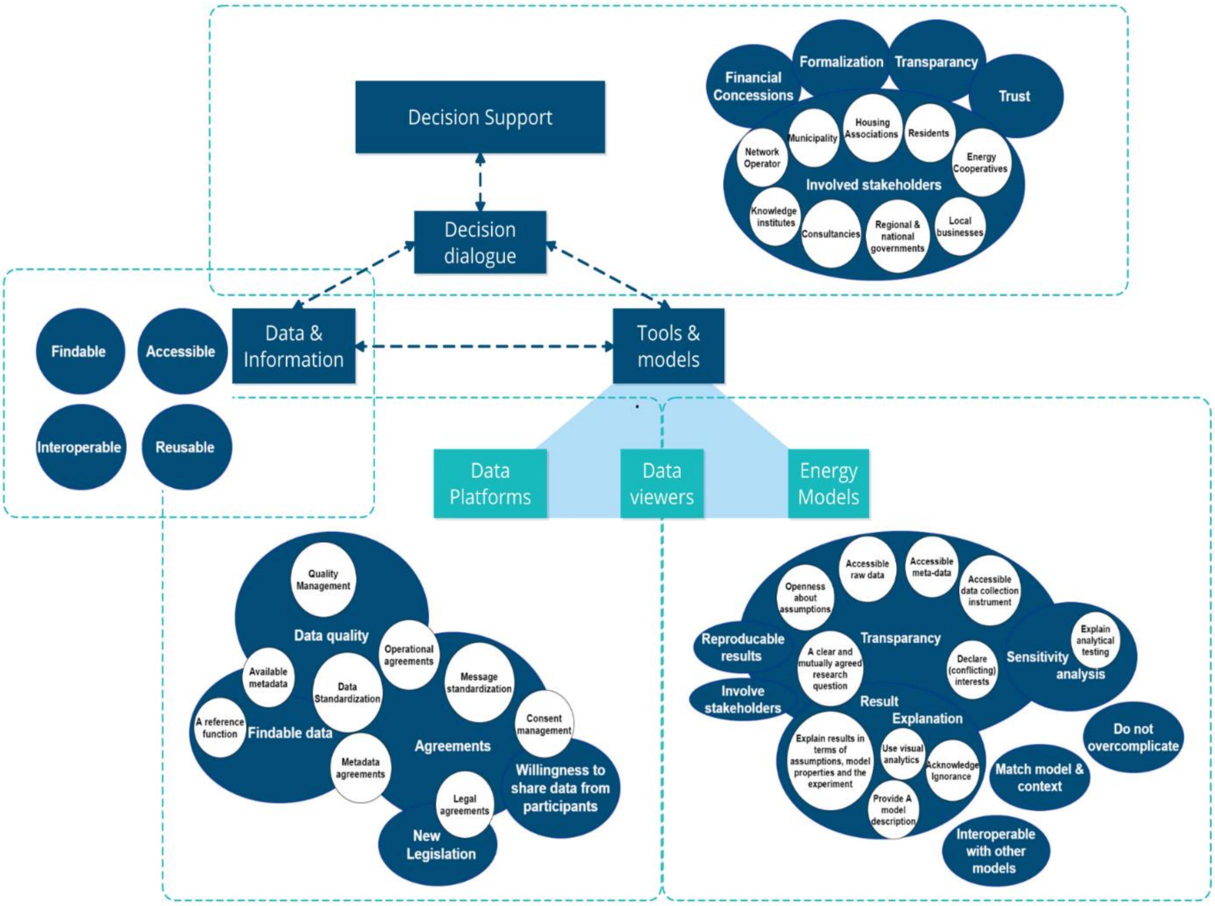


*Figure 7 Overview of the information supply and utilization for energy transition decision-making by municipalities*

Effective use of the available decision support by local decision makers for the energy transition is a challenge, both to find the right information and to make optimal use of this information to draft and implement local energy transition plans and strategies. The current available decision support offered by data, models and tools for local decision makers in the energy transition is highly fragmented and designed for different purposes. That is why the decision dialogue is so important to optimize the available decision support. Essential is that this dialogue encompasses not only the human-computer dialogue, but also the dialogue between policymakers, local stakeholders and citizens to gather the necessary and validated data, and derive the collective knowledge to support decisions via the utilization of models and tools. The findings of this study point towards the importance of a collaboration strategy to create and maintain familiarity, understanding, and trust among policymakers, among others, to support information sharing. This can be considered part of the transition from technocratic decision-support systems, towards participatory decision support systems in a response to contemporary governance challenges. These novel forms of participatory decision support systems, extent processes of dialogue toward processes of decision deliberation to channel the generated knowledge in decision support tools and models to courses of action.

