Decision-making by network operators in the Dutch energy transition

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Abstract

The energy transition is a pressing and widely debated topic in society and is creating global challenges. As the switch is made to sustainable energy carriers, more pressure is being put on to our electricity grids and the network operators managing them. They, however, face the uncertain future capacity needs of the grid and operate in a complex socio-technical system. The energy transition will require many collaborations and interactions which suggests a new decision-making process to facilitate the energy transition. An insight into the current decision-making processes of these network operators is however still lacking in literature and remains an open question. Therefore, in this thesis, I develop a conceptual model of the decision-making process by network operators for long term decisions under uncertain conditions. To achieve this aim, I first collected data about the decision-making system using semi-structured interviews of decision makers in the Dutch energy network. I then investigated models of decision-making in policy making, economic theory, and psychology literature and eventually chose the recognition primed decision-making (RPDM) model as fitting the most requirements. The model is built step by step and adapted to describe the analyzed decision-making system. The model is ultimately conceptualized in three layers: interactions between decision makers, individual decision-making, and changing problem perception. Significantly, the model is adapted to include the concept of a problem perception. The model has some limitations, as the face validation was not included in the modelling process and several mechanisms remain unspecified, such as the interactions between decision makers. Two decision situations that network operators themselves described facing in their current decision-making were used to run the model qualitatively. Given the limitations, the model was still able to provide insight into the decision-making of network operators. The model describes that decision makers respond to uncertainty by looking for more information, posing question to what extent reflection on the problem perception are also used to cope with uncertainty. The problem perception influences the model substantially, suggesting that a change in perception would make decisions such as the dilemma of prioritizing clients more adequate. Further implementation of the model is recommended to provide insight into the decision-making process to help facilitate the energy transition.

Keywords: Energy transition, decision-making, recognition primed decision-making, problem perception

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1. Introduction

The energy transition has become one of the most urgent challenges of our time as it will force us to shift towards sustainable and renewable energy sources (Gielen et al., 2019). Electricity is increasingly used as an energy carrier, so building an electricity grid that can transport the future electricity demand and production is a major challenge of the energy transition. One essential part of the electricity system are network operators, which are utility companies that build and maintain the electricity grid. To facilitate a rapid energy transition, these network operators will have to make substantial investments in the electricity grid in the near future, and regional and national network operators are already planning to make substantial investments in the upcoming 10 years (Liander, 2022). For example, TenneT, the Dutch national grid operator, announced that they will have to invest 7,8 to 8,7 billion euros in the coming 10 years to fix identified bottlenecks in their high voltage network (TenneT, 2022).

As Ed Nijpels, chair of the Dutch Climate Agreement (at the time), put it, the network operators are "being overtaken by the success of the energy transition" (Koster, 2021). In more rural parts of the country the capacity of the grid is insufficient to distribute solar-generated electricity to the rest of the Netherlands. In the bigger cities insufficient grid capacity makes it so new businesses are not able to be connected to the grid within the legally required time. This means that network operators are facing new dilemmas, such as prioritizing clients, that they did not face when the grid was still operating under capacity. Overall, the problems that network operators are facing are negatively influencing the Dutch energy transition because electricity plays such an essential role.

One major problem for network operators is how they make key investment decisions. An important characteristic of their decision-making system is that the investments must be made under uncertain conditions. Before the energy transition, network companies could more or less predict future energy needs using simple models based on economic activity (Jongepier, personal communication, 2021). Now, energy sources are intermittent, such as wind and solar energy, which can create high peak loads on the grid. Additionally, households and industries are increasingly electrifying their energy use, but the eventual mix of energy types remains uncertain. This uncertain energy supply and demand creates a future capacity of the grid that is difficult to predict. Thus, decision makers are facing a dilemma where they will have to make important decisions now for the future needs of a society that cannot fully be predicted.

Another characteristic of the investment decisions of network operators is that the investment processes in infrastructural projects are typically long. It requires a lot of space, material, and work-hours to build or update the vast networks of the electricity grid (Thacker et al., 2019). Furthermore, these resources are limited, and this scarcity creates another challenge for the network operators. Additionally, these big new structures are built in an existing system (Thacker et al., 2019), and in the Netherlands competition for the limited space is strong, and sufficient direction on spatial planning is lacking (PBL, 2021). Taken together, network operators must make decisions about the future of the grid within a complex landscape that faces many limitations.

The electricity grid, like other infrastructures, is not just physically intertwined with other systems, but is characterized by its interactions with a variety of actors and stakeholders. The electricity grid fulfils a basic societal function and therefore public values play a role in the decisions made by network operators and must be weighed against each other (Glachant, 2012). Also, many different actors, sometimes with conflicting interests and needs, are involved in those systems. For example, network operators interact with the regional and (intern)national grid, clients, and producers. Additionally, some actors can play multiple roles in these systems. Municipalities can simultaneously be clients of the network, shareholders of the network operators, and responsible for spatial planning. The national government, on the other hand, strictly regulates the network operators through the Authority for Consumers and Markets (ACM), for example by giving time limits for new clients to be connected to the grid (TenneT, 2022). These diverse social dependencies make the decision-making on investments by network operators even more complex.

Historically, the main focus of network operators was ensuring that the energy infrastructure works at all times, while incurring the lowest costs. As such they are strictly regulated by the ACM (Haffner et al., 2010). Until now the network companies have proven to do this successfully; currently, the Netherlands electricity system is considered one of the most reliable systems worldwide (Wilks and Bloemhof, 2005). The strict regulation influences the decision-making processes of network operators who are focused on reducing costs and ensuring the reliability of the grid.

Overall, we can see that the network operators are not just physically interdependent on the system that they work in because of the technologies they install, but they also have to socially interact with many diverse actors. Therefore, instead of seeing the social and the technological dimensions as separate systems, they can be viewed as one socio-technical system (Geels, 2004). However, as described above, the characteristics of investment decisions in the energy transition illustrate the complexity of this socio-technical system. The necessity for the energy transition to take place within this complex socio-technical system will require many collaborations and interactions and will cross traditional boundaries between private and public sector. This requires the network operators to work in networks that are new, and where "their standard operating procedures are no longer adequate" (Koppenjan and Klein., 2004). Therefore, it may be necessary to develop a new decision-making process for network operators to change these historic patterns and adequately build and maintain grids that can facilitate the energy transition.

1.1. Problem definition and aim of the research

To reflect on whether a different decision-making process might be more suitable for network operators in the energy transition, the first step is to gain insight into the current decision-making processes of these actors. Insight into the decision-making processes at the individual level can be used to describe the emergent behavior from a complex system. Such an insight is however still lacking in literature and remains an open question. Making models of decision-making can help to provide insight into the mechanisms behind these processes. Further, they can be used to simulate decision-making processes and test interventions or changes in behavior. However, currently no model exists that explores the individual decision-making process of network operators under uncertain conditions. Building such a model would give us a better understanding of the decision-making process of network operators that could eventually help them to facilitate the energy transition.

This thesis aims to create insight into the decision-making processes of network operators for long-term decisions under uncertain conditions. To achieve this goal the first step in the process is to build a conceptual model of decision-making. Therefore, the focus of this research will be to answer the question:

What is a conceptual model of the decision-making process by network operators for long term decisions under uncertain conditions?

1.2. Outline

To answer the research question this report is divided into eight chapters, including this introduction. In Chapter 2 I present the research approach and the selected methods. In Chapter 3 the decision system of network operators is analyzed. Chapter 4 starts by translating the system analysis into requirements for the conceptual model, which are then used to evaluate decision-making models found in literature. The best fitting model from the literature will represent the first conceptualization of the model. Chapter 5 adapts the model step by step to the decision-making system of network operators and concludes with a presentation of the conceptual model. Chapter 6 evaluates the model in several validation and verification steps before demonstrating the use of the model in Chapter 7. Finally, in Chapter 8 I interpret the main findings of the research and discuss their implications for the network operators and suggest directions for future research.

2. Research approach and methodology

To answer the research question, a research approach and various methods were selected. Below, the research approach and the methods are presented in chronological order as performed in the research and presented in the results section.

2.1. Research approach

The research describes the decision-making processes of Dutch network operators that operate both the high-voltage national grid and the regional grids. The Dutch network operators present their long-term investment plans in bi-yearly reports (TenneT, 2022, Lliander, 2022). The decision-making of Dutch network operators has been scoped to the decision-making processes leading up to these bi-yearly investment plans, as they represent the long-term investments of the network operators.

Research conducted on building simulation models of complex systems has shown that when building a model three phases are always reflected (Montevechi et al., 2015). The process starts with the model building phase, where the real system is defined, the problem is formulated, and the conceptual model is built (sometimes using requirements for model specification). The model building phase can be separated into two steps, starting with a model design, followed by a more detailed design specifying details required to program the model (Nikolic and Ghorbani, 2011). The developed conceptual model is validated and input data is collected. The next phase, model implementation, includes building the computer (sub) model and the verification and validation of that model. In the final analysis phase the experiments are designed, conducted and analysed and conclusions and recommendations are made (Montevechi et al., 2015). However, this modelling cycle is not entirely within the scope of this thesis which influences the model implementation phase. More specifically the model verification and validation and the model analysis have been adapted to a conceptual model, instead of an implemented model.

This thesis takes an explorative approach and as such, the model was not built to test a specific hypothesis. Instead, it was designed using models on decision-making from literature to describe the current decision-making process of network operators and explore the capabilities and implications of the conceptual model.

Based on the model building steps described in literature and this explorative approach, the thesis follows six steps: analysis of decision-making system, conceptualization based on literature, adaptation to the decision-making system, verification and validation, demonstration of model use. The methodology for each step is discussed below.

2.2. Methodology

2.2.1. Analysis of decision-making system

Network operators report on the decision-making process of in their investment plans which are published on their websites biennially. In these policy documents, the decision-making processes are described step by step in a formalized overview. Sourcing these documents is advantageous because the network operator institutes have developed them based on their own working processes. However, in reality, the decision-making processes might be different or more complex from what they describe.

Therefore, data on the perception of the decision makers was gathered. These data were gathered through semi-structured interviews (Harrel and Bradley, 2009). In contrast to unstructured or structured interviews, semi-structured interviews were found to be most suitable for this research as they are structured in topics but leave room for deviations where necessary. The semi-structured interviews were held with professionals from the Ministry of Economic Affairs and Climate Policy (EKZ), as well as regional and national network operators that were familiar with the decision-making processes under study. One interviewee worked at GasUnie, a company who maintains and builds the national gas network and faced challenges similar to those of the national electricity grid operator and was therefore considered relevant.

A list of interviewees can be found in Appendix I. All interviews were held in Dutch and summaries can be acquired by emailing the researcher. Quotes used from interviews have been translated to English. The interviews were recorded and recordings were deleted after finishing the research. The interviews present unpublished, personal information. However, this information is sensitive to subjective interpretation of the researcher whose norms could be projected on the information of the interviewees. The interviewees are from different departments, from different companies, representing different parts in the decision-making process. An interviewee is lacking from the committee that has decision-making power when choosing between decision alternatives.

The decision-making system was then analyzed by going over the steps as mentioned in the investment reports of network operators. Information was added on the perception the decision makers derived from the semi-structured interviews. This systems analysis provided the basis for further research steps.

2.2.2. Conceptualization based on literature

To better compare and select a model from literature some generalization of the analyzed decision-making system is needed. This generalization is done by summarizing requirements for the conceptual model based on the decision-making systems analysis (Section 2.2.1) (Balci, 2011). As the selection of requirements is sensitive to subjectivity, motivation for selection is included to improve the transparency of the research.

The conceptual model was based on existing models of decision-making in literature. decision-making is discussed in many academic fields so an exploratory study using grey literature and conversations with researchers working on decision-making was performed. This led to a focus on three different academic fields from which existing models were selected: policy making theory, economic theory, and psychological theory. Literature reviews from the three research fields were used to compile a list of decision-making models which were relevant to this analysis. The conceptual models in literature were screened and evaluated on their fit to the requirements derived from the decision-making system analysis. The conceptual model that could fulfill the most requirements was then selected.

2.2.3. Adaptation to the decision-making system

The selected model from literature was then further adapted to describe the decision-making system. Each step proposed by the model from the literature was discussed. At each step, it was analyzed whether the model from literature required adaptations to better reflect the decision-making system of network operators. If required, new concept were introduced into the model based on existing models in the literature previously identified in Section 2.2.2. The final conceptual model was presented in multiple figures where each figure reflects a layer of the model. A table was also developed with a step-by-step description of the model. To further illustrate the final conceptual model, a narrative is presented to simulate a decision maker approaching a fictive decision problem.

2.2.4. Verification and validation

To judge the accuracy of the conceptual model before use the model was verified and validated. The conceptual model was verified to check whether the model represents the intended concepts and relationships. It was then validated to ensure that it represents the intended decision system.

Conceptual model verification is different from implemented model verification because the model cannot be run to check its internal consistency and the structure. Therefore, the assessment of the capabilities of the model as expected from the description in the conceptual model is the only way to check the model performance. As such, the verification of the model is limited, and it will be beneficial and more rigorous to use two different methods of verification. First, the requirements were analyzed by evaluating to what extent each requirement has been met by the developed conceptual model. Second, the model was evaluated on whether it was internally complete, consistent and correct (DMSO, 2006). This was done using traces; tracking entities through each sub model and the overall model to determine the logic and accuracy (Maria, 1997). A narrative of the model, tracking the individual decision maker was presented as a conclusion of Chapter 5 - Adaptation to the decision-making system. This qualitative description of the model implies that the model can be assessed as consistent and complete.

The validation of the conceptual model was performed to evaluate whether the model is a correct representation of the analyzed decision-making system. The best-practice method for this evaluation is face validation, where an expert on the problem evaluates the conceptual model to judge whether they believe it is correct and reasonable for its purpose (Sargent, 2010). This would require another round of interviews with decision-makers. Such a face validation has not been performed due to the limited scope of this research. This validation of the conceptual model is seen as a crucial step to be taken before any further use of the conceptual model is considered. However, as the conceptual model was built based on existing literature, a validation step was included to evaluate the accuracy of the underlying theories and assumptions (Sargent, 2010). The existing models of decision-making that were used to build the conceptual model were reviewed and it was determined whether the analyzed decision-making system had the right properties to be able to be described by that existing decision-making model. A reflection was performed on the applicability of these theories, using insights from model building.

2.2.5. Demonstration of model use

In order to demonstrate insights that the conceptual model is able to provide on the decision-making of network operators, the model was run qualitatively. As described above, it is outside the scope of this thesis to run the model using an existing case study. Instead, two different decision situations, both described by network operators as typical for their current decision-making, were used to conduct a parametrization of the model. As the model was developed to describe the decision-making in a non-quantified manner, the parametrization was done by describing the parameters qualitatively and their motivation was explained. Only general effects of parameter changes are discussed as the qualitative nature of this approach makes it difficult to estimate the order of magnitude of these effects.

