Power plant investment processes

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Graduation Committee

Prof.dr.ir. P.M. Herder
Professor, TU Delft, faculty TPM, section Energy & Industry

Dr. ir. L.J. de Vries
First supervisor, TU Delft, faculty TPM, section Energy & Industry

Dr. M.L.C. de Bruijne
Second supervisor, TU Delft, faculty TPM, section POLG

Ir. J.C. Richstein
External supervisor, TU Delft, faculty TPM, section Energy & Industry

Author

Name
D.T.Groot

Student number
1027573

Contact
e-mail: dtgroot@gmail.com, phone: +316 41058368
Preface

This research was started in the summer of 2012 to gain more insight in how investment processes in power plants actually happen in real life. The subject could not have been more relevant right now for many aspects of Dutch society. At the time of writing this final closure to what might be described as a ‘tried and tested’ student life, a (last) report came to my attention;

The report by ‘Energie-Nederland’ states fundamental changes in market fundamentals and the impacts that changes in the power sector will have on society (Energie-Nederland, 2013). Despite the stable image of this sector, prospects do not look promising in all scenarios at present. After having gaining (a modest amount of) insight, I will review the course of events with even greater interest. And I hope this thesis can add value for its readers.

Acknowledgements to all the people that I owe gratitude to would require writing a separate thesis in this preface. So for now, I will limit my acknowledgements to the participants of the interviews and my exam committee. Many others were a great help in the last years though. Especially two of the most authentic, resourceful and kindhearted people I know have my sincere gratitude.

The participants to the interviews also turned out to be a real joy to meet. Many tuned in to the subject at hand within minutes and I am very grateful for the time, expertise and interest that the participants supplied for this research. This really superseded expectations.

The exam committee turned out to be an excellent choice in many ways. And all members require separate acknowledgements. I would like to thank Laurens de Vries in particular; for stating the initial idea, giving great guidance and showing considerable patience. Paulien Herder in turn showed great flexibility, effort and humor in a time and place I suspect to be at constant ‘peak load’ for her. ‘No further questions, your honor’. Mark de Bruijne supplied such excellent comments that I almost felt embarrassed from time to time. The combination with our talks is also much appreciated Mark. Last but certainly not least I would like to thank Jörn Richstein for his essential comments, pleasant attitude throughout and his late night work allowing me to improve the Agent-based modeling chapter. Thanks everybody.

Joris Groot, 2-5-2013.
Executive summary

The research presented in this thesis was performed to improve the representation level of the power plant investment module in an existing electricity market simulation model. The research focuses primarily on conceptualizing power plant investment processes in the Netherlands. In addition, initial simulation modeling recommendations are made.

A literature study is performed first in this thesis. It showed that limits to information access and information processing exist in the investment processes. Limitations originate from inherent characteristics of project management and corporate finance. Other limitations originate from power sector complexity in combination with power sector uncertainties and risks. These limitations complicate decision making in the investment process.

The limitations lead to deviations from ideal-typical rational decision making during the investment process. These deviations can be represented by several ‘coping strategies’ stated in the theory of ‘bounded rationality’ (Simon, 1982). This theory is used as a basis for propositions regarding investment processes. The first proposition states that common coping strategy categories can be used to represent similar investment processes. The second proposition states that differences between investment processes can be explained by regarding underlying causes for decision making constraints (e.g. company size affecting limits to information processing capacity).

Empirical results were obtained by semi-structured interviews with investment process experts. These represent companies that own more than half of the total power generation capacity in the Netherlands. The results added substantive specifications to the proposed coping strategies. Another review indicated that common investment practices show undeniable aspects of the bounded rationality perspective (but to a varying degree for different decision making categories).

Differences in coping strategies were also found for different organizations. The reasons stated by experts led to a concise set of initial ‘investment process differentiators’ in order to explain the differences. These initial differentiations for investment processes are: company size, ownership, level of vertical integration, geographic focus, asset base, technology specific uncertainties and intra-organizational dynamics (e.g. individual interests, culture). It is recommended to specify intra-organizational dynamics as well as the connections between the differentiators and the diverging coping strategies.

The outcomes result in an investment concept; investment processes can be represented by stating common coping categories, augmented with (only) applicable diverging coping strategies.

The investment concept is used as a basis towards an investment module in an ‘Agent-based’ simulation model. A selection of coping strategies was made, based on existing problem formulations and Agent-based modeling literature. Specific modeling recommendations were stated for Agent-based modeling experts. These can improve the representation of rules leading to improved model fidelity and validity. Recommendations were made towards these ends.
## Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ABM</td>
<td>Agent-based model</td>
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<tr>
<td>Capex</td>
<td>Capital expenditure</td>
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<td>CAPM</td>
<td>Capital asset pricing method</td>
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<td>Devex</td>
<td>Development expenditure</td>
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<td>EIA</td>
<td>Dutch fiscal scheme for energy investments</td>
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<td>EU ETS</td>
<td>European emission trading scheme</td>
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<td>FED</td>
<td>Front end development in projects</td>
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<tr>
<td>IRR</td>
<td>Internal rate of return</td>
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<td>NPV</td>
<td>Net present value</td>
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<td>Opex</td>
<td>Operating expenditure</td>
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<td>RAROC</td>
<td>Risk adjusted return on capital</td>
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<td>SDE+</td>
<td>Dutch subsidy scheme for stimulation of renewable energy production</td>
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The confidential Appendix is accessible by the graduation committee stated above.
1. Power plant investments in agent based models

*This chapter identifies the issues and resulting research actions required for improving (representation of) power plant investments in an electricity market simulation model.*

Firstly the context and problem definition of (modeling) power plant investments are stated to indicate the context and the core of the representation problem in section 1.1. Secondly the research objective is stated to allow for an effective research approach in section 1.2. Thirdly a set of research questions is stated to indicate knowledge gaps in section 1.3. The chapter concludes with a review of the resulting research approach that will be used in order to meet the research objective in section 1.4.

1.1. Introduction

Changes in the Dutch power sector

Little explanation is needed to indicate the high societal value of a well-functioning power sector in the European Union. The sector has large direct and indirect effects on prosperity through e.g. environmental stress, security and reliability of energy supply and affordability (European Commission, 2006; Ministerie van Economische Zaken, 2005). This means it is vital to have a well-functioning power sector. However changes seem to be on the horizon for the power sectors of European member states. And these changes might affect performance of the sector. This research will focus primarily on the Dutch power sector.

Public authorities actually state that structural changes are necessary and unavoidable for the Dutch power sector (European Commission, 2006; Ministerie van Economische Zaken, 2005). Several important drivers for changes are stated by the European centre on change (2008):

- Liberalization (allowing competition in certain parts of the power sector infrastructure).
- Creation of the European internal market.
- Environmental debates.
- Investment in infrastructure renewal and improvements.
- Unexpected energy demand growth patterns.
- Innovation and Research & Development.

These drivers indicate that the Dutch power sector (among others) is changing from its present state towards a different and unknown future state. This integral change process will be referred to as the ‘energy transition’. Several issues arise when policy makers want to manage this energy transition (based on their policy objectives). One of the problems that the policy makers will have to face is the power sector’s large degree of complexity. This complexity makes it difficult for a policy maker to grasp which effects potential policy interventions will actually have in the power sector. For policy intervention, this research focuses on carbon based policies (e.g. Carbon taxing, CO₂ price floors) as well as renewable energy policy (e.g. feed-in tariffs) (Laurens J De Vries & Chappin, 2011; p.1) (Richstein et al., 2012; p.1). Effects of implementing these policy interventions are difficult to forecast due to sector complexity.

Complexity is an ambiguous notion, but it holds high relevance for this research. So first the perspective on complexity will be introduced for this research by using a system’s perspective to review the power sector. This perspective will be elaborated on later in sub section 0.

Power sector complexity

Seminal work regarding complexity has been performed by Nobel Prize winning scientist Herbert Simon. Simon (1962; p.468) described ‘complex’ systems to be systems containing “a large number of parts that
interact in a nonsimple way”. This system perspective can be applied to the power sector to enhance insight in power sector complexity.

The power sector as a system is inherently linked to its infrastructure (e.g. transmission lines, power plants and convertors). Also, the sector clearly consists of many interrelated parts (e.g. power markets, infrastructure and regulators). Haas et al (2006) have shown that many of the interactions between these parts can be quite complicated and to some extent unknown. This makes the power sector a complex sector. This complexity holds challenge for many parties, including policy makers. For policy makers, the diversity of parts and their complicated interactions make it difficult to answer questions of how desirable changes in this sector could best be reached.

One example of a desirable change is the policy goal to reduce carbon emissions in the Dutch power sector. It is very hard to realistically predict how elements of the Dutch power sector will react to a policy measure (e.g. imposing a carbon tax measure). All kinds of parties in the market could show unanticipated behavior due to interactions with other parts of the power sector. This can result in undesirable societal effects.

The past has shown that this is a realistic scenario; an extreme example of unanticipated behavior was experienced during the Californian power crisis in 2000 and 2001. During this power crisis, parties such as Enron manipulated the California power market. This was not the sole reason for the power crisis but it contributed to extremely negative societal effects such as power outages and soaring wholesale prices (Federal energy regulatory commission, 2001).

This example shows that in certain circumstances, imposing policy measures without sufficient insight in power sector behavior can lead to considerable negative effects in society. This means more insight in the complex behavior of the power sector would be useful for efficient transition management. It would allow policy makers to make better informed decisions. However the research needs to cope with power sector complexity. One research initiative (of many) to address these issues is the ‘Next Generation Infrastructures’ research foundation (“NGI”). NGI research is the cause for this research and is elaborated in the following sub section.

Modeling power sector complexity
The NGI performs research in order to deal with complexity in future infrastructures through a multidisciplinary effort (NGI, 2012). Dealing with this complexity leads to more insight on how to safeguard the “future reliability and quality of infrastructure-related services” (NGI, 2012). One of the research projects undertaken by this institute is aimed at gaining insight in transitions and transition management in the energy domain.

Among others, this is done through the use of electricity market simulation models (Chappin, 2011; Laurens J De Vries & Chappin, 2011). The faculty of Technology, Policy and Management (“TPM”) works together with the NGI to develop research methods such this (group of) simulation model(s). The TPM simulation model can be used for e.g. ex ante evaluations of policy interventions. Such an evaluation of policy intervention can allow for avoidance of unwanted effects such as supply chain vulnerabilities and societal costs in real life which were already stated above.

The electricity market simulation model is an ‘object oriented model’. This allows for dealing with complexity by regarding the power sector as set of related, interacting objects (K H Van Dam, Nikolic, &

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1 Infrastructure is elaborated on in section 2.1.
Lukszo, 2012). This modeling paradigm is a fundamental difference compared to conventional simulations (which are based on performing a list of subroutines and a fixed modeling structure).

Agent-based model

In this research this type of model is called an Agent-based model (“ABM”). This name is due to the research’s focus on market parties. These market parties (such as power companies) are represented in the model as ‘agents’. Agents will be discussed in more detail in section 6.2. The electricity market simulation model from TPM is referred to as ‘the ABM’ in this research. The researchers that develop and use these models are referred to as ‘ABM researchers’.

Two concepts of representing organizations or persons in the power system are related and require some delineation here. These are the concepts of ‘actors’ and ‘agents’:

Actors

- Actors are a frequently used term in research at TPM and other research institutes that use a ‘systems approach’ in their research. Van Dam states that actors in general are still seen as real-life “entities” that influence some part of the real world (which is under review in the research). They do this through the decisions they make (K.H. Van Dam, 2009; p.4).

Agents

- The representation of any actor in an ABM calls for an abstraction of actors toward the formalized concept of “agents”. Agents are pieces of software code that are written to represent certain parts of the actor’s behavior in real life to some degree (K.H. Van Dam, 2009; p.4).

‘The’ ABM

ABM researcher Chappin states that in the ABM: “the energy industry is represented as interconnected agents. Simulations show the evolution of actor behavior and the emergence of system structures under different policies and scenarios” (Chappin, 2011; p.9).

These agents are the smallest element in the ABM and represent parties that influence the power sector. The ABM has several types of agents. One of these types of agent in the model is a simplification of power production companies. Among others, these companies make decisions on building new power plants. These agents in the model are referred to as ‘power plant investors’. In real life these decision makers will be primarily be the executive boards of power companies in an investment process.

Investment processes are concluded by a ‘final investment decision’. This final investment decision determines whether a new power plant will be built and what its characteristics will be. This is assumed to be the key moment in the decision process on whether or not to build new power plants (Pulles, 2012). The addition of new power plants is a structural change in the power sector that is represented in the ABM.

Investment processes leading to the final investment decisions in new power plant are the object of this research. Some delineation is required. Only investment processes for mature technology power plants with investment requirements of over 50 million € are taken into account in this research.

During these power plant investment processes, it is evident that the power plant investors will try to enhance insight on factors determining the success of the project. Examples are aspects such as technical design and legal structure. Also this type of agent will try to reduce different uncertainties during the investment processes (Pulles, 2012). These uncertainties are a key issue in this research. They will be discussed in section 2.3.

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2 Research at TPM is performed by using a wide range of models. However they are usually founded on a systems approach.
3 Addition of power plants changes the power sector structure because the power production portfolio in the market changes. This in turn is expected to have a heavy impact on the power sector behavior. This will be explained in more detail in section 2.2.
4 Here, ‘mature’ is meant to indicate power plant types which are already in use in the power sector.
Gaining insight in real life investment processes can enhance the way we can represent real life actor behavior in the ABM. This could allow for more realistic simulations. This could lead to better informed policy interventions, which in turn can lead to lower societal costs and supply chain vulnerabilities. This indicates the societal value of this research;

*Improving the representation of power plant investors in the ABM allows for better informed policy interventions.*

Several issues need to be addressed throughout this research in order to come to an improved representation of investment processes in the ABM. These issues are introduced in the problem definition in the following section.