To improve the current decision dialogue it is recommended to increase attention for the decision dialogue in local energy transition decision-making processes. The value of data, information, models and tools – on its own – is limited for local policy makers. Value can be created in the decision dialogue with multiple stakeholders, by developing a common understanding of the information (e.g. outcomes of tools and models) and a joint knowledge base. The joint formulation of questions is also important, to either match these questions to the available decision support, but also to identify information and knowledge gaps for energy transition decision-making. In case of information gaps, a joint solution can be found during the decision dialogue, that can be solved by for instance new data and information collection, involvement of new stakeholders, development of other or new tools. This should get explicit attention in the decision dialogue process, to ensure that the right insights are derived and delivered in an appropriate manner and timeframe. Formalising the exchange of information and joint generation of knowledge in agreements can improve the decision dialogue. This is to instance cover parties unwilling to share information in later stages of the collaboration, e.g. after they already benefitted from information from other partners. To help formalise commitment between partners financial funds can be allocated to a decision dialogue. Organizing and facilitating a well-designed decision dialogue process, requires expertise, skills and time. This can be supported by an independent and objective process facilitator. In the case an external process facilitator is acquired we recommend to put in place clear arrangements which guarantee the continuation of the decision dialogue, also after the external facilitator leaves the municipality to be replaced by another external facilitator or a facilitator internal to the municipality. This prevents "reinventing the wheel" every time the facilitator role changes which can imply a set-back on the progress made.

It is recommended to reduce and manage the dependency of municipalities on external expertise regarding data, tools and models to draft energy transition plans and strategies. This by improving knowledge and expertise within a municipality on data and information management, tools and models, and the decision dialogue to draft, implement and evaluate energy transition strategies and plans. And be conscious on the role of commercial energy companies in the decision-dialogue. Energy companies may impact the process of tenders in a later stage as parties intensively involved in the decision dialogues have an advantage over other market parties. Also be aware of the influence of external third parties in the definition of the decision-making questions. The PBL assessment of the concept RES observe that the influence of the external parties can be seen in the definition of the questions to be answered (Matthijsen et al., 2020). This can relate to external parties defining questions in such a way that they can actually support in answering those questions, given the data, tools and models they have in-house.

To make optimal use of the available decision support for local energy transition decision-making the right expertise and knowledge is required at municipality level. Developing knowledge and expertise about available decision support tools and models would enable practitioners from municipalities to either use decision support tools and models themselves or to correctly and critically interpret and reflect on studies conducted with these tools by third parties. Moreover, more knowledge about tools such as energy models could make it easier for municipalities to explain the results and their impacts to other stakeholders, such as network operators and residents, which could increase the legitimacy of the decisions that follow from using these tools.

The decision-support tools and models discussed (regardless of whom utilizes them) have their respective limitations. The energy transition requires a whole of different models and data about the different systems ("multi-model ecology"). This is even more complex than the individual systems. Necessary information does not only relate to the technical solutions for a subsystem, but to the integral energy system taking into account the interdependencies between stakeholders, technologies, and the environment, over time and in the spatial dimension. Over the last years, multiple guidelines have been developed to decrease these limitations and to improve the effectiveness of these tools and models. For energy models these guidelines relate to providing transparent models, using the right models that fit the context and scope, providing sensitivity analysis, involving stakeholders, creating interoperability between models, and providing sufficient result explanation to make modelling results comprehensible for non-experts. For energy models, linking existing and complementary models to create a multi-model ecology could help in reducing the information gaps for municipality decision-making introduced in section 2.3, especially those relating to the system perspective, i.e. gaining insight into relations between heat, electricity, energy storage, transport etc. However, creating such an ecology is complex due to the large differences in modelling scope, assumptions made, the techniques used, and the languages used.