3. Analysis of the decision-making system

This chapter provides an analysis of the system in which the network operators make their decision on their investment plans. The process for investment planning has been formalized, with partial decisions divided in phases which combine to form a comprehensive policy document. Tennet, with the most detailed description available, serves as the main reference for this explanation, however other documents are considered (Tennet, 2022). Regional network operators describe similar processes (Liander, 2022). The steps as described in their formal reports are analyzed and enriched with perceptions of the network operators.

Generally, we can consider the development of the investment plan as a policy document, rather than a single decision. Over time, different partial decisions, made by different decision makers are made. These partial decisions build upon each other to form the investment plan together. The decision makers interact with each other and use each other's output. This happens in a fuzzy process where the interactions are not strictly defined.

3.1. Mapping out developments and scenarios

The investment process starts by developing a reliable estimate of capacity requirements for the electricity grid (Figure 1). To get an understanding of the future generated capacity and development of electricity demand and load patterns, network operators use both internal and external sources of information. The Integrale Infastructuurverkenning 2030-2050 (II3050) is used to let the scenarios fit within the plans until the year 2050. Examples of other documents used are the Dutch Klimaatakkoord, ElaadNL outlooks for scenarios on electric mobility, data centers, and law proposals on phasing out coal power plants. The data on potential developments is used to determine scenarios. Decision makers mention that, especially in this part of the process, the amount of information available is so high that it needs to be filtered, which obviously influences the rest of the decision-making strongly.

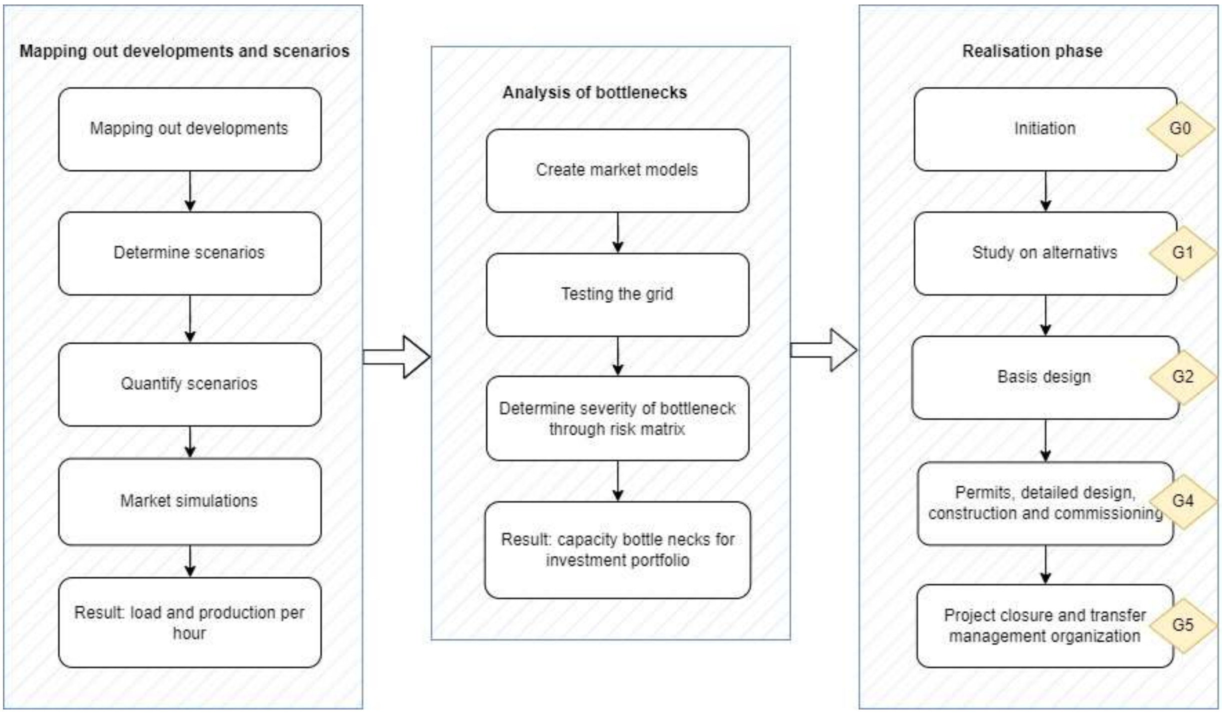

Figure 1. *Phases of decision-making process of investment plan adapted based on TenneT (2022).*

Currently, network operators use three different scenarios to capture the uncertainty inherent in future developments. These scenarios are developed in a collaboration with TenneT, Gasunie and regional grid operators—a new collaboration to try and synchronize developments throughout the country. Each scenario represents a possible future trend regarding the energy market and other developments. The number of scenarios that are used for calculation is limited in number because of limited modeling and calculation capacity. Together, the scenarios encompass the developments that network operators consider potential futures of the grid. Some decision makers mention that the models used currently are insufficient to deal with uncertainties or do not have the right focus. However, the simulation models still aim to reduce uncertainty, rather than using uncertainty as a starting point for analysis.

Next, these scenarios are quantified and are used to calculate the demand and production in electricity in three different benchmark years. Afterwards, market simulations are used to calculate the demand and production every hour, for example the peak load at night is different than during the day. Next, the production is calculated per hour and corrected by, for example wind availability in different provinces. This results in final analysis calculating a load and production per hour of the grid in the future.

3.2. Analysis of bottle necks

Analyzing bottlenecks is an important next phase of the decision-making model. The first step of this phase is creating a grid model (Figure 1). Here, the load on the grid is calculated spatially across the grid. These results are used by the net strategists to calculate the grid load of every scenario in the benchmark years. These power flow calculations have certain legal criteria for power outages, such a n-2 criteria for some sections in the grid, meaning that even when a part of the grid is under maintenance and there is an outage, the section of the grid should still function. This focus on reliability of the grid, among others, reflects the risk minimizing character of the decision-making process.

Next, the severeness of bottlenecks is determined by risk managers using a risk matrix. The effect on the grid is tested combining the production and demand from the market analysis from Section 3.1. The grid is tested for overload bottlenecks and possible bottlenecks in quality of the grid. Bottlenecks are evaluated in a risk matrix, including elements such as: safety, quality of the supply, expected financial costs, compliance to legislation, possible irreparable damage done to the environment while working on the grid, and potential damage to stakeholder relationships. These risk matrices have a strong focus on minimizing uncertainties and potential negative outcomes. All factors that could potentially risk investments are captured and quantified in such risk matrices, even factors that might be considered more social, like the impact on relations with stakeholders. All these aspects are quantified and scored, and if the score exceeds a threshold direct action is required. This results in the bottlenecks that are used for the investment portfolio.

One of the interviewees, working at the Ministry of Economic Affairs and Climate Policy mentions that the network operators perceive the regulations of the Authority for Consumers and Markets as quite strict. He hypothesizes that these values of risk reduction are not just there because of external regulations but have over time become internalized by the network operators. This reduction of risk also reduces freedom of movement for the network operators and might make their decision-making more conservative.

3.3. Realization phase

When the bottlenecks have been set, a process follows where multiple gates are identified that are used to formalize the governance around the decision process (Figure 1). It ensures the decisions made are as structured as possible. When bottlenecks require direct action, a study initiation form and/or a gate 0 document on initial alternatives are issued. These include a first exploration of alternatives. Then, a gate 1 document with decision on alternatives, with a preferential alternative is drawn up. This alternative might be investing in the infrastructure, but it also might be a different solution, as long as it solves the bottleneck. Next, a process follows where the right permits are arranged and the project is closed. The phase of arrangement of permits and closing of the project lies outside of the scope of this thesis.

3.4. Changing decision-making processes

In the report of TenneT a section is dedicated to the new issue of prioritizing different clients and bottle necks. Because the network operators are reaching their capacity and now have to decline requests to be connected to the grid, new decision problems arise such as prioritizing clients. Infrastructures such as the electricity grid are no longer unlimited and can no longer endlessly facilitate the needs of society. The reality where anything could be manufactured with enough money, people, time, and environmental boundaries is over. Westerga put it like this: "We are not yet equipped to make choices in the energy transition. We haven't got a clue. The targets are clear, but we still don't know what are the wise choices" personal communication, 2021).

TenneT mentions that they are in contact with ACM, EZK, regional stakeholders and other stakeholders to continuously update their strategies regarding this, but no full strategy has been developed. Pioneering does take place, and attempts are made to involve more stakeholders in their decision-making process to prevent the prioritization dilemma from occurring. "The network operators have the wish to interact more to make the investment plans. No more 'your wish is our command.' Instead, a more proactive communication saying, 'this is the infrastructure we can build'" (Westerga, personal communication, 2021). This also means that the network operators will have to increasingly work together with external partners. Jongepier (personal communication 2021) confirms this: "We are carefully trying to communicate what we can deliver. That means we ask municipalities to take the limitations of infrastructure into account. That's new."

However, most of the decision-makers have no experience with making such decisions and it requires another decision-making strategy. Interviewees mention that the political and societal factors that come into play in these prioritization dilemmas are hard to grasp and require different approaches to decision-making. For example: Westerga (personal communication,

2021) described a situation where "[you] have capital injections from municipalities, but then you tell the same municipality afterwards that they are at the back of the waiting list. This decision-making does not go through that kind of formal process and steps." That's however hard, as Jongepier (personal communication 2021) mentions: "The people working at network operators are technicians, used to calculations and certainty."

4. Conceptualization based on literature

In this chapter the analysis of the decision-making is simplified by summarizing the requirements for the conceptual model. These requirements are used to evaluate decision-making models in literature from three relevant fields where decision-making is well discussed: policy making theory, economic theory, and psychological theory. The chapter concludes with selecting the theory that can best fulfill the requirements and will be used to further conceptualize the model.

4.1. Requirements for the conceptual model

The requirements describe what the developed conceptual model shall be able to do. The motivation for the researcher to include a requirement is linked to the context of the Dutch energy transition (Chapter 1), the research approach (Section 2.1) or the decision system analysis (Chapter 3). The selection for each requirement is motivated below. Each requirement is given an alphabetical indication for future reference.

A. Modelled precisely and unambiguously

As described in the research approach, the conceptual model is a step towards the larger ambition to simulate decision-making processes of decision makers. Therefore, the conceptual model will be made with the implementability of the conceptual model in mind. This means that the decision-making process should be described in a precise and unambiguous way and should provide a clear structure.

B. Descriptive foundation

This research aims to describe the observed behavior of the decision maker, rather than describing what decisions *ought* to be taken. A theory of decision-making in the conceptual model should therefore not conflict with observed behavior from decision makers. Ideally it would be based on and validated with empirical data, and be as descriptive as possible when describing what has been observed to be a process of decision-making .

C. Interaction between decision makers

This thesis describes a complex system and therefore the model should be suitable to describe a complex system. The network operators function within a network of actors with which they interact, and through these interactions and individual learning emergent patterns arise. This means the conceptual model should describe the individual decision-making process of one decision-maker, in interaction with the actors around them. This is also reflected in the investment plan development process, where all smaller decision-making processes can be viewed as policy making process. The conceptual model should provide a structure on how to view these partial decisions in relation to each other.

D. Learning of decision maker

The learning of the decision maker should also be reflected in the conceptual model to allow for the complexity of the system. When making their investment plans, the decision makers base their decisions on the output from earlier decisions. They build on their experience from their earlier decisions and build upon decisions made by others. Decision makers also indicate a development in their decision-making processes, changing their opinion on what is necessary as the system develops.

E. Perception of decision-maker on information selection

Another characteristic of a complex socio-technical system is that it can interpreted in multiple ways. Network operators indicate that the information available on the energy system is so abundant that interpretation and selection is needed. This information selection is thought to be influential on the rest of the decision-making, given the wicked nature of the decision problems.

F. Describe decisions that are made in uncertain conditions and use simulation models

Network operators typically make decisions under uncertain conditions, as also mentioned in the research question. In the first phase of their investment plan the decision makers use simulation models to grasp the uncertainty of the future energy system. The conceptual model should be able to describe decisions made under uncertainty and include the use of models to cope with this uncertainty as this is the observed coping mechanism of the network operators.

G. Risk-avoidant evaluation of alternative decision options

Network operators have to weigh alternative decision options for development in various parts of the investment plan. Decision makers focus on reducing risk throughout the decision-making process, for example in the use of risk matrices and multiple formalized gateways. The network operators do not necessarily strive for maximization of profit or success, but rather look for ways that they can ensure compliance to the (high) standards on the service they provide. The conceptual model should include this risk-avoidant character.

To summarize, the requirements are:

A. Modelled precisely and unambiguously
B. Descriptive foundation
C. Interaction between decision makers
D. Learning of decision maker
E. Perception of decision-maker on information selection
F. Describe decisions that are made in uncertain conditions and use simulation models
G. Risk-avoidant evaluation of alternative decision options

4.2. Decision-making models from policy making

Decision-making is a topic in the field of policy analysis. The literature review from Teisman and van Buuren (2012) is taken as an overview here, which focusses on the question of how complex decision-making can be analyzed. Three conceptual models for analyzing decision-making are compared: the phase, streams, and rounds models (Figure 2). The latter is introduced by the authors themselves. All models of decision-making have different takes on what decision-making is and how to it should be analyzed.

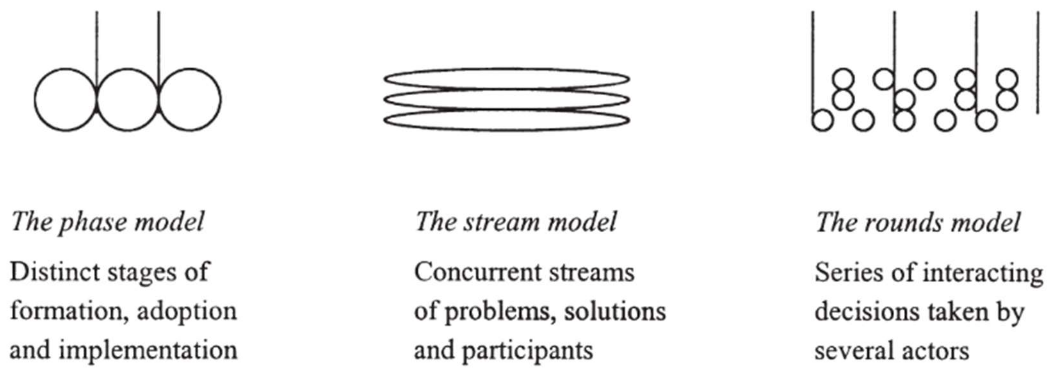

Figure 2. *A depiction of three models for the analysis of decision-making processes, adopted from Teisman and Van Buuren (2012).*

4.2.1. The phase model

The phase model describes the process of policy making in different phases, which are distinctly different and succeed each other. They are often divided into a problem definition phase and a solutions phase. In the problem definition phase, a problem or crisis is identified. In the second phase, several different actors (both governmental and non-governmental) work on developing policy to address specific problems. In the third phase of policy making, the policies are adopted and in the fourth stage implemented (Altman & Petkus, 1994). Note that in each phase, a different actor is working, and they are not active simultaneously in different phases, as the phases are thought to be separated in time.