**Problem definition**

In order to come to an efficient problem definition the problem owner is specified before the issues are introduced. This research will be performed from the perspective of the ABM researchers at TPM as the problem owner.

The software module of the ABM representing the investment processes is called the investment module. At present, an investment module has already been modeled in a preliminary version (Chappin, 2011 p.239).

Two main issues arise when confronting this module with an initial consultation and a preliminary literature scan. The main results of this confrontation will be explained in two main problem areas of this problem definition. The first problem area deals with the nature of decision making. A second problem area arises separately with regard to the inability to indicate model fidelity and validity with regard to the investment module. This is clarified in the second part of the problem definition. First the nature of decision making is reviewed.

In the current ABM the investment module is represented by a rational assessment through a `Multi criteria decision analysis` ("MCDA") followed by a `Net Present Value calculation` ("NPV") (Chappin, 2011; Laurens J De Vries & Chappin, 2011).

An initial literature review and consultations with investment process experts confirm the frequent use of the combination of MCDA’s and NPV’s as evaluation tools in investment processes (Graham et al., 2001; Pulles, 2012; Strategist, 2012).

However, the literature review and consultations also indicates that there are two main influential issues in the investment processes that are discarded when simplifying it to a combined MCDA and NPV decision.

Firstly the current investment module assumes rational behavior in decision making by its agents. Rationality has to do with a specific process of choice that is followed given the knowledge on preferences and the utilities derived from all options (Weber, 1947). This will elaborated on in sub section 0. For the investment process, specific procedures (such as structured financial evaluations) are followed in order to

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5 Belton and Stewart (2002) define MCDA as “a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter”.

6 Berk and Demarzo (2011) define an NPV as ‘the difference between the present value of a project or investor’s benefits and the present value of its costs’. This will be elaborated on in section 3.2.

7 De Vries and Chappin (2011) already indicate the early phase of ABM research and also state that perfect information is not assumed.
come to an expected utility (such as a MCDA score or an NPV). This means that rational elements are used in the real life decision making processes.

However several axioms seem demanding for the agents to be instrumentally rational. Among others, these axioms include that an agent should have the ability to at least attach definite probabilities to each outcome, have unambiguous preferences and should have the resources to process all the information needed (Simon, 1955).

The literature review and consultations indicate that these axioms are not met in the case of the investment process (Hirshleifer, 2012; Strategist, 2012). This becomes clear when regarding the situation faced by the actors (when reviewing statements of energy strategists):

- There is a large amount of information that should be analyzed during the investment process. But frequently information is also missing or ambiguous (Strategist, 2012). One example is found in uncertain future power prices and fuel prices. More uncertainties are stated in section 2.3.
- There is only a limited amount of time and resources to process this information (Pulles, 2012).
- In the investment process multiple parties with (partly) varying goals are involved in decision making which makes it challenging to have unambiguous preferences for the representation in the investment process agent (Pulles, 2012). Examples are banks, power companies and consultants.

Deviation of ideal-typical rationality can emerge in all kinds of facets of investment processes, even if formalized evaluation methods such as an NPV are used. For instance, the opportunity cost for capital used in financial evaluations (such as the NPV) will eventually be subject to subjective risk assessments. MCDA’s also need subjective assessments (Belton & Stewart, 2002).

This means decision making in the investment processes can be assumed to have rational aspects but only to a limited degree. Finding a more suitable decision making perspective would add to the investment module’s validity. Representing a realistic form of decision making is a frequent problem in ABM’s given the behavior based nature of its agents (Bonabeau, 2002, p.7287).

To deal with this decision making perspective it is necessary to have a clearly specified concept of the actual behavior that the investment processes agent displays in real life. However this information is not yet available to the ABM researchers at present.

A second issue also arises (which is linked to the first issue). It is described by Bonabeau as “the model has to be built at the right level of description, with just the right amount of detail to serve its purpose; this remains an art more than a science”(Bonabeau, 2002; p.7287).

When a investment process concept was clearly specified, the question remains which issues could be expected when translating the concept to an investment module in the ABM. To this end, recommendations for translating the investment concept would have much added value for the ABM researchers.

During the translation (from investment concept to investment module in the ABM) the ABM researchers need to make a very important trade-off (among others). This tradeoff is in simulation fidelity versus computational limitations of the ABM (as well as ABM researcher resources).

Simulation fidelity is seen as the extent to which a simulation replicates the system it represents. Increasing fidelity means that the ABM can represent more aspects of the power sector which could be useful. In theory, this maximum fidelity for investments could be reached by coding all aspects of an exhaustive
investment concept. However, this will lead to a large model with undesirable computational requirements. So ‘model parsimony’ is a relevant issue in this research.

Initial issues in coming to a satisfying trade-off are expected. Currently any insight in the added value of adding unique investment concept aspects to the ABM investment module is still lacking. So there is no way to tell what improvements in model fidelity will result from adding parts of a potential investment concept. This means the translation trade-off is not possible yet.

These issues of the incomplete investment concept and the necessary recommendations are addressed further in the research objective.

1.2. Research objective

A general research objective is stated based on the problem definition:

- The research objective is to improve the representations of investment processes for power plants in an agent based model-

The translation trade-off indicates the necessity to review the integral process of finding and structuring empirical information through to actual ABM coding. Otherwise no concept of the level of representation can be formed (in following modeling steps).

The scientific objectives are to come to:

- An empirical description of real life power plant investment processes in a well-founded theoretical framework which can be improved upon. While showing under what premises the concept is applicable and what its pros and cons are.
- Recommendations on translating a (realistic) investment concept into an ABM investment module. In order to contribute to insights on how tradeoffs in model fidelity vs. model parsimony are made in ABM’s.

The societal added value has already been indicated in the problem statement: The resulting insights can contribute to better informed policy interventions. This in turn can lead to avoidance of unnecessary societal costs and supply chain vulnerabilities in the power sector.

In order to reach the research objective a research question is stated in the following section.

1.3. Research question

A research question has been formulated based on the research objective and problem definition stated above. The research question is split up in sub questions. The main research question of this research is:

- What is the most fit for purpose way of representing power plant investment behavior in an agent based model?-

‘Fit for purpose’ can be an ambiguous concept without delineation. For this research, the notion is based on coming to a parsimonious model that still enables reaching research objective stated by ABM researchers at TPM.
In order to answer the research question it is split up in sub-questions:

**Sub question 1:**
*How are defining aspects of power plant investment processes described in scientific literature?*

**Sub question 2:**
*How are power plant investment processes currently performed in the Dutch power sector?*

**Sub question 3:**
*Which insights explain the similarities and diversities between power plant investment processes seen in Dutch power sector?*

**Sub question 4:**
*Which recommendations can be made in order to translate the power plant investment processes concept into an agent based model?*

The research material needed and the strategies chosen to answer the sub questions are stated below in the research approach.

**1.4. Research approach**

This section explains the research approach that will be followed for answering the sub-questions stated in the section 1.3. Basic information on the research context is stated in the previous sections. The construction of this research approach is based on the research prescription indicated by Verschuren en Doorewaard (2005). However, some preliminary problems were expected given the characteristics of the power sector. More ‘inside information’ was needed first in order to come to an effective research approach here.

Therefore, a preliminary scan of scientific literature and a short expert consultation have been performed first. The outcomes act as an extra guideline for coming to a research approach.

Three main issues have been drawn this preliminary scan. These issues will be stated below. The research approach is based on reaching the research objective (stated in section 1.2) while avoiding these potential research issues. The review concludes with the resulting research approach.

**Expected issues before choosing the research approach**

**Multidisciplinary nature**
The first issue that arose from the preliminary scan is that power plant investment decisions have a multidisciplinary nature. E.g. technical, legal, financial, regulatory, political, project management and other issues are taken into account in investment processes. In-depth reviews of all the underlying disciplines would result in an insurmountable task. This means that adequate literature selection and processing choices are needed in order to deal with this multidisciplinary nature.

**Lack of existing theoretical framework for investment processes**
Secondly, available descriptive literature on setup of power plant investment processes was scarce during
the preliminary literature scan. Empirical descriptions of investment decisions were incomplete at best. And the shortcomings of ideal-typical models were already stated in the problem definition.

In addition, a theoretical framework (allowing for some structuring investor’s investment processes) has not been found during the preliminary scan. Current disciplines such as corporate finance and project management prescribe how to shape an investment process. But they do not indicate why real life investment behavior (based on these investment processes) can diverge from these theoretical, ideal-typical prescriptions. The absence of such a framework indicates that explorative data collection methods are necessary in the approach.

**Information sensitivity of investment process content**
The third issue is closely linked to the second issue. Investment processes frequently contain information that is highly sensitive to the strategic interests of power plant investors. Examples are an investor’s ‘weighted average cost of capital’ ("WACC") or details on their electricity price forecast methods. Stating this type of sensitive information will weaken the company’s competitive position. It is expected that investors will protect their interests at all cost. This means that full disclosure on investment processes cannot be expected for any of the participants.

In addition, participation of all parties cannot be expected due to information sensitivity and scarcity of resources needed for this research. Examples for resource scarcity are the investor’s availability, but also data collection budget of this research. This means an effective strategy is needed to collect as much useful data as possible. But the data collection method needs to be able to deal with incomplete information and scarce resources.

The research approach is adjusted to deal with to these three potential issues. The approach is stated below, structured per research sub-question.

**Research methods**

**Answering the first sub-question**
The first sub question will be answered through performing a literature review. This review has two main outcomes:

1. A power sector overview (i.e. technical, institutional characteristics augmented with its main risks and uncertainties). This overview defines the main substantive issues and definitions in the power sector (in chapter two). These are needed to understand the specific setup of power plant investment processes. It also allows for insight in the increased level dynamicity, uncertainty and complexity of large scale capital investment in the power sector.

2. Key notions of investment processes and propositions to a theoretical framework that can explain (differences in) investment processes. This is achieved through performing a literature review of key knowledge disciplines for the actual investment process.

The reviews needed for the two outcomes are elaborated in the sections stated below.

**Power sector overview**
The power sector overview will indicate the main context in which the investment processes are performed in chapter two. The preliminary scan indicated that the sector’s risks and uncertainties are complicated notions which can hold ambiguous aspects. Therefore the notions of risks and uncertainties are defined
after the main sector descriptions. A key outcome of this overview is the indication of specific uncertainties and risks for the power sector. This is stated in section 2.3.

**Key notions and methods of the investment processes**
The literature review needed for these outcomes require more attention in this research approach description. A selection in reviewed disciplines (and their respective level of depth) has to be made due to the multidisciplinary nature of the investment processes. The choice is made to focus primarily on the organization and key decision making methods during the investment process. This allows for investment process descriptions that are not dependent on a power plant’s specific setup (such as substantive technical or legal issues that differ for each power plant). This allows for stating propositions, yet without limiting the substantive outcomes to what is known in scientific literature.

The initial consultation indicated that the processes are usually *organized* by using standard project management methods. All consulted parties further considered financial issues to be of key interest in their investment process outcomes (e.g. project valuation). Therefore literature on project management and corporate finance will be reviewed. These reviews do not give an exhaustive overview of these disciplines. Their goal is to define key methods and issues seen in power plant investment processes. These definitions will serve as a common ground throughout this research.

It was stated in the problem definition that investment behavior cannot be explained by an ideal-typical rational approach (e.g. corporate finance prescriptions in isolation). So in order to reach the research objective a third theoretical discipline is needed. This discipline should allow for gaining the insights needed to explain the real-life investor behavior. It will be the theoretical foundation of the representation of the investment process. This is an important choice for this approach.

**Decision science**
From the preliminary scan, it became apparent that investment decisions contain both rational and more informal aspects (e.g. analytical, political, social, and personal aspects). Decision science is a scientific discipline that allows for a formal representation of real-life decision making behavior. Its unique advantage is that it contains theories that allow for reviewing rational as well as non-rational aspects of a decision process.

The integral discipline of decision science will be shortly reviewed. From this review, one theory will be chosen based on the best fit with the outcomes of preceding literature reviews. The theory will be reviewed separately. The review will be performed to a point to where it can act as a basis for propositions on how investment processes actually take place (stated below). These propositions are the key outcome of chapter 3.

The outcomes of these reviews will answer the first sub-question. The outcomes are stated in chapter 2 (power sector review) and chapter 3 (review of scientific models for investment processes).

**Answering the second sub-question**
The second sub question will be answered through conducting a series of semi-structured interviews. This type of data collection will allow for dealing with the explorative nature of the research substance as well as the limited number of participants. Methods such as case studies hold advantages too. They would allow for reviewing actual practice instead of measuring perceptions of single experts. Unfortunately, this was stated to be less feasible during the preliminary consultation. This was due to the information sensitivity of the investment process content.
Organization of interviews and results
Some organization of the interviews is necessary to allow for effective analysis. The interviews will be structured to a limited degree. The starting points of the interviews are notions in the propositions from chapter 3.

This choice has two distinct advantages. Firstly it allows for analysis based on well documented scientific theory (performed in chapter 5). Secondly the decision science supplies the theoretical basis but still leaves maximum room for a diversity of substance related outcomes. This is due to the fact that the theory only deals with the decision process’s form and not its substance. This is a key requirement since the substantive outcomes cannot be proposed yet.

Therefore the decision theory allows for a theoretically founded creation of an investment concept. The premises of the decision theory will be checked separately with a senior power plant executive. This is done in order to indicate the fit of decision theory premises with actual investment practice.

To maximize the quality of the perception measurement the participants are recruited from several company positions (e.g. business analysts, business development directors and executives) and several types of companies (e.g. consultants, power companies, banks). Due to practical limitations not all parties can be represented. However the level of representation is stated in chapter 4.1.