**Future research recommendations**

This report has shown that for effective energy transition decision-making, improvements are needed for both the information demand, i.e. knowledge question formulation, and the information supply via i.e. data, information and models and tools. Figure 7 shows the key insights of this report, the conditions that could facilitate more effective decision dialogues and use of data, models and tools for local energy transition decision-making. Follow-up practice based research is recommended which is two-fold. On the one hand research should assess to which extent, and how, these requirements and principles are applied by the local policymakers and the stakeholders. On the other hand, research need to assess to which extent these requirements and principles improve the quality of decisions. We recommend a multidisciplinary research project team of decision support experts, local decision makers and stakeholders and a municipality use case. This knowledge sets the stage to develop widely applicable and practice-based methods of decision support addressing the contemporary uncertainties and complexity of the energy transition, with innovative means for decision support relating to models and tools, data and information management, and decision dialogues and processes. This action research would include case studies in which the principles from these guidelines would be actively applied to improve the energy transition decision-making process, in the specific local context. Including the translation of lessons learned from front-runner cities, into concepts or typologies of collaboration and dialogue with stakeholders in future research. This from the perspective of information sharing, the joint generation of knowledge, characteristics of the local stakeholders and politics, and the interaction with external/commercial knowledge partners. It can build on current ongoing TNO research on these subjects and requires multidisciplinary expertise pertaining to: the technical, environmental, economic and social aspects of the energy system, decision support systems, policy and governance, social innovation and evidence based policy making all available within TNO.

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# Appendix

## A) Information demand and requirements

Various research projects have investigated energy transition information demands and requirements (Henrich, 2020) (Geels et al., 2016) (Matthijsen et al., 2020) (Bodem+, 2018) (Katz, 2017) (Hanna et al., 2019) (Van der Linden & Akkerboom, 2018) (NWO, 2019) (Pont Berghauser & TwynstraGudde, 2019). By reviewing these projects it became clear that the current information supply at municipalities is not sufficient for informed energy transition decision-making. Some examples of current information gaps, formulated as knowledge questions, are discussed below.

**Supply-side**

Information about the energy supply shows the quantity of energy (electricity, heat) available and needed now and in the future. Information in this theme is crucial for designing any energy plan, yet there are still gaps in the current information provision regarding energy supply, summarized in the following questions:

- What are the locally and regionally available types of renewable energy generation potential?
- What is the availability, temperature and price of residual heat (Henrich 2020)?
- What is the uncertainty regarding the potential of locally and regionally available renewable energy sources?
- What are the environmental, economic, political, and social impacts of the (combined) deployment of sustainable energy sources (Hanna et al., 2019)?
- What is the cost-effectiveness, socio-political feasibility, social acceptance and legitimacy and flexibility of renewable energy sources and technology (Geels et al., 2016)?

**Demand-side**

Information about energy demand is equally crucial for designing energy plans. Demand and supply have to match and an expected rise in demand may, for example, lead to the development of new supply sources or demand management policies. Policymakers currently experience a lack of information to adequately assess the current and future demand for energy, summarized in the following questions:

- What is currently installed in dwellings regarding e.g., heat pumps, PV, battery storage, district heating connections?
- How will energy (electricity and heat) demand develop over time and space?
    - How will the functionality of dwellings change over time? (residential to service and vice versa).
    - How (the type of), where (distributed over the municipality) and when (distributed over time) will dwelling renovation pick up?
    - What is the impact of urbanization on the development of energy demand in quantity and patterns?
    - What are the trends in disaggregated energy consumption (disaggregation over lighting, appliances, heating, EV etc.) over time and space, per type of energy consumer?

**Infrastructure and resources**

Information about infrastructure and resources includes information about available infrastructure and resources, but also on the future demand of both. Assessing electric grid constraints, storage potential and 'no-go' areas are important for decision-making about the technical and spatial design of the energy transition. Currently, policymakers are missing information in these themes, as summarized in the following questions:

- What is the (legal, geographic, environmental) interference area of individual and collective geo- and aqua-energy (geothermal, heat cold storage, TEO/TEA/TED) projects?
- Each RES entails an offer for locally generated renewables (solar, wind), what are the constraints on the grid to facilitate this offer? (Matthijsen et al., 2020)
- (Related to this) What are the cost-effective, flexible, reliable and supported alternatives to grid reinforcement to facilitate the local generation? (Matthijsen et al., 2020)
- What are the effects of the energy transition (and specifically the growing demand for district heating, heat storage and the removal of gas pipes) on the underground infrastructure (Bodem+, 2018)?
- What is the potential and risk for hydrogen storage in empty natural gas reservoirs as (temporary) energy storage (Bodem+, 2018)?
- What are the risks of geothermal extraction of reservoirs that are also used for oil/gas extraction (Bodem+, 2018)?
- How to couple energy transition plans with infrastructural projects with different temporal planning, for example, sewer renovations (Henrich 2020)?
- How to ensure there is enough human capital to conduct energy transition execution activities (for example, installation of solar panels, installation of heat pumps, insulating houses, building wind farms) (Katz, 2017)?