Researchers who use the phase model acknowledge that the real-world situations of policymaking rarely conform to the linear decision-making process that is proposed by the model. As Bryson and Crosby (2005) note that "planning in shared-power situations hardly ever follows a rigidly structured sequence from developing problem definitions and solutions to adopting and implementing proposals. Serious difficulties arise when people try to impose this rigidly sequential approach on situations in which no one is in charge". Reconstructing policy making as though it was taking place in phases can be useful still, but this is good to know.

4.2.2. The stream model

The stream model has been developed in reaction to the phase model by Cohen et al. (1972) and developed further by Kingdon and Stano (1984). The streams model is based on the idea that policy making consists of three streams: problems, solutions/policies, and politics. In the first stream the decision-making consists of the discussion of the problems. In another stream the solutions are discussed. And the third stream consists of the normative context of a policy: the attitude of the public, campaigns by pressure groups, and ideological contributions (Kingdon and Stano, 1984). The three streams are thought to exist simultaneously. The three streams can be seen as three separate worlds which follow their own dynamics. Actors can be working in multiple streams at the same time, having different objectives. According to this conceptual model, major policy changes are likely to occur only if the three streams become linked (Teisman and van Buuren, 2012).

4.2.3. The rounds model

The rounds model combines elements from both the phase model and the three streams model (Teisman and van Buuren, 2012). In the rounds model the focus is brought back to the actors. However, in contrast to the phase model, the problems and solutions are not bound to a single actor. Complex decision-making is thought to involve many policy makers who take decisions. To understand this complex process, the rounds model takes into account a variety of elements and their interactions.

As the name suggests, the policy process is thought to occur in rounds. A round can be defined post-hoc and represents the process leading to a decision on a topic that is deemed to be crucial and serves as an important point of reference for later behavior of actors (Teisman and van Buuren, 2012). In such a round, multiple actors contribute to the outcome by taking decisions, even if they are unaware of each other. Decisions are clustered in rounds and the different actors either build upon other decisions, combine results, or anticipate future decisions.

4.2.4. Evaluation of requirements met by policy making theories

In Table 1 the selected theories are evaluated on the requirements developed earlier in this model. Based on the reflection it can be stated that the theories do not provide sufficient guidance or structure for a large part of the requirements. The models are able to describe the context of the policy processes in which the individual decisions are taken rather than the individual processes. The policy models could provide insight into the interactions between actors and the process of partial decisions forming a policy document together. In particular, the rounds model provides insights in how different decision makers relate to each other, but it does not provide enough structure upon which to base the conceptual model.

Table 1 Requirements for the conceptual model and a reflection on the phase, streams and rounds models

	Requirement	Phase	Streams	Rounds
A	Modelled precisely and unambiguously	Model only provides high level structure	Model only provides high level structure	Model only provides high level structure
B	Descriptive foundation of individual decision-making process	Individual decision-making process is not described, but model has a focal actor. The model has shown to not match empirical observations (Kingdon and Stano, 1984)	Individual decision-making isn't described and is not the focus of the model. The accuracy to empirical data unclear	Individual decision-making process is not described. The accuracy to empirical data unclear
C	Interaction between decision makers	All phases have different actors interact with the focal actor	In the streams decision makers are assumed to interact with each other	This model explicitly described interactions between actors over the whole system
D	Learning of decision maker	Not included	Not included	Not included
E	Perception of decision-maker on information selection	Not included	Not included	Not included, although actors within a round have similar problem perceptions
F	Describe decisions that are made in uncertain conditions and use of simulation models	The use of simulation models is not included	The use of simulation models is not included	The use of simulation models is not included
G	Risk-avoidant evaluation of alternative decision options	In the second phase alternatives are weighed, not specified	Not specified	Not specified

4.3. Decision-making models from economic theory

4.3.1. Expected value, utility, and prospect theory

The expected value theory proposes a rational procedure when a decision maker is faced with a number of actions, each of which could give rise to more than one possible outcome with different probabilities (Simon, 1959). The decision maker would identify all possible outcomes, determine their values (positive or negative) and the probabilities that will result from each course of action, and multiply the two to give an "expected value". The alternative with the highest expected value should be chosen. Value in this case is something objective, measurable in whatever unit (Simon, 1959).

In response to this the expected utility theory was introduced, where the utility is used as a measure instead of the absolute values (von Neumann and Morgenstern, 1947). Utility is subjective to the decision maker, as it describes how utile, or useful, the decision maker expects the outcome to be to them. A utility function describes the preferences the decision maker will use when faced with alternatives. In order to use the utility function, the decisions to be made should have clearly described alternatives, probabilities describing when they will occur, and the value each option would generate. Similar to expected value theory, the expected utility values are calculated as the weighted sum of adding the respective utility values of payoffs multiplied by their probabilities and then weighed against each other. However, the theory has shown to be violated in psychological experiments (Simon, 1959).

Tversky and Kahneman are two psychologists that did influential work to modify the utility function in such a way that it represents reality more accurately (Kahneman and Tversky, 1979). They did this by extending the utility curve to also include the negative quadrant (Figure 3) and introduced this as the prospect theory.

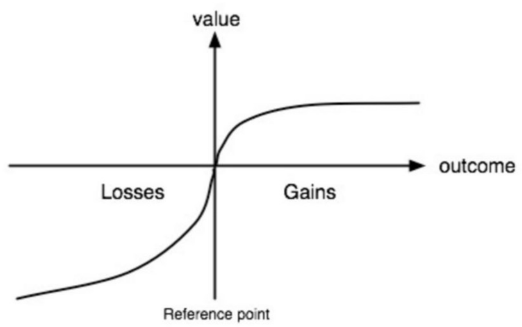

Figure 3. Utility curve as introduced by the prospect theory. Taken from Kahneman and Tversky (1979).

This utility function can explain several observations that were seen in real life decision-making. First of all, decision makers are loss averse. The slope on the negative side of the graph is very steep. Here, small losses have large consequences on the utility experienced by the decision maker (Kahneman and Tversky, 1979). Second, the evaluation of the decision makers is relative. So, people's choices are not based on objective values but on the psychological values of the outcome (i.e., how it feels) (Kahneman and Tversky, 1979). The origin of the curve (the reference point as referred to in Figure 3 decides what is considered as a gain or a loss.

The expected value theory, expected utility theory, and prospect theory are evaluated as one because in many ways they are similar. When there are specific differences for every theory, these are mentioned.

4.3.2. Random regret minimization

In making choices in travel behavior, individuals have been observed to reduce the regret of failing to choose an option that turns out to be the most ideal (Chorus et al, 2008). Random regret minimization (RRM) is rooted in the utility theory and attempts to describe this behavior observed in travel choices. It can describe multiple alternatives and can compare a set of different attributes to each other (multi-attribute decision-making). For travel behavior this would apply to cases such as travel time, number of traffic lights etc. It compares different attributes against each other for different alternatives (for example taking the car vs the train), given a certain state of the world (it's raining and there's a traffic jam). Random regret minimization assumes that individuals base their choice between alternatives on the wish to avoid the situation where a non-chosen alternative turns out to be more attractive than the chosen one, which would cause regret (Chorus et al., 2008).

4.3.3. Evaluation of requirements met by economic theories of decision-making

In Table 2 the economic theories are evaluated on each of the requirements. In general, all theories are only describing the specific process of how alternatives are compared by an individual. The Random regret minimization describes most clearly how alternatives are compared and weighed. Only the prospect theory and the RRM show consistency with real life behavior. None of these models can function as the base of the conceptual model, however, the random regret minimization theory might provide insights into the specifics of weighing alternatives. The theory describes how the decision maker will try to minimize regret in a decision situation, which is not immediately the same as being risk averse.

Table 1. Requirements for the conceptual model and a reflection on the economic theories

	Requirement	Expected value, expected utility and prospect theory	Random regret minimization
A	Modelled precisely and unambiguously	Model is precise but leaves room for own interpretation	Provides clear, detailed structure
B	Descriptive foundation of individual decision-making process	Developed as normative theories. Prospect theory has been adapted to resemble real-life behavior	Describes individual decision-making process. Theory is rooted in empirical observations and shows consistency with real behavior.
C	Interaction between decision makers	Not included	Not included
D	Learning of decision maker	Not included	The decision maker bases the expected regret on a personalized beta function, which could be related to earlier experiences of the decision maker
E	Perception of decision-maker on information selection	Not included	Not included, the model does 'simulate' how different alternatives play out over the attributes, depending on the different states of the world
F	Describe decisions that are made in uncertain conditions and use of simulation models	Do not take uncertainties into account, or the use of simulation models	A relatively popular candidate for risky choice analysis, not necessarily for long term decisions, high uncertainties or high stakes
G	Risk-avoidant evaluation of alternative decision options	Alternatives are compared on expected value or utility. In prospect theory, the decision makers are loss averse	Compares attributes for different alternatives. Focuses on minimizing regret

4.4. Decision-making models from psychology

4.4.1. Theory of planned behavior

The theory of planned behavior is widely used and is a psychological theory that links beliefs to behavior (Ajzen, 1985). The theory postulates that someone's intended behavior is the best indicator for a displayed behavior. Three elements, attitude, subjective norms and perceived behavioral control, are thought to influence the behavioral intention, which in turn is the greatest indicator for the actual usage or decision (Ajzen, 1985). Attitude refers to the subjective probability of the decision maker that the chosen behavior will produce a certain outcome. The subjective norms include perceptions of whether the environment of a decision maker expects a particular behavior from them. Lastly, the perceived behavioral control describes how difficult or easy the decision maker perceives choosing for a particular behavior (Ajzen, 1985).

4.4.2. Recognition primed decision-making theory

Recognition primed decision-making theory (RPDM) originates from the field of naturalistic decision-making (NDM). NDM arose as a response to classical decision theories, and the founders had the opinion that theories of decision-making should be based on observations rather than theories tested under laboratory conditions (Lipshitz and Strauss, 1997). Classical decision theories were thought to often originate from normative theories, rather than empirical observations. NDM aims to understand how people use their knowledge and experience to make decisions in complex dynamic situations. The best-known theory of NDM is the RPDM model(Klein, 2008).

NDM describes situations where there are: ill structured problems, uncertain dynamic environments, shifting, ill-defined or competing goals, action/feedback loops, time stress, high stakes, multiple players, and organization goals and norm. These situations can be seen as opposite to situations where there are: relatively unfamiliar tasks, low time pressure, requirements for optimization and justification, presence of conflict about the way the situation is viewed, or the way options are regarded. In these situations, analytical decision-making, as opposed to recognition primed decision-making, is likely to be used by the decision maker (Klein, 1993).

The RPDM model states that decision-making processes are strongly influenced by the experience of the decision maker. The researchers state that experts will use their knowledge and experience to size up the situation in a mental simulation, determine if a problem exists and, if so, whether and how to act upon it (Klein, 1993). How the situation is assessed by the decision maker plays a central role in this model.

4.4.3. Evaluation of requirements met by psychology theories of decision-making

The results of the evaluation of the models can be found in Table 3. Although the theory of planned behavior does describe individual decision-making, almost all other characteristics are not met by this theory and therefore the theory of planned behavior can be rejected as a main theory for further model building. The RPDM model, however, is descriptive and quite precise, and it is developed for decisions that are made under uncertainty. Additionally, the model describes the selection of information based on experience. Some requirements are partly met: there is a description of how alternatives are weighed, but they are not compared but evaluated on by one and the model assumes decision makers use mental simulation instead of model simulations. Additionally, there is a mention of memory of the decision maker, through their experience, but it is not further specified. There are also still some requirements unmet, such as the interactions between decision makers. All in all, this theory is thought to be the most suitable as a basis theory for the conceptual model.

Table 2. Requirements for the conceptual model and a reflection on the theory of planned behavior and RPDM model

	Requirement	Theory of planned behavior	Recognition primed decision-making theory
A	Modelled precisely and unambiguously	No precise description	Relative precise description of the different steps
B	Descriptive foundation of individual decision-making process	Describes individual decision-making and is descriptive in nature	Describes individual decision-making process and is rooted in observations
C	Interaction between decision makers	Not included	Not included
D	Learning of decision maker	Not included	The decision maker bases their decisions on expectations on the situation and uses mental simulation, based on earlier experiences, to select the best decision option

E	Perception of decision-maker on information selection	Not included	The model acknowledges that the decision maker will need to select information that takes into account from all possible information. This mechanism is included as 'critical cues'
F	Describe decisions that are made in uncertain conditions and use of simulation models	Simulation models not included. Attitude refers to the subjective probability of the decision maker that the chosen behavior will produce a certain outcome, for which they would have to make some estimation	Drawn up specifically analyzing high-stake decision-making under uncertainty. However, the time scale is very small and describes actions that will have an immediate effect. Decision maker uses simulation, however, mental simulation instead of simulation models
G	Risk-avoidant evaluation of alternative decision options	Does not weigh alternatives, it looks at intended behavior	The model distinguishes between various different elements used by the decision maker to come to a decision

4.5. Conclusion

Having evaluated theories from three different academic fields, the rounds model, from policy analysis, and the random regret minimization, from economic theory, have shown promise for use in this research. However, they were not considered suitable enough to be selected as a first conceptualization of the model. Instead, the recognition primed decision-making model is chosen as a first conceptualization of the decision-making model of network operators. This naturalistic decision-making model does not fulfill all requirements but is found to be the most suitable, as it has a relatively precise description, includes learning of the decision maker, is developed for decisions made under uncertainty, and is rooted in empirical observations. In the next chapter the recognition primed decision-making model will be explained further and the model will be adapted to describe the analyzed decision-making system.

5. Adaptation to the decision-making system

The recognition primed decision-making model will be further adapted to describe the decision-making process of network operators. The chapter starts with a more detailed description of the RPDM model, after which the structure of the RPDM model is followed to build the model step by step. It is discussed if each step is able to describe the decision-making processes of network operators or whether changes or improvements are needed. The chapter concludes with the presentation of the developed conceptual model of decision-making in three figures each represent a layer of the conceptual model (interactions between decision makers, individual decision-making, changing problem perception), complemented with a model narrative, and lastly an in-detail description of each step in the model.

5.1. Further introduction of the RPDM model

5.1.1. More in detail description of the RPDM model

In the previous chapter the RPDM model has been introduced explaining its capabilities and origin. Here, a more detailed step by step description of the model will be presented for which the schematic representation of the model in Figure 4 will serve as a guide. An elaborate description of the RPDM model can be found in Appendix II. Essential in this model is the situation assessment where the decision maker experiences the situation in a changing context (Klein, 1989). Four aspects of recognition are identified: (1) relevant cues, where decision makers decide which information seems critical to them, (2) plausible goals, that according to the decision maker can be reasonably accomplished in the situation, (3) expected cues, these expectations can serve as a check on the accuracy of the situation assessment and (4) actions, which are typical responses identified using the assessment of plausible goals, the relevant cues and the expectancies.

Based on this situation assessment and their prior experience the decision maker decides whether they identify this situation as familiar. When the decision maker does not recognize the situation as familiar, the model will loop back to 'seek more information' until the decision maker assesses the situation as familiar. When the situation is familiar to the decision maker they make a mental simulation of a possible action, starting with the most typical action. When this mental simulation shows that this action might not work, the action can still be modified by the decision maker. If it is assumed to be effective, the action will be undertaken. Every option will be examined in turn until a workable option is found.

