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Incorporating Stakeholder Perspectives into Model-Based Scenarios: Exploring the Futures of the Dutch Gas Sector

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Abstract

Several model-based, analytical approaches have been developed recently to deal with the deep uncertainty present in situations for which futures studies are conducted. These approaches focus on covering a wide variety of scenarios and searching for robust strategies. However, they generally do not take the multiplicity of stakeholder perspectives into account in analytic terms, which could bring in diverse opinions and views, not only on possible futures but also on values and interests. In this study, we present an approach to incorporate stakeholder perspectives into model-based scenarios for exploring the future dynamics of the Dutch gas sector. The results demonstrate that the scenario space can be demarcated according to the perspectives. This allows for a systematic comparison of the perspectives and provides a basis for identification of robust strategies. Also, the analysis shows that incompatible elements between the model and perspectives, or within perspectives can be identified. This provides insights about the problem complexity and potential barriers to the futures envisioned by the perspectives. Future research can strengthen this approach by involving stakeholders in modelling and in the model-based representation of the perspective narratives to enhance learning and credibility, and can extend the analysis to identify (socially) robust policies.

Highlights

- Analytical scenario techniques do not explicitly consider stakeholder perspectives.
- We incorporate stakeholder perspectives into model-based exploratory scenarios.
- We systematically find the scenario sets that correspond to perspective narratives.
- We identify the incompatibilities within perspectives and barriers to their envisioned futures.
- Perspective-specific scenario sets facilitate identifying socially robust policies.

Keywords: Deep uncertainty, exploratory scenarios, exploratory modeling and analysis, stakeholder perspectives, energy futures

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1. Introduction

Scenario-based foresight techniques are often used in futures studies to deal with the challenges posed by complexity and uncertainty (Enserink, Kwakkel and Veenman 2013, Walker, Marchau and Kwakkel 2013). Scenarios are developed in different ways. The two major categories of scenario construction approaches are intuitive (soft) methods that are based on qualitative knowledge and insight of experts or stakeholders, and formal (hard) methods that are based on best scientific knowledge and quantitative models (Van Notten et al. 2003, Berkhout and Hertin 2002). Intuitive approaches facilitate learning, eliminate overconfidence in a dominant expected future and broaden stakeholder views to the multiplicity of future possibilities (Schoemaker 1993). However, they often focus on a limited number of scenarios, usually biased towards the best or worst case scenarios, and on a limited number of uncertainties (Groves and Lempert 2007, McJeon et al. 2011). Formal approaches often take a larger number of factors and uncertainties into account, and explore a more exhaustive set of scenarios. They enable using analytic techniques to investigate the relations between variables and to test the performance of decision alternatives. Yet, the modeling assumptions play an important role in the results of this approach.

These two approaches can benefit from each other. On the one hand, an explicit consideration of stakeholder perspectives brings salience, credibility and legitimacy to policy-oriented foresight studies (Kunseler et al. 2015). Namely, it enables addressing more relevant issues, bringing in diverse opinions and views on what the future may or should look like, and including the diversity of values, beliefs and interests. It strengthens the modelling assumptions by providing a credible ground. On the other hand, model-based formal approaches can complement intuitive and qualitative techniques by expanding the scope and number of scenarios explored (Trutnevyte et al. 2016), by formally describing the visions and trajectories, testing their feasibility (Folhes et al. 2015), by processing the research material in a systematic and well-balanced manner (Kunseler et al. 2015), and by revealing the areas that may be incorrectly receiving too much importance (McDowall 2014).

Recently, a variety of model-based scenario approaches and tools has been introduced to support *decision making under deep uncertainty* such as robust decision making (Lempert et al. 2006) or exploratory modelling and analysis (Kwakkel and Pruyt 2013), multi-objective robust optimization (Kasprzyk et al. 2013), info-gap decision theory (Ben-Haim 2004), adaptive policy making (Walker, Rahman, and Cave 2001, Van der Pas et al. 2013) and dynamic adaptive policy pathways (Haasnoot et al. 2013, Kwakkel, Haasnoot, and Walker 2014)[1]. These model-based, highly analytical approaches are strong in exploring a wide variety of futures and providing insights for decision making (Maier et al. 2016). Yet, they do not explicitly take the multiplicity of stakeholder perspectives into account, especially in scenario generation. They address various sources of uncertainty, such as uncertainties associated with system inputs (Halim, Kwakkel, and Tavasszy 2015), model structures (Pruyt and Kwakkel 2014), and metrics and methods used in the analysis (Kwakkel, Eker, and Pruyt 2016). With this broad view on uncertainties, they explore a wide variety of futures that potentially cover different stakeholder perspectives, yet they lack an explicit account of these perspectives. However, considering the abovementioned benefits of combining intuitive and formal scenario approaches, these analytical

[1] These methods and tools use ‘exploratory’ scenarios to address deep uncertainty, which refers to situations where multiple possibilities can be listed but the likelihood or plausibility of these possibilities cannot be represented by probability distributions or even a rank-order (Lempert, Popper, and Bankes 2003, Kwakkel, Walker, and Marchau 2010). As Maier et al. (2016) discuss, exploratory scenarios are better suited to address deep uncertainty and identify multiple possible futures than predictive, normative or what-if scenarios are, since they answer the question “what could happen?” and provide a rich description of possible future states.

tools can potentially be strengthened by incorporating stakeholder perspectives into them explicitly. Furthermore, such an explicit account of stakeholder perspectives enables identifying social robustness of policies, i.e. the extent to which a diverse group stakeholders can agree upon them, in addition to their robustness against uncertainties.

One approach that takes stakeholder perspectives explicitly into account in uncertainty analysis is the 'Perspectives method' of Van Asselt and Rotmans (1996). This method is based on a predefined set of perspectives derived from Cultural Theory (Thompson, Ellis and Wildavsky 1990), such as hierarchist, egalitarian and individualist, and proposes to follow different routes in modelling, scenario generation and analysis of response strategies for each of these perspectives[2]. However, with its predefined perspectives of Cultural Theory, the perspective method has been acknowledged to be limited in covering the real world variety of perspectives in specific socio-economic and political contexts (Rotmans and van Asselt 2001). Therefore, identifying the perspectives that are specific to each problem context can be helpful in incorporating the diversity of stakeholder views into model-based studies for decision making under deep uncertainty.

In this paper, we present a combination of intuitive and formal scenario approaches. Namely, we investigate how stakeholder perspectives that represent intuitive scenarios can be incorporated into model-based formal scenarios that are used for decision making under deep uncertainty. Rather than a predefined set of perspectives, we use problem-specific stakeholder perspectives. The purpose of this incorporation is to enrich the understanding of stakeholder perspectives and to strengthen the model-based approaches, and we examine whether these benefits are achieved.

Our study originates from a research program that involved two projects to develop robust strategies for the Dutch gas sector. One of the projects adopted a 'formal' scenario approach and used a simulation model to explore multiple possible futures (Eker 2016), whereas the other project followed an 'intuitive' scenario approach to identify the stakeholder perspectives about the future of the Dutch gas and energy sector (Ligtvoet et al. 2016). In this paper, we use the problem-specific stakeholder perspectives identified by Ligtvoet et al. (2016) to be incorporated into model-based scenarios and to form a basis for policy-oriented foresight.

In the remainder of the paper, Section 2 provides a brief overview of the Dutch gas sector, the model used to explore possible futures and the stakeholder perspectives identified by Ligtvoet et al. (2016). Section 3 describes the method of incorporating the qualitative stakeholder perspectives into a quantitative model-based analysis. Section 4 presents the results, followed by a discussion in Section 5 on the implications and potential of such an analysis. The paper ends with conclusions in Section 6.

2. The Dutch gas sector and six stakeholder perspectives

With an extraction history of more than fifty years, natural gas is the primary energy source and a prominent economic driver in the Netherlands, accounting for 39% of the total primary energy supply (CBS 2016) and contributing around 15 billion euros to the annual state budget (EBN 2014). This role of natural gas in the Dutch energy system is expected to change in future. A main indicator of this change is the declining natural gas production related either to resource depletion or to the capping policies that aim to prevent extraction-induced earthquakes. Another indicator is the transition towards a renewable energy system where natural gas is expected to lose its leading role and play a

[2] The perspectives method has been applied to cases in sustainable development and water management (Hoekstra 1998, Middelkoop et al. 2004, Offermans, Haasnoot, and Valkering 2011), and has been incorporated into the Dynamic Adaptive Pathways method of Haasnoot et al. (2013).

complementary one. The most recent energy agenda of the Dutch government emphasizes this, by stating their intentions to reduce gas consumption especially in households and to invest more in sustainable energy (MEZ 2016). Several technological, societal and political deep uncertainties regarding the supply, demand, market and infrastructure of gas exist, and they make it difficult to assess how the future can unfold. Moreover, there is ambiguity in the Dutch gas sector about the desired future state, which stems from the multiplicity of actors in the sector and the variety of their interests. These interests are often conflicting. For instance, the production goal of natural gas producers contradicts with the renewable energy goal of the government and environmentalists. Eker (2016) outlines this policy problem in detail and presents an analysis to seek robust policies in view of uncertainties and conflicting objectives. This analysis is based on a simulation model and a wide variety of scenarios generated with it.