**Multi-actor and stakeholder engagement**

The energy transition is highly dependent on various stakeholders: citizens, private and public parties. Stakeholders influence and are influenced by the energy transition, and even have data and information that is required to develop and realise energy strategies. Social aspects, such as behaviour and attitude of the public, influence proposed or implemented policies (Androutsopoulou & Charalabidis, 2018). Policymakers currently experience a lack of information on the stakeholders' interest, data, etc, as summarized in the following question:

1. What are the drivers behind and the interaction between decision-making (investments, participation (individual or collective), and lifestyle processes of actors?
2. Which knowledge (drivers, interest and capacity) is needed to enthusiast stakeholders and develop initiatives?
3. How do different (partial) decisions, parts of the energy supply and investments of different parties at different moments in time add up? (Woestenburg et al. 2020)
4. What do the investment cycles of actors look like? Such that investments can be aligned with each other? (Woestenburg et al. 2020)
5. Which information is needed from relevant transition partners to build system wide knowledge with insights on various interdependencies in the energy chain (from energy supply to energy networks and energy consumers), and where possible barriers may arise towards a sustainable energy system?

**System integration**

Information about system integration shows whether plans for one part of the system (for example extension of all-electric heating in residential areas) affect other parts of the system (for example the electrical grid, electric transport or industrial processes). Energy plans, policy and decisions in different parts of the system have to match to prevent, for example, overcharging the electrical grid.

Policymakers currently experience a lack of information to test the effect of energy transition choices across (energy)domains and stakeholders, summarized in the following questions:

- What is the impact of individual choices (e.g. all-electric heating, EV acquisition, PV installation) on the pathways of system integration, while maintaining reliability, cost efficiency and availability of key infrastructure?
- What is the impact of a changing heat supply (e.g. more electric heating) on the electrical grid (Henrich 2020)?
- Should the living environment be a leading factor when choosing between different carbon transition paths? Should energy infrastructure 'fit into' existing landscapes (PV-installations on roof, offshore wind turbines) or should new landscapes be developed where energy installations are concentred in so-called 'national energy landscapes' (Van der Linden & Akkerboom, 2018)?

**Institutions, Policy and instruments**

Institutions, policy and instruments influence the decision-making process in the energy transition. For example, laws and regulations offer instruments that can be used to incentivize residents or organisations to participate and policies provide direction about the activities that need to be undertaken. Information needs in these themes can be summarized in the following questions:

- Policies are drafted and implemented domain-specific, what is the cross-domain impact of these policies? (e.g. Policy on the circular economy, Mobility Policy, Healthcare Policy vs. Energy Transition Policy, The National Strategy on Spatial Planning and the Environment)
- What is the cost-effectiveness of support schemes for renewable energy and renovations?
- Which informal rules exist in the minds of actors and are sometimes shared as implicit knowledge rather than in an explicit and written form'?
- Which financial arrangements are available for residents to make their houses more sustainable (solar panels, insulation, change of heat supply) (Henrich 2020)? What are suitable (techno-economic) models that can be used to assess high-temperature heat storage in urban areas (e.g. business models, management concepts) (Bodem+, 2018)?
- Is there a need for more knowledge and insights on the societal aspects of the energy transition (there is a multitude of projects that delay or get cancelled because societal effects had not been taken into account) (NWO, 2019)?
- The 'Environment and Planning Act' will offer instruments that can be used to align the energy transition with other activities and plans of the Dutch (residential) environment. But which instruments will be offered and how can these be used to fasten the energy transition (Pont Berghauser & TwynstraGudde, 2019)?
- What is the effect (local, regional and national) of budget cuts in the Social Support Act (Wet Maatschappelijke Ontwikkeling) on the energy transition (de Vries et al., 2019)?
- Which legal frameworks exist regarding new thermal options such as geothermal heating (there is currently much unclarity and uncertainty about rules and regulation regarding new (innovative) thermal options (de Vries et al., 2019))?
- How to align energy transition policy plans (climate agreement, RES, RSH, TVW, implementation plans that are (sometimes) made simultaneously, with different scopes, by different parties with different tools (Henrich 2020)?

**Transition Progress Monitoring**

A study of the knowledge and learning programme of the Programme for Natural Gas-Free Districts (Groene Bij, 2019) concludes that municipalities have a growing need for monitoring of the energy transition. This demand for monitoring can be summarized in the following questions:

- What is the impact of specific energy transition projects on municipal goals?
- What is the potential of specific energy transition measures?
- How can municipalities (best) communicate achieved results to other parties, such as residents?