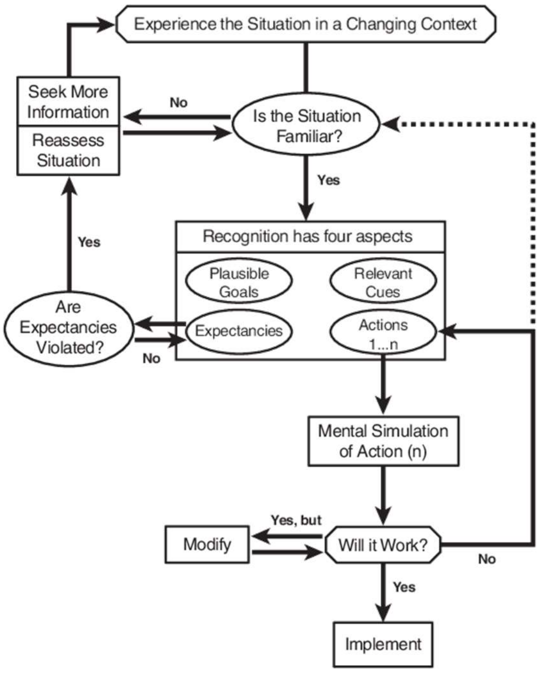

Figure 4 Recognition primed decision model (Klein, 1989)

5.1.2. Comparison between decision types

The decisions described by the RPDM model are not the same as the decisions made by infrastructure providers like network operators. Their decisions are typically made for long-term decisions, the decision processes are long and try to reduce risk. Additionally, investments have to be made under uncertain conditions in the energy transition. The recognition primed decision-making model is a naturalistic decision-making model and is made to describe decisions that have a high time stress and high stakes, such as rescuing someone from a burning building. The characteristics of such a naturalistic decision-making situation have been described in literature, as well as the conditions of decision situations where naturalistic decision-making models might not apply. These characteristics and their applicability to the network operator decision system are evaluated below.

Naturalistic decision-making is applied to problems that have the following characteristics: ill structured problems, uncertain dynamic environments, shifting, ill-defined or competing goals, action/feedback loops, time stress, high stakes, multiple players and organization goals and norms (Klein 1993). Some of these naturalistic decision-making conditions seem to apply well to the decision-making situation of the network operators. Namely, the problems network operators solve have been described as often being ill structured and are taken in highly uncertain and dynamic environments. Furthermore, the decisions have high stakes, involve multiple actors and are influenced by organization goals and norms. Lastly, the goals that the decision makers strive for in their decision-making process are increasingly competitive, as the energy transition and reliability of the grid have competing interests. These conditions especially apply to the phase in the decision-making situation where alternative solutions to a bottleneck are selected.

As opposed to naturalistic decision-making, analytical decision-making conditions can be described under which naturalistic- decision-making models, and therefore the RPDM model, are not likely to be applicable (Klein (1993). These are: relatively unfamiliar tasks, low time pressure, requirement for optimization and justification, presence of conflict about the way the situation is viewed, or the way options are regarded. Some of these conditions seem to partly apply to the decision situation of the network operators. While the network operators do function under time pressure, as the energy transition is an urgent challenge, the time is on a different scale. It can therefore be perceived as a low time-pressure decision. Also, the action feedback loops are much slower as described in the introduction, where the feedback of taking a certain action can take up to a decade to become clear. Additionally, there is a requirement for optimization and justification, because the network operators are utilities and spend large sums and are under strict regulation. This is especially reflected when the decision makers use risk matrices and gateways to structure their governance process. The decision situations are also wicked problems, meaning that they have an inherent conflict on how the situation is viewed. Finally, the tasks network operators are facing are familiar to them to some extent, however, in the energy transition, more and more unfamiliar tasks are being encountered as explained in Section 3.4.

Therefore, although the recognition primed decision-making model was found to meet the most requirements, the applicability of the model to the decision-making situation of network operators is not complete. The conceptual model will be built using the RPDM model and complemented with other theories. In Section 6.2.1 the validity of using the RPDM model is discussed.

5.2. Adaptation of steps of the recognition primed decision-making model

The RPDM model is a first conceptualization of the model and will be further adapted to the decision maker process of network operators. This will be done by a step-by-step evaluation of the model as introduced above, adapting each of them to the analyzed decision-making system.

5.2.1. Experience the situation in a changing context

In the first step of the recognition primed decision-making model the decision maker experiences their situation in a changing context. This process can also be observed in the decision-making process of the network operators who also have to make sense of the situation around them. The step in the RPDM model does not provide enough detail to be a functional model element and therefore will be further specified for the 'aspects of recognition' that are identified in step 5 of the RPDM model and are used as a main structure. This will be elaborated on below.

Relevant cues

The decision maker selects for cues in their environment that are seen as relevant. This implies that the information is selected by the decision maker based on their personal view. In the interviews with decision makers, it was also found that all of them have different perceptions on the problem and use that selected information in their decision-making processes. This element is therefore kept in the model, but is further specified.

For the decision-making the network operators get their information from various sources, both internal and external from their organization. For example, policy documents, and conversations with other institutions and their direct colleagues. They also build upon work done by others and/or provide input for the next step in the decision-making. The conceptual model does not yet provide a structure to describe these interactions. In Section 4.2.3 the rounds model (Teisman and van Buuren, 2012) was found to be suitable to describe these interactions between decision makers on a policy making level. Therefore, the rounds model can be incorporated into the conceptual model at this step to provide greater depth and accuracy.

The rounds model describes complex decision-making which involves many policy makers who take decisions. As the name suggests, the policy process is thought to occur in rounds. A round can be defined post-hoc and represents the process leading to a decision on a topic that is deemed to be crucial, and serves as an important point of reference for later behavior of actors

(Teisman and van Buuren, 2012). In such a round multiple actors contribute to the outcome by taking decisions, even if they are unaware of each other. As can be seen in Figure 5, decisions are clustered in rounds and the relationship between them can be illustrated with the arrows. Every black dot depicts a decision taken by an actor, and the policy results from interactions between those decisions. Either building upon other decisions (the small back arrows), combining results (in the white rectangles), or anticipating future decisions (the white arrows). This means the decision-making processes are interdependent.

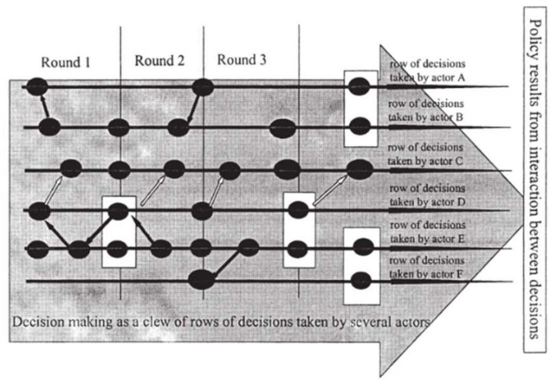

Figure 5. Rounds model (Teisman and van Buuren, 2012)

Because of the dependencies between actors they need to agree on perceived problems and solutions. When perceptions do not overlap, some dependencies may become problematic (Termeer 1993). Different decision makers interpreting available information differently is also described in literature when describing wicked problem decision-making. According to Koppenjan and Klijn (2004) wicked problems as those arising when actors have different perceptions of problems and view them from different frames of reference. This is called the frame of reference and is based on how the actor views the world right now, why they think the world looks like that, what they think might happen in the future, and what solutions might help.

In interviews, differences in problem perceptions have also been observed, for example when decision makers developing the simulation model were very aware of all assumptions and uncertainties around their models. However, later in the process, when interviewing other decision makers, the information generated by the models was only perceived as given and they identified uncertainties mostly within their own part of the decision-making process. Another observation on the different problem perceptions was that some interviewees were highly aware of the need to change their working processes, while others had confidence in their decision-making processes to get them through the energy transition.

Concluding, the rounds model and the concept of problem perceptions are used to conceptualize the information exchange between actors, both within the network operators as external stakeholders. Which cues are perceived as relevant by the decision makers is influenced by their problem perception, which functions as a filter and the use of information from other decision makers, When the one person sends information (for example writes a policy document) with one perception on the problem, and the other person receives this information with another perception, what they interpret out of this information will be different than what the first person had intended it to be.

Plausible goals

The plausible goals in the RPDM are goals that are thought to be feasible within this project by the decision maker. The interviewed decision makers and the network operators as an institution together have their own goals that are thought to be feasible. For example, if a decision maker is very focused on building an electricity grid that always works, that will seem like a plausible goal. However, when they're focused on facilitating the energy transition, different outcomes will seem more apparent. This would also include the wickedness of these decision problems in the conceptual model.

The RPDM model does not provide a process of how these plausible goals are set and therefore this process needs to be further specified. The goals that network operators have for their institution are thought to be independent from the information on that specific decision problem, but instead they are part of their perception on the problem. Conceptualizing the goals in this way means that the goals that the decision maker does not think they should or can achieve, regardless of the information on the decision situation, can never be selected as the plausible goals for that project. The problem perception of a decision maker thus includes the goals they strive for in decision problems. Each goal can be evaluated on several attributes. For example, cooking a nice meal can be evaluated on temperature, taste and texture. Therefore, the plausible goals are conceptualized as part of the situation assessment and are dependent on the situation assessment and each contain several attributes for evaluation.

Expectancies

In the RPDM model, the expectancies are some cues that the decision maker uses to check whether their assessment of the situation is still correct. In the RPDM model the expectations serve as a check on the accuracy of the situation assessment. When they are changed, decision-makers turn to reassess their situation (see Section 5.2.5). How and when this happens is not specified. Network operators also have certain expectancies of their environment that they base their situation assessment on. For example, a decision maker might assume that the government will provide guidance in spatial planning.

To further specify this element in the conceptual model, the expectancies are modelled as part of the problem perception. To ensure that indeed the expectancies serve to check the situation assessment, the expectancies are assumed to be continuously checked by the decision maker. Therefore, they are not part of the situation assessment which the decision maker only goes through in the beginning of the process. Expectancies can be both in the environment as well as within the decision-making process. For example, decision makers might expect simulation models to give them certainty in their decision problem. Or decision makers might expect a positive public opinion on electrification as a solution in the energy transition. Concluding, expectancies are modelled as a continues process of checking a set of values, both from the environment as within the decision-making process and are considered dependent on their problem perception.

Typical actions

The last element of the situation assessment in the RPDM model are the possible actions a decision maker can take, ranked on typicality. In naturalistic decision-making, the experience of the decision maker helps them to generate promising options first. This is therefore also the point in the model where decision options are selected by the decision maker. Network operators also tend to try decision options first that they think are most likely to work. A difference is, however, that decision-making processes at network operators are much more standardized, using risk matrices and gateways. In the RPDM model the actions are evaluated one by one and the typicality determines which ones are evaluated first. Network operators, however, compare multiple decision options at the same time.

Typicality relies on earlier experiences. Therefore, to include this in the model the concept of memory is included. Earlier decisions are memorized together with the information available at that time and the goals they were striving for then. The current relevant cues and plausible goals are used to rank the options. In the RPDM model the expectancies are also used to rank the options on typicality, however this mechanism is not specified there. Because network operators evaluate their decisions in a comparative way the ranking of the possible decision actions can be made for a set of decisions instead of each one.

Network operators not only evaluate different decision options (for example, which alternative to a bottleneck should be executed), but also select models that they use to aid their decision-making. As explained before, the selection of models influences what comes out of these models, and therefore influences the decision-making process. Modelling the selection of simulation models is therefore interesting, and is done so by following the same steps as the selection and evaluation of decision options. Concluding, based on the plausible goals and relevant cues decision makers rank their decision options and model options on typicality, which are later evaluated comparatively in sets of multiple decisions.

5.2.2. Is this situation familiar?

A next step in the model is the evaluation of familiarity of the situation by the decision maker, where the current situation is compared to prior experiences to decide whether the decision maker has enough context to continue the decision-making process. In interviews, the network operators described similar mechanisms present in their decision-making process. Specifically, they prefer to work in familiar situations and look for ways to make sense of the current situation based on their prior experiences.

For further conceptualization the concept of memory of a decision maker is introduced to allow for a comparison between the current situation and prior experiences,. The situation is assessed by a decision maker based on the same aspects each time and these aspects will be compared between each other. The memory of the decision maker as introduced in Section 5.2.1 will be used for this step. For assessing the similarity between these known and new situations a threshold is used. The higher this threshold, the more familiar a situation needs to be for a decision maker to move forward.

In interviews the different decisions makers were observed to have different levels of familiarity required to view a situation as familiar. Some network operators agreed that uncertainty was just a part of the process and should be embraced, while others were trying to reduce this uncertainty. Therefore, conceptualization of the comparison for familiarity is based on memory and different thresholds for accepted familiarity are introduced to explain differences in dealing with uncertainty. This threshold value will be included in the problem perception.

5.2.3. Seek more information

When a situation is not considered familiar the decision maker will look for more information in the original model. Also, network operators will try to get more information on the decision situation before they feel comfortable with working on it. However, different decision makers do seem to handle unfamiliarity of a situation differently. As described above, some decision makers have a different attitude towards the uncertainty in their decision-making process. How this might influence their reaction to unfamiliarity of the problem has not become clear from interviews and is therefore not included in the model.

When seeking more information, network operators will add information to the relevant cues gathered as described in Section 5.2.1. The gathering of relevant cues is influenced by the problem perception, so note that, except for when their problem perception has changed, the same information is perceived by (or available to) the decision maker. They will merely add more information to their relevant cues and reevaluate whether this time they will have enough information to feel sufficiently familiar with the situation. Concluding, decision makers seek more information by adding information to their relevant cues after which they continue with the process of evaluating familiarity.

5.2.4. Recognition has four aspects

In the RPDM model this step explains the four aspects based on which a decision maker recognizes their situation. This is not a functional step but rather explains which elements the evaluation of the situation is based on. In Section 5.2.1 these elements have been used to structure the situation assessment, therefore this step in the model has been left out, which does not remove any functionalities compared to the RPDM model.

5.2.5. Expectancies violated

The RPDM describes that when there are changes in the situation assessment the expectancies, described in Section 5.2.1, can be violated. In interviews, decision makers also described the changes in their work context from what they expected this to look like. This element is therefore included in the conceptual model and specified. To determine whether expectancies have been violated each expectancy needs to get assigned a value and a range that the value is expected to stay within. The next step shows what happens when the expectancies have been violated.

5.2.6. Reassess situation

Originally, this step in the RPDM model redirects the decision maker to the situation assessment when their expectancies on the decision system have been violated. When this exactly happens in the process does not become clear. Network operators reevaluate their situation when expectancies change. For example, decision makers who repeatedly found that their way of working did not lead to satisfying results, changed their perspective towards the decision problem. Note that expectancies can be cues outside of the system as well as expected results from the actions of the decision maker.