In this study, the same simulation model is used to explore a large number of scenarios and the stakeholder perspectives are aligned with the elements of this model, as will be explained later. The model was built based on the best available scientific and expert knowledge, with a particular attention to represent uncertainties. It was developed prior to the identification of stakeholder perspectives, and did not account for them explicitly. It holds a broad view of the energy system and the multidimensional energy policy in the Netherlands, and focuses on natural and renewable gas. The model includes the interactions between various supply options and demand groups, and the competition between the supply options for market share as the key mechanisms. The supply options covered by the model are domestically produced natural gas, imported natural gas, and domestically produced renewable gas. On the demand side, the gas demand from households and commercial buildings, industry, agriculture, transport, and electricity production are included in the model to be balanced by the supply options. Regarding the gas demand from the electricity sector, the competition of renewable technologies and fossil fuels is explicitly taken into account. A detailed description of this model and the data used for quantification can be found in (Eker 2016).

Ligtvoet et al. (2016) have identified six perspectives that describe what several aspects of the Dutch energy system are expected to look like in the next fifty years according to the key stakeholders in the sector. They consider these perspectives as qualitative exploratory scenarios that describe visions on the future of the energy system. The two dominant perspectives they identified are either pro-gas or pro-renewable, reflecting the main debate in the energy sector. More nuanced perspectives focusing on economic conditions or uncertainty have also been uncovered. A brief summary of these perspectives is presented in Table 1, while a more extended description of perspective narratives can be found in (Ligtvoet et al. 2016).

These perspectives have been derived from an application of Constructive Conflict Methodology (Cuppen 2012) that combines Q-methodology (Brown 1993) and stakeholder dialog. Q-methodology is based on the assessment of a set of statements by stakeholders in individual interviews, and a statistical analysis of the results of this assessment. These specific and succinct statements named Q-statements provide an analytic component to the perspective narratives and facilitate incorporating them into an analytic, model-based scenario development framework. Furthermore, the perspectives were reinforced and elaborated on by the stakeholders in two participatory sessions as Ligtvoet et al. (2016) describes.

Table 1: Summary of the six stakeholder perspectives presented by Ligtvoet et al. (2016)

Perspective name	Key concept
P1 - In gas we trust	Natural gas will still be an important energy source.

P2 - In renewables we trust	Renewable technologies will prevail.
P3 - Adaptive gas sector in an uncertain future	The gas sector will be able to adapt to changing conditions.
P4 - Gas in times of austerity	Natural gas, as a cheap energy source, will prevail due to austerity conditions.
P5 - We need all energy sources!	A wide variety of energy technologies will be required and used to be able to satisfy demand.
P6 - Entrepreneurs serve the market better	To steer innovation and reduce costs, entrepreneurs and small companies will gain importance.

3. Methods used to quantify and analyze the perspectives

As mentioned before, we aim to incorporate stakeholder perspectives into model-based scenarios so that the understanding of possible futures can be enhanced and a basis for identifying socially robust policies can be constructed. In this section, we describe our method of translating qualitatively defined stakeholder perspectives into quantitative, analytical terms so that they can be represented by model-based scenarios. Firstly, we briefly introduce the analytical framework and tools these scenarios are based on, then describe the approach we followed to combine the perspectives with this framework. Lastly, we describe how we further analyzed the relationships between perspective elements to examine their achievability and plausibility.

3.1. An analytic framework for model-based scenario exploration

Most model-based policy analysis studies are based on a problem structuring framework that defines a policy problem based on its various components. These components are (1) value systems of the stakeholders and policymakers which include objectives and preferences, (2) outcome indicators that represent a policy goal and help assessing the performance of policies, (3) policy variables that are used to intervene in the system and improve the outcomes, (4) external factors that affect the system and (5) the system model representing the 'real' system within certain boundaries (Thissen 2013, Walker, Marchau, and Kwakkel 2013). Within this framework, uncertainties may exist in external factors, corresponding to model parameters, in the system model corresponding to model functions and structures, or in the value system such as preferences.

In the context of such a model-based study, each scenario corresponds to a different simulation of the model with different combinations of the instances of model uncertainties, e.g. parameters, functions and structures. Figure 1 exemplifies a scenario space generated in this way, where each black line corresponds to a simulation result, hence a scenario, and the gray region denotes the scenario space covered by a large number of individual simulations. The instances of uncertainties are picked up from the alternative ranges (of parameters) or sets of uncertain model elements (of functions and model structures). In the case where no particular stakeholder perspective is considered, these uncertainty ranges cover all alternative values obtained from different data sources (such as governmental, industrial or academic databases or scientific publications), or correspond to the entire possibility range such as [0, 1] for a fraction, or a wide interval around the reference values. The entire list of uncertainty ranges for parameters and sets for functions used for the Dutch gas sector model can be seen in (Eker 2016), as well as a description of the alternative model structures used to represent structural uncertainty. Using this simulation model and sampling from the uncertainty ranges and sets, a large number of simulations is generated. This large number of simulations is handled using the EMA

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Workbench (Kwakkel 2017), which is a free software package created with the Python programming language to conduct numerous simulations in an automated manner and to analyze the resulting data.

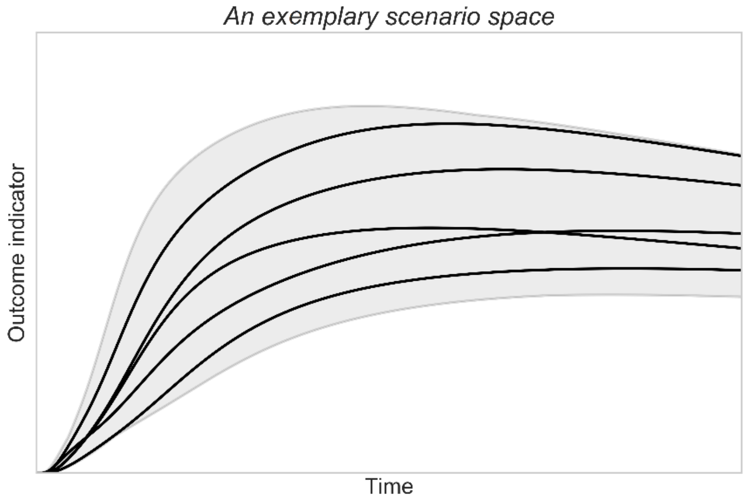

Figure 1: An example of a scenario space

3.2. Model-based representation of the six stakeholder perspectives

The approach we followed in this study to incorporate stakeholder perspectives into model-based scenarios is based on the assumption that the narrative of each perspective corresponds to a subset of model-based scenarios generated by the entire uncertainty ranges and sets mentioned above. Figure 2 exemplifies such a subset for Perspective 1 (see Table 1) for the outcome indicator *Share of Renewables in the Energy Mix*. In this figure, the green lines correspond to the Perspective 1 scenarios, where each line depicts the trajectory of *Share of Renewables* in the corresponding scenario between 2012 and 2062. The grey shaded area depicts the envelope[3] of such trajectories generated by the model without considering any particular perspective. For each perspective, we formed such subsets of the scenario ensemble generated by the model after deriving a model-based representation of the perspective narratives. The procedure we followed for this model-based representation has three main steps explained below.

[3] An envelope illustrates the bandwidth between the minimum and maximum value of an outcome indicator in these scenarios at each time point.