Given the lack of an existing investment concept, participants are asked to supply two types of information. Firstly they will supply investment process descriptions (‘how they do it’). Secondly they will also recommend perceived reasons for choices that are different between respondents (‘why they do it’). An effort will be made to separate these two different types of outcomes. The empirical substantive data will be summarized in chapter four. The second set of outcomes will be used in answering sub question three (in chapter 5).

This still leaves the issues of information sensitivity and resource scarcity to be dealt with. Information sensitivity is already limited due to the chosen method of interviewing. This is because participants can choose what information they want to share and in what form. Every interview is summarized by the researcher. These summaries have to be accorded (in writing) by the participants for publication. This gives the participants extra control (improving chance of participation) and can also increases the quality of the summaries. This way of working is communicated straightaway from the initial contact moment. This was done in order to maximize participation and build trust (increasing the chance gathering good information).

Dealing with classified information
The summaries are collected in the classified Appendix. This research’s exam committee has access to the classified Appendix to verify the analyses. The empirical outcomes are all made anonymous. They are represented in consolidated form in chapter 4. Specific statements are cited by interview number to enable verification while also allowing for anonymity. A consolidated (anonymous) description of the participants is also added to indicate the level of representation of the measurement.

Empirical outcomes
The outcomes of this chapter are separate descriptions of common and varying investment process aspects amongst investors. For example; a common outcome could be that all participants perform project valuation by use of a formal Discounted Cash Flow-method (‘DCF’). An example of a potential varying

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8 The financial notions are elaborated on in section Error! Reference source not found..
outcome is that the participants use different financial decision rules (e.g. NPV-rule versus discounted payback time).

Chapter 4 only holds empirical results and does not contain any analyses. The analysis of the empirical outcomes is treated in the approach for sub question three (described in chapter 5).

**Answering the third sub-question**

The third sub question will be answered through analyzing only the varying investment process aspects from the empirical outcomes. This analysis is performed in chapter five.

Several methods could be used to come to insights on why the investment processes vary. For explorative research at participants the “grounded theory approach” is a proven method. Unfortunately a full “grounded theory approach” method is not feasible due to the small number of participants expected in the interviews.

Therefore the choice for a more basic analysis method has to be made, with the disadvantage of losing insight in differences of perception. The analysis is done in the form of a simple matrix. This matrix consists of many rows (a host of substantive choices stated by experts) and several columns (reasons for varying substantive choices between participants). Firstly the rows and columns of the matrix will be explained. Secondly the relevant outcomes inside the matrix will be elaborated. The goal of this analysis is to find common investment process features but also reasons for differing investment processes in a structured way.

**Investment concept organization**

The rows in the matrix constitute of the stated options in substantive choices made by the investors. One example is the project’s financial valuation method (e.g. using the NPV-rule). It is expected that this will be a long list. It is organized via the decision theory categories (e.g. one category could be all the “goals” of a decision).

The columns consist of determinants. Determinants are the stated reasons that influence certain substantive choices. The determinants are the previously stated “perceived reasons for differences” derived from the participants. It is expected that a selection has to be made for a parsimonious framework. Stated rationales are only included if they add significantly to the research objective. Significance of determinants is defined as: rationales stated by multiple participants or if stated to be a key driver by any of the participants. One hypothetical example is company ownership. E.g. many investors state that their municipal ownership is an important reason for their choice to take carbon footprints into account in the investment process. In this case ownership would become a determinant (stated in the column of the matrix). These links are a first step in explaining differences between investment processes.

It is expected that there will only be a limited number of “hits” between choices and determinants. These are the relevant cells in the research matrix. These hits will allow for an explanation of differences in the investment processes (e.g. caused by different types of company ownership).

These differences are combined with the common aspects of investment processes (separately stated in chapter four). One investor’s expected investment process would be the sum of the aspects common for all investors augmented with the specific aspects (based on the setup of the investor’s determinants). This theoretical framework is a main outcome of the analysis in chapter 5. It is a high level investment process proposition.

**Investor Choices**

<table>
<thead>
<tr>
<th>Determinants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investor Choices</td>
</tr>
<tr>
<td>Investment concept</td>
</tr>
</tbody>
</table>
The fourth sub question will be answered through reviewing the investment concept constructed in chapter 5 into recommendations for an investment module in the ABM in chapter 6. Two main steps are taken towards coming to such a translation. Firstly a selection has to be made out of all elements of the investment concept. Secondly the selection has to be specified according to Agent-based modeling notions.

This requires several insights in Agent-based modeling.

**Review of ABM literature**

Agent-based modeling literature is reviewed first in order to come to several insights.

Firstly the review explains how Agent-based modeling for socio-technical systems is structured. This structure is followed in stating modeling recommendations for the ABM investment module.

Secondly, the review leads to insights in how investment concept improvements lead to improvements in model validity and fidelity of the ABM. This is a crucial step towards understanding the representation issues stated in the problem definition in section 1.1.

Lastly, the review leads to a concise overview of problem formulations stated in the ABM research at TPM. These formulations are used to come to an efficient selection of the investment concept for ABM implementation.

**Concept selection and review**

The selection of investment concept aspects is based on their unique added value to Agent-based modeling problem formulations of ABM researchers at TPM. This added value is indicated by stating which aspects of real power sector behavior can be replicated by adding the investment concept aspect.

The resulting selection is linked to the Agent-based modeling structure and expected implementation issues are stated. These result in a concise set of recommendations for coming to an investment concept in the ABM. These recommendations (and corresponding reflections) answer sub question 4.

**Answering the main research question**

The answers to the four sub questions are combined to conclusions and recommendations in chapter 7. Reflections are stated in chapter 8. These answer the main research question

**Overview of approach and key results of this research**

The research approach stated is visualized in the figure stated below. The figure links the research methods, key outcomes and their locations in this thesis.
Power plant investment decisions in the real world

1. Introduction and problem formulation

2. Literature reviews
   Ch. 2 & 3

3. Empirical analysis of outcomes
   Ch. 4 & 5

4. Agent-based modeling review
   section 6.2

5. Analysis for ABM recommendations
   section 6.3

6. Critical reflections
   Ch. 8

Research answers:
   Ch. 7
   (Reflection in ch.8)

Figure 1 Overview of research and thesis
2. Power sector overview

This chapter introduces key technical and institutional aspects of the power sector and their resulting risks and uncertainties. This indicates the context in which the investment processes are situated.

Technical aspects are introduced first by stating simplifications to this research’s concept of complicated power plant installations and infrastructure. This concept is used to introduce a diversity of parties as well as the most relevant rules and regulations in the sector. Next, the ambiguous notions of risk and uncertainty are specified. This allows for the creation of an overview of main changes, uncertainties and resulting risks relevant for power plant investment processes. This overview concludes the chapter. It serves as a starting point for understanding why real investment processes deviate from ideal-types of applicable theories (reviewed in chapter 3).

2.1. Technical characteristics of the power sector

Basic insight in the technical system is needed to explain other power sector characteristics relevant for power plant investments. Only the notions deemed essential for understanding power plant investment processes are elaborated on.

Due to scope, this research simplifies power plants to generators converting fuel or alternative energy sourcing to electricity at varying energy efficiencies. More information on energy efficiency is stated in Appendix 3. This simplification means that other properties such as the value of residual heat for thermal power plants are not taken into account. Some indication of scale of current production as well as power demand curves in the Netherlands is also stated in Appendix 2.

Supply chains

To indicate the basic infrastructure setup, a representation of a conventional, centralized power system’s ‘supply chain’ is given. The supply chain is defined as the system “in which the particular resources are combined to create and deliver specific products and services to end consumers, who derive ‘value in use’ from consumption” (Cox, 1999; p.174). This will be referred to as ‘the power supply chain’ throughout the research.

A conventional, centralized supply chain starts with sourcing of fuel for generation. The fuel is converted into electricity (and other outputs outside the research scope) during the generation step in a power plant.

The power is transferred from the power plant through the high voltage transmission grid. The transmission grid delivers the power to the lower voltage distribution grids, which in turn allows for delivery of the power to customers.

Figure 2 Conventional supply chain of the power sector based on description by Kessides (Kessides, 2003).
This is the classic variant of power supply chain in the Netherlands. However, several supply chain variants are possible based on this basis. Main variations are caused by two degrees of freedom coupled to the generation step of the power supply chain:

1. **Feedstock dependency of the power plants**: Many plants are dependent on fuel (e.g. natural gas, nuclear, hard coal, lignite and biomass powered plants). Other power plant types do not require energy contained in a fuel but require alternate energy sourcing (e.g. windmill parks, photovoltaic or geothermal plants). This category requires energy sourcing from the power plant’s local environment (e.g. wind, solar radiation, thermal energy). In some cases these local sources have ‘intermittent’ availability. This means the energy sources are not continuously available to the power plant on demand and cause output to vary. One example of this is the variation in wind speed at a windmill park. Under many circumstances these wind speed variations can lead to unrequested variation in power output or intermittence.

2. **Level of centralization of generation**: Power plants such as hard coal plants enjoy considerable energy efficiency improvements with scale growth. For other power plants such as photovoltaic cells there is no energy efficiency improvement with scale growth of the generation unit(s). This allows for placement of (smaller) production units near the delivery point. This does not necessarily make transmission and distribution superfluous. However the function of the transmission and distribution networks in the supply chain will change more toward power system balancing in such a system.

**Technical characteristics of power plants**

Several technical characteristics of power plants hold relevance for this research. These characteristics influence the setup of power plant investment processes. An (in exhaustive) overview of characteristics stated below:

- **Asset specificity**: Power plants cannot simply be redeployed elsewhere in a cost effective manner. Also the assets are optimized for a use at a specific industrial site. This makes the power plant’s technical and economic value at this site much higher than it would be in alternate locations or setups. This characteristic is called ‘asset specificity’. This high level of asset specificity leads to high sunk costs of power plants after the initial investment has taken place.

- **Long operational lifespan**: The initial expert consultations indicate operational life spans of 15 to 40 years for conventional power plants. For instance the Dutch nuclear power plant “Borssele” has been in operation for 40 years (EPZ, 2013). This means the investment process needs a long term focus.

- **Operation coordination dependency**: Supply and demand need to be balanced in time as well as locations in order for the power system to function properly. Lack of proper balancing or power transport issues can easily lead to rapidly decreasing power quality (ranging from power frequency changes to power outages) (Paap, 2012). Storage of power is very expensive and so are the effects of decreasing power quality. This means that supply and demand variation constantly requires close coordination between several actors in the power sector.

- **Power plant ramping characteristics**: Power plants take time to increase or decrease their power production (the process is called “ramping”). This ramping speed can vary significantly between

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9 E.g. if the wind speed is already over the ‘cut-out’ speed, a higher wind speed does not necessarily have to lead to power output variations.

10 It should be stated that short term performance is usually much more important to investors than long term performance. One reason for this is the use of discount rates. This is explained in section Error! Reference source not found.
power plant types. Ramping will also frequently increase installation wear (e.g. due to changes in thermal loads) and can change the power plants energy efficiency. Ramping influences performance and costs of the power plants in time (Gerhardt & Blaney, 2010).

- **Grid connection requirements:** Large commercial power plants are usually connected to the transmission grid. Development of a new power plants frequently requires transmission expansion or network capacity additions by the Dutch Transmission System Operator (“TSO”) ‘Tennet’. These expansions and expansion also require considerable investments and can take years to implement. The current infrastructure can also drive future considerations. This is one example of ‘path dependency’ in the power sector. In this research, path dependency is used to indicate that choices made in the past influence choices in the future. Path dependency is an important notion in this research11.

- **Cooling water dependency:** thermal power plants commonly require large amounts of cooling water in order to control the thermal balances. This strongly limits the location possibilities for these kinds of power plants.

- **Interconnection:** Power systems in Western European countries have cross border connections called “interconnectors”. The Netherlands is already connected to Norway, Germany, Belgium and Great Britain. Several interconnectors are being developed to Denmark (Cobra), Norway (Norned II) and Germany (Wesel) (Tennet, 2012). This means the (previously national) infrastructures are becoming more connected internationally.

- **Base load and top load:** Every power plant can produce power at a certain production price. The cost of producing one extra unit of power is the “marginal cost” of production. Power plants such as hydro power plants or nuclear power plants usually have low marginal costs but high fixed costs (Fraser, 2003). Which mean they attractive to produce power for every timeslot (“base load”). Power plants such as natural gas turbines will have higher marginal cost of production and usually lower fixed costs. In the current market setup, they will only produce during the timeslots where demand is larger than the base load capacity (called “base load”). Higher demand will lead to higher prices which will attract more power plants (with increasingly high marginal costs) to produce power. More on this subject is stated in the section 2.2.

These technical realities lead to several financial characteristics when regarding the resulting investment processes. This will be discussed in the following sub section

**Resulting financial requirements of technical characteristics**

Financial notions crucial for the power plant investments are summarized by Olsina et al (2006). This serves as a basis for research in long-term dynamics of electricity markets (quoted sections all retrieved from (Olsina, Garcés, & Haubrich, 2006; p.1415):

- **“Capital intensive”:** installations requiring “huge financial commitments”. An extreme example is stated by ECN (2013). The institute indicates that large scale12 nuclear power plants in the region can range up to 2,5 to 3,7 billion € (ECN, 2013).

- **“One-step investments”:** installations only function after committing the majority of the total required sum of these huge financial commitments.

- **“Long payback periods”:** “expected to be paid back after several years”.

- **“Long-run uncertainties”:** these are stated in more detail in sub section 2.3.5.

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11 Path dependency is elaborated in the review of Agent-based modeling in chapter 6.
12 1600 Mwatt
“Investment irreversibility”: Meaning the action cannot be easily be undone to recover the initial investment. This is heavily linked to the issue of asset specificity stated above.

“Investment postponement option”: Relative small expenditure (e.g. an option on a land-lease agreement) can supply power plant investors with the choice (but not the obligation) to time the majority of their investment “likely to be treated as a financial call option”.