The flow of a developed model would be unrealistically disrupted when decision makers would go back to reassess their situation by stepping back to step 5.2.1 and continue from there once an expectancy has been violated. To overcome this, the model states that when the decision maker notices that the problem situation no longer looks as expected, they might change their view. However, problem perceptions are hard to influence and don't change based on a simple stimulus response reaction (Koppenjan and Klijn, 2004), and therefore a threshold mechanism is introduced. Each time expectancies are violated there is a potential that threshold is reached and the problem perception is changed. This mechanism is displayed in Figure 8 in Section 5.3.1.

5.2.7. Mental simulation of action

In the RPDM model the decision maker uses mental simulation to evaluate how successful the decision option will be in a one-by-one evaluation. As described in Section 5.2.1 network operators use comparative evaluation instead. The network operators do use their experience and expectancies on the situation to predict how something might play out, which can be considered a mental model. The mental simulation is considered personal to the decision maker and is conceptualized by including the expectancies, relevant cues, and plausible goals in their problem perception and modelling the experience of decision makers by use of the memory.

Network operators have been observed to use simulation models to provide information about how decision options might play out, using scenarios early in the investment plan process. This is modelled by using the simulation model considered most applicable for the decision situation. That selection of simulation models follows the same steps as when choosing a decision option: ranking of options on typicality (see Section 5.2.1) and selecting a most suitable option (see Section 5.2.8).

An additional step is added called 'model simulation' where the selected simulation model is used to create additional information on the decision situation, which can be added to the relevant cues already gathered in the situation assessment. These steps take place directly after the situation assessment and before the evaluation on familiarity. The use of models is seen here as a way to generate more information on the problem, and therefore should be inside the loop of the familiarity check and the action of looking for more information.

Concluding, mental simulation is conceptualized by including the expectancies, relevant cues, and plausible goals in their problem perception and modelling the experience of decision makers by use of the memory. Additionally, typical simulation models are evaluated and selected following the same steps as when evaluating decision options and the models are used to create more information on the decision problem.

5.2.8. Will it work?

In the original RPDM model, decision options are evaluated one-by-one and the evaluation is based on satisfaction instead of optimization. This this has not been observed by the network operators as their decision processes are focused on risk minimization and therefore they strive for the best option. Therefore this part of the model needs adaptation. The adapted mechanisms should evaluate the alternatives comparatively with a risk avoidant character. In Section 4.3.2 the theory of random regret minimization (RRM) was evaluated to be sufficient for describing the specific weighing of alternatives. Here the specific mechanisms will be elaborated on further and incorporated in the conceptual model.

The RRM states that when an individual given a choice between alternatives they will aim to avoid the situation where a non-chosen alternative turns out to be more attractive than the chosen one, which would cause regret. This means that decision makers have a regret avoidant decision-making characteristic. Individuals achieve this by anticipating for each possible state of the world.

In RRM all choice alternatives have attributes, which are dependent on the states of the world (Chorus et al., 2008). To weigh alternatives, a decision maker will have:

- Different alternatives (i, j,k)
- Multiple attributes (x, y,z)
- Different states of the world (s out of S)
- Beta function, with preferences of the individual for one alternative over the other

Then, the attributes of every alternative are weighed against each other (xi compared to xj and xk). The expected regret can be calculated for each alternative, which is a sum of the regret associated with every possible state of the world, weighed by their probability of occurring. Expected regret values of the different alternatives are compared and the lowest is selected. The RRM has a threshold for regret, which is the highest regret an individual will accept for a decision alternative. When all expected regret values are higher than the threshold none of them will be chosen and judgement will be postponed.

The network operators make use of risk matrices to evaluate their decision options, where multiple attributes are evaluated for every alternative and are compared between each other. To model this more explicitly, the alternatives, as described in the RRM, are the decision options in the conceptual model. The attributes for every decision option depends on the plausible goals which have attributes on which they are evaluated and will differ per goal. The state of the world that the decision maker assumes is defined by the relevant cues gathered by the decision maker in Section 5.2.1. Lastly, the beta function (of personal preferences) and the threshold for regret both are elements where the problem perception of the decision maker comes into play. Concluding, evaluating the decision options in this way will result in a decision option with the lowest regret associated with it, depending on the plausible goal selected, their attributes, the relevant cues and the problem perception of the decision maker.

5.2.9. Modify

In this process in the original RPDM model the decision maker changes the decision option they evaluated when needed. This modification to a selected decision option has not been observed in the decision-making process of network operators and is therefore left out.

5.2.10. Implement

Decision options are eventually implemented by the decision makers, (the realization phase of the decision-making system, Section 3.2). This phase includes gateways that formalize all different steps towards realization. However, this phase lies outside of the scope of the research and this step is left out.

5.3. Presentation of conceptual model

The conceptual model developed in this thesis describes decision-making by network operators when making long-term decisions under uncertain conditions. The model focuses on the individual decision-making process and describes how decision makers interact. The main contribution of the model is the introduction of the concept of problem perception which influences the information selection, perceived goals and evaluation of options of individuals, and the information exchange between individuals. A problem perception can be changed when the decision maker is presented with new information or outcomes that contradict their expectancies to the system.

In this section the conceptual model is presented in three different ways. First, the model is presented in figures that explain the different layers of the conceptual model. Next, a description of the model is given where a 'run' of the conceptual model is described qualitatively. Finally, a table is presented with a detailed description of every model step.

5.3.1. Overview of the decision-making process of network operators

Interactions between decision makers

In Figure 6 the interdependencies between actors are explained by depicting two different decision makers that each go through the decision-making process twice over time. For clarity, the situation assessment step is displayed separate from the rest of the decision-making process, as that is the step where they receive input from other decision makers. Note that this input can come from a decision maker within their organization as well as outside and can be through a policy document as well as through direct contact. Both decision makers have a problem perception which influences their information exchange. Several decisions can be analyzed in a round together which represents the process leading to a decision on a topic. Not all decisions that are displayed here are included in one round, so as to illustrate that one decision made by a person can be included and the other can be excluded from a round, depending on the topic they work on. The rounds function as a reference for further analysis.

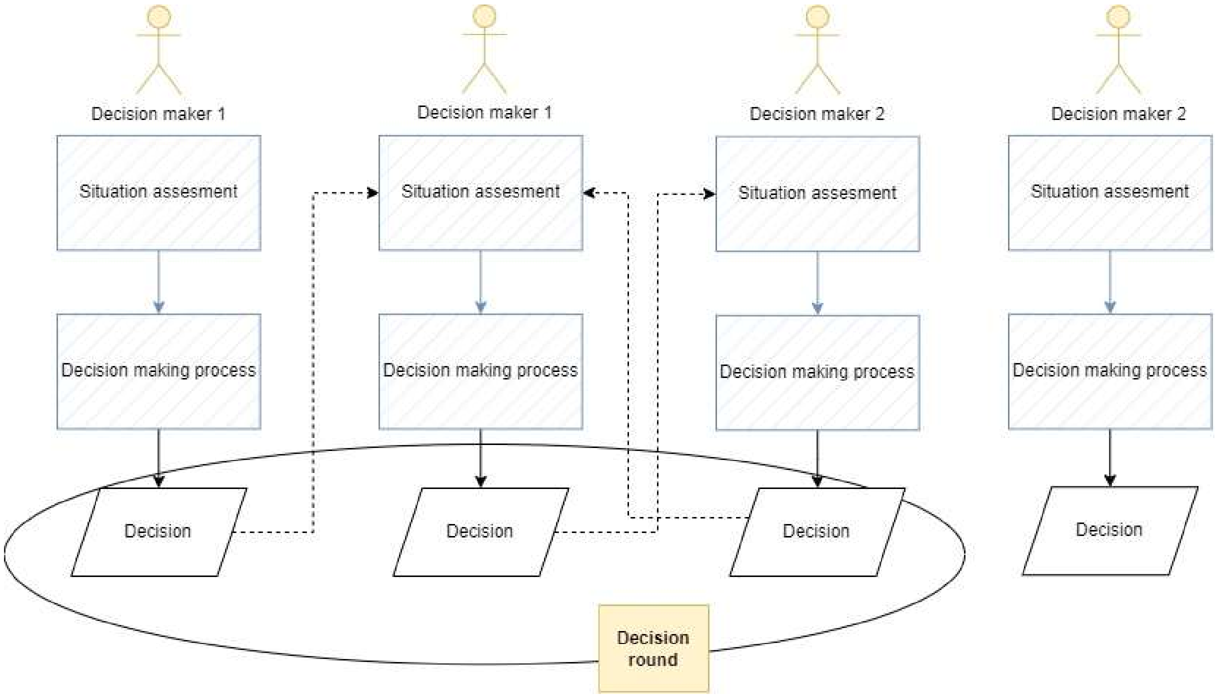

Figure 6. Depiction of the conceptual model where two actors (Decision maker 1 and 2) go through the decision making process twice. Solid lines indicate paths through the process. Dotted lines indicate influences between decision making processes. Solid oval indicates a post-hoc decision round designation.

Individual decision-making process

The decision-making process each individual goes through before reaching a decision is explained in more detail in Figure 7 all steps described in the previous sections are included and numbered, starting with the situation assessment (1). The decision maker starts with gathering relevant cues (1.1) and set plausible goals (1.2), both based on their problem perceptions. As explained in the previous figure, these cues can come from other decision makers. Both elements are used to sort the decision options and model simulation options on typicality based on the memory of earlier decisions of the decision maker (1.3). When continuing in the decision-making process the decision maker starts by evaluating the first set of most typical simulation models by calculating the associated regret for each decision alternative over a set of attributes set by the goals of the decision maker (2). When the regret does not exceed the threshold (3) the simulation model is used (4) and adds information to the relevant cues which are used for evaluating the decision options in the next step.

Next the familiarity of the situation is assessed by the decision maker (5), and if the situation is not familiar enough, they will look for more information before continuing, including the use of simulation models (9). Again a set of most typical decision options are evaluated comparatively (6) and their expected regret is compared to the threshold value (7). When the threshold is reached the next set of decision options is evaluated (6). When the sets of decision options do not provide a low enough associated regret the decision maker returns to the situation assessment. In case the threshold is not reached the decision maker has made a decision (8) which is used as the output of the process.

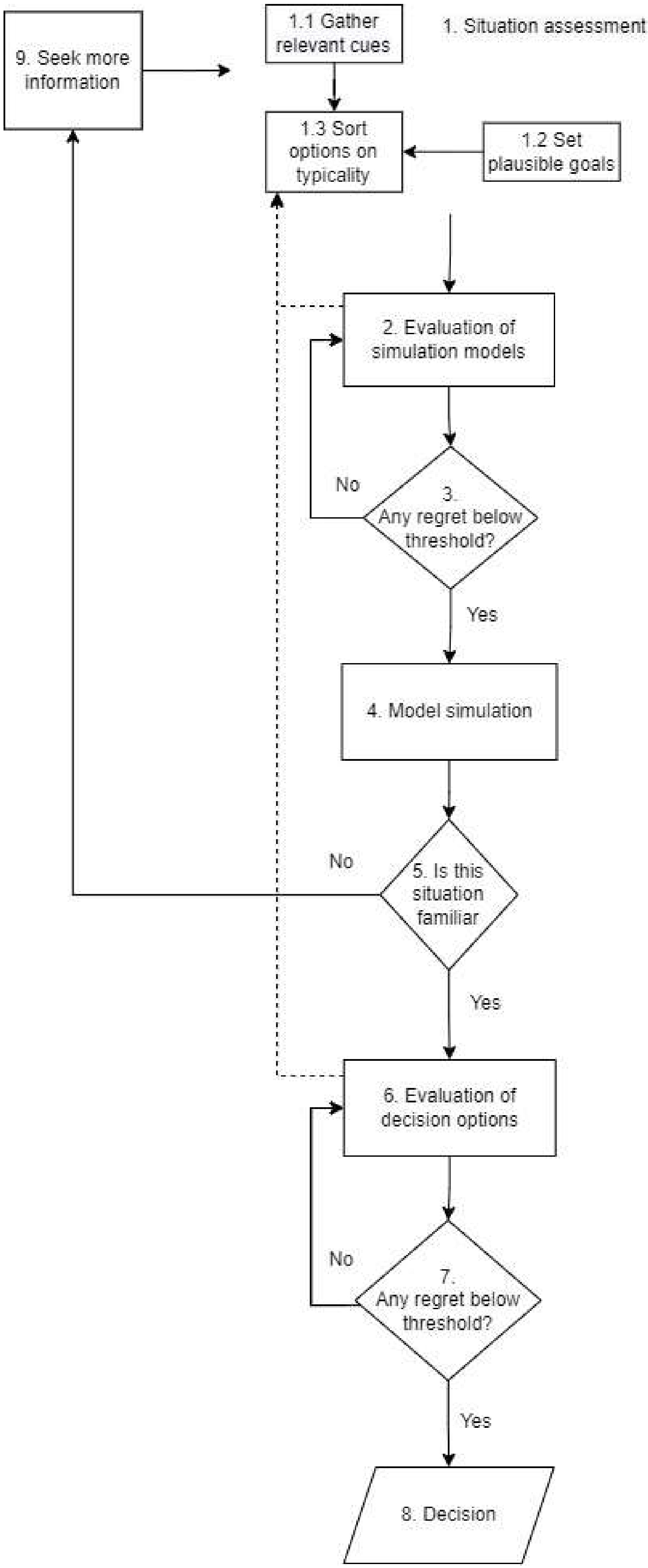

Figure 6. Depiction of the model of the individual decision-making process.

Changing the individual problem perception

Parallel to the decision-making process that an individual decision maker goes through, the conceptual model describes another process that takes place with every step of the decision maker steps and can therefore be seen as a continuous process. In Figure 7 this process is explained step by step, numbered using the Roman numeral system to contrast the decimal numbering system as used in Figure 6. The decision makers continuously check whether the world still looks like they expect it to (I), based on a set of expectancies determined by their perception on the problem. These expectancies come from outside of the decision-making process (for example the political landscape) (VI) as well as from within (VII), where the decision maker expects the process to yield certain results. When the expectancies are not violated, nothing happens that step and the cycle continues. When the expected values are different than the decision maker assumed them to be, this adds to a value of 'distortion of worldview'(III) that when the threshold is reached (IV) leads to a change in problem perception (V).

The problem perception relates to the other layers of the conceptual model in various ways. One of the mechanisms of interaction between the layers is described in step VII, where expectancies on the individual decision process are used as input. These expectancies from the decision process (VII) can for example be step 5: each time a decision maker does not recognize the decision situation as familiar and step 4 and 7: each time there is no workable option found below the threshold for regret.