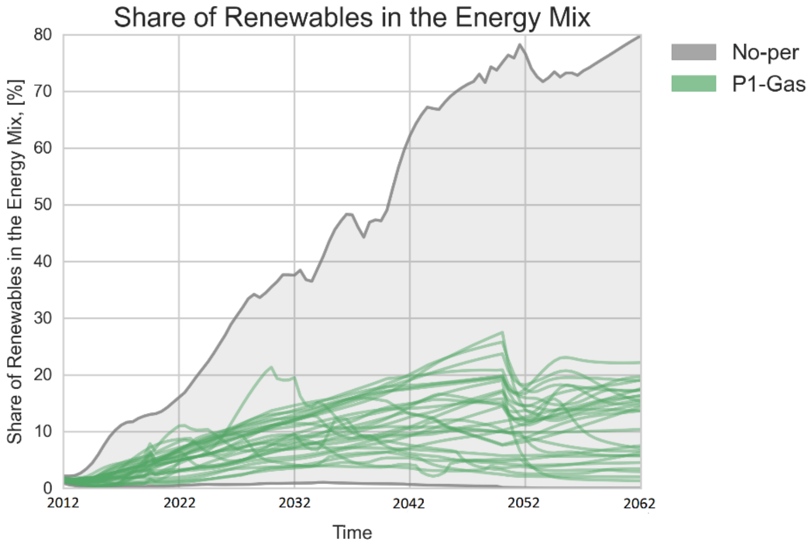

Figure 2: The subset of scenarios corresponding to Perspective 1 (P1-Gas), and the entire set of scenarios (No-per) for the variable *Share of Renewables in the Energy Mix*

Step 1: Matching the Q-statements and model elements

In the first step, detailed descriptions of the perspectives and their defining Q-statements were examined. The defining Q-statements of a perspective are the statements agreed or disagreed with most by the stakeholders who are associated with that perspective after the statistical analysis. The entire list of these statements and how they are scored in each perspective can be seen in (Ligtvoet et al. 2016). Since each Q-statement is focused on a particular aspect of the energy sector, these statements can be matched with a model element. For instance, "*Liquefied Natural Gas (LNG) imports will increase, contributing to security of supply.*" is a statement agreed with most in Perspective 1. We matched this statement with the model variable *Annual Import Volume by LNG*. In this way, we formed a comprehensive list of model elements corresponding to the Q-statements that define the perspectives, including both inputs (parameters and functions) and dynamic output variables (system variables or outcome indicators) of the model.

The Q-statements used by Ligtvoet et al. (2016) refer to one or many of the dimensions of a policy problem mentioned in Section 3.1, i.e. to system variables, outcome indicators, and/or uncertainties. Therefore, to outline a perspective's model-based representation, the model components related to Q-statements can be given numerical values corresponding to the narrative of that perspective. However, the Q-statements used in Ligtvoet et al.'s study include not only statements about what is *expected* to happen in the future, but also normative statements about what *should* be done. In other words, they consist of both future views and expectations of the stakeholder groups corresponding to outcome indicators, system variables or uncertainties, and their preferred prescriptions corresponding to value systems and policy options. For our purpose, we assume that the perspectives describe how various stakeholder groups envision the future, rather than describing their desired futures or suggested solutions. Therefore, the perspectives are considered as descriptive scenarios which are assumed to be formed based on system variables, outcome indicators and uncertainties.[4]

[4] An exemplary descriptive statement is "*Natural gas at the household level will be substituted by electricity and district heating networks.*", whereas an exemplary normative statement is "*An all-electric society based on renewables should be achieved and gas should play a minor role.*" Our assumption implies that the latter is considered as "*An all-electric society based on renewables will be achieved…*"

Step 2: Collaborative discussion on the match between the model elements and perspectives

The second step involved the team of five researchers who worked on identification of the stakeholder perspectives with the Q-methodology and who facilitated the stakeholder dialog workshops where these perspectives were elaborated. The team was presented with the list of model elements resulting from Step 1 to discuss each model element in terms of its relevance to each perspective. Eventually, the research team identified the representative model elements of each perspective with consensus, and decided on whether each of these elements is expected to take high or low values in the future according to that perspective. It must be noted that none of the perspectives included quantitative indicators about the future values. Therefore, this assessment has been done with qualifiers such as 'high' and 'low'. Also, this assessment benefited from the profound understanding of the research team about the perspectives based not only on the Q-statements but also on the stakeholder dialog.

Step 3: Quantification of the perspective definitions

In the last step, the information collected in the previous steps was translated into a quantitative specification of perspectives in terms of model inputs and outputs. First, input conditions are set as modified uncertainty ranges. For instance, according to Perspective 1, the natural gas industry will invest more in exploration activities to discover new small fields. The parameter corresponding to this statement is *Normal Intended Investment in Exploration*, and its uncertainty range is narrowed down to [0.3, 0.35] from [0.15, 0.35] as an input condition of Perspective 1. In general, if a parameter is determined to have a low value, its uncertainty range is reduced to the first quarter of the entire range, if a high value is specified, the upper quarter is used.

Following such revision of uncertainty ranges of inputs corresponding to each perspective, we generated an ensemble of 10000 simulations for each perspective. Next, we identified the subspace within each ensemble that complies with the output conditions of the corresponding perspective. In other words, the scenario subspace representing a perspective is defined as a set of assumptions on input and output conditions that reasonably matches the perspective.

Since there is no quantitative specification of output conditions, we opt to use the median value of the end states (the values at the end of the simulation horizon) of each output variable mentioned in a perspective narrative as a threshold for dividing the scenario space. In other words, if a variable is specified to have high values in a perspective narrative, the scenario subspace representing this perspective includes the scenarios only with end states above the median. An example of this representation is provided in Appendix A.

Appendix B presents the input and output conditions of each perspective resulting from this procedure and specifies their model-based representations.

3.3. Identifying the incompatible elements in model-based perspective representations

As explained in the previous section, the scenario subspaces representing each perspective are filtered from an ensemble of 10000 simulations based on the output conditions. (Note that these 10000 scenarios are generated according to the input conditions of the corresponding perspective.) These subspaces show a variety in size, but each of them is a small portion of the entire set of 10000 scenarios as Table 2 lists.

These small numbers are attributed to the difficulty of finding model-based scenarios where all output conditions of a perspective are satisfied simultaneously, given the input conditions of this perspective which, of course, also affect the co-occurrence of certain output conditions. To investigate which outcome conditions mainly cause this decrease in the size of scenario subspace, we adopt a pairwise comparison approach. We first define an 'incompatibility measure' in order to determine the extent of incompatibility between each pair of output conditions, and to compare this to other pairs. This measure enables an ordering of the output condition pairs in terms of how much their joint occurrence restrains the scenario space.

Table 2: Number of scenarios found, representing each perspective

Perspective name	No of Scenarios in 10000
P1 - In gas we trust	28
P2 - In renewables we trust	341
P3- Adaptive gas sector	69
P4 - Gas in times of austerity	63
P5 - We need all energy sources!	92
P6 - Entrepreneurs serve the market better	70

This 'incompatibility measure' is defined as the percentage decline in the number of scenarios when two outcome variables are taken into account simultaneously compared to the number of scenarios when one of these is considered alone. Equation 1 shows the formulation of this measure $C_{i,j}$, where N_i is the number of scenarios found when only the output condition of variable i is considered, and $N_{i,j}$ is the number when the conditions for variables i and j are considered simultaneously. These scenario counts are determined according to the median value obtained from 10000 end state values of each scenario ensemble formed with the perspective-specific input conditions, as mentioned before. Figure 3 illustrates these scenario subsets, where each dot represents a scenario with corresponding values of the variables i and j in the two axes. In this example, the two outcome variables take 'high' values, hence the regions above the median values are shaded. N_i and N_j are the number of scenarios in the sets they refer to, and N_{ij} is the number of the scenarios in the intersection.

$$C_{i,j} = \frac{N_i - N_{i,j}}{N_i} \quad (1)$$

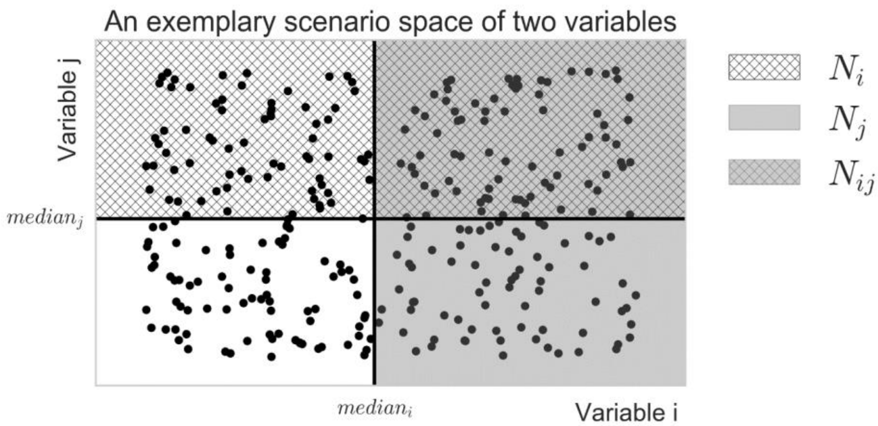

Figure 3: Illustration of scenario subspaces corresponding to two output conditions

Such an incompatibility measure could be defined in different ways, for instance by considering the increase in the number of scenarios when one of the outcome conditions is removed from the entire set of outcome conditions of a perspective. Different indicators, such as the range of scenarios, could as well be used instead of a cardinality measure. Yet, we select the above mentioned measure due to its

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simplicity, and its ability to represent the independent effect of an outcome condition on the scenario space.