These considerations are relevant for understanding long term investment behavior in the power sector. They will form constraints on choices on the financial decision making review in section 3.2.13

The technical and financial characteristics of power plants beg the question of how the generators lifespan can be simplified for use in this research.

**Technical lifecycles**

This can be done by stating its lifecycles. Weijnen et al state steps in the total power plant’s technical design life cycle (Weijnen, Herder, & Thissen, 2001; p.181). Examples for power plants are also added. This is based on the description by Weijnen et al (2001) and is stated below;

1. **Analysis**: a detailed analysis of the problem the power plant needs to solve
2. **Conceptual design**: considering alternative solutions to the specified design problem
3. **Basic engineering**: design of the most crucial power plant components
4. **Detailed engineering**: design to the level that the power plant can be constructed
5. **Construction start-up**: physical plant construction according to the detailed engineering design
6. **Operation**: the functional life of the power plant (possible to generate power)
7. **Demolition**: decommissioning and removal of the power plant to a required level

The first four steps of the life cycle can be linked to the ‘front end development’-phase of a project based approach for coming to an investment proposition (“FED-phase”). The steps in a front end development phase lead to the final investment decision. This is elaborated on in the project management review in section 3.1. The cost of preparing the design for the final investment decision (in steps 1-4) is called development expenditure or ‘Devex’. The Devex will usually increase exponentially in steps 1-4.

This research does not focus on detailed power plant designs. However certain basic choices in the technical design of any type of power plant are crucial in order to understand the investment processes.

**Basic technical choices for investment processes**

During the life cycle a limited number of initial technical plant design characteristics have a defining influence on the outcomes of the first four life cycle steps. These are chosen in conceptual design and basic engineering. De Vries states these to be the following (L. J. D. Vries, 2004; p.22):

- “Size” (e.g. power producing capacity in MWe),
- “Controllability” (speed with which they can react to changes in demand),
- “Availability” (with regard to scheduled and unscheduled outages)
- “Reactive power generation capacity”
- “Energy source” (e.g. natural gas, nuclear)
- “Environmental impact” (e.g. carbon emissions, cooling water effects)

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13 For instance, long run uncertainties and long payback times indicate that the financial decision making method needs to be able to work with the time value of capital as well as uncertainties that cannot be transformed in project specific risks.
These choices are expected to have considerable influence in the power plant’s performance.

**Conclusions of the technical review**

The technical review indicated the basic concepts for (the design and context of) power plants. These technical characteristics lead to the financial requirements stated by (Olsina et al., 2006). These requirements show that the investment process will have to be able to deal with large, long term investments that are exposed to uncertainty. More on uncertainty is stated in section 2.3.

The technical infrastructure is linked to all kind of institutional aspects of the power sector. A review of the power sector’s institutional arrangements is stated in the following section.

**2.2. Institutional characteristics of the power sector**

In this section several non technical arrangements for actors the power sector are introduced: institutional characteristics. These are “a market-specific body of rules and conventions” (Correljé & Vries, 2006; p.2). Examples are formal and informal notions such as power market design, regulations, subsidies and legal issues that apply to actors in the power sector. Only the notions deemed essential within the scope of this research are elaborated on in this section.

To this end, the power market is introduced first based on market design variables by Correljé and De Vries (2006). The scope is limited to the Netherlands. Secondly the Dutch power supply chain (introduced in section 2.1.) is coupled to the main actors in the institutional environment. Thirdly the main market mechanisms linked to the production part of the supply chain are introduced. The section is concluded with a particular part of the market mechanism (the “merit order”).

**Power sector design**

Relevant power sector design variables, their consequences and an overview for European countries are explained in more detail in Appendix 5. The Dutch power sector has liberalized generation, with decentralized power markets and competition in retail (Correljé & Vries, 2006; Ministerie van Economische Zaken, 1998). Only the transmission part of the power supply chain is not liberalized. Takeovers and mergers within the sector are allowed (Haas, Glachant, & Keseric, 2006).`

**Main actors and regulations in the Dutch Power sector**

The transmission system operator (“TSO”) and the trading exchange (Amsterdam power exchange or “APX”) are (state owned) companies.

Some liberalized power companies in distribution and generation (still) have a large share of municipal ownership (e.g. ‘Delta’ and ‘Eneco’). Foreign power companies have also entered the Dutch generation sector (e.g. ‘Electrabel’ and ‘RWE’). State owned companies are also active in the Dutch market (e.g. ‘Statkraft’).

The power companies are subject to several regulations. The Dutch regulator administering these is the ‘Energiekamer’, a subsidiary of the ‘Nederlandse mededingings authoriteit’ (‘NMA’). It is stated to be a strong regulator which oversees maximum transport rates, TSO responsibilities, grid connections and conditions for a well functioning (inter-) national wholesale market (Energiekamer, 2013). This means power companies have to deal with a diversity of regulatory risks.
In addition, there are three separate schemes based on desired energy transition policy goals. These are stated in the following sub section. These three incentives can be seen in the wider context of ‘policy interventions’ which can also include other options.

**Energy transition schemes**

The three main schemes are focused on different policy goals. These are carbon emissions, renewable energy production (in the Netherlands) and renewable energy investment (in the Netherlands). These vary in structure and geographic focus;

**EU ETS**

In the European Union, power companies are obligated to own emission rights for the CO₂ emissions of their power plants. These emission rights are settled in the European emission trading scheme (‘EU ETS’). The system is based on the principle of ‘cap-and-trade’. A maximum amount of emission rights is set in a political process by the European Union member states (European Commission, 2003). In order to comply, power companies can buy emission rights on ‘carbon markets’. But these markets are dependent on political choices.

**SDE+**

In the Netherlands, the Dutch ministry of economic affairs has a subsidy scheme for stimulating renewable energy production called ‘SDE+’. SDE+ gives financial compensation per kWh of renewable energy generated. The height of the compensation is set on a yearly basis per generation type. This height is set as a function of a basic compensation figure minus a correction (based on average yearly power price). Several uncertainties arise from the scheme. There is a fixed total budget for SDE+, and the correction stated above is sensitive to political choices on corrections (Ministerie van Economische zaken, 2013).

**EIA**

A third scheme is the ‘Energie investering aftrek’ (‘EIA’). The EIA gives fiscal incentives for investment in renewable energy or energy efficiency investments by giving tax deductions to corporations. The EIA advantages can also be shut down when the budget is spent. Both the EIA and SDE+ are administered by ‘Agentschap NL’, a subsidiary of the Dutch ministry of economic affairs (Agentschap NL, 2013).

These national incentives (e.g. SDE+ and EIA) vary for different countries in Western Europe. This can provide an incentive for internationally oriented power companies (and financial investors like banks) to compare national incentives when reviewing renewable power plant investments.

It is concluded here that these schemes are particularly relevant for renewable plants (i.e. SDE+ and EIA) and low carbon generation plants (e.g. also conventional power plants with carbon capture and storage avoid buying emission rights)\(^{14}\). Also it as important to note that international ‘competition’ between national incentives is possible from the perspective of power plant investors.

These schemes only vary for depending on power plants. However, all power plant owners are dependent on the power prices they can charge. The mechanisms are explained in the following sub section.

**Power price mechanisms**

This review is focused on power price mechanisms linked directly to the power plants (e.g. retailing systems are not discussed). There are several options for power producers to sell their power: bilateral contracts with large consumers or via several power markets. Especially power markets are a key mechanism for

\(^{14}\) Low carbon means low CO₂ emissions (e.g. this can also be a coal plant with carbon capture and storage option but also an offshore wind park); while renewable means that the generators energy sourcing is continuously replenished (e.g. wind, solar or hydropower plants).
understanding the power plant investment process, and it requires more explanation. The power markets are organized on different time scales: day ahead and continuous.

In the day ahead market the trading is done for each hour of the following day. The continuous market allows for trading in freely definable blocks. APX Power NL is the Dutch independent power exchange that enables the trading (APX power NL, 2013).

The Dutch power market for generation is a ‘decentralized market’. This means that power companies and power consumers interact to come to a market price (opposed to ‘mandatory pool’ markets) (L J De Vries, 2004). The market mechanism is designed to match power demand and supply in an efficient way.

To this end, the marginal costs of production for power plants are used. This marginal cost is mostly dependent on the fuel costs, power plant efficiency and carbon emission costs of the power plant.

These marginal costs are combined in a marginal supply curve or ‘merit order’. The merit order decides which power plant can supply power (or ‘dispatch’). The figure below illustrates the basic mechanism of the power markets. The red line indicates the collection of marginal costs of power plants in this market. The blue lines indicate demand (low and high demand). The power price should ‘clear’ at the spot where the merit order curve meets the demand curve. To fulfill demand this power price is chosen for the first power plant ‘in line’ to dispatch in the merit order. All plants that can dispatch receive the same market price.

This mechanism has several effects on the power sector:

- The power plants with the lowest marginal costs will always dispatch (e.g. wind, nuclear, coal). Renewable power plants will also have priority access.

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Cost of producing one additional unit of power.
Plants with high marginal costs only dispatch at periods of high demand (e.g. natural gas turbines have higher marginal costs and will only dispatch during peak load periods).

The system can lead to ‘competitive interaction’ (Murto, 2003; p.2). Changes in the aggregated set of power plants can occur (e.g. addition of a wind park or a nuclear plant). These change the merit order stated in Figure 3. In turn the power price is cleared at a different level. This means all dispatching plants receive a less favorable power price. Also power plants that are just above this clearing price do not get to dispatch power any more (and miss out on income).

These effects are critical considerations for the understanding power sector behavior.

Conclusions
The institutional review indicates that power plant investors have to deal with several key institutional issues in their investment processes. Among others, these are sector regulation (regulatory risk), policy interventions (e.g. emission rights, SDE+, EIA), and power market structure effects (e.g. competitive interaction or power price volatility).

For investment processes, additional risks and uncertainties are present in the power sector. These are reviewed in the following section.

2.3. Risks and uncertainties in the power sector

Risks and uncertainties are key notions for understanding power plant investment processes. Several steps are stated below in order to come to a concise overview of risks and uncertainties in the power sector. Firstly the notions of system complexity and project complexity are reviewed in sub sections 0. and 0. Secondly the notions of uncertainty and risks are reviewed in section 0. These reviews allow for a review of risks and uncertainties in the power sector in section 0.

Complexity in the power sector

Varying descriptions
Respective definitions of risks and uncertainty vary in description both within and between different scientific disciplines (Bosch-Rekveldt, 2011; Ward Edwards & Tversk, 1967). Some of these differences have to do with the focus of those disciplines (three relevant disciplines will be elaborated on in chapter 3).

Some clarification is necessary first, to enable clear use of risks and uncertainties in this research. Firstly the context of these notions is indicated by describing several types of complexity. This complexity makes it more difficult for power plant investors to assess the risks and uncertainties.

System complexity versus project complexity
We delineate between (exogenous) system complexity and project complexity. System complexity is not influenced by the investment process to a large degree whereas project complexity is.

In this section, firstly exogenous system complexity is indicated by the three layer model by Herder and Thissen (2003). Secondly, a literature review performed by Marian Bosch (2011) is used as a basis for understanding the links between project complexity and uncertainty. Thirdly, three notions will be introduced that are deemed critical for understanding the notions of risks and project uncertainties throughout scientific disciplines. These three notions will then be used to indicate the perspective of risk.
and uncertainty in this research. The third section will be concluded with an overview of project risks and uncertainties deemed critical for the power sector.

The part of complexity in the power sector which cannot be influenced (to a large degree) by the setup of investment processes can be explained by reviewing interactions. These are interactions inside and between several conceptual layers of the power sector. These are indicated in the following section through the use of several conceptual layers.

**Conceptual layers of the power sector**

The physical value chain described in section 2.1 is seen as the first of three layers proposed in Thissen & Herder’s adapted ‘general infra system model’ (Herder & Thissen, 2003). In this model, infrastructure bound systems are represented in separate conceptual layers that interact. This allows for multidisciplinary analysis. According to Thissen & Herder (2003), each layer also contains its own “physical/technical, operational, institutional and regulatory components”. The figure is stated below.

![General infra model](image)

**Figure 4 General infra system model by Thissen & Herder, adopted from (Herder & Thissen, 2003, p.286).**

The second layer in this infra system model is ‘Operation and management’ which encompasses “network operations and management processes and actors”(Herder & Thissen, 2003). In this layer, the circumstances in the power supply chain set high demand on the coordination in the second layer. Initiatives such as unbundling of the value chain in layer 1 increase the number of organizations that have to work together in layer 2. An example of this is the balancing of power demand and supply throughout the day. This requires a lot of interactions between operators, traders, and transmission system operation et cetera.

The third layer is ‘Services on infrastructures’ which encompasses “the supply and use of infrastructure based products and services” (Herder & Thissen, 2003). To supply high quality power services it is imperative that all elements of all three layers function well together.

The high amount of interactions creates a large amount of system complexity which is mostly exogenous to the investment process. This complexity will grow since more elements are currently introduced in the sector (e.g. through interconnections, liberalization).

However another for complexity can exist for power plant investors. It is based within the investment processes. This is explained in the following section.
Project complexity and uncertainty

The complexity within the investment process can be explained through the notion of ‘project complexity’.

In Bosch’s PhD thesis “managing project complexity”, project complexity is linked to notions of uncertainty and project risk. The analysis of project complexity is specified for ‘projects’. Projects are characterized by having particular reasons, a (unique) scope, a temporary character and certain constraints (Bosch-rekveldt, 2011; p.13). Projects will be reviewed in more detail in a project management review in section 3.1.

According to Williams (2002) project complexity has two main dimensions: structural complexity and uncertainty. The main elements of structural complexity are similar to those indicated by Simon\textsuperscript{16} in section 3.3.