Another relationship between the two levels of the conceptual model is that when there is a change in problem perception (V) it has multiple effects on the individual decision-making model. First, a different problem perception influences several steps in the individual decision-making process as explained in Figure 6. In the situation assessment, the cues that are relevant to the decision maker might change because their perception changes (1.1). Also in their situation assessment, the goals that a decision maker views as plausible can change (1.2). When evaluating the simulation model and decision options the model uses a personal beta function to calculate the associated regret of each decision option (3 and 6). Both this function and the threshold for the expected regret will change when the problem perception changes. In the next step the familiarity threshold will change (5), influencing the amount of information with which the

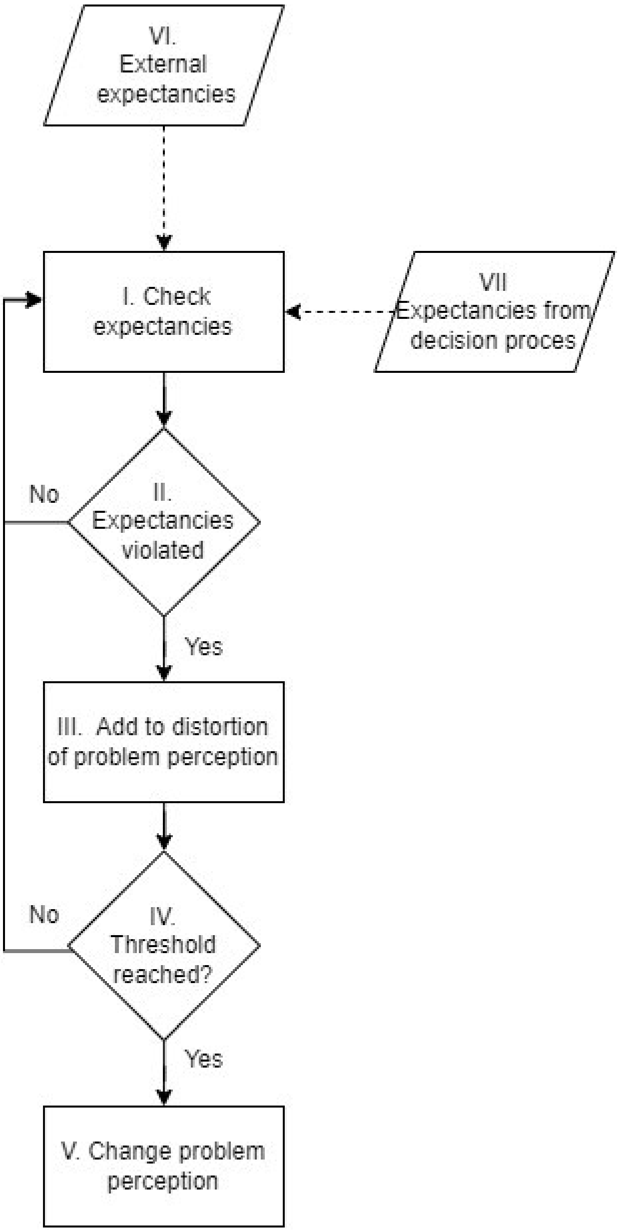

Figure 7. Depiction of the model for changing the individual problem perception.

decision maker is comfortable to continue their process. Note that when a problem perception changes the amount of information that is visible to a decision maker can also change.

A changing problem perception also influences the layer of the model that describes interactions between decision makers. The decision makers gather expected cues and get information from others and these interactions are influenced by a change of problem perception. A change can mean that one person might view the problem more similarly as the next person which will make it easier to interpret each other's information.

5.3.2. Model narrative by using a simple fictive scenario

In this section the model is described in a qualitative way by creating a model narrative of a fictive situation. Note that the aim is to create more insight into the conceptual model, which is different from using the model to create insight in the decision-making process itself. The use of the model is demonstrated in chapter 7.

The fictive situation is the following: Maria, a decision maker working at a Dutch regional network operator, is presented with the decision problem of having to choose alternative solutions to a grid capacity bottleneck in her region. Maria, as any person, has her own perception of the world, and therefore her own perception on her decision problem. She views that the decision-making process is done most perfectly when all risk is minimized, and the network operators succeed in providing cheap and reliable energy. Maria has lately become a bit more dissatisfied with her current way of working, as she experiences that she can't always find suitable decision options within her decision process and the lack of spatial planning from the government made her work difficult.

The narrative will include references to the individual decision-making process as presented in Figure 6 in decimal numbering and references to the problem perception in roman numbering as shown in chapter 7. Maria will start the decision situation by assessing the situation (1), looking for information (1.1) and setting goals for the project (1.2). Both these two elements she views through her own 'lense', i.e., her own perception on the problem. She reads policy documents and finds information that she thinks is relevant for the problem (1.1). Next, she will use her goals for this decision problem and the information she found to determine what might be options that are worth considering and what might be simulation models she can use to create more insight in the decision problem (1.3). Then, she evaluates whether one of the simulation model options might be good enough for this decision option (2 and 3) and she uses it to create more information on the problem using some scenarios (4). She picked the scenarios and models that she always uses, not risking the possible effort and uncertain outcomes of more explorative new models.

However, Maria now feels that, even after using these models, she still does not have enough information to be able to move forward (5), because she wants to really make sure she doesn't take any risks. She will take some more time, talk to some more people, and use another simulation model to get enough information before she feels comfortable enough to continue (9). This makes her slightly more dissatisfied with her way of working (II, III and IV).

Now that she feels like she has enough information she compares her options in sets, going over the first 5 most typical options first (6). Because she wants to make sure she doesn't take any risks, she has a set of attributes over which she evaluates all the decision options with a focus on safety and reliability of the grid. In the first set of 5 options she finds one that she believes causes a low enough regret that she is happy enough to continue (7). She writes a report about her final decision and it is passed to the next decision maker who will continue working on it (8). Eventually all decisions that were taken leading up to the execution of the solution to the grid bottle neck can be evaluated together in a round.

Note that because Maria was already quite dissatisfied with her way of working, and during this process some more expectations of her decision process were changed, perhaps she would look for information in one of the next decision-making processes, and her problem perception might change (V).

5.3.3. In detail description of model elements

The individual decision-making process of the decision maker is described below in Table 4 and the process of changing the problem perception is described in Table 5.The steps follow the same numbering as above in Figure 6 and 7. Each step is introduced with the element title, the type of element and a short description followed by some additional explanation, when required.

Table 4. Description of the individual decision-making process.

	Element name	Type of element and a short description	Additional explanation
1	Situation assessment	Process: consisting of three different processes, the situation is assessed by the decision maker	Processes are described in detail below
1.1	Gather relevant cues	Process: information that is considered relevant by the decision maker is selected based on their problem perception	The decision maker selects information that they find relevant. Information that does not fit within their problem perception will not be selected by them, so the problem perception serves as a filter. This selection of information is what the decision maker bases the decision-making process on. Information can come from other decision makers, with possibly other problem perceptions. When the problem perception is different this will influence the interpretation of that information.
12	Set plausible goals	Process: based on the selected goals and the relevant cues on the decision situation, the goals that the decision maker will strive for in this project are set	This process uses the relevant cues gathered by the decision maker in process 1.1. The selected goals (process 1.2) are 'matched' with the information on the decision problem. Goals each need different types of information, so next to attributes, goals will have a certain need for information. Goals that the decision maker does not think they should or can achieve, regardless of the information on the decision situation, can never be selected as the plausible goals for this project.

1.3	Sort options on typicality	Process: based on the plausible goals and relevant cues, decision options and simulation model options are ranked on how typical they are for this decision situation	In order to use plausible goals and relevant cues for ranking options on typicality, the memory of the decision maker is used as earlier decisions are memorized together with the information available at that time and the goals they were striving for then
2	Evaluation of simulation model options	Process: the different simulation model options are evaluated in a comparative manner by random regret minimization.	The models that come out of the previous process (the alternative options) are evaluated along multiple attributes. The attributes that are taken into account depend on the plausible goals. Information has been selected on the decision situation in step 1.1 The attributes depend on the 'state of the world', which is made up by the relevant cues and the problem perception of the decision maker. How this is done specially is not decided on in this thesis. Using the beta function for personal preferences (included in problem perception) the regret for each simulation model option is calculated.
3	Any regret below threshold?	Decision: if the evaluation of simulation model options results in a simulation model option that is lower than the regret threshold, the decision-making process continues.	The threshold for minimal regret (parameter value included in problem perception) is used to assess whether a decision option can be chosen. The regret of the evaluated options is compared to threshold for what the minimal regret should be in order to be satisfied with the result. When this is the case, the process continues. If not, the next set of options in line of typicality are considered. If the options are depleted at some point, the situation is reassessed (back to step 1)

4	Model simulation	Process: the selected simulation model is ‘run’ to create extra information	The extra information created by the simulation model is added to the situation assessment of the decision maker. Running different models will produce different information on the decision situation. The decision maker has chosen a model that fits within their problem perception (consequence of how the decision process is structured). The information that the model produces will however not per se fit the problem perception and can add to the distortion of the decision maker.
5	Is this situation familiar	Decision: the decision maker assesses whether they recognize this situation as familiar and continues with the decision-making process or goes back to finding more information on the decision situation (9)	The goals, relevant cues and possible are compared to the memory of the decision maker. The threshold for assessing the similarity between these known and new situation is determined by the problem perception
6	Evaluation of decision options	Process: the different decision options are evaluated in a comparative manner by random regret minimization	See process 2
7	Any regret below threshold?	Decision: if the evaluation of decision options results in a decision option that is lower than the regret threshold, the decision-making process continues.	See process 3
8	Decision	Output: a decision option has been selected and will be executed by the decision maker	The decision action selected and the information on the decisions situation is added to the memory of the decision maker.

9	Seek more information	Process: when the decision maker doesn't recognize the decision as familiar, they will look for more information	The decision maker takes time to find more information, and goes again through the situation assessment and the use of simulation models to create more information

Table 5, Description of the process of changing a problem perception.

#	Element name	Type of element and a short description	Additional explanation
I.	Check expectancies	Process: decision maker has expectancies on the decision situation that they check every step (continuously)	Expectancies are based on the problem perception of the decision maker and function as a check whether their perception on the problem is correct
II.	Expectancies violated?	Decision: decision on whether the expectancies have exceeded their expected values	If yes, continue to step III, if no, nothing happens and step I will be performed the next time step. Expectancies have a value range that they are expected to stay within. Also the qualitative expectancies need to get conceptualized this way
III	Add to distortion of problem perception	Process: when expectancies are violated a certain level of 'distortion' is added to a value	The violation of one expected value won't directly lead to a shift in problem perception. This step builds up towards a threshold
IV.	Threshold reached?	Decision: when the threshold is reached, continue to step V otherwise go back to I	-
V.	Change problem perception	Process: the problem perception changes	Changing your problem perception has consequences for several elements of the individual decision-making as presented in Table 4 among which the plausible goals, expected cues and threshold for familiarity

VI.	External expectancies	Input: expectancies dependent on external changes	The problem perception of a decision maker can be changed when some outside expectancies are different from expected, such as for example the public opinion on electrification as a solution to the energy transition. In step 1.1 and step 9 the decision maker looks for information and are therefore moments that these expectancies can be violated.
VII.	Expectancies from decision process	Input: expectancies on the decision-making process	Some suggestions to steps in the decision-making process that can have expectancies: step 5: each time a decision maker does not recognize the decision situation as familiar, step 4 and 7: each time there is no workable option found below the threshold for regret

6. Verification and validation

6.1. Verification

Model verification is done to check whether the model is fulfilling the mechanisms and elements as it was intended to and is internally consistent and complete. This is done by performing two different analyses. First it is evaluated whether the model is capable of doing what it was intended to do by evaluating whether it meets the requirements that have been developed before in Chapter 3. Second, the model narrative presented in Section 5.3 is reflected upon to evaluate the models internal consistency and completeness.

6.1.1. Reflection on requirements for conceptual model

In Section 4.1 requirements for the conceptual model were developed and used to select decision-making literature. To verify whether the conceptual model indeed has these characteristics and functions, the fulfillment of each requirement is evaluated below.

A. Modelled precisely and unambiguously

The main structure is modelled precisely, and the different elements have been described in detail. However, there are still elements of which the exact mechanisms remain unclear. These are, for example, how the interpretation of information by the decision maker is influenced by their problem perception, or how to structure the expectancies that the decision maker has of the system around them.

B. Descriptive foundation

The conceptual model has been developed based on data on the decision-making system of Dutch network operators setting up a long-term investment plan. Whether this thesis is accurately describing this system should still be validated using expert interviews.

C. Interaction between decision makers

The conceptual model conceptualizes interactions between agents as gathering relevant cues from others in their situation assessment. The mechanisms by which this takes place and the conditions for interactions have not been described in a detailed way. The model does not include the characteristics and boundaries of the environment. A structure for analyzing the interactions between decision makers as a policy process has been conceptualized by analyzing various decisions from various decision makers together as a decision round.

D. Learning of decision maker

The learning of the decision maker is included in the conceptual model by providing a threshold mechanism through which their problem perception can change. A change in problem perception comes about from the interpretation of the decision maker of their surroundings and the decision process itself. Section 6.2.2. reflects on the timescale at which these problem perceptions change.

The conceptual model includes no direct feedback from the decisions made so there is no 'reward' for making certain choices. This means that all learning is related to the context (cues) or the satisfaction of decision makers as they go through the decision process.

Another mechanism of learning has been included through the memory of decision makers, as each decision is memorized by the agent and is used in the decision-making process when assessing familiarity and ranking options on typicality.

E. Perception of decision-maker on information selection

The problem perception of decision makers includes a parameter for information and model option selection. How the problem perception exactly influences the information perceived by the decision maker is not included.

F. Describe decisions that are made in uncertain conditions and use simulation models

The conceptual model is based in the recognition primed decision-making model, which is designed for decisions made under uncertainty (Klein, 1993). A mechanism by which decision makers respond to uncertainty can be included with the use of the threshold for desired amount of information gathered before continuing with the decision-making process. A lower acceptance of uncertainty by the decision maker would lead to a demand for more information. In the current mechanism, this would lead to a delayed decision-making process, assuming the decision maker will take more time looking for information to reach their desired level of information. It is likely the acceptance of uncertainty has a much more profound effect on the decision-making process, which has not been modelled or identified in this thesis (Marchau et al., 2019).

The observed decision-making process has various checkpoints and mechanisms that deal with the uncertainties of the decision-making process. These checkpoints are not reflected in the presented conceptual model.

G. Risk-avoidant evaluation of alternative decision options

In the conceptual model, the alternatives are weighed based on the random regret minimization theory (Chorus et al., 2008) and are done so in a comparative way. To do this, for each state of the world, different attributes are weighed for different options. However, the process minimizes regret, not necessarily risk. Focusing on minimizing regret means that decision makers don't need to find the best functioning options, but instead can stop going over the alternatives when one is found that has a low enough level of regret. There is not a focus on minimizing the likelihood and severity of negative outcomes, but on choosing a 'good enough' decision. This is also reflected in the step where a regret threshold is used to check whether there are any decisions that are good enough to pass. When this threshold is set very low, so very little regret is accepted, this could resemble a risk avoidant characteristic, but it still isn't the same. To include a more risk avoidant way, the same elements can be used, but instead of evaluating the associated performance of a decision option, the associated risk could be calculated. Risk avoidance is therefore not included in this conceptual model of decision-making.