4. Results

This section firstly presents the scenarios generated by the simulation model corresponding to each perspective, discusses their characteristics and comparison to each other. Then, it investigates the incompatible output conditions of the perspectives to obtain insights not only about the problem complexity but also about the differences between the model-based scenarios and perspective narratives.

4.1. Exploring the perspective-specific scenarios

This section presents a visual comparison of the model-based perspective scenarios with respect to two outcome variables related to the policy goals of the Dutch government. These two variables are certainly not the only representatives of the policy goals, but they are chosen for illustration purposes, i.e. to provide a common ground for the comparison of perspectives to each other, and to the entire set of model-based scenarios. Similar figures for other outcome indicators can be seen in the supplementary material. The set of scenarios generated without any perspective restriction is named 'No-perspective' in the rest of this section. In the figures below, the scenario sets corresponding to each perspective are visualized in envelopes as exemplified in the previous section and in density graphs of their end states. Density graphs show the Gaussian kernel density estimate (KDE) of end states, which is an indicator of the distribution of the output data at the end of the simulation horizon.

Import Dependency

Import Dependency, which is defined as the ratio of imported natural gas to the total gas consumption in the Netherlands, is the first outcome variable we use to compare the perspectives. Figure 4 shows the envelopes of the trajectories this variable follows in the final scenario subsets corresponding to each perspective, and the no-perspective case. According to all perspectives except Perspectives 2 and 6, the possible values of *Import Dependency* move towards the upper ranges of the spectrum over time. In other words, there are scenarios where future import dependency is still low according to only Perspectives 2 and 6, which expect a renewable-based and a market-oriented energy market, respectively. For all other perspectives, the Dutch gas supply is almost 100% import dependent by 2062.

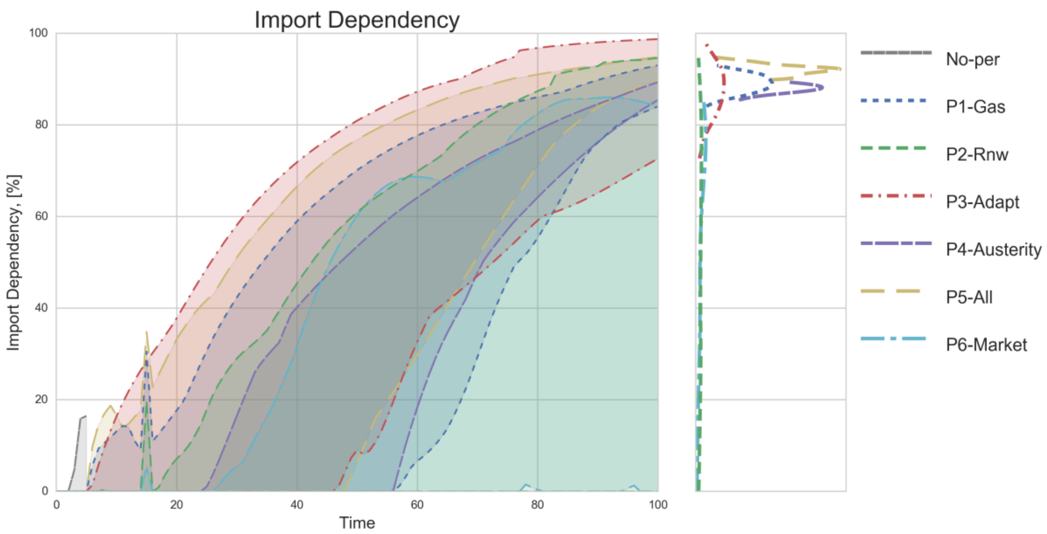

Figure 4: Envelopes of *Import Dependency* for each perspective and the density graph of end states

Additionally, Figure 5 indicates that the density of scenarios with high import dependencies increases over time, regardless of the perspective. In 2020, import dependency is at the zero level in almost all scenarios according to P2 and P6 indicated by very steep density curves around 0, yet the scenario ranges expand and densities shift towards higher values even for these two perspectives. In the scenarios of Perspectives 1, 4 and 5, import dependency at the end of the simulation horizon is very high, as the steep density curves point out. These results are attributed to the specification of the output conditions of Perspectives 1 and 5, expecting high import volumes, and the lack of domestic production in the case of austerity (Perspective 4) although the perspective definition includes low import dependency. Such high values of import dependency are conceivably not in line with the low import dependency goal of the government. According to Perspective 3 which primarily expects an adaptive gas sector, the end state values are still in a high band, yet with a flatter distribution, indicating the potential for a lower import dependency. The density estimates of Perspective 2 and 6 cover a wide range including very low values. While such low import dependency is specified in the definition of Perspective 6, for Perspective 2 it is attributed to low gas demand expectations.

Share of Renewables in the Energy Mix

The share of renewable energy in the total energy mix is a distinctive factor for the perspectives. As Figure 6 shows, Perspective 1, 4 and 5 include scenarios with very low (0-10%) share of renewables in 2062, which is to be expected considering the gas-dominant view of especially Perspectives 1 and 4. Still, a large number of scenarios even in these perspectives fall above 10%. In the other three perspectives, the minimum end-state value of the share of renewables is above 10%, showing scenarios with up to 60% contribution. Such a scenario range is conceivable for Perspective 2, yet it also shows similar results for Perspective 3, which expects the gas sector to adapt to future conditions, indicating a complementary role of gas to renewable energy. Despite their distinctive views on the share of renewables, the scenario ranges of six perspectives are not mutually exclusive. They still have a considerable intersection region, indicating a shared vision.

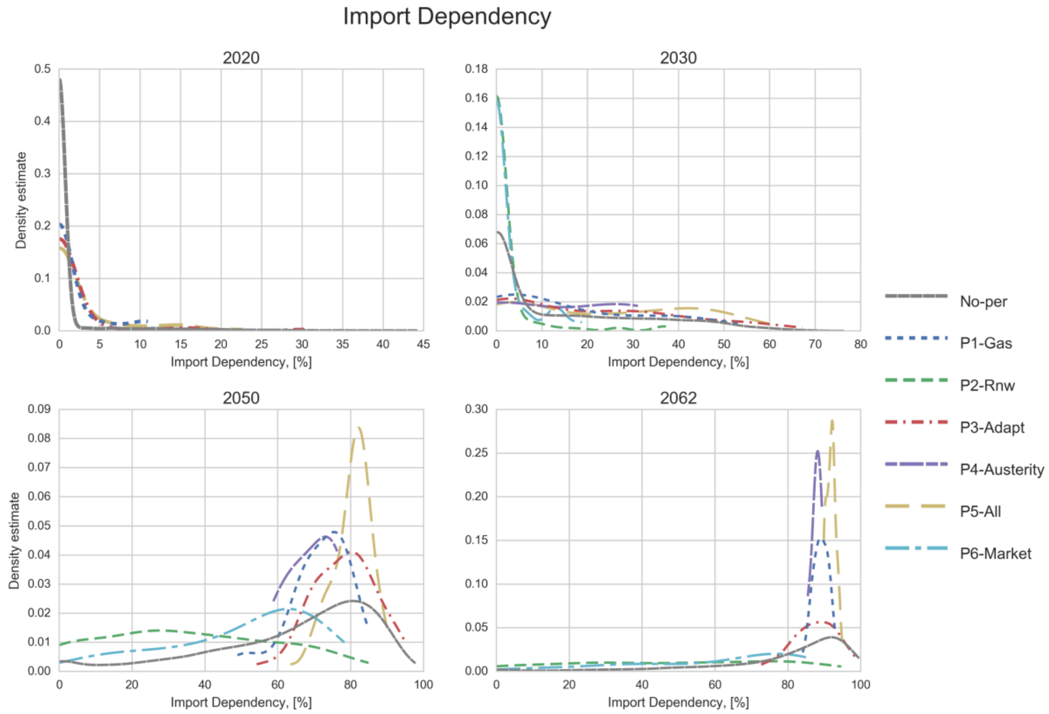

Figure 5: Density graphs of *Import Dependency* for each perspective in 2020, 2030, 2050 and 2062; with density values on the y-axis and Import Dependency values on the x-axis