The sources of project uncertainty (uncertainty in goals and in methods of the project) influence project complexity. But they also have indirect influence on project complexity through interdependence with structural complexity (Bosch-rekveldt, 2011; p.36). These connections are clarified in the figure stated below;

\begin{center}
\textbf{Figure 2.2: Overview of dimensions of project complexity (Williams, 2002)}
\end{center}

An applicable example is given for the investment process. This process can be linked to several organizations (e.g. banks, contractors, power companies) which in turn contain many departments (e.g. legal, operations, commercial). All these parties can have varying goals. But these parties also need to work together to come to results. This can be a difficult task to manage in its own right due to project complexity.

Conclusions

It can be concluded that the power system is a highly complex system, making it difficult to assess during power plant investment processes. Furthermore, these investment processes also have their own, internal dynamics which can lead to considerable project complexity. Dealing with these characteristics will be a challenging task for power plant investors\textsuperscript{17}. The risks and uncertainties that investors have to deal with are clarified in the following sections.

\textsuperscript{16} “a large number of parts that interact in a non-simple way”(Simon, 1962; p.468)

\textsuperscript{17} The methods they use in order to deal with these issues is indicated in chapter 3.
Risk and uncertainty definitions

To distinguish between risks and uncertainties, three notions have to be defined first. These allow for distinction between uncertainty, risk and their respective relevance within projects. These are future consequences, chance of occurrence, and relevance of the consequence.

1. Future consequences of an action:
   This notion assumes that actions performed at present will have effects in the future. In turn these effects can be relevant for the project at hand or not. If so, they can be measured as impact on the project deliverables (Vrancken, 2012). According to Hillsion and Simon (2007), both risk and uncertainties can have both negative as well as positive outcomes.

2. Chance of occurrence of this future consequence:
   Edwards states this chance to be “a proposition about the future to which a number can be attached” (Ward Edwards & Tversk, 1967: p.27). Using this chance always involves a combination of predictable elements and random elements in the system on which the proposition is made. If this is not the case it would be a deterministic or a random system. Deterministic models can only be used when consequence is sure (not) to happen. Given the complexity of the power sector, this ideal-typical option will be quite rare. Chances of occurrence are often simplified numerically. Examples are simplification to a point estimate (e.g. a chance of occurrence of 40%) or some form of a probability distribution (e.g. a chance of occurrence of 40-80% but most likely 60%).

3. Relevance of the consequence (with regard to the actor’s project scope).
   Actors can behave differently when actions have consequences which fall inside or outside their project scope. When the consequences fall outside the scope they would be ‘externalities’. For instance, a power plant owner might react differently on events that will affect the power plant’s profitability compared to the effect on a ‘non-internalized consequence’. Policy interventions such as carbon tax can be seen as a means to internalize the previously ‘external effects’ of emission of green house gasses for its producers. Another example is in allocation of risks between partners. Risks that do not impact a party will matter less in the consideration. So the way parties manage risk is relevant. This is stated in section 3.1.

These notions allow for the explanation of project risks and uncertainty;

Project risks are events that have a consequence within the project scope which is known to some degree. Also some kind of probability distribution can be attributed to the chance of occurrence (Bosch-Rekveldt, 2011).

For uncertainty it is impossible to attribute a chance of occurrence (Ward Edwards & Tversk, 1967). According to Bosch, uncertainties can be reduced during projects but there will always be residual uncertainty (Bosch-rekveldt, 2011: p.38).

These definitions of risks and uncertainties will be used throughout the research. The following section states main risks and uncertainties present in the power sector based on the definitions stated above.
Risk and uncertainty in the power sector

There is a principal problem that makes dealing with risk and uncertainty difficult in investment processes in the current state of the energy sector in Western Europe. The timescales of the power plant lifecycle are very large compared to the dynamics of the project risks involved with the investment. Power plants under review usually ask for an investment of sunk costs for 15-40 years (Fraser, 2003). However many risks cannot be forecast with a high degree of reliability on such a long timescale anymore.

Fraser (2003) states that before the liberalization many kinds of the risks (stated below) were not impacting the power companies. Power companies could pass negative impacts of ‘firing risks’ on to customers in the shape of increased prices. Since the liberalization, generators are no longer guaranteed to recover costs in this way. Furthermore the guarantee of future price levels has disappeared. This means that uncertainty levels have risen, although the classical ‘shield’ of simply passing the negative effects on to customers is no longer an option.

Next to the liberalization there are several changes (exogenous to the investment processes) that have increased the levels of uncertainty and risk that the power companies have to face.

Power sector changes, uncertainties and risks
The stated below figure has been constructed based on analysis of statements in several international power sector investment analyses (Fraser, 2003; Gerhardt & Blaney, 2010; Gross, Heptonstall, & Blyth, 2007).

The figure gives a (non-exhaustive) overview of frequently stated important exogenous changes, resulting power sector uncertainty categories and project risk categories for power plant investment considerations. This will act as a basis for further analyses.
Most of the notions stated in the figure are self explanatory. However ‘black swan events’ require some explanation. According to Bosch-Rekveldt (2011) black swans are events with a very low chance of occurrence, an extreme impact on the power plant investors and the possibility to predict in hindsight.

One example is the tragic event of a tsunami leading to a nuclear disaster at the Fukushima power plant in Japan. This changed the public acceptance in Germany leading resulting in unexpected changes in this countries set of power generators. This type of ‘black swan appearance in the Dutch power sector is becoming more likely through tightening markets (IEA, 2011). It does not take much imagination that black swans are difficult to assess in a power plant investment process (but by definition they will have a heavy impact).

A general statement can be made on changes, uncertainty and risk volatility in conclusion of the figure state above. The large degree of exogenous changes in current society (e.g. technology dynamics) stated in
the figure will increase uncertainty (e.g. merit order uncertainty). This uncertainty growth will cause growing volatility of project risks (e.g. power price risk).

**Conclusions**
Several notions present challenges in investment processes:

- The growing volatilities (stated as a key analysis result in Figure 6) and long, committed investment horizons make it increasingly difficult to make a well-founded investment decision for power plants. And due to liberalization, power plant investors are no longer ‘shielded’ from the impacts of negative risk outcomes.
- Power sector (system) complexity makes it challenging to understand the consequences of events in the sector. This complexity has grown since more parties entered the sector and sectors are becoming interconnected. This results in added challenges in forecasting power sector behavior.
- The investment process is linked to many parties (e.g. several departments at banks, power companies, construction companies). These can hold uncertainties with regards to their goals. These notions can interact to create considerable investment process project complexity.

These issues beg the question of how these challenges are met in current investment processes. A review of project management, corporate finance and decision science is used to come to propositions in the following chapter.

In addition, it is expected that the type of power plant will change the emphasis of the reviewed risks in the investment process. For instance, operation of an offshore windmill does not require fuel and it does not produce CO₂ (directly). This means an investment process for wind farms does not need to consider the (direct) negative impacts of fuel cost risk or carbon exposure risk. However offshore wind parks are currently dependent on financial support mechanisms. This exposes them much more exposed to subsidy (allocation) risk. So this type of risk should be taken into account in the investment process.

An outcome of analysis on the link between power plant characteristics and risk exposure is stated in (Gerhardt & Blaney, 2010; p.42).

An important conclusion from this concise analysis is that a power plant investment concept has to be adapted to different types of generators (particularly for renewable versus conventional plants). Otherwise the relevant risks will not receive attention or the FED-phases will be inefficient with regard to research resources.
3. Theories for the investment process concept

The previous chapter indicated the increasing levels of system complexity, investment process project complexity and uncertainties and risks in the power sector. These considerations lead to the question of how power plant investors should deal with the resulting issues in their investment processes.

In this chapter, relevant notions from the disciplines of project management, corporate finance and decision science are reviewed. This done to come to propositions on how investment processes can best be represented in an investment process concept.

Firstly, project based approaches are introduced to indicate how information collection and processing is organized (with a focus on project management). Secondly, notions of corporate finance are reviewed to indicate how financial decisions are prescribed (whilst dealing with scarcity). Thirdly, the field of decision science is reviewed to indicate the perspective on decisions used in investment processes. Special attention is given to the decision theory of bounded rationality due to its high level of fit for this research. Finally, the reviews lead to two main groups of propositions. These state how power plant investments can be conceptualized in section 3.4.

3.1. Organizing the investment process

The preliminary scan indicated project management as a means of organizing the process of coming to adequate strategic information needed for the investment decision. The discipline of project management consists of an extensive body of knowledge. It fits in a broader context of ‘project based approaches”. This chapter will give a summary describing several notions relevant for the practice of investment processes. This summary is based on literature sources which are shortly introduced first.

Bosch-Rekveldt supplies an elaborate introduction of the discipline in the literature survey of her PhD thesis on ‘managing project complexity’ (Bosch-Rekveldt, 2011; p.13). Meredith et al have created a well known handbook for a managerial approach to project management (Meredith & Mantel Jr., 2006). Miller and Lessard (2000) review project management approaches for dealing with the complexity and uncertainty in ‘Large Engineering Projects’. These are projects which are defined as a specific type of project with special hallmarks (Miller & Lessard, 2000; p.9). The Project Management Institute (‘PMI’) is one of the larger (of many) project management associations. Other well known associations are also named by Bosch-Rekveldt (Bosch-rekvedlt, 2011; p.16). The PMI describes best practice project management in its widely used guide called the ‘Project management body of knowledge’ (’PMBOK’) (PMI, 2008).

This literature is used to explain key notions in these fields connected to project management.

Projects and project management

The key object of attention in project management is the project. The PMI defines a project as “a temporary endeavor undertaken to create unique product, service, or result” (PMI, 2008; p.1). Bosch-Rekvedlt concludes in a literature review that all researchers definitions of projects include a temporary character, a unique scope of work, certain constraints and particular reasons (Bosch-rekvedlt, 2011; p.13).

However, the attributes of projects need to be addressed in more detail in order to understand the characteristics of the investment processes as a project. Meredith and Mantel supply an overview of key project attributes:
For now, it is important to state that these attributes impose clear limitations on the investment process. This includes ‘information processing capacity’ (e.g. limited resources) as well as access to information (e.g. no routine possible due to uniqueness) in making decisions. These two issues will play a key role in the decision theory section. Also the stated scarcity issues necessitate a group of financial decision theories. Effects of these attributes will be discussed later on in conjunction with corporate finance and decision science.

Projects with these attributes can be organized by a diversity of ‘project based approaches’.

Project based approaches

Bosch-Rekveldt explains several approaches such as relational or information processing approaches (Bosch-Rekveldt, 2011; p.15). However, for this research the focus will be mainly on traditional project management approaches. The PMI defines (traditional) project management as “the application of knowledge, skills, tools and techniques to project activities to meet the project requirements” (PMI, 2008; p.6).

Meredith and Mantel state that the reason for organizing a task as a project is primarily to focus the responsibility and authority within the organization(-s) (Meredith & Mantel Jr., 2006; p.13). They also state several pros and cons in using a project based approach. Possible advantages include: improved responsiveness, improved control, higher project returns and better customer relations. Possible disadvantages include: increased organizational complexity, violations of company policy, higher costs, increased management difficulties and decreased personnel utilization (Meredith & Mantel Jr., 2006; p.13). Organizational complexity affects the project complexity that was already stated in sub section 2.3.3.

The disadvantages clearly indicate that project approach is not the solution for all work in organizations. Not surprisingly, Meredith and Mantel conclude that “on the whole, the balance weighs in favor of project organization if the work to be done is appropriate for a project” (Meredith & Mantel Jr., 2006; p.13). Investment processes are linked primarily to a certain stages of the entire project. These will be explained next.

Front end development
For new plants, the investment process will take place in the beginning of the (new) power plant’s (technical) lifecycle. Many projects go through similar stages from origin to completion. Meredith et al (2006) define the collection of all these stages as the ‘project lifecycle’. Several names have been coined for the different stages of the project lifecycle. The figure stated below shows several descriptions in order to indicate variation in concepts and jargon in the industry. The names in the table are not linked to the same stage in the column (the table only summarizes the consecutive notions).

<table>
<thead>
<tr>
<th>Stated in</th>
<th>First stage</th>
<th>Second stage</th>
<th>Third stage</th>
<th>Fourth stage</th>
<th>Fifth stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meredith et al (2006; p.16)</td>
<td>conception</td>
<td>Selection</td>
<td>planning, scheduling, monitor and control</td>
<td>Evaluation and termination</td>
<td></td>
</tr>
<tr>
<td>Bosch-rekveldt (2011; p.25)</td>
<td>identify&amp;assess</td>
<td>Selection</td>
<td>Define</td>
<td>execute</td>
<td>operate</td>
</tr>
<tr>
<td>PMI (2008; p.16)</td>
<td>starting</td>
<td>organizing and preparing</td>
<td>carrying out the work</td>
<td>closing the project</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 several organizations & of project lifecycle stages in project based literature

The first three phases of Hutchinson’s project lifecycle description (identify, select and define) are the front-end development phases (“FED”-phases). The FED-phases are concluded with a final investment decision. After that the construction can start.

A definition of FED is stated by the construction industry institute in Gibson et al (Gibson, Wang, Cho, & Pappas, 2006): “the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project”. This definition holds key notions for conceptualizing the investment process. It deals with information gathering and processing, probability of outcomes, uncertainty, reaching goals and scarce resources.

How the investors deal with these key notions in the FED-phases are key issues of this research. Bosch-Rekveldt supplies an overview of common FED-phases as well as their evaluation moments, frequently called “stage-gates” or gate reviews (Bosch-Rekveldt, 2011; p.25-28). The preliminary scan in this research indicated that the specific setup of FED-phases might differ between the investment processes. However the use of stage-gates is expected to be commonplace. A frequently used visualization of project phases is stated in (Hutchinson & Wakebe, 2006). It states the importance of good project definition in the FED-phases (given its high impact on value realization).
The figure also shows the critical impact of the FED phase on project success compared to phase 4 and 5. This means good project definition is critical for the project’s success as whole. Several connected notions to project definition are explained in the following sub section on project management activities.