6.1.2. Reflection on the consistency and completeness of the model

In Section 5.3.2 a narrative of the model is presented to create more insight into the developed model. While this reflection is limited because the model is not yet implemented and its accuracy cannot be determined by running the model, the narrative will provide the opportunity for a rudimentary check. This check will assess whether the conceptual model is logically coherent and free from internal contradictions.

The narrative takes a fictive decision maker from a regional network operator through a simple scenario. As she followed the steps of the model she does not meet any internal contradictions. Maria's responses to the model remained logically coherent. The narrative did not suggest anything inconsistent with interviews performed with decision makers.

6.1.3. Conclusion on verification

In conclusion, the conceptual model introduces various mechanisms that can explain the required functions of the conceptual model, such as the perception of information selection, learning of the decision maker and the interactions between decision makers. These mechanisms still require further specification before they can reflect the functionality in the conceptual model. The model does not fully describe the risk avoidant character of decision option evaluation and lacks explicit conceptualization of the effects of uncertainty on the decision-making system. While the model appears consistent and complete based on a model narrative check, some mechanisms within the model may not contain sufficient detail to fully assess if there are logical inconsistencies inherent in the model. In conclusion, the model can represent the required characteristics and mechanisms, although some need further specifications, and is consistent and complete based on an evaluation of the model narrative.

6.2. Validation

The validation of the model functions to check whether the model is able to describe the system it is meant to describe. This is done in two steps. First, this chapter evaluates the validity of the using the RPDM model as an underlying theory to describe the conceptualized decision system. Second, this chapter will reflect on the validity of some main assumptions that were made in the modelling process. However, because a face validation with an expert was outside the scope of this research, validation as part of the modelling process has not been sufficiently executed. Validation with an expert on the ability of the model to describe the observed decision-making is recommended as a first step before developing, interpreting, or implementing the conceptual model further.

6.2.1. Validity of using the RPDM model for conceptualization

The RPDM model forms the theoretical basis for this conceptual model. The model was chosen based on the evaluation of the requirements that were made based on the systems analysis. This section evaluates the applicability of the RPDM model for the decision-making system of network operators. In Section 5.2.1 the differences between decision situations described by the RPDM and the decision situation of the network operators were elaborated on.

The decision situation has characteristics that would be considered both naturalistic and analytical. As the decision makers are increasingly facing new decision problems, such as prioritization, this might lead to more decisions made under an analytical framework. Therefore, as these situations become more prevalent the model's basis in the RPDM model may become less valid. However, as the model has not been tested, it is still unclear whether decision processes in the prioritization dilemma are well captured in the conceptual model.

The RPDM model is also best applied in situations with high time pressure. Therefore, while decisions currently being made in the energy transition are long and may not fit well, smaller components of these processes may be well captured by the model. Overall, while some foundational assumptions of the RPDM model may reduce the validity of the conceptual modes, it is still valid in many contexts. Therefore, the expert validation of the model needs to be conducted before the full extent of its validity is understood. And even then, careful application of the model is needed.

6.2.2. Validity of assumptions made in model building process

Several key assumptions have been made when developing the conceptual model. The four assumptions considered to have the greatest impact are discussed here.

First, the problem perception is modelled such that it determines the parameterization of several variables. This means that the model assumes that all these model elements change at the same time. As the problem perceptions have not been defined in this research the validity of this assumption is still hard to assess. However, generally speaking, problem perceptions have a profound effect on how the decision situation is perceived by a decision maker (Koppenjan and Klijn, 2004). Therefore, this assumption is valid, although in reality a diversity of problem perceptions might exist that influence the decision-process in a more nuanced way.

Second, the model describes that problem perceptions change through the violation of expectancies, both internal as well as external of the decision system. For this mechanism to be relevant to the model it is assumed that the decision maker's problem perception undergoes changes within the timeframe in which the model is utilized. However, in reality, problem perspectives are not easily adjusted (Geldof 2004, Koppenjan et al., 2004). Decision makers can adapt and renew their perceptions gradually from experiences or learning and can sometimes change abruptly in disruptive crisis situations. The speed at which this process happens varies between people (Geldof, 2004). The representation of changing problem perceptions in this model might therefore be too simplistic and optimistic towards perception change, but overall this assumption describes a valid mechanism.

Third, based on the analysis in Section 4.1 the conceptual model is required to include the use of simulation models (Requirement F). Therefore, the use of these models has been included in the individual decision-making model of network operators (Step 4). However, the use of simulation models is only found in the first phase of the investment plan process, as described in Section 3.1. Additionally, network operators use other similar models, for example risk matrices, to evaluate their decision options. Therefore, if a decision maker would be confronted with part of a decision that does not use scenarios in simulation models, the conceptual model still prescribes the use of simulation models. Simulation models are selected as frameworks to create more information, based on the problem perception. In every step of the decision process actors make use of frameworks that they think are relevant to create more insight into their decision problem. Therefore, the assumption of using simulation models is not completely valid but could be easily generalized thereby improving the validity.

A fourth assumption made when developing the model is related to the interactions between decision makers. Input from other decision makers is interpreted in the situation assessment based on the problem perception. This interpretation can be seen as an interaction between the one decision maker and the other. This mechanism is reflected in the decision process of network operators, who use information from various sources and interpret those in their own way. However, describing all interaction between network operators and other decision makers, both within and outside the network operator institute, in a single model step does not provide a complete representation of the actual decision-making process. Therefore this assumption limits the completeness of the model when describing interactions between decision makers.

6.2.3. Conclusion on validity

Overall, issues are present with the validity of the model. First, face validation is needed to sufficiently evaluate the validity of the conceptual model. Second, some characteristics of the decision situation are not described by the RPDM model. Specifically, the new tasks that decision makers are faced with, such as prioritization dilemmas, might reduce validity of the use of the RPDM model. Third, multiple assumptions made while developing the conceptual model limit its validity and applicability of the model. Namely, assumptions about the effect of a problem perception change and their timeframe, describing interactions between decision makers and the use of simulation models. Overall, these should be taken into consideration and will require careful application of the model.

7. Demonstration of model use

This chapter demonstrates the insights that the conceptual model can provide on the decision-making of network operators. This is done by running the model qualitatively using a parametrization based on two decision situations that network operators themselves described facing in their current decision-making. The chapter starts with introducing the problem situations and the motivation for their selection by the researcher and continues with describing the parametrization and their motivation. The chapter concludes by describing the outcomes of the model given the parametrization. Descriptions of the decision problems

To provide insight into the decision-making system the model is used twice, with different decision problems. Both decision problems are representative of the current decision-making processes of network operators, but each provides a different lens with which to view the decision-making process. Both decision problems have been introduced in Chapter 3 when analyzing the decision system, and can be described and illustrated as follows:

1. Network operators have identified a bottleneck in the grid that needs to be solved. They have different options that might work, among which is installing a new cable through a nature area or upgrading the current grid through a neighborhood.
2. The network operators face difficulty providing grid connection to all their clients within the legal timeframe and will have to prioritize between clients. One of the clients is a municipality which is also a shareholder of the utility company.

7.1. Parametrization

Before the conceptual model of decision-making of network operators can be used, several variables still need to be parametrized. The parametrization is done qualitatively as the model is not yet implemented. Additionally, some variables that represent quantifications within the model are therefore not specified in this analysis. This includes variables, like the expected range of expectancies, the amount of information gathered by decision makers, and how this is related to the amount of information needed for the decision maker to be familiar with the situation. The other variables are described below, starting with the problem perception.

7.1.1. Parametrization of problem perception

The model is run to provide more insight into the decision-making of network operators for which two different decision problems are used. To see what insights the model can create in both decision situations this model run will evaluate both decision problems using the same problem perception for the decision-maker. The problem perception influences a set of parameters in the conceptual model so when the problem perception would also be changed the effects on the decision-making would become multi-interpretable. Running the model with different problem perceptions for the same decision situation is recommended for future research.

The conceptual model of decision-making describes the concept of a problem perception, which is a variable to be determined by the model user. This thesis does however not provide a classification for the different perceptions, so a problem perception has to be described here. Thus, the decision maker will focus on reducing risk and working safely. These are the values that network operators have held for decades and this problem perception was observed in some of the interviewed network operators. It is considered to be representative of the major share of the network operators. What that problem perception means for the decision model will be illustrated below.

7.1.2. Further parametrization

Further parametrization of the model partly depends on the selected problem perception, which is the same for both decision situations. As described in Section 6.1.1 the use of some variables within the model are not standardized yet so an example is given to illustrate the mechanism. First, the variables influenced by the decision context are parametrized in Table 4 after which the parametrization influenced by the problem perception is given in Table 5.

Parametrization depending on decision situation

Table 3. Parametrization depending on decision situation.

Variables	Decision problem 1	Motivation	Decision problem 2	Motivation
Information input in the form of documents and interactions	Regional and national spatial planning, nature area regulation, socio-political input from neighborhood	This problem is multi-faceted and has different aspects that need to be considered	Legal responsibilities (ACM), Ministry of EZK, client interactions, internal board politics	Relevant stakeholders when facing prioritization issues (see Section 3.4), municipality plays multiple roles within the decision problem, i.e. internal board politics
Interactions with other	Interactions between external	A diversity of actors are consulted when	Interactions between external	A diversity of actors are consulted when

decision makers	decision makers occur with different problem perceptions. Interactions within network operators in the same problem perception	making this decision, each representing a different perspective on the system. Direct colleagues in network operators have the same common problem perception	decision makers occur with different problem perceptions. Interactions occur internally in the same problem perception	making this decision, each representing a different perspective on the system. Direct colleagues in network operators have the same common problem perception
Plausible goals	Fixing the bottleneck with the least associated costs	Focus on reducing risk and focusing on reliability (problem perception)	Complying as much as possible to the legal responsibilities, reducing conflict	Focus on reducing risk and compliance with requirements (problem perception)
Expectancies external	Expect there to be some degree of spatial planning from government	Political activity of spatial planning is considered the responsibility of the government and typically does not require political action from network operator	Expect to be able to meet the legal requirements without conflict	The problem perception is focused on compliance and does not expect a political role for the network operator

Parametrization depending on problem perception

Table 4. Parametrization depending on problem perception.

Variables	Parametrization for both decision problems	Motivation
Relevant cues	Practical, technical information that will help decide on the most effective, cost-efficient decision.	The problem perception will filter out information that the decision maker is not focused on. Therefore, information related to the socio-political situation within a community or a complex interpersonal relation will be filtered out to a large extent.
Attributes of goals	Quality of the supply, expected financial costs, compliance to legislation, possible irreparable damage done to the environment while working on the grid and whether working on the bottleneck might damage relationships with stakeholders.	These aspects are used in the risk matrix of network operators to asses the risk associated with a bottleneck. The same aspects are used here as the decision maker focusses on risk reduction
Expectancies internal	Network operators expect that they will have a familiar situation to work with and will be able to find a good enough option when evaluating them	The same internal expectancies as suggested in Section 5.3.3 of this thesis are used

Thresholds for familiarity	High threshold for familiarity	The decision-maker focusses on risk reduction and it is assumed this will lead to the need for a lot of information before continuing in the decision process
Threshold for regret	Low treshold for regret	The decision-maker focusses on risk reduction and it is assumed this will lead to a low acceptance of regret associated with a decision option

7.2. Qualitative runs of the model

The parametrization defined in Section 7.1 will be used to run the model in a qualitative manner. The outcomes are presented using the same three levels of the conceptual model as the model presentation in Section 5.3.3, namely the interactions between decision makers, the individual decision-making process, and the process of changing the problem perception.

7.2.1. Decision problem 1: Alternative solutions to bottleneck

Interactions between decision makers

When working on this decision problem, information is used from various institutes and decision makers. They depend on other decision makers within the network operators with the same problem perception and they build on each other's decisions. The information used from external institutes is developed based on a different problem perception and that will influence the interpretation of information. All decisions from various decision makers leading up to solving this bottleneck can be analyzed in a round. Running the model for one individual once, as is done here does not provide enough information for insights into the decision round as a whole.

Individual decision-making

The decision maker starts with selecting relevant information from all information on regional and national spatial planning, nature area regulation, socio-political input from neighborhood. The problem perception of the decision maker makes it so that mostly practical, technical information that will help decide on the most effective, cost-efficient decision will be interpreted. The socio-political situation related to, for example, the community's connection to the nature area, will be filtered out to a large extent.

This selected relevant information, and the memory of the decision maker are used to find a decision option that will most likely lead to reaching the goal of fixing the bottleneck with the least associated costs. The first set of most typical models is evaluated by calculating the associated regret for each model over the quality of the supply, expected financial costs, compliance to legislation, possible irreparable damage done to the environment and whether working on the bottleneck might damage relationships with potential stakeholders. When the regret does not exceed the threshold the simulation model is used and adds information to the relevant cues. Although the threshold for regret is low, it is assumed a satisfying model option is found because the attributes of goals that the alternatives are evaluated on are in the same perception of the problem as the relevant cues and they have selected satisfying simulation models in the past.

Next the decision maker assesses the familiarity of the situation, using their high threshold for familiarity. The decision maker will not have enough information to continue because this decision problem asks for socio-political input and that was mostly filtered out when gathering information. Therefore, the decision maker will return to find and create more information. When the decision is familiar enough, they will continue with evaluating a set of most typical decision options comparatively, such as installing a new cable through a nature area and upgrading the current grid through a neighborhood. The expected regret is compared to the low threshold for regret. This threshold is not reached because of similar reasoning to the regret threshold above. Therefore, the individual decision process is finalized and is used as the output.

Changing problem perceptions

The problem perception can change by expectancies not being met during the decision-making process. The expectancy of the decision maker in the context is that there should be some degree of spatial planning from government. Whether this expectancy changes is not dependent on the decision process but is based on changes in the environment. From the model run an assumption can be made that the expectancy has been violated to some extent, as the decision maker was evaluating documents on spatial planning and could initially not assess the decision situation as familiar. The expectancy on the decision-making process is that the network operator will have a familiar situation to work with. This was not the case, the decision maker had to return to find more information before the situation was assessed as familiar. Another expectancy on the process was that they will be able to find a good enough option when evaluating options, which was the case in both evaluation moments.

This means some value was added to the threshold leading up to a change in problem perception. Because the model is only parametrized qualitatively no definitive conclusions can be drawn on whether this perception is changed or not.

7.2.2. Decision problem 2: Prioritization of clients

Interactions between decision makers

The parametrization differences between the two decision problems do not lead to different outcomes on this level of the conceptual model because both decision problems require interaction with stakeholders that have a different problem perception.

Individual decision-making

The decision maker starts with selecting relevant information from all information on legal responsibilities (ACM), Ministry of EZK, client interactions, internal board politics. The problem perception of the decision maker makes it so that mostly practical, technical information that will help decide on the most effective, cost-efficient decision will be interpreted. The socio-political situation related to, for example, complex interpersonal relations will be filtered out to a large extent.

This selected relevant information, and the memory of the decision maker, are used to find a decision option that will most likely lead to reaching the goal of complying as much as possible to the legal responsibilities, while reducing conflict. The first set of most typical models is evaluated by calculating the associated regret for each model over the quality of the supply, expected financial costs, compliance to legislation, possible irreparable damage done to the environment and whether working on the bottleneck might damage relationships with the stakeholders. The threshold for regret for finding a model option is low and finding a model that can describe the above-mentioned aspects of regret evaluation is likely because these requirements are based on models currently being used. Therefore, an option with a low enough regret to pass the threshold will be found.