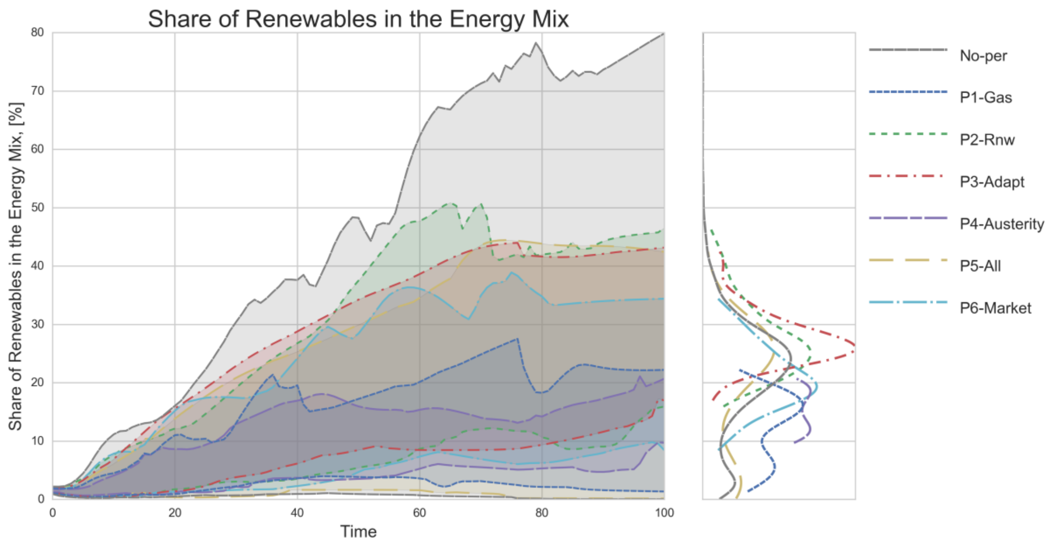

Figure 6: Envelopes of *Share of Renewables in the Energy Mix* for each perspective and the density graphs of the end states

4.2. Investigating incompatible elements of model-based perspective representations

In this section, we analyze the relationships between the perspective elements using the incompatibility measure described in Section 3.3. Here we present the results only for Perspectives 1, 2 and 6. The remaining results can be seen in the supplementary material. Below, the incompatible output conditions of each perspective are visualized in a bubble graph, which is based on a grid of the output variables. A circle is plotted on this grid if the incompatibility metric (C_{ij}) of the corresponding two output variables is higher than a certain threshold, i.e. to mark the combinations which cause more than 50% reduction in the number of scenarios. Variable *i* of the metric is located on the x axis, whereas variable *j* is located on the y axis[5]. The circles are plotted in bigger size and darker color, as the incompatibility measure increases.

Perspective 1 - In gas we trust

According to Figure 7, it is most difficult to find scenarios in which both *Coverage of Domestic Gas Demand* and *Total Natural Gas Demand* are high, which are the two variables marked by the largest and darkest circle. *Coverage of Domestic Gas Demand* is a variable that indicates to what extent the domestic demand is met, and it is defined as the ratio of total supply in the Dutch gas market to the total domestic demand. Therefore the inverse relation between these two output conditions of *Coverage of Domestic Gas Demand* and *Total Natural Gas Demand* explains the conflict. This finding implies that the supply levels are not sufficiently high to maintain high demand coverage values, as opposed to the expectation in Perspective 1.

The second highest incompatibility is between a high *Coverage of Domestic Gas Demand* and a high *Annual Import Volume*, which can be attributed both to perspective expectations and model formulations. In the model, it is assumed that the purpose of imports is to cover the domestic supply shortage, i.e. to make the demand coverage 100% if the domestic gas production does not suffice. In this perspective, *Coverage of Domestic Gas Demand* has a narrow uncertainty range at the end of the simulation horizon with a median value around 100% (Figure S.1 in the supplementary material). Due to the model formulation of imports, scenarios where *Coverage of Domestic Gas Demand* is more than the median are not observed together with high imports, but only with high domestic production.

Another combination that causes a high reduction in the number of scenarios is *Total Natural Gas Demand* and *Total Domestic Gas Production* which are both expected to be high in future in Perspective 1. Such scenarios are rare in the scenario set, because in the model the depleting reserves limit the production and increase the price, which leads to low demand, as opposed to the expectations in that perspective.

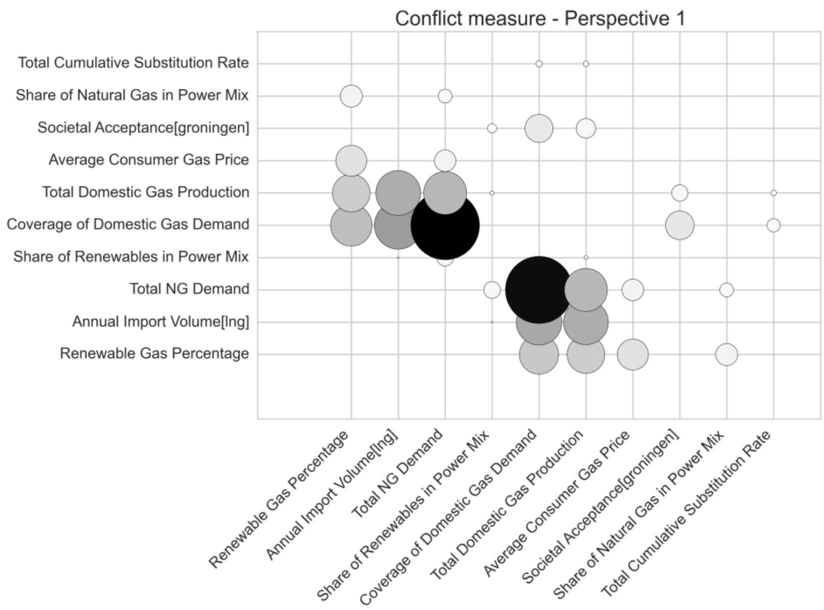

Figure 7: Incompatible outcome variables of *Perspective 1 – In Gas We Trust*

[5] The symmetric incompatibility measures $C_{i,j}$ and $C_{j,i}$ are very similar to each other, since N_i and N_j are similar to each other due to the division of the scenario space at the median value. Therefore, the figures shown in this section to depict the incompatibilities are mostly symmetrical.

Perspective 2 – In renewables we trust

Figure 8 visualizes the most incompatible output variables of Perspective 2. A high *Renewable Gas Percentage*[6] and a low *Share of Natural Gas in the Power Mix* are the two conditions which cause the highest reduction in the number of scenarios when considered together. This incompatibility is attributed to the underlying causal structure of the model and scenario assumptions. Namely, in the case of low natural gas share in the power mix, electricity prices are expected to be high because other technologies are costlier in the model. High electricity prices attract more biomass sources to the electricity sector and leaves less for the renewable gas production. Therefore, *Renewable Gas Percentage* cannot grow. Since we do not consider any policy interventions yet in these scenarios, e.g. different financing mechanisms or market regulation structures, there is an inverse relation between the levelized cost of an electricity generation technology and its share in the power mix in the model-based scenarios. However, the stakeholders of this perspective may already be taking different financing mechanisms into account while expecting a high *Renewable Gas Percentage* and a low *Share of Natural Gas in the Power Mix* simultaneously.

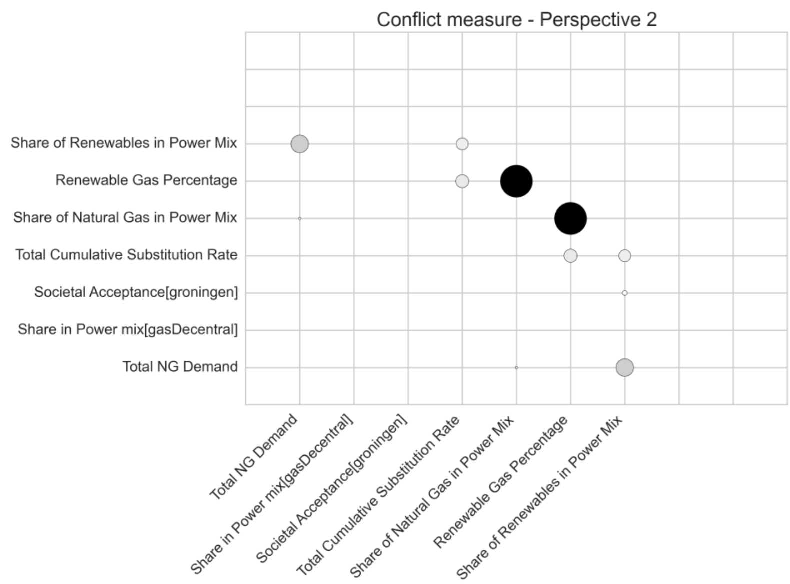

Figure 8: Incompatible outcome variables of *Perspective 2 – In Renewables We Trust*

The following substantial conflict is observed between the *Share of Renewables in the Power Mix* and the *Total Natural Gas Demand*, since the former is expected to be high and the latter to be low in Perspective 2. The reason for this incompatibility is the following causal relations in the model: Low natural gas demand brings high *Coverage of Domestic Gas Demand*, which leads to lower natural gas prices. A low gas price makes it more attractive for the electricity production, increases its share in the power mix, and reduces the share of renewables. It must be noted that demand is not the only factor affecting the Dutch gas prices in the model, and gas prices are not the only factor that affect the share of renewables in the power mix. However, the above analysis indicates that these causal mechanisms are frequently dominant in the model-based scenarios, and the scenarios that comply with the vision of Perspective 2 are rare. Therefore, it can be said that either the stakeholders of Perspective 2 have not

[6] *Renewable Gas Percentage* is the variable that represents the share of renewable gas (biomethane) in the total gas consumption. It is produced from biomass resources, upgraded to the natural gas quality and injected into the natural gas grid. The simulation model used in this study captures the competition between the electricity and biomethane sectors for using the limited biomass sources.

considered these causal relations, or the causal mechanisms underlying the mental models of the stakeholders are not dominant or present in the model-based scenarios.