Currently, monitoring is difficult as municipalities rather spend their limited resources on implementation than on monitoring. Besides, offering tools for monitoring is complex, as every municipality has slightly different demands. A monitoring tool, therefore, needs to be customizable. The demands regarding a monitoring tool of municipalities can be summarized as one set of national key-figures, clarity of the location of data and clarity of the actualisation interval of data (Groene Bij, 2019).

## B) Overview of decision support tools

*Table 4: An overview of available decision support tools: energy models, data viewers and platforms.*

| | Information source | Goal/Scope | Access | Developer | Model, data platform or data viewer |
|---|---|---|---|---|---|
| 1 | Energie Transitie Atlas (ETA) | Heat supply and local RES | Over Morgen | Over Morgen | Model |
| 2 | Transform | Simulation & optimization for the analysis of energy data | Not available yet | Accenture, AIT & Macomi | Model |
| 3 | Vesta MAIS | Techno-economic analysis of natural gas alternatives | Open access | PBL | Model |
| 4 | HEAT | Choice of heating infrastructure (visualization effects) | Alliander | Alliander | Model |
| 5 | DIDO (in development) | The effects of policy measures and the roles of actors in the energy transition | Open access | TNO | Model |
| 6 | Energietransitiemodel (ETM) | Simulation of the energy system (entire value chain, multiple domains) | Open access | Quintel | Model |
| 7 | Gebiedsmodel | Quantification & visualization of energy transition measures | Alliander and D-Cision | Alliander and D-Cision | Model |
| 8 | Opera | Optimization of long term energy supply for the entire country | ECN | ECN | Model |

| | | | | | |
|---|---|---|---|---|---|
| 9 | Win3D | Visualization of the changes in the landscape and environment due to RES | ROM3D | ROM3D | Model |
| 10 | Windplanner | Impact on the living environment of wind and solar projects | The Imagineers | The Imagineers | Model |
| 11 | CEGOIA | Techno-economic analysis of natural gas alternatives | CE Delft | CE Delft | Model |
| 12 | Powerfys | Assessing techno-economic feasibility of technologies and forecasting energy storage needs | Ecofys | Ecofys | Model |
| 13 | Chess | Simulation of hybrid energy systems | TNO | TNO | Model |
| 14 | Caldomus | Techno-economic analysis of natural gas alternatives | Innoforte | Innoforte | Model |
| 15 | Integraal kosten model | Techno-economic analysis of natural gas alternatives | DWA | DWA | Model |
| 16 | Wijkwarmte model | Techno-economic analysis of natural gas alternatives | DWA | DWA | Model |
| 17 | Artis (Availability and reliability tracking information system) | Systemintegration and reliability of energy transition projects | SecuoS | SecuoS | Model |
| 18 | CEGRID | Effects on the electric grid of different energy scenarios | CE Delft | CE Delft | Model |
| 19 | DSSM (Smart Grid Scenario model) | The effects of the energy transition on the electrical grid and market | DNV GL | DNV GL | Model |
| 20 | ITSF | Simulation of future energy systems, assessment of future | DNV GL, TNO and TU Eindhoven | DNV GL, TNO and TU Eindhoven | Model |

| | | | | | |
|---|---|---|---|---|---|
| | | technologies and flexibility | | | |
| 21 | MKbins (model kosten en baten intelligent netbeheer Stedin) | Cost-benefit analysis of flexibility options & grid reinforcement | Stedin and CE Delft | Stedin and CE Delft | Model |
| 22 | Competes | Optimization of the electricity supply | ECN | ECN | Model |
| 23 | PV_+ Opslag in Woning | Optimization of individual residential PV supply and storage | Open access | Alliander | Model |
| 24 | Energeyes | Energy performance of residential buildings | | EnergyGO | model |
| 25 | Energiepotentiekaart | Assesses the suitability of locations for wind turbines, PV and geothermal energy | Generation. Energy | Generation. Energy | Energy model |
| 26 | Energy Storage Integration tool (ES-IT) | Integration of energy storage systems in microgrids/residential buildings | DNV GL | DNV GL | Model |
| 27 | Local Energy Analysis & Planning (LEAP) | Techno-economic analysis to design roadmaps for residential or industrial energy transition projects | ETG | ETG | Model |
| 28 | Moter (Modeller of Three Energy Regimes) (in development) | Multi-commodity energy systems (matching demand and supply) | DNV GL | DNV GL | Model |
| 29 | Warmtevraagprofielen | Demand and capacity heating networks | ECN | ECN | Model |
| 30 | ESSIM | System model: The Energy System Simulator (ESSIM) simulates network balancing and the effects thereof, in an interconnected hybrid energy system over a period of time | TNO | TNO | Model |
| 31 | ENSYSI | With this model, the development of the Dutch energy system can be simulated, for the period from 2010 to 2050, annual increments | PBL | PBL | Model |