**Key project management activities**

This relevance of good project definition the questions of what the goals surrounding this ‘project definition’ are. Meredith & Mantel state that the traditional project management approaches focus on managing the trade-off between several ‘direct’ project objectives (or ‘goals’) as well as several ‘ancillary goals’.

The direct goals are “*performance (or scope), time and cost*” (Meredith & Mantel Jr., 2006; p.3). For the direct goals, Meredith & Mantel also include client expectations in their definition of scope. Ancillary goals can vary between projects but common examples are “*improving project management competency…, increased managerial experience,… and similar goals*” (Meredith & Mantel Jr., 2006; p.5). Both the direct and ancillary goals can vary between and in organizations. Sometimes this can lead to goal conflict. Goal conflict is an important issue for the investment process concept and is elaborated on in the decision science review in section 3.3.

The trade-off in goals but also other project work and the project’s environment influence project success. Shenhar et al (1997) conclude in their paper “mapping the dimensions of project success” that project success has four dimensions (cited in (Meredith & Mantel Jr., 2006; p.4). These are

- “project efficiency”
- “impact on the customer”
- “the business impact on the organization”
- “opening new opportunities for the future”.

As stated by Gibson risks are addressed to maximize the chance of project success in the FED. Project management has several methods available to address risks. Active threat and opportunity management (“ATOM”) is a structured method to come to a qualitative risk assessment of probability and impact of a

![Diagram](image.png)

*Figure 2.1 The influence of front-end development on the value of a project. (Hutchinson and Wakebe, 2006)*

<table>
<thead>
<tr>
<th>Table 2 Value growth indication dependent on project definition adopted from (Hutchinson &amp; Wakebe, 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The figure also shows the critical impact of the FED phase on project success compared to phase 4 and 5. This means good project definition is critical for the project’s success as whole. Several connected notions to project definition are explained in the following sub section on project management activities.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Project definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct goals</td>
</tr>
<tr>
<td>Ancillary goals</td>
</tr>
<tr>
<td>Goal conflict</td>
</tr>
<tr>
<td>Project success</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Risk management</th>
</tr>
</thead>
</table>
risk (Vrancken, 2012). Quantitative risk assessment (“QRA” is a “numerical/statistical analysis of the total risk profile of a project” (Vrancken, 2012; p.40). QRA is used to come to ‘risk profiles’ or probability distributions of the outcomes of a decision. This can be done analytically or e.g. via “Monte Carlo” type simulation (Meredith & Mantel Jr., 2006; p.66).

These analysis lead to insights needed for managing risks. Supplementary, Lessard and Miller (2000) identify and explain 5 strategies of managing the risks in a layered fashion. These are cited in (Miller & Lessard, 2000; p.88):

- “transfer/hedge”: e.g. placing part of the financial risks at a bank.
- “diversify/pool”: e.g. investing in varying types of power plants (this is linked to a portfolio
- “create options/flexibility”: e.g. the (disputed) strategy of making a coal plant ‘capture ready’.
- “transform risk drivers/mitigate”: e.g. initiating risk control procedures in the investment process that allowing for adequate responses to unexpected events.
- “embrace residual risks”: stated below.

After treatment, several categories of risks can still remain. These are the ‘Residual risks’. It is the remainder of original risks after mitigation. While ‘secondary risk’ is risk resulting from the mitigating actions (Vrancken, 2012; p.34).

Conclusions on project management review for this research

After review of this information, it is concluded that projects have many attributes that complicate and limit decision making processes. The organization of an investment process through project management notions gives coping strategies to come to ‘sufficient strategic information’ in the FED-phases. The table stated below is a summary of the findings stated in this section;

<table>
<thead>
<tr>
<th>Cat.</th>
<th>Project (management) attribute</th>
<th>Example of effects on investment process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes of projects</td>
<td>importance</td>
<td>separate organization (own dynamics), Development expenditure budgets possible</td>
</tr>
<tr>
<td></td>
<td>performance oriented</td>
<td>coordination and control necessary to reach goals</td>
</tr>
<tr>
<td></td>
<td>finite due dates</td>
<td>limits processing capacity and information access</td>
</tr>
<tr>
<td></td>
<td>interdependencies</td>
<td>complexities in FED-phases organization, uncertainty</td>
</tr>
<tr>
<td></td>
<td>Uniqueness</td>
<td>limits to information access, uncertainty</td>
</tr>
<tr>
<td></td>
<td>resource limitations</td>
<td>drive for efficiency, need for trade-offs and coping strategies</td>
</tr>
<tr>
<td></td>
<td>conflicts for resources</td>
<td>comparing added value between projects or between actions</td>
</tr>
<tr>
<td></td>
<td>focus responsibility at organization</td>
<td>parent organization vs. project organization goal conflicts, complexity</td>
</tr>
<tr>
<td>Success</td>
<td>project efficiency</td>
<td>Search cost criteria (see section 3.3)</td>
</tr>
<tr>
<td></td>
<td>impact on customer</td>
<td>links to market dynamics &amp; regulation in investment processes</td>
</tr>
<tr>
<td></td>
<td>business impact</td>
<td>goals of parent organization usually part of the total set of project goals</td>
</tr>
<tr>
<td></td>
<td>future opportunities</td>
<td>ancillary goal addition to investment decision, need for trade-offs</td>
</tr>
<tr>
<td>Means</td>
<td>adress risks</td>
<td>▪ ATOM/ QRA type elements expected in investment process ▪ Use of 5 risks management strategies by Miller and Lessard (stated above)</td>
</tr>
</tbody>
</table>
Assessing unavoidable residual risks at FID (and making trade-off)
- Risks can be divided between parties in the power plant project

| stage-gates | decision process split up in stages |

Table 3 Project (management) attributes and their expected investment process results

This table gives an indication on how information gathering is organized. However it also states the necessity for making trade-offs due to multiple goals and scarce resources. In addition, project management allows for dealing with power sector risks. One important conclusion is that risks can be divided between parties.

These conclusions beg the question of how the information from the work performed in FED-phases is used to come to a final investment decision. Corporate finance notions are introduced in the following section to this end.

3.2. Corporate finance
This section gives a short introduction in the discipline of corporate finance and the notions most relevant for this research. This serves as a basis for understanding the (financial) decisions that are made in the investment process.

Literature overview

This introduction is based on several literature sources which can also act as a basis for further reading. Brealey and Myers (2003) is a well known book on theory and practice of corporate finance. Berk and Demarzo (2011) focus on explaining key methods used in corporate finance. Goetzmann (2012) states relevant theoretical notions of investment theory from the perspective of investors (used for portfolios of assets). Graham and Harvey (2001) have done empirical research to indicate which methods are actually used by Chief financial officers at large firms in real life.

This literature is used in the following sections.

Making financial trade-offs

The preliminary scan indicated that financial considerations usually have a substantial influence throughout the investment process. The strategic information can be gathered and organized by using the stated project management methods. This results in prepared information for financial trade-offs.

The classical tradeoff for the financial investor using this information is in ‘risks versus financial return’. However, for power plant investors there are also tradeoffs to be taken into account and several knowledge fields available to make these tradeoffs (Miller & Lessard, 2000; p.166). Examples of other trade-offs are effects on cash position or effects on reputation.

The fields of managerial economics and corporate finance are closely linked and can both offer ways of making the trade-offs. The difference is found in that managerial finance studies the financial decisions of all firms (rather than only for the corporations).
Corporations distinguish themselves by being “a legally defined, artificial being (a judicial person or legal entity), separate from its owners” (Berk & DeMarzo, 2011 p.5). This distinction holds for all the parties whose investor behavior will be modeled in the ABM. Therefore the research will focus on relevant corporate finance notions. This will enable more focus in the literature review. It also allows for the possibility of treating issues such as goal conflicts due to the separation of ownership and management (Brealey & Myers, 2003; p.9).

Brealey and Myers (2003) state that the objective of corporate finance methods should be “maximizing the current market value of the firm’s outstanding shares” (Brealey & Myers, 2003; p.13). They explain that this objective has advantages over other plausible goals such as ‘maximizing profit’. Some unique advantages are the inclusion of the risk and time value considerations in the financial trade-off. These are considerable for power plant investments given the long term of sunk costs and challenging risk profiles of new power plants (stated in chapter 2). The objective also allows (at least to some degree) for “efficient separation of ownership” as well as other shareholder (and indirectly stakeholder) perspectives since “their firm’s most valuable asset is its reputation” (Brealey & Myers, 2003; p.25&26). The less than real life outcomes of the latter argument have given reason for much debate in current political and societal discussions.

Brealey and Myers (2003) state that ‘value’-objective raises two main questions for financial managers. The first is which investments to choose in order to maximize this market value (or ‘capital investment decisions’). The second is how to pay for the investments (or ‘financing decisions’). Given the research objective the main focus of this introduction will be on the main notions in capital investment decisions. Financing decisions will only be elaborated on when deemed critical for the investment process representation of this research.

Capital investment decisions
Capital investment decisions need some form of valuation of the assets in order to make decisions that maximize the current market value of a corporation. In this case, a formal method of valuation is needed (given the obvious lack of a large, transparent market for complete power plants). Brealey and Myers (2003) indicate that this valuation needs to take the time value but also risks of (future) cash flows into account. This is especially true for power plant valuations given the long term of these investments and the nature of their risk profiles (stated in chapter two).

Discounted cash flows
Discounting all the project’s cash flows gives formal methods to these ends. This group of methods shall be referred to as ‘discounting cash flows’ (“DCF”). One of the most well known methods of discounting cash flow is the Net Present Value method (“NPV” method). In the NPV method “we discount expected payoffs by the rate of return offered by equivalent investment alternatives in the capital market. This rate of return is often referred to as the discount rate, hurdle rate, or opportunity cost of capital” (Brealey & Myers, 2003; p.15). In this research the term discount rate will be used (except for summaries of statements by the interview respondents).

It should be noted that many other methods than the present value method can also be used. This begs the question of which methods to review here.

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18 The effectiveness of this argument of ‘reputation’ (linked to ‘goodwill’-valuation) can be contested when regarding everyday news. And pitfalls have also been indicated by Brealey and Myers (2003) to begin with. However this does not change the fact that the value-objective at least gives the option to include shareholder and stakeholder value. It suffices to say that many believe that reputation is not a sufficient structural assurance to guarding public values by managers. Causes in corporate structure are stated in (Brealey & Myers, 2003; p.23).
Use of the capital investment rules

To delineate in the capital investment review, the research draws on a well known empirical analysis by Graham and Harvey. Graham and Harvey (2001) have performed empirical analysis on a survey performed on 392 chief financial officers ("CFO’s") in a broad diversity of corporations. Due to scope, this research will focus on the widespread methods used in corporate finance (by more than 25% of the respondents).

Graham and Harvey’s outcomes indicate that large corporations tend to rely on discounted cash flow methods and the ‘capital asset pricing model’ ("CAPM") (Graham et al., 2001; p.187). The CAPM will be discussed later in review of discount rate assessments. Several decision rules can be used to decide between investment options using the method of present value. The most well known are ‘Internal Rate of Return’ ("IRR”), NPV and ‘hurdle rate’. These decision rules all use discount cash flows to include time value and risk assessments. They have many aspects in common. Their characteristics are elaborately documented by Berk and Demarzo (2011).

The figure stated below by Graham and Harvey (2001) shows that valuation by ‘payback period’ and ‘earnings multiples approach’ is primarily used by smaller companies given their ease of use. It is assumed that they are primarily used for first assessments by large corporations and not as final decision rule methods19.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Survey responses to the question: how frequently does your firm use the following techniques when deciding which projects or acquisitions to pursue?</th>
</tr>
</thead>
<tbody>
<tr>
<td>% always or almost always</td>
<td>Mean</td>
</tr>
<tr>
<td>(b) Internal rate of return</td>
<td>75.61</td>
</tr>
<tr>
<td>(a) Net present value</td>
<td>74.93</td>
</tr>
<tr>
<td>(f) Payback period</td>
<td>56.74</td>
</tr>
<tr>
<td>(c) Hurdle rate</td>
<td>56.94</td>
</tr>
<tr>
<td>(i) Sensitivity analysis (e.g., “good” vs. “fair” vs. “bad”)</td>
<td>51.54</td>
</tr>
<tr>
<td>(d) Earnings multiple approach</td>
<td>38.92</td>
</tr>
<tr>
<td>(g) Discounted payback period</td>
<td>29.45</td>
</tr>
<tr>
<td>(j) We incorporate the “real options” of a project when evaluating it</td>
<td>26.59</td>
</tr>
<tr>
<td>(i) Accounting rate of return (or book rate of return on assets)</td>
<td>20.29</td>
</tr>
<tr>
<td>(k) Value-at-risk or other simulation analysis</td>
<td>23.66</td>
</tr>
<tr>
<td>(e) Adjusted present value</td>
<td>10.78</td>
</tr>
<tr>
<td>(h) Probability index</td>
<td>11.87</td>
</tr>
</tbody>
</table>

Table 4 Survey results of corporate finance methods adopted from (Graham et al., 2001; p.198)

This leaves the methods of ‘sensitivity analysis’ and ‘real options analysis’. Sensitivity analysis is well known as a generic modelling exercise but for corporate finance it “often boils down to expressing cash flows in terms of key project variables” (Brealey & Meyers, 2003; p.257). It is expected to have much influence in the final capital investment decision but it will not be used as a decision rule on itself (whereas the other methods will). Though it is expected to be of great interest given the project risks indicated for building power plants in the current circumstances of the power sector.