Perspective 6 – Entrepreneurs serve the market better

Perspective 6 envisions more market orientation in the future, and low gas and electricity prices as well as high share of renewables. However, low prices reduce the competitiveness of renewable energy technologies compared to natural gas, given that no support mechanisms are included in these scenarios. Hence, a high *Share of Renewables in the Power Mix* and a low *Average Consumer Gas Price* result as the two outcome conditions most difficult to co-exist in the scenarios, as seen in Figure 9.

The second major reduction in the size of the scenario subspace is found for a high *Share of Renewables in the Power Mix* and a low *Cumulative Biomethane Production via Gasification*[7]. This finding can be traced back to the effect of the natural gas price on these two factors. High gas prices stimulate a high share of renewables in the electricity sector, and enable biomethane production via gasification, which is economically competitive only when gas prices are high. Hence, low gas prices, which is a defining outcome condition of this perspective, enable a low biomethane production as expected in the perspective but not a high share of renewables.

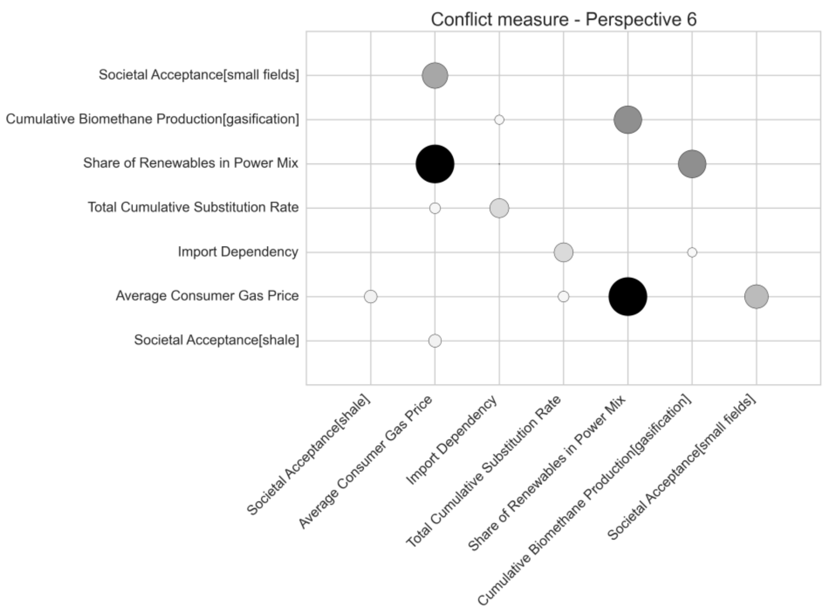

Figure 9: Incompatible outcome variables of *Perspective 6 – Entrepreneurs Serve the Market Better*

The examples above show that the incompatibilities between the output conditions of perspectives could have three main reasons. Firstly, the reason may be an internal inconsistency in the perspective narrative, which is mostly due to unconsidered but potentially present causal relationships, as exemplified by the conflict between the share of renewables in power mix and the biomethane production in Perspectives 6. In other words, some causal relationships might have been overlooked in perspective narratives due to the difficulty of capturing the complexity of a problem only by intuitive approaches.

Secondly, some incompatibilities found in the above analysis could be explained by model assumptions. As discussed with regard to Perspective 1, the model assumes that import values are positive only when

[7] Gasification is a biomethane production technology, which converts solid biomass into gas form. Compared to the more common digestion technology, gasification is more expensive, yet more promising in terms of its gas yield.

there is a domestic supply shortage, and this is the main reason of rare co-occurrence of high import values and high demand coverage in the model-based scenarios. Since the model development and perspective identification was not directly linked in this study, it is possible that the model does not cover all implicit or explicit assumptions of the perspectives. Alternatively, the model or stakeholder assumption could be incorrect.

Lastly, the reason of incompatibilities may lie in the model-based representation of the perspectives, i.e. in the assumptions made to translate perspective narratives into specifications of model elements. For instance, *Coverage of Domestic Gas Demand* is a model variable that resulted in major incompatibilities in Perspective 1, which expects a 'strong' gas sector in future. We (and the research team involved in Step 2) have set the high values of this variable as a precondition of Perspective 1 scenarios, with the idea that no supply shortages would occur in a strong gas sector. Despite the legitimacy of this link based on common sense, it lacks a one-to-one match with the Q-statements of Perspective 1 or a confirmation by its stakeholders.

5. Discussion

In this section, we reflect on our approach to incorporate stakeholder perspectives into model-based scenarios and on the results of this combination. We firstly discuss the potential of this approach for policy analysis and decision making under deep uncertainty, then its implications for futures studies, namely for the formal and intuitive scenario approaches. We also discuss the limitations of this study and how they can be overcome in future research.

5.1. Implications for decision making under deep uncertainty

The *decision making under deep uncertainty* techniques identify robust policies or strategies based on a wide set of scenarios. Namely, they find the decision options which can perform well in future regardless of how current uncertainties unfold. In this study, we explored the perspective-specific scenarios based on a systematic demarcation of the scenario space, and compared them in terms of the futures they foresee for various aspects of the energy sector. We consider this demarcation of the scenario space as the first step to explicitly account for various perspectives in model-based decision making processes under deep uncertainty. The analysis we demonstrated in this paper facilitates understanding the differences and commonalities of the perspectives better, based on their descriptive future visions and underlying causal models.

Further research can use the potential of this study and proceed with policy analysis based on the perspective-specific scenario sets. With perspective-specific scenarios, the techniques of decision making under deep uncertainty can be used to find robust policies for each perspective. Further analysis can investigate whether these policies are acceptable by other perspectives or not, and what the reasons are for both agreements and disagreements. In that way, the implications of various policy options for different perspectives can be communicated with the decision makers and stakeholders, and a more informed policy debate can be stimulated.

Furthermore, besides the differences between the perspectives, their commonalities can be a starting point for policy design. Section 4.1 showed that the scenario spaces of the perspectives have considerable intersection regions even for the variables corresponding to the most distinctive elements of perspective narratives. Scenario discovery techniques (Bryant and Lempert 2010; Kwakkel and Jaxa-Rozen 2016) can be used to analyze the characteristics of these intersection regions, so that we can learn which assumptions lead to these commonalities in the perspectives and we can use this information for developing socially robust policies.

5.2. Implications for formal and intuitive scenario approaches

This study where we incorporated stakeholder perspectives into model-based exploratory scenarios was a combination of intuitive and formal scenario approaches in methodological terms. Our motivation for this combination was to better understand the stakeholder perspectives identified with an intuitive approach, and to strengthen the model-based approaches by bringing in an explicit account of stakeholder perspectives.

In terms of better understanding the perspectives, the model-based scenarios explicitly demonstrated the shared and distinct future visions of the perspectives. This can potentially help not only in the policy debate as discussed in Section 5.1, but also in further quantitative analysis of the futures and policy options. The model-based incompatibility analysis provided insights about the potential barriers to the futures envisioned by the perspectives. Furthermore, as the incompatibility analysis showed, the perspective narratives possibly overlooked some causal relationships that can play an important role in how the future unfolds. This finding indicates the potential of formal approaches to complement the intuitive ones in capturing complexity, systematically describing the visions and trajectories, and testing their feasibility.