Next, the decision maker assesses the familiarity of the situation, using their high threshold for familiarity. The decision maker will not have enough information to continue because this decision problem asks for socio-political input on the power relations between stakeholders and that was mostly filtered out when gathering information. Therefore, the decision maker will return to find and create more information. When the decision is familiar enough, they will continue with evaluating a set of most typical decision options comparatively. It is assumed it will be difficult for the network operator to find a suitable decision option given the applicability of the aspects of evaluation mentioned above to the decision problem. For example, its difficult to get useful information when comparing the environmental impact of evaluating one client over the other when the problem is socio-political in nature. Therefore, when comparing the lowest expected regret to the low threshold for regret of the decision maker, it is assumed a workable option will not be found right away and the next set of decision options will be evaluated. It is assumed in that set of options a workable option is found and a decision has been made.

Changing problem perceptions

The problem perception changes due to expectancies not being met during the decision-making process and the distortion of the problem perception reaches a threshold. The expectancy of the decision maker on the context is that they can meet the legal requirements without conflict. This has been violated and therefore adds to the distortion of the problem perception. The expectancy on the decision-making process is that the network operator will have a familiar situation to work with. This was not the case, the decision maker had to return to find more information before the situation was assessed as familiar. Another expectancy on the process was that they will be able to find a good enough option when evaluating options, which was not the case when evaluating the different options for overcoming the prioritization problem. This means some value was added to the threshold leading up to a change in problem perception three times. Because the model is only parametrized qualitatively no conclusions can be drawn on whether this would directly lead to a change in perception.

In case the problem perception changes, the parametrization of relevant cues, goals and their attributes, the expectancies, and the threshold for regret and familiarity would change too. The change in cues will influence the level of information present at the familiarity check. A problem perception taking the socio-political aspects into consideration would create more information for decision makers on the prioritization dilemma. The goals and their attributes can influence what decision options are considered typical, which can lead to a change in how suitable the typical decision options are to solve the problem. When thresholds become more flexible, this could speed up the overall process, as the decision maker would not have to compare different options or look for more information.

8. Discussion and conclusion

This thesis provides insight into the decision-making process of Dutch network operators under uncertain conditions by developing a conceptual model of decision-making. The model is based on existing models of decision-making in literature and is adapted to the situation of the network operators through model building based on interviews with network operators. The model focusses on the problem perception of an individual decision maker and their situation assessment. This chapter interprets four main findings of the research and discusses their implications for the network operators and directions for future research. The research is concluded by answering the research question.

8.1. Discussion

8.1.1. The developed conceptual model

A model of decision-making was developed and demonstrated its use with multiple decision-making processes faced by Dutch network operators. Overall, the conceptual model could be used successfully in these situations and provided insights into the decision-making processes. However, the validation of the conceptual model is lacking and the model is not completely verified. Taken together, while careful consideration is needed in applying the model, these successes do show that this model has the potential to be used as the conceptual basis for further implementation.

The first step in achieving this is to start with expert validation of the model. When further implementing the model, special attention should be paid to the elements of the model that remain unspecified, such as how information is interpreted with different problem perceptions.

8.1.2. Coping with uncertainty by searching for more information

In this thesis the model showed that when decision makers are not familiar with their decision situation, they return to look for more information using models, which takes time and effort. Koppenjan and Klijn (2004) also found that a common strategy used by decision makers facing uncertainty in wicked problems was to search for more information. Additionally, other responses of the network operators have been identified in the paper that approach uncertainty by creating more knowledge. Specifically, when uncertainty about the problem arises due to the complexity of the problem, a typical response is attempting to split these complex problems into individual elements and calculate these variables and their relationships independently. When uncertainty is related to a lack of knowledge about the future, decision makers will design future scenarios, which are always unlimited, and arriving at a robust scenario requires adaptive policies. Both strategies have been observed in network operator decision-making, where they use risk matrices to describe individual elements of the problem and use scenarios when mapping out developments in the energy system.

This information gathering strategy, however, cannot cope with differences in problem perceptions and does not seem to reduce uncertainties in a wicked problem, but rather increases them. Additionally, creating more knowledge typically doesn't question the frame from which the problem is approached, and reduction of uncertainty is seen as an intellectual and not social activity (Arentsen et al., 1999). Recently, in the development of the II3050, network operators are starting to interact with some of the stakeholders more which would suggest they are acting more socially. Future research is suggested to check to what extent they are building knowledge more as a social activity while discussing their problem perception. For transition processes, a critical success factor is to create a common language which can be achieved through co-production (Loorbach and Rotmans, 2010). Thus, this research implies that development of the II3050 is beneficial and may help create a common language at this critical step. More research is suggested into how decision makers cope with uncertainty and to what extent they reflect on problem perceptions.

After future improvement of the model it could function as a boundary object to aid reflection with network operators and other stakeholders on their decision-making processes. It can provide insight into how decision-making processes are affected when having a different problem perception, and how this influences information perception and collaboration with other stakeholders. This could help to open a conversation about problem perceptions which might help the network operators to deal with uncertainties in their work.

8.1.3. Problem perceptions influence the decision-making substantially

Central in the model is the problem perception which influences decision-making in different ways. The best demonstration of this is in discussing what a change in problem perception would mean in the prioritization dilemma (Section 7.2.2). The goals and their attributes can influence what decision options are considered typical, which can lead to a change in how suitable the typical decision options are to solve the problem. When the goals change, the evaluation of all decision options change, which mean different options might perform better. However, it is important to note that evaluation of alternatives is partly standardized in the institutes and might not change as easy.

Additional examples of the effects of a changing problem perception include, a change in threshold for familiarity, which would make it so less information is accepted and the decision maker doesn't get stuck looking for more information. Another example is when a change in cues that are considered relevant by the decision maker, influences the level of information obtained. Including the input of more sociopolitical cues would help the prioritization dilemma as it better reflects its nature.

However, in this thesis, the influence of the problem perception on the model seems to be out of proportion. When the model was used in two different contexts, the decision problem hardly influenced the parametrization of the model. Another limitation is that the mechanisms of changing a problem perception might be too simplified and not represent the timescale at which they take place.

Future research can create more insight in the mechanisms of the problem perception after validation and further implementation by running the model with different problem perceptions for the same decision situation. More empirical research into the current problem perceptions of network operators is also recommended. Lastly, when implementing the model the problem perceptions should be classified further. Suggestions for literature for further development Van de Riet (2003) who applied actors perspectives and primary drivers to infrastructure domains and the Cultural Theory, from Thompson (1990). Development of the concept of problem perception can focus on distinguishing between static and dynamic parts of the problem perception (Geldof, 2004) and evaluate the timescale of problem perception change in the conceptual model.

8.1.4. Miscommunication between decision makers by information selection

The model shows that miscommunication between decision makers occurs when they have a different perceptions because information is filtered based on individual problem perceptions. This finding may provide insight on how the problem perception influences the interactions between decision makers. However, the model does not conceptualize the interactions between decision makers completely. This was demonstrated when using the model , when the analysis of interactions between decision makers did not change based on the differences in parameterization discussed. Future implementation of the model should elaborate on this level of the conceptual model.

8.2. Conclusion

Insight is needed into decision-making as network operators are facing the energy transition. A conceptual model has been developed describing the decision-making of network operators under uncertain conditions. Overall, this thesis aimed to answer the research question:

What is a conceptual model of the decision-making process by network operators, on long term decisions under uncertain conditions?

Expert validation of the model is still lacking and validity of the models chosen from literature is limited and verification of the model is not complete as several mechanisms, such as the interactions between decision makers, remain unspecified. However, given these limitations, the model was still able to provide insight into the decision-making of network operators. The model describes decision makers respond to uncertainty by looking for more information, posing question to what extent reflection on the problem perception and common knowledge production are also used to cope with uncertainty. The problem perception influences the model substantially, suggesting that a change in problem perception would make decisions such as the dilemma of prioritizing clients more adequate.

The energy transition is a pressing and widely debated topic in society. Like in any transition, the system changes on a structural level, which means that new responsibilities arise that are not yet fully embraced by any particular party. This situation can be seen as a game of hot potato, where the parties involved pass the responsibility back and forth, but nobody wants to hold onto them. Consequently, network operators may find themselves in a position where they eventually need to assume a new role. Developing this conceptual model further can provide insight into how decision-making processes can be changed to help them adopt this new role.

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Appendix I

Below a table is presented with the details of all interviewees.

Table A1. Details of all interviewees

Name interviewee	Organization*	Type of organization	Function*
Arjen Jongepier	Enduris	Regional network operator	Pioneer of the Energy Transition
Jarig Steringa	GasUnie	National gas network operator	Senior Advisor
Lennert Goemans	The Ministry of Economic Affairs and Climate Policy	Governmental institute	Clusterleader Energysystem
Luuk van den Brandt	TenneT	National high-voltage network operator	Advisor and project manager
Martti van Blijswijk	TenneT	National high-voltage network operator	Market analysis (Unit Energy System Planning)
Richard Westerga	TNO	National independent research organisation	Researcher Energy Transition
Walter Bien	Alliander	Regional network operator	Chief Financial Officer

*at the time of the interview

Appendix II

The recognition primed decision-making model will be described in more detail here. In Figure 4 the schematic representation can be found. Essential in this model is the situation assessment, which is often left out in descriptive decision-making models (Klein, 1989). The decision maker experiences the situation in a changing context (top) based on which they decide whether they identify this situation as familiar. When this is the case, based on the four aspects of recognition, the decision maker makes a mental simulation of a possible action (one out of 1…n). When this mental simulation shows that this action might not work, the action can still be modified by the decision maker. If it is assumed to be effective, the action will be undertaken. If not, a next action will be considered and simulated mentally. A more detailed explanation will follow below, discussing every described step in the model subsequently based on Klein, 1989.

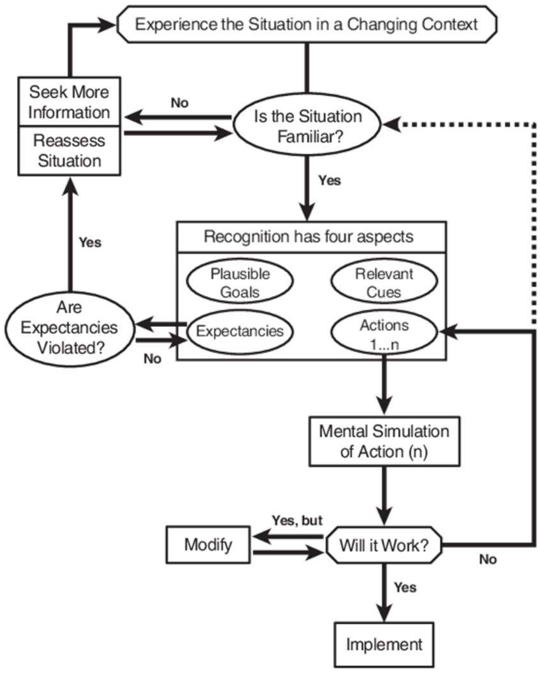

Figure A1. Recognition primed decision model (Klein, 1989), also included as Figure 4 in the body of the thesis

Experience the situation in a changing context

The decision maker will start the decision-making process by gathering information (experiencing) the decision problem and its context

Is this situation familiar?

This model is based on recognition of the situation by the decision maker, for which the decision maker uses their prior experience for guidance. When the decision maker does not recognize the situation as familiar, the model will loop back to 'seek more information' until the decision maker assesses the situation as familiar. This does not say anything normative about whether the decision maker does this assessment correctly or not.

Recognition has four aspects

Here, the model identifies four aspects based on which a decision maker can recognize a situation. Important to mention when discussing this step, is that these elements are not a theory of situation assessment, but rather a convenient convention. These aspects grew out of the conducted interviews with the observed decision makers and are thought to be helpful to what a theory should explain.

- Relevant cues – to make sense of the decision problem and its context, the decision maker needs to select information from all information available to them. The more experience a decision maker has, the less likely they are to be overwhelmed by stimuli. With growing experience, decision makers have been observed to have an increase in attention to critical cues.
- Plausible goals – decision makers decide in each situation what they think are goals that can be reasonably accomplished in the situation. Here, the goals do not refer to generic goals (maximize profit for example), but to specific outcomes that a decision maker tries to achieve within the context.
- Expectancies – when confronted with a decision problem, decision maker form expectations of how the situation will unfold. What's likely to happen, and when. These expectations can serve as a check on the accuracy of the situation assessment. For an inexperienced decision maker, there are few expectancies, and they are vague and hard to test. A more experienced decision maker has more clear expectancies that can serve as a better check for the accuracy of the situation assessment.
    - When these expectations are violated, in the model the decision makers are assumed to re-evaluate their situation assessment (see Figure A1)

- Actions - given a decision problem, a decision maker will have several options of courses of actions they can take. In this aspect, these typical responses are identified. The actions are selected from an action queue one by one, where they are arranged according to this 'typicality'. The first action evaluated is that rated as the most typical response in the particular situation. The assessment of plausible goals, the relevant cues and the expectancies are thus used in this step to identify which are the most typical responses.

  Some descriptions of the model rank the different elements, stating that the relevant cues are used to decide which goals might be feasible. Based on those two, the actions are sorted on typicality. Other sources to not specify how these different elements interact with each other.

Mental simulation

Decision makers will mentally simulate how the action they chose might perform. This is evaluation is done using the context specific information gathered in the previous steps. 'If I do this, that might happen, which will result in …'. This mental simulation is done in a serial assessment, where options are assessed on at a time until a satisfactory option is found. This stand opposed to concurrent evaluation of options, whereby a set of options is selected and evaluated comparatively. The observed decision makers did not compare every strength and weakness of one option with another, but every option was examined in turn until a workable option is found.

An example of how this serial evaluation is done, is by using emotions. Chess players, which have to constantly make decision under the described naturalistic conditions, are reported to use options to make their decisions. Some reported that they would reject options that just 'feel dangerous', although they could not identify a trap directly. The option that evoked the most enthusiasm would be chosen to continue with. Here, there is probably some implicit comparison of enthusiasm for different options, but not strengths and weaknesses of pairs of options are not compared.

When a decision maker is more experienced, they will have more previous decisions and contexts to base their mental simulation on.

Will it work

The action that has been mentally simulated is evaluated on whether it will work. This is a decision moment, where satisfaction, rather than optimization, is the focus. The action is evaluated on whether it would work, not if it's the best action available. Because the actions that are thought to be most typical for the decision maker are evaluated first, a decision maker can already have a viable decision option after the first 'run' of decision-making.

Modify

When the action does not work out in the mental simulation, a decision maker might wish to make some adaptations to the action in order to make it work. This can be done because the options are evaluated serial. When the evaluation would be comparative, this adaptation of the action would disrupt the evaluation process.

Implement

When an action is considered to be successful, the action will be implemented.