19 Berk and Demarzo (2011) indicate this for corporate practice, and give one possible explanation for a misleading phenomenon in the original measurement by Graham and Harvey. Simple methods such as payback rules can be used by CFO’s of big companies to get a quick initial ‘sense of scale’ (and not as a final decision rule). The measurement by Graham and Harvey does not allow for this (Berk & DeMarzo, 2011; p.165).
Lastly, ‘real options analysis’ is “the application of option pricing theory to the valuation of non-financial or ‘real’ investments with learning and flexibility” (Borison, 2003; p.1). Brealey and Myers (2003) explain how this allows for valuation of active, project management throughout the project life cycle. Options to make managerial choices in time can be built into the financial forecast. This is fundamental difference with models that have a static structure; these models cannot deal with changes in the original plan during the project lifecycle.

This active management cannot be taken into account in the other valuation methods stated above (Brealey & Myers, 2003; p.619). So those methods cannot value flexibility. Valuing this flexibility can turn out to be increasingly important issue, given the growing uncertainty levels in the power sector.

Real options typically builds on discounted cash flow methods, which means that structural issues in coming to a discount rate for power plants will still persevere for both static DCF methods and also real option use. These will be introduced shortly.

**Discount rates**

The discount rate itself is not a complex notion: “the value today of $1 received in the future”. This figure can be calculated by a simple formula\(^{20}\): The discount rate = \(1/(1+r)\). Here, ‘\(r\)’ is the required rate of return for the investment opportunity (Brealey & Myers, 2003; p.14). The discount rate is set as an exponential function in time to compensate for the time value and risk issues.

The discount has all kinds of effects in investment behavior, one of which is directly derived from the DCF method. It will be less interesting for investors to focus on long term effects. The effects to current value are becoming smaller in time to an exponential degree in the DCF method. So the first years of a power plants performance are much more important from a financial ‘current value’-perspective.

**Rate of return**

The discount rate’s critical element is the Rate of return (also called cost of equity). It is the return that shareholders require for their share of ownership based on a perceived risk profile in time. This links the financial decision to the fact that investors will compare the power plant options to other alternatives for investing capital.

Complicated issues arise when attempting to calculate a realistic required rate of return (and the expected cash flows) for a specific power plant. But these have to be analyzed in order to make investment options comparable. It necessitates assessment and conversion of all the risks and uncertainties relevant to a power plant’s financial success.

One key method used in power plant investment is CAPM (Graham et al., 2001; p.187). This is a formal method that comes to a rate of return by summing two parts:

- A risk free interest rate
- An interest addition for the power plant investment risks, based on a “risk premium comparable to what they would earn taking the same market risk through an investment in the market portfolio” (Berk & DeMarzo, 2011; p.378).

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\(^{20}\) This should not be confused with the actual DCF methods, these will apply an exponent on the discount rate and become much more complicated when applying them in investment practice.
Berk and Demarzo conclude that CAPM directs managers to “think about risk in the right way” (Berk & DeMarzo, 2011; p.399). However the model still requires approximations and the model is not perfectly realistic.

Conclusions on corporate finance and project management reviews
It is expected that the investment process will use the basic prescriptions of corporate finance stated above (e.g. DCF methods and CAPM analysis). However due to lack of complete information on future power sector developments, subjective assessments will have to be made. These are most clearly visible in assessing the required rate of return and also in predicting future cash flows of the power plant.

Corporate finance and project management theories have shown methods used in power plant investment processes. The reviews also showed limitations to the decision making process. It is unclear what effects these limitations have on the actual decision making. To this end, decision science is reviewed to come to propositions for the investment concept. This is performed in the following section.

3.3. Decision science theories
This section introduces decision science and several of its most well known theories. This serves as a basis for understanding real life deviations from the previous prescriptions by corporate finance and project management theories. Insight in the real life deviations of ideal-types (indicated as ‘coping strategies’) enables the construction of hypotheses about investment processes at the end of this chapter.

To this end, first a general overview of decision science is constructed in sub section 0. The arguments leading to the adopting of a bounded rationality perspective are explained here. Bounded rationality is elaborated on in sub section 0. Discussion of decision making constraints and decision making coping strategies is fundamental for the creation of hypothesis in section 3.4. The review is based on the literature stated below.

Literature
This decision science review is based on several literature sources which can also act as a basis for further reading. Groenleer (2012) gives a broad introductory course on a wide diversity of decision making theories for technical policy and management students. Hansson (1995) introduces readers without prior experience to modern decision theory. Edwards (1954) is a frequently cited work which explains several decision theories and their theoretical bases in detail. March (1994) introduces key concepts of decision making with an emphasis on how decisions are actually made. Several statements in March (1994) are key considerations for this research. Simon (1955,1962,1982) introduces the foundations for bounded rationality theories. Other principal works and/or starting points in bounded rationality are (Conlisk, 1996; Ward Edwards & Tversk, 1967; Gigerenzer & Todd, 1999; Kahneman & Tversky, 1979; March, 1994; Rubinstein, 1998).

Decision science
Decisions are the object studied in decision science. Hansson describes decisions as ‘goal-directed behavior in the presence of options’ (Hansson, 2005; p.6). Hansson’s definition of decisions captures a very broad spectrum of decisions. It does not imply choices in the way the behavior is displayed, nor which goal (-s) are strived for. This definition will be the starting point for the theoretical basis.
The discipline of decision science has a multidisciplinary background and constitutes of a wide variety of theories about decisions (Hansson, 2005). However the concepts of behavior and goals allow for an initial organization of decision science theories. According to Groenleer (2012), combinations of behavior and goals can differ significantly. He indicates two extremes to indicate the range of theoretical decision perspectives: the political perspective and the analytical perspective (Groenleer, 2012; p.15).

**Decision science perspectives**

Firstly, the political perspective assumes coming to a workable compromise by multiple parties through the means of “permanent struggle” and “exercise of power” (Groenleer, 2012; p.15).

Secondly, the analytical perspective assumes deliberate choices based on a rational process performed by a single actor. The emphasis of this process is on information processing (Groenleer, 2012; p.15). The rationality aspect of the analytical perspective is an important starting point for this research. It will be elaborated on in more detail later on in this section.

The political and analytical perspective are presented as complementary ideal-types which should be used as lenses to review decision processes (Groenleer, 2012). Both (extreme) perspectives suffer from a misfit with the actual circumstances stated in chapter two and three. These are stated separately for both perspectives in the following two sub sections.

**Shortcomings to analytical perspective**

The rational aspect of the purely analytical perspective assumes complete information, an unequivocal preference structure, maximization of goals and to a lesser degree ‘infinite sensitivity’ (Edwards, 1954; Groenleer, 2012). However this is not possible in the power sector due to several reasons;

- Complete information is most unlikely due to the power sector uncertainties and the sector complexity (both stated in section 2.3)
- An important issue in the preference structures is found in the simplification of an organization to one actor. In the ABM, organizations are represented as single actors (i.e. agents). However the actual party is in fact a corporation (comprised of diverse individuals with diverging motives). For bounded rationality, the differences need only be taken into consideration when considerable differences in the level of goal conflicts arise between individuals and organizations (Simon, 1982: p.409). In this research goal conflict will be addressed in a similar manner (and as context to the investment process studied otherwise). An example of such goal-issues was already indicated in the corporate finance review (on ‘agency problems’ between owners and managers). Another was found in the project management review (direct project goals vs. ancillary project goals in project definition). This means that it is likely that the preference structure is not unequivocal.
- The initial consultation stated the use of goals that did not have maximizing characteristics. Such as attaining a positive NPV in the project valuation. This type of goal will be elaborated on in the following section.
- Infinite sensitivity in turn assumes: continuous alternatives, infinite sensitivity by man an infinite divisibility of functions such as prices (W. Edwards, 1954). These assumptions on rationality do not coincide with the power sector description in chapter 2. Examples are the limited number of power plant location options and limited number of power plant setups.

These reasons indicate that the analytical perspective has shortcomings for representing the investment process. However the political perspective also has shortcoming, which will be indicated shortly.
Shortcomings to political perspective

The political perspective does not allow for rational elements of the investment process. However it was made clear in the initial consultation that evaluation of expected utility is a key element of the investment process.

This indicates that both extreme perspectives in decision science would not enable the construction of an effective theoretical basis for the investment process concept. This begs the question which theory would be more applicable.

Appropriate decision theory selection

The preliminary scan indicated a focus on information processing by organizations (which are simplified to a single actor). And despite the power sector’s risks and uncertainties technical, regulatory and financial natural laws exist that enable analysis. This can indicate expected consequence of options. This indicates that a choice with analytical aspects would produce the highest level of fit with the theoretical framework requirements.

To this end, the rationality aspect stated in the analytical perspective is elaborated on first. This will be a starting point for introducing a theoretical framework with a high level of fit for the framework requirements.

Rationality

Rationality is described by March as: “a particular and very familiar class of procedures for making choices” (March, 1994; p.2). March distinguishes between:

- “procedural rationality” as “the rationality of a process” (March, 1994; p.2).
- “substantive rationality”: the intelligence of the actual outcomes of this procedural rationality (March, 1994; p.2).

March states that the link between the two should be demonstrated and not assumed. So in other words: a very smart decision making process does not necessarily lead to the most intelligent decision. The two definitions will be used throughout the research.

However the theoretical framework should be able to deal with:

1. Incomplete information (stated in the rationality critique above).
2. Informal aspects (such as influence of company culture, stated in initial consultation).
3. Real life limitations to the front end loading phase (especially those concerning research budgets and processing time need little explanation). Leading to limits to information processing capacity.
4. Risks and uncertainties (indicated in chapter 2).
5. Ambiguous and/or non-maximizing goals that can change in time (opposed to unequivocal maximizing goals).
March states that rational procedures will leave the decision maker with two fundamental issues: “the first is a guess about future states of the world, conditional on the choice. The second guess is guess about how the decision maker will feel about that future world when it is experienced” (March, 1994; p.3). The first issue is linked to the first four requirements stated above. The second is linked to the fifth requirement stated above. This leads to certain issues in rationality use within the context of this research.

Critique to rationalism in research context
According to March use of the assumptions underlying rationalism are widespread however not without critique by experts (Simon, 1982). March indicates the “less than perfect success in predicting individual behavior” (March, 1994; p.8). This was already discussed in the initial problem statement in section 1.1. Apparently rationalism holds merits but not all of its premises are met in full in real life.

Thus creating a more fitting framework will entail implementing limits to rationalism in a form of limited or “bounded rationality”. This would allow for a better prediction of agent behavior whilst still allowing for the research’s focus on information processing in the power sector.

After an extensive review of research focused on bounded rationality, Conlisk indicated that the theory allows for explaining agent behavior beyond formal prescribing theories (such as stated in sections 3.1 and section 3.3 (Conlisk, 1996). Therefore bounded rationality is elaborated on in the following section.

Bounded rationality
Some of the first (and certainly the most well known) notions of limits to rationality were coined by Nobel prize winner Herbert A. Simon (Simon, 1955). In his article “behavioral model of rational choice” Simon made an effort to “replace the global rationality of man with a kind of rational behavior that is compatible with the access to information and the computational capacities that are actually possessed by organisms” (Simon, 1955; p.101). The added value of this effort for the research objective is the possibility to add real life decision making aspects to the representation in the ABM.

In his article Simon indicates that modeling decision makers with bounds of limited information access and cognitive capacities gives a better representation of organizational behavior when compared to boundless rationalism (Simon, 1955; p.114). These limitations were already stated in the project management review.

Several notions are applicable to the power sector.

Notions in bounded rationality
Simon (1982) states several issues that allow for better representation of organizational behavior in his article “theories of bounded rationality”:

- **Risks**: these can be represented in functions of cost, demand or both. The assumption of perfect knowledge on the function can then be changed into perfect knowledge on the distributions of these functions (Simon, 1982; p.410). However for the definition of uncertainty in this research this it is difficult to model uncertainty in this way.
- **Incomplete information**: information processing for alternatives can change. In certain circumstances, specific actions become available to obtain information (e.g. random sampling such as used in Monte Carlo simulations). The issue can then be framed as a ‘search costs allocation question’ (Simon, 1982; p.410).
Both the issues of power sector-as well as cost function complexity can be addressed by an optimization of a function incorporating computational effort cost and the expected approximation improvement obtained through computational effort of the complexity issue (Simon, 1982; p.411).

The nature of the goals used for modeling can be changed. Simon indicates the maximization goal can be changed to the goal that a “less than a specified ‘satisfactory’ level” should be met (Simon, 1982; p.411). Simon coins the term ‘satisficing’ for this type of goal and links its use to the use of ‘heuristics’. Heuristics are experienced based techniques aiding in a focused search for plausible alternatives (Simon, 1982).

These notions are most useful for understanding investment processes. But they do not allow for propositions and organization of the information supplied by investment experts. To these ends, coping strategy categories are explained next.

**Coping strategies**
In his work “a primer on decision making”, James G. March (1994) supplies an overview of real life strategies for deciding under the constraints stated above. These shall be referred to as coping strategies. Insight in these coping strategies is very useful for this research. March organizes bounded rationality considerations in categories:

March states that goals of bounded rationality decision making have satisficing aspects. Maximizing goals are focused on choosing the optimal outcomes, whereas satisficing has to do with searching for alternatives until one is found that is expected to perform good enough. March states that “neither Satisficing nor maximizing is likely to be observed in its pure form”(March, 1994; p.18).

Differentiation can be cumbersome. March states that circular definition can be used by advocates for explaining imperfections of both maximizing and Satisficing aspects. March proposes a criterion for differentiating between the two:

“Maximizers will be sensitive to shifts in relative prices but not to whether they reach a target or not (except secondarily). Satisficers will be sensitive to whether they reach a certain target but not to shifts in relative prices (except secondarily).”(March, 1994: p.21). Within the scope of this research this basis of relative or absolute scoring is used to determine to what degree a goal is maximizing or Satisficing.