Section 4.2 also showed that the incompatibilities can be attributed to modelling assumptions and to assumptions made for the model-based representation of the perspective narratives. This finding implies that intuitive approaches help to detect the contested assumptions of modelling and analysis, which can be revised if necessary to better align with the important mechanisms in stakeholders' mental models. Moreover, intuitive approaches can reveal possible dynamics that cannot be captured by the model scope or a socioeconomic and technical modelling framework. In these ways, intuitive approaches can enhance the salience and credibility of formal approaches. Besides contesting the modelling assumptions, the intuitive approach in this study brought an explicit account of the diversity of views into the formal one as mentioned in Section 5.1, which can form a basis for identifying socially robust policies.

5.3. Limitations and future research

The approach we presented in this paper for model-based representation of stakeholder perspectives has a number of limitations. A primary limitation relates to the representation of perspectives only based on input and output values of an existing model. The input and output values provide a systematic and coherent connection between the model and the perspectives. However, as Section 4.2 identified, there are several examples of incompatibilities in the model-based perspective scenarios, and these may be due to the differences between the causal mechanism underlying the model and those underlying the stakeholder perspectives. In this study, there was no opportunity to collect feedback from stakeholders on the model-based representations, therefore we cannot say if some causal relationships were consciously disregarded by stakeholders, or if the model-based representation did not adequately align with the perspective narrative in stakeholders' minds. This limitation can be the primary point of departure for further research. Similar to the stakeholder dialog sessions used in Ligtvoet et al.'s (2016) study to elaborate on the perspectives, future studies can include participatory sessions where model-based representation and quantification of the perspectives are explicitly discussed. This is expected to address the reasons of incompatibilities identified in this study, to enrich the perspective narratives and to improve the credibility of perspective representations in analytical terms.

Furthermore, future research designs can benefit from a parallel development of the perspectives, the model and the model-based representation of the perspectives. Namely, an approach similar to the 'modelling route' of van Asselt and Rotmans (1996) can be followed to develop a specific model structure for each perspective, prior to scenario generation and analysis or iteratively to accommodate stakeholder perspectives in the scenarios generated by the model. Such a study undeniably requires more research resources and higher stakeholder commitment, yet it is deemed valuable for enhancing the benefits of model-based and intuitive scenario approaches.

Another limitation relates to the interpretation of Q-statements for model-based representation of perspective narratives. In this study, the analytical foundation of Q-methodology provided a promising opportunity for positioning the perspectives in a modelling framework. However, the perspectives were not identified purposefully considering the modelling framework, therefore we encountered a number of caveats. One of these caveats was the mixed nature of Q-statements, i.e. both descriptive and normative, which do not only refer to future visions but also specify preferred actions and values. Although these concepts are differentiated in model-based analysis frameworks, in this preliminary study, we assumed all Q-statements refer to future visions hence 'describe' the future scenarios. This assumption that blends descriptive and normative statements potentially reduces the richness of perspective definitions and distinctions between them. Therefore, differentiating between the descriptive and normative concepts, such as system assumptions, policies/actions, and preferences for outputs in future studies, especially in defining and analyzing the Q-statements, can provide multiple benefits. It not only helps to understand the stakeholder perspectives better, but also facilitates a more thorough model-based representation of the perspectives. Taking these caveats into account earlier in the research design can help avoid several drawbacks and enhance the benefits the formal and intuitive scenario approaches can gain from a combination.

6. Conclusion

This paper investigated how qualitatively defined stakeholder perspectives can be incorporated into quantitative, model-based scenarios used for dealing with deep uncertainty. The investigation focused on the scenario spaces specific to each perspective, and the incompatible elements within each perspective's narrative. The former, namely a systematic demarcation of the scenario space, highlighted the differences and similarities of the perspectives, potentially constituting a basis for identification of socially robust strategies. The latter, namely identifying the incompatible elements of perspectives, helped to identify relationships which are either not taken into account in the perspective narratives, or formulated differently in the model. Hence, this analysis provided more information about the problem complexity and potential barriers to the futures envisioned by perspectives.

To our knowledge, this study is the first attempt to incorporate stakeholder perspectives identified with Q-methodology into model-based scenarios. This combination is promising due to the analytic nature of Q-methodology which enables matching the perspective narratives and model elements rigorously. The method we used in this study for such a combination can be improved with customized research designs where stakeholder participation contributes to model-based representation of the perspectives. The modelling framework and a model-based analysis that incorporates perspectives can in return contribute to perspective elaboration and policy debate.

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7. References

Ben-Haim, Yakov. 2004. "Uncertainty, probability and information-gaps." *Reliability Engineering & System Safety* 85 (1–3):249-266. doi: http://dx.doi.org/10.1016/j.ress.2004.03.015.

Brown, Steven R. 1993. "A primer on Q methodology." *Operant subjectivity* 16 (3/4):91-138.

CBS. 2016. Energy Balance Sheet; key figures. Statistics Netherlands.

Cuppen, Eefje. 2012. "Diversity and constructive conflict in stakeholder dialogue: considerations for design and methods." *Policy Sciences* 45 (1):23-46.

EBN. 2014. Focus on Dutch Oil and Gas. Utrecht: Energy Beheer Nederland.

Eker, Sibel. 2016. "Dealing with Uncertainties in the Dutch Gas Sector: An exploratory modeling and analysis approach." PhD Thesis PhD Thesis, Faculty of Technology, Policy and Management, Delft University of Technology (doi:10.4233/uuid:1c03192c-135d-4db0-8df9-49cf1d52540b).

Eker, Sibel, Jill Slinger, Els van Daalen, and Gönenç Yücel. 2014. "Sensitivity analysis of graphical functions." *System Dynamics Review* 30 (3):186-205. doi: 10.1002/sdr.1518.

Groves, David G, and Robert J Lempert. 2007. "A new analytic method for finding policy-relevant scenarios." *Global Environmental Change* 17 (1):73-85.

Haasnoot, Marjolijn, Jan H Kwakkel, Warren E Walker, and Judith ter Maat. 2013. "Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world." *Global environmental change* 23 (2):485-498.

Halim, Ronald A., Jan H. Kwakkel, and Lóránt A. Tavasszy. 2015. "A scenario discovery study of the impact of uncertainties in the global container transport system on European ports." *Futures*. doi: http://dx.doi.org/10.1016/j.futures.2015.09.004.

Hoekstra, Arjen. 1998. "Perspectives on water: An integrated model-based exploration of the future."

Kasprzyk, J. R., S. Nataraj, P. M. Reed, and R. J. Lempert. 2013. "Many objective robust decision making for complex environmental systems undergoing change." *Environmental Modelling and Software* 42:55-71. doi: 10.1016/j.envsoft.2012.12.007.

Kunseler, Eva-Maria, Willemijn Tuinstra, Eleftheria Vasileiadou, and Arthur C Petersen. 2015. "The reflective futures practitioner: balancing salience, credibility and legitimacy in generating foresight knowledge with stakeholders." *Futures* 66:1-12.

Kwakkel, Jan. 2017. "Exploratory Modeling Workbench [Computer Software]." https://github.com/quaquel/EMAworkbench.

Kwakkel, Jan H, Sibel Eker, and Erik Pruyt. 2016. "How Robust is a Robust Policy? Comparing Alternative Robustness Metrics for Robust Decision-Making." In *Robustness Analysis in Decision Aiding, Optimization, and Analytics*, 221-237. Springer International Publishing.

Kwakkel, Jan H, Marjolijn Haasnoot, and Warren E Walker. 2014. "Developing dynamic adaptive policy pathways: a computer-assisted approach for developing adaptive strategies for a deeply uncertain world." *Climatic Change*:1-14.

Kwakkel, Jan H, and Erik Pruyt. 2013. "Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty." *Technological Forecasting and Social Change* 80 (3):419-431.

Kwakkel, Jan H., Warren E. Walker, and Vincent A. W. J. Marchau. 2010. "Classifying and communicating uncertainties in model-based policy analysis." *International Journal of Technology, Policy and Management* 10 (4):299-315. doi: 10.1504/ijtpm.2010.036918.

Lempert, R. J., D. G. Groves, S. W. Popper, and S. C. Bankes. 2006. "A general, analytic method for generating robust strategies and narrative scenarios." *Management Science* 52 (4):514-528.

Lempert, R. J., S. W. Popper, and S. C. Bankes. 2003. *Shaping the Next One Hundred Years: New methods for quantitative, long-term policy analysis*. Santa Monica, CA: RAND.

Ligtvoet, Andreas, Eefje Cuppen, Olga Di Ruggero, Kas Hemmes, Udo Pesch, Jaco Quist, and Donna Mehos. 2016. "New future perspectives through constructive conflict: Exploring the future of gas in the Netherlands." *Futures* 78:19-33.