| | | | | | |
|---|---|---|---|---|---|
| 32 | Planheat | A tool to map, plan and simulate low-carbon, economically viable scenarios for heating and cooling systems | Open access | Consortium funded by Horizon 2020 | Model |
| 33 | THERMOS | A tool for designing heat networks. Designed to optimise local district energy network planning processes and results according to user and project specific requirements such as budget, climate and energy targets | Open access | Consortium funded by Horizon 2020 | Model |
| 34 | Hotmaps | Open source heating / cooling mapping and planning toolbox | Open access | Consortium funded by Horizon 2020 | Model |
| 35 | DHAT | A tool performing economic feasibility studies for establishing district heating | Open access | Danish Energy Agency | Model |
| 36 | CELINE | Need charging infrastructure for electric vehicles | CE Delft | CE Delft | Model |
| 37 | PowerFlex | A predictive model of electricity prices. (spot market and imbalance market) | CE Delft | CE Delft | Model |
| 38 | EnergieConversieModel | Energy demand scenarios for 2050 (transport, high and low-temperature heat, light, appliances etc.) | CE Delft | CE Delft | Model |
| 39 | Prosumers and Energy Citizens | The model shows the possible contribution of prosumers (both consumer and producer) to the generation of decentralized renewable energy and flexibility | CE Delft | CE Delft | Model |
| 40 | COLONY- model | Techno-economic analysis of natural gas alternatives | The Earlybirds | The Earlybirds | Model |

| | | | | | |
|---|---|---|---|---|---|
| 41 | ComSof Heat | Business cases & visualisation of district heating systems | ComSof | ComSof | Model |
| 42 | CBS in uw buurt | characteristics of neighbourhoods /residents | Open access | CBS | Data viewer |
| 43 | Atlas van de regio | Information relevant for spatial development | Open Access | PBL | Data viewer |
| 44 | NOM kansenkaart | Overview of potential NOM-buildings | Open access | Platform Toegankelijke Energie Informatie | Data viewer |
| 45 | Ruimtelijkeplannen.nl | Overview of spatial plans of municipalities, provinces and the national government | Open access | Kadaster & Geonovum | Data viewer |
| 46 | ThermoGIS | Geothermal potential | Open access | TNO | Data viewer |
| 47 | Warmte(koude) Atlas | Viewer to assess available and potential heat | Open Access | RVO | Data viewer |
| 48 | PICO (still in development) | A platform for spatial, social-economic and financial models and data | Might become partially open access | GEODan, TNO, Alliander, Ecofys, NRG031/Waifer, Esri NL | Data & model platform |
| 49 | Het duurzaam data platform | Data of residential dwelling characteristics created with 3D models | BackHoom | BackHoom | Data platform |
| 50 | Geodans Energietransitie-viewer | De basis voor Geodans Energietransitie-viewer zijn datasets en energiemodellen van onder meer het PBL, het Nationaal Programma RES, de BAG, CBS, Geodans Energiedata (PICO-data). De viewer kan worden uitgebreid met eigen data(sets) | Geodan | Geodan | Data viewer |

## C) Data collection challenges

*Table 5: Overview of data collection challenges*

| | |
|---|---|
| Restricting privacy regulation | (Diran, 2019)<br>(Diran, Hoppe, et al., 2020)<br>(Henrich, 2020)<br>(Diran et al., 2020b)<br>(VIVET, 2019)<br>(Tillema, 2020) |
| Time-consuming & expensive data collection | (Henrich, 2020)<br>(Nijsink et al., 2020)<br>(Diran et al., 2020b)<br>(Diran, Hoppe, et al., 2020)<br>(Diran, 2019) |
| A lack of supporting tools for data analysis | (Diran et al., 2020b) |
| Complexity in formats & standards | (Diran et al., 2020b)<br>(Henrich, 2020)<br>(Diran, Hoppe, et al., 2020)<br>(VIVET 2019)<br>(Van Putten et al., 2020) |
| The difficulty of finding and accessing data | (Diran et al., 2020b)<br>(Diran, Hoppe, et al., 2020)<br>(Diran, 2019)<br>(Nijsink et al., 2020) |
| Lack of openness and data sharing | (Diran et al., 2020b) |