McJeon, Haewon C, Leon Clarke, Page Kyle, Marshall Wise, Andrew Hackbarth, Benjamin P Bryant, and Robert J Lempert. 2011. "Technology interactions among low-carbon energy technologies: What can we learn from a large number of scenarios?" *Energy Economics* 33 (4):619-631.

Middelkoop, Hans, Marjolein Van Asselt, Susan A Van't Klooster, Willem Van Deursen, Jaap CJ Kwadijk, and Hendrik Buiteveld. 2004. "Perspectives on flood management in the Rhine and Meuse rivers." *River research and applications* 20 (3):327-342.

Offermans, Astrid, Marjolijn Haasnoot, and Pieter Valkering. 2011. "A method to explore social response for sustainable water management strategies under changing conditions." *Sustainable Development* 19 (5):312-324.

Pruyt, Erik, and Jan H Kwakkel. 2014. "Radicalization under deep uncertainty: a multi-model exploration of activism, extremism, and terrorism." *System Dynamics Review* 30 (1-2):1-28.

Rotmans, Jan, and Marjolein BA van Asselt. 2001. "Uncertainty management in integrated assessment modeling: towards a pluralistic approach." *Environmental monitoring and assessment* 69 (2):101-130.

Schoemaker, Paul JH. 1993. "Multiple scenario development: Its conceptual and behavioral foundation." *Strategic management journal* 14 (3):193-213.

Thissen, Wil A.H. 2013. "Diagnosing Policy Problem Situations." In *Public Policy Analysis: New Developments*, edited by Wil A.H. Thissen and Warren E. Walker. New York: Springer.

Van Asselt, Marjolein, and Jan Rotmans. 1996. "Uncertainty in perspective." *Global environmental change* 6 (2):121-157.

Van der Pas, JWGM, WE Walker, VAWJ Marchau, B van Wee, and JH Kwakkel. 2013. "Operationalizing adaptive policymaking." *Futures* 52:12-26.

Walker, Warren E, Vincent AWJ Marchau, and Jan H Kwakkel. 2013. "Uncertainty in the framework of policy analysis." In *Public Policy Analysis*, edited by W. A. H. Thissen and W. E. Walker, 215-261. New York: Springer.

Walker, Warren E, S Adnan Rahman, and Jonathan Cave. 2001. "Adaptive policies, policy analysis, and policy-making." *European journal of operational Research* 128 (2):282-289.

APPENDIX A: The median approach to quantification of perspective definitions

In this study, the median value of the end states of each output variable is used as a threshold to divide the scenario space. In other words, if a variable is specified to have high values in a perspective narrative, the scenario subspace representing this perspective includes the scenarios only with end states above the median. Figure A.1 exemplifies this division of the scenario space of an arbitrary outcome variable based on the median value. In this figure, x axis includes the end state values of this variable, whereas the y axis shows the density estimate, i.e. distribution, of these values in the scenario set. If this variable is expected to take high values according to a particular perspective, then only the scenarios that fall into the darker shaded area above the median will be included in the scenario subset of this perspective.

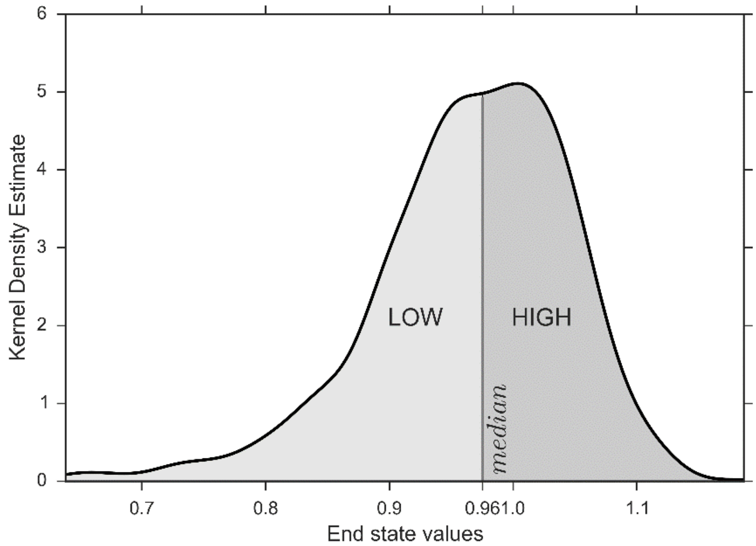

Figure A.1: Dividing the scenario space with the median value

The major disadvantage of this median approach is a potential failure to realistically represent the perspectives, because the scenario subspace related to a perspective definition may be wider or narrower than the median approach identifies. The median approach is chosen as a simple and transparent way to represent scenario subspaces, although further research can lead to more customized definitions.

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APPENDIX B: Model-Based Representation of the Six Stakeholder Perspectives

Input conditions

Model element	Normal uncertainty range	Perspective 1		Perspective 2		Perspective 3		Perspective 4		Perspective 5		Perspective 6	
		Ind.	**Range**	**Ind.**	**Range**	**Ind.**	**Range**	**Ind.**	**Range**	**Ind.**	**Range**	**Ind.**	**Range**
Normal Intended Investment in Exploration[small fields]	0.15-0.35	High	0.3-0.35	Low	0.15-0.2					High	0.3-0.35		
Normal Intended Investment in Exploration[shale]	0.15-1	High	0.75-1	Low	0.15-0.35					High	0.75-1		
Normal Intended Investment in Development[small fields]	1-2.5	High	2.1-2.5	Low	1-1.5					High	2.1-2.5		
Normal Intended Investment in Development[shale]	0.5-2.5	High	2-2.5	Low	0.5-1					High	2-2.5		
Effect of Disturbance on SA Lookup[8]		Low		High						Low		Low	
m	-0.5-0.5	Low	-0.05-0.05	High	0.25-0.5						-0.5-0		-0.5-0
p	0-2		0.5-1.5		0.5-1.5						0-1		0.5-1.5
l	0.75-1.5		0.75-1		0.75-1						0.75-1		0.75-1
u	0-1.5		1-1.5		0-0.5								1-1.5
Weight of Societal Acceptance	0-1	Low	0-0.25	High	0.75-1			Low	0 – 0.25	Low	0 – 0.25	Low	0 – 0.25
Effect of Prices on SA Lookup		Low		High				High		Low		High	
m	-0.75-0.75		-0.05-0.05		-0.25-0.25				0.25-0.75		-0.05-0.05		-0.25-0.75
p	0-2		0.5-1.5		0.5-1.5				0.5-1.5		0.5-1.5		0.5-1.5
l	0.5-2		1.5-2		0.5-1				0.5-1		1.5-2		0.5-1.5
u	0.75-1.25		0.75-1		0.75-1				1-1.25		0.75-1		1-1.25
Demand Switch Fraction [households]		Low		High		High		Low					

[8] Lookup (graphical) functions are commonly used in system dynamics modeling to represent nonlinear relationships. To include various forms of this function in the uncertainty analysis, the functions are parameterized by using the method described in (Eker et al. 2014)(Eker et al. 2014)(Eker et al. 2014)(Eker et al. 2014)(Eker et al. 2014)(Eker et al. 2014)(Eker et al. 2014). The reader is referred to this source for the meaning of parameters *m*, *p*, *u* and *l*.

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2015	0-0.01	0-0.001	0.005-0.01	0.005-0.01	0-0.001		
2025	0-0.02	0-0.005	0.01-0.02	0.01-0.02	0-0.005		
2035	0-0.05	0-0.01	0.025-0.05	0.025-0.05	0-0.01		

Output conditions

Model element	**Perspective 1**	**Perspective 2**	**Perspective 3**	**Perspective 4**	**Perspective 5**	**Perspective 6**
Total Domestic Gas Production	High			Low	High	
Annual Import Volume (LNG)	High				High	
Share of Natural Gas in the Power Mix	High	Low				
Total Natural Gas Demand	High	Low	High	High	High	
Societal Acceptance (Groningen)	High	Low				Low
Average Gas Price for Consumers	Low			High		Low
Renewable Gas Percentage	Low	High		Low		
Share of Renewables in the Power Mix	Low	High	High	Low		High
Coverage of Domestic Gas Demand	High		High	Low	High	
Coverage of Domestic Electricity Demand				Low	High	
Substitution Of Natural Gas By Renewable Gas	Low	High				High
Share in Power mix[gasDecentral]		Low		Low		
Transport Capacity Utilization Rate			High		High	
Total Natural Gas Demand except Industry			Low			
Societal Acceptance (small fields)			Low			Low
Societal Acceptance (unconventional)			Low			Low
Import dependency				Low	High	Low
Foreign Demand Coverage				Low		

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Biomethane Production via Gasification					Low