## D) Overview of the TVW outsourcing strategies of eight municipalities

Based on interviews with the eight municipalities in a TNO study commissioned by VNG – (Diran et al., 2020b)

Table 6 provides an overview of different municipal strategies for developing a 'Heat transition Vision' (Transitievisie Warmte, TVW in Dutch): the municipality in the lead, (fully or partially) outsourced, and collaboration with stakeholders in the use of data for the TVW. In the hybrid strategy the municipality is still in the lead, but consultancies are contracted for data collection and analysis. Who is selected or collaborated with depends also on existing relationships.

*Table 6: The role of the municipality, outsourcing of activities, and collaboration with other stakeholders for utilizing data to develop the Heat Transition Vision (TVW).*

| Municipality | Role | Third-party involvement | Collaboration with local stakeholders for knowledge exchange |
|---|---|---|---|
| Rotterdam | In the lead | Ad hoc mix of internal and external expertise | Convenant: municipality, Stedin, Evides to align plans |
| Groningen | In the lead; collect data for external energy models | CE Delft, Quintel en Greenvis | - Municipality, Enexis and Gasunie joint client for commercial parties<br>- Advisory group with local parties |

| | | | |
|---|---|---|---|
| Haarlem | In the lead | DWA, CE DELFT en OverMorgen | Ad hoc; mostly with housing corporations and operator |
| Nijmegen | Coordinating role, outsource decision support process. | OverMorgen | Advisory group with local parties |
| Amsterdam | Coordinating role, outsource decision support process, and take the lead in the internal decision process | OverMorgen | Collaboration (CityDeal, since 2017) – municipality, four housing corporations, Vattenfall, operator, Waternet, stichting Woon en de Organisation of housing corporations |
| Utrecht | In the lead, with own data team | NA | Data sharing agreement with operator Eneco |
| Hengelo | In the lead of the internal decision process | Ecofys and CE Delft supports | Already existing collaboration (since 2013) with local parties: operator, housing corporations, energy provider and heat company |
| Den Haag | In the lead of the internal decision process | OverMorgen supports | Already existing collaboration (Haags Energie Netwerk): three housing corporations, operator, citizens association, energy producers, Province South-Holland. |

## E) Modelling & Data platform guidelines

**Data sharing & Data platforms**

The "FAIR guiding principles" were published with the intention to improve the Findability, Accessibility, Interoperability and Reuse of data (Wilkinson et al., 2016). These four principles emphasize machine-actionability, i.e. the capacity of computer systems to find, access, interoperate and reuse data with minimal human intervention, as we rely on computational support to deal with the increase in volume, complexity and creation speed of data:

- Findable data: metadata and data should be easy to find for humans and computers. Machine-readable metadata is essential for automated discovery of datasets and services.
- Accessible data: once the required data found, one needs to know how this data can be accessed. Making data accessible can include authentication and authorisation processes.
- Interoperable data: data often needs to be integrated with other data and data needs to interoperate with applications for analysis, storage and processing.
- Reusable: the goal of the FAIR principles is to optimise the potential of data reuse. Metadata and data should be well described to achieve this, which allows data to be replicated and/or combined in different (contextual) settings.

The FAIR principles are a good starting point, but they do not solve (all) issues regarding unavailable and inadequate data for decision-making in the energy transition. To decrease such challenges, the VIVET programme (VIVET 2019) proposes to develop a data platform for the energy transition that unburdens involved stakeholders and that allows all parties to execute and monitor the energy transition. To achieve a platform the VIVET study proposes to (VIVET 2019):

- Adjust laws and regulations regarding the registration of networks, energy use and available residual heat.
- Set up/improve data sets regarding:
  - The location/position of heat networks

  - Final energy use on the lowest scale level
  - Socio-economic resident data
  - Energy use utility sector and greenhouses
  - Location of restricted areas (e.g. wind turbine free zones).
- Develop dynamic data about energy networks (needs new sensor technology or modelling of demand profiles).
- Develop an installation register (for all installations (all sizes), coupling with smaller existing databases).
- Develop a 'Regional Energy Strategy' register/overview
- Develop a 'reference' function (to more easily find data)

Diran (2019) and Diran et al.(2020) present four barriers that need to be overcome for an energy transition data platform: 1) restricting (privacy) legislation, 2) data ecosystem barriers e.g. difficult and cumbersome data search and acquisition and poor data quality and detail level, 3) stakeholder barriers, e.g. lacking the willingness to share data, and 4) high perceived costs. A future data infrastructure could use technologies such as blockchain, Big and Open Linked Data (BOLD), and crowdsensing to reduce these barriers (Diran et al. 2020a). First, blockchain provides opportunities to store, organize and exchange data, while addressing challenges regarding transparency, trust, data quality and integrity, security, and data access. Second, BOLD offers attractive opportunities for enhanced insights from distributed and diverse data in the context of the energy transition. Third, crowdsensing and citizen engagement in the evidence-informed approach (Diran, Hoppe, et al., 2020).

Diran et al. (2020) further propose that an adequate quality management system, which includes new roles, such as a data ecosystem manager, and a process for stakeholder participation and data ecosystem collaboration is essential for an effective data-ecosystem. The data ecosystem manager is not only responsible for data standards and quality assurance but also needs to coordinate the process of stakeholder participation and collaboration (Diran et al. 2020a). The role of standards is important for energy data platforms to ensure data quality and interoperability, however, this currently only exists for government geo-data (Diran et al. 2020a).

(Innopay, 2018) also proposes requirements for successful data-sharing initiatives in the Dutch economy. Six requirements proposed by this institute are:

- Data and message standardization: ensuring data and message standards allows machines to process data without human intervention.
- Operational agreements: needed to determine the operational processes of sharing data.
- Legal agreements: to ensure that rules and regulations regarding the organization, the use of data, finances, operational aspects, arbitrage and technical aspects are followed.
- Metadata: to describe data sets. Agreements about metadata ensure that machines and people can easily navigate through data sets and their respective content, location and access rights.
- Consent: consent allows the data owner to retain control over their data. The data owner will be able to provide access rights to data sets to third parties. Consent management ensures that the data owner can specify who will get access to which data and under which conditions.

## Good modelling practice

Table 7 shows an overview of principles of 'good modelling practice'.

*Table 7: The principles of 'good modelling practice'*

| | | |
|---|---|---|
| Transparency | Transparency should be a design principle. The input data, assumptions, modelling formalisms and calculation rules of the model should be discussed and presented as transparent as possible. Input data should be publicly accessible and uncertainty in input data should be explicitly discussed. | (Wiese et al., 2018)<br>(Nikolic et al., 2020a)<br>(Henrich, 2020)<br>(Nationaal Programma RES 2019)<br>(Manfren et al., 2020)<br>(Ben Amer et al., 2020)<br>(Crout et al., 2008) |
| A model should fit the context and scope | Energy models are tools and they are most effective if they are used for those research questions/projects that they are designed for. | (Nationaal Programma RES, 2019)<br>(Saltelli et al., 2020)<br>(Crout et al., 2008) |
| Provide sensitivity analysis (analytical testing) | Inaccuracies in data, assumptions and calculation rules should be assessed with a sensitivity analysis.<br>Parameters should be varied within reasonable ranges and the sensitivity of the parameters and the effect that has on modelling results should be explicitly discussed. | (Nationaal Programma RES, 2019)<br>(Nikolic et al., 2020a)<br>(Argyrous, 2012)<br>(Saltelli et al., 2020)<br>(Crout et al. 2008) |
| Clear result explanation | It should be possible to explain modelling results in terms of (1) the assumptions made, (2) the properties of the model, the model type (3) and the experiment. | (Nikolic et al., 2020a) |
| Involve stakeholders and create a collective understanding | Citizens are increasingly demanding to be engaged in planning decisions that affect them and their communities. Collective understanding and usage of models are vital for the shared understanding of modelling objectives and outcomes. | (Saltelli et al., 2020)<br>(Geerdink et al., 2020)<br>(Voinov et al., 2016) |
| Interoperability among models | Work towards interoperability among models. Comparative analysis and/or multi-model ecologies can improve the transparency and robustness of modelling results. | (Henrich, 2020)<br>(Wiese et al., 2018)<br>(Nikolic, Warnier, et al., 2019b) |
| Do not overcomplicate | Complexity can be the enemy of relevance. There is a trade-off between the usefulness of a model and the breadth it tries to capture. Many modelers are seduced by the idea of adding complexity in an attempt to capture reality more accurately. Overly detailed models may suggest a closeness to the reality that is not there if details are irrelevant. | (Nikolic et al., 2020a)<br>(Saltelli et al., 2020) |