Four ways of dealing with information processing under real life constraints are stated: editing, decomposition, heuristics and framing. Information accessing and processing in the investment processes is therefore also divided into common bounded rationality categories (March, 1994; p.12-14):

- Decomposition: reducing problems into their component parts
- Editing: how problems are simplified and edited before making a decision
- Heuristics: recognizing patterns in the investment process and applying rules of appropriate behavior
- Framing: choosing a perspective on decisions in their problem definition, information requirement and relevant dimensions.

One choice needs to be clarified concerning uncertainties and project risks. Project risk holds information to be processed. Especially the impact of an event on the project and a probability distribution of the event happening. So it will be categorized under information processing. The bounded rationality expectation is that bounded rationality decision makers seek technical and socially valid estimates of risk.
For uncertainty less information processing options are available. Therefore this will be a separate category for investment process structuring. This separate category of uncertainty will be treated next.

March (1994) reviews studies on how decision makers deal with uncertainty. Here three issues are selected:

- Several considerations lead decision makers to see “uncertainty as something to be removed rather than estimated” (March, 1994; p.38). So many uncertainties are simply not taken into account in the considerations in the first place. An example of this is the selection of a limited number of ‘uncertainty axis’ in scenario analysis such as developed by Shell (Postma & Liebl, 2005).
- In addition, decision makers try to remove uncertainties that arise specifically from knowledge gaps. Because of this, decision makers believe that they can remove these uncertainties by “diligence and imagination” (March, 1994; p.38).
- Lastly, decision makers also try to remove certain uncertainties that result from “incomplete contracting” (March, 1994; p.38). This can be linked to the review of project complexity in sub section 0 and also risk strategies in section 3.1. Contracting can remove uncertainties in goals among parties in the power plant project, thus reducing project complexity. Contracting can also be used to allocate responsibilities and risks among parties. This is one of the risks strategies stated in (Miller & Lessard, 2000).

In conclusion, it is expected that decision makers will deal with uncertainty by ignoring many uncertainties and reducing known ones by diligence, imagination and elaborate contracting. These conclude the key outcomes of the bounded rationality review. The outcomes are translated to propositions in the following section.

3.4. Review of key outcomes and resulting propositions

This section summarizes key outcomes of all previous chapters in order to come to a concept used for the propositions. First the reasons for bounded rationality are reviewed. Secondly resulting coping strategies are summarized. This leads to a concept that can explain similarities and differences between the investment processes.

This concept is used as the theoretical basis for the propositions in the following sub sections.

Reasons for bounded rationality decision making

The review in chapter 2 and 3 have led to the following main conclusions:

In sub section 0 it was indicated how the power sector has become a more dynamic, uncertain and complex environment for power plant investments. In this challenging environment, power plant investors have to ‘cope’ with increasing constraints throughout their investment processes. These decision process constraints include:

- limits to information processing capacity (e.g. budget and time constraints combined with sector complexity)
- limits to information access (e.g. strategic plans of competitors will not be shared due to their competitive interactions through power markets stated in section 2.2)
- increasing uncertainty in power sector (e.g. due to liberalization and interconnections)
- Ambiguity in preferences (e.g. different departmental goals, direct vs. ancillary project goals, management vs. ownership goals). These in turn increase project complexity.

Insight in the resulting coping strategies will be crucial to realistically forecast how agents will invest. The basic concept is stated in the following sub section.

**Basic concept of decision making for this research**

Bounded rationality is one of several decision science models that can be used to indicate these coping strategies. It was indicated in sub section 0 why bounded rationality is the most fitting theories of increasing ABM fidelity in this research. Other theories in review usually lack the power to deal with realistic decision constraints in the investment process or omit information processing aspects. Bounded rationality can indicate the effects of these issues on how real investment processes are performed. So using bounded rationality coping strategies could increase the representation of investment behavior by agents in the ABM. This improvement is explained in more detail in section 6.2.

The bounded rationality review (in sub sections 3.3.2) indicated several expected ‘coping strategies’:

- Satisficing goals (e.g. ‘the NPV should be positive’).
- Information processing by decomposition (e.g. distributing responsibilities between departments or setting decision stages).
- Information processing by editing (e.g. simplifying project risks to distributions of their cost and income functions in a financial DCF model).
- Information processing by framing (e.g. simplifying investment processes to the goal of coming to a accurate DCF forecast).
- Information processing by heuristics (e.g. use rules of thumb for location choice based on previous "lessons learnt").
- Reducing uncertainty (e.g. using scenario analysis, elaborate contracting).

These are the basic elements for the theoretical framework stated below.

**Concept for differences between investors**

It is apparent that there are differences between investors that influence decision process constraints. These will be referred to as ‘investor differentiations’ in the research. For instance, a very large power company can afford to build expertise in power price forecast models. And they could spread the costs over many projects. In contrast, a small power company might not have similar means in this particular respect. This investor differentiation could affect the previously stated decision process constraint of ‘limits to information processing capacity’. Another example is difference in insight in local politics. It will need little explanation that certain power companies will have better local informal connections than others. This investor differentiation will affect the decision process constraint of ‘limits to information access’. The resulting changes in decision constraints can affect the investment coping strategies. These changes in coping strategies will cause differences between investor behaviors.

No existing framework was found for the power sector on the link between investment process differentiations and their effects on the resulting coping strategies. However this link could explain a large part of the differences seen in investor behavior between agents. So it will be interesting to see which

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21 Such as foreign power companies that have just entered the Dutch sector compared to incumbents.
reasons that experts will state for their differences in coping strategies. This insight can allow for insight leadings to a representation of different (or ‘heterogeneous’) agents in the agent based model.

For this reason, the empirical outcomes chapter has a separate section for coping strategies that differ between participants. This separation allows for initial analysis of the link stated above. These considerations lead to the following framework to explain (differences in) investment processes;

![Investment process differentiations](image)

**Figure 7 Basis for the second proposition on heterogeneous power plant investment processes**

The figure stated above can also explain how similar coping strategies for all investment processes are shaped. Decision constraints that are common for all party lead to common coping strategies.

It also indicates how difference can be explained. Differences in all kinds of attributes of an investment process of an investor (differentiators) lead to differences in their decision process constraints. In turn these lead to different coping strategies for different companies.

This framework leads to two main propositions stated in the next section.

**Propositions**

Several propositions have been formulated to specify and check the preliminary concept stated above. These are stated below.

**Proposition 1:** (for common coping strategies)

*Bounded rationality coping strategies can be used to represent power plant investor behavior (given*
Proposition 2: (for differences in coping strategies)

*Investment differentiators will change their decision process constraints which in turn change the investors’ coping strategies.*

These propositions will be reviewed through confronting them with the outcomes of analysis of the interviews. The empirical outcomes of semi-structured interviews with power plant investment experts are stated in chapter 4. A separate review of bounded rationality premises is also performed in this sector by a senior power company executive. The confrontation of the propositions with empirical outcomes is stated in chapter 5. The results of these chapters are an overview of investor coping strategies, an indication of the validity of the first proposition and preliminary insights in the links between investor differentiations and the resulting coping strategies.

These will form the basis for analysis of considerations towards ABM investor algorithms in chapter 6. Reflections on these analyses and outcomes are stated in chapter 8.
4. Empirical results

This chapter reviews the empirical outcomes derived from the semi-structured interviews with power plant investors. This is done in order to add substance to the investment process concept stated in chapter three. Another important reason is to check the level of validity of the main propositions stated in the previous chapter (in chapter 5).

To this end, first background information on the interviews (e.g. representation level) is stated. Secondly, outcomes on common coping strategies are summarized (the preceding propositions are stated in sub section 0). Thirdly, diverging outcomes in coping strategies are summarized. These will allow for analysis of coping strategies based on investor differentiations in chapter 5. Fourthly, basic characteristics of bounded rationality were evaluated by a senior executive in chapter 4.4. Finally, conclusions are drawn in section 4.5.

4.1. Background information

All empirical results are stated by a limited group of experts and are applicable to large scale power plant investments only. The level of representativeness for the sector is stated below by stating aggregated characteristics of experts.

An effort has been made to differentiate between the empirical descriptions versus reasons stated for certain choices in the processes. This allows for separate use of factual statements in the descriptive work with a minimal level of interference.

When value statements were observed, the statements were not included in the empirical review.

Referencing
Throughout this chapter references to the interview summaries are stated. The interview number is coupled in to experts and companies in a classified appendix table. The interview summaries are also in classified appendices (for review by the exam committee).

Many interviewees stated the requirement of not being traceable. Only aggregated characteristics of the interview group are stated to this end. Characteristics are specified to geographic focus, type of company, and the interviewee’s position inside the company.

Eight companies participated in the research in nine interviews. Per interview one to two interviewees were present. The interviews were all performed by the researcher and in one case the external supervisor were present (ir. J.C. Richstein).

Due to the interviewee’s frequent requirements of not being traceable, the representation level in the Dutch power generation market cannot be stated in detail. However the participants represented companies which own more than half of all generation capacity in the Netherlands (Enipedia, 2012).

The companies and their interviewees have the following aggregated characteristics:

Geographic focus
The majority of the interviewees were stationed in the Netherlands. However a minority of the interviewees was also stationed in Belgium or Germany.
The companies differed in their level of geographic focus. Among the group were companies that had their operations confined to respectively the Netherlands, Europe, or a global geographic scale.

**Company types**
The interviewees work at several types of companies:

- One banks with a specialized energy desks
- Five power companies
- One energy sector consultants (with experience in valuation and strategic advice on investment processes at several power companies)

**Interviewee positions**
The interviewees work at several positions in the companies:

- Two partners
- Five heads of business development departments
- One vice president (in portfolio management)
- Two business analysts
- One former CEO of an energy company subsidiary

**Interviewers and procedures**
The interviews were performed by the author and in one case by the external supervisor and the author. The original notes are made available to the review board. The interviews were translated to summaries. All interviewees revised and approved these summaries. Two interviewees have not reviewed the summaries. Those results are excluded from this research.

### 4.2. Common coping strategies
This section states common use of goals, information processing and dealing with uncertainty amongst power plant investors. The section will be concluded by an overview of the most important findings in Table 5.

**Common goals**
There is a large diversity of key drivers in the investment considerations which are shared amongst the participating companies. Overlap of the goals is possible in some cases. The overlap is stated if present.

Firstly a summary will be given of the drivers stated in many interviews (or emphasized as a key driver in several interviews). Secondly a short overview of other alternative goals that received less emphasis (or stated not to be a key driver) is given.

**Business case attractiveness**
The “business case” is very broad term which holds of a host of aspects that differ per project and even between persons. In all case, the business case consists of financial forecast outcome and risk assessment outcomes in some shape or form. Next to these elements it holds differing elements dependent on the project summarized as `business considerations` (e.g. aspects in partnering) (S).

The business case was stated by many companies to be the key consideration (2,4,5). Actually the business case is such an important driver in the investment process that many experts saw it as a given.
The host of aspects is subjectively combined to a perceived level of attractiveness. This is certainly one of the vaguest notions among the goals but generally experts speak of a ‘good’ business case when they have a high level of trust in gaining good financial results throughout the power plant lifecycle (4,5).

**Meeting a financial hurdle rate**

“Meeting the financial hurdle rate” is a key goal stated by many of the companies in the research (2,4,5,10). The financial hurdle rate is often used:

- to compare to an internal rate of return (6)
- together with some form of a discounted cash flow model (e.g. NPV or NPV margin (4,5,7,10).

The hurdle rate should lead to a positive NPV (margin)(6) or should be larger than the internal rate of return for the project to be financially attractive.

The hurdle rate is communicated to indicate that a minimum financial performance is expected across projects in the company. The hurdle rate is a figure which is constructed by a summing a weighted average cost of capital figure with a project specific risk addition figure (7,10).

The first is usually often set periodically by finance department (7,10) and this is very sensitive data which was not divulged by any of the companies during the interviews (7). For companies with a diverse number of product-lines it is set separately for regulated and unregulated industry (7).

The risk addition is constructed by risk assessments of the country, technology and project specific setup of the project.

**Acceptable risk assessment outcomes**

Risk assessments are stated by all companies to be a critical consideration in several ways. Risks are usually stated as chance of occurrence and monetized impact of occurrence. ‘Tornado plots’ are frequently used to indicate and compare risks (4,6,7). Every company has elaborate guidelines on the way risks should be analyzed for all of their investment processes (investment guides). This will be elaborated on in the information processing section.

If expected impacts of certain risks in the project are too high for ensuring continuity of the company the project, it will not be undertaken (all companies). In all other cases, the (perceived) chance and impact of risk categories will influence the risk management costs in the project as well as the hurdle rate (the latter due to the residual risks after risk management)(all companies). The risks do not only influence the financial outcomes. Every company also adds the residual risk assessment outcome to the final investment package used by the final decision makers. Dealing with risks will be elaborated on in the information processing section.

For project attractiveness its perceived risk impact indication should be acceptable and the risks should be small or at least balanced in comparison the returns (all companies). The latter is taken into account in the financial performance models and is also presented separately.

**Avoiding opportunity costs**

Avoiding opportunity costs is stated frequently to be an important driver (4,7,9). It has very close ties with meeting a financial hurdle rate. But the notions are frequently stated separately. This is because of the nature of the two goals.

Hurdle rates are often seen as selection tool for efficient allocation of resources (the project should achieve a benchmark within the company to become a good option)(7).
The notion of opportunity cost is indicated more with regard to the perception of ongoing losses when no projects are undertaken. This becomes even clearer when competitors are starting new power plants and making profits on these plants.

Power company managers do not want the company to perform under industry standards in the long run. This will lead to issues with shareholders. So the executive board will feel the pressure that ‘something needs to be done’ with the available resources to retain their positions (4, 6, 7). A closely related aspect of this behavior (“mirroring the market”) will be elaborated on in section 4.3.

**Maintain a healthy cash position**

This is a critical consideration for all companies. The consideration is extra important for the companies that are not state owned or have moderately sized balance sheet (4, 6, 9). One reason for its importance is that cash position dictates the company’s level of freedom to undertake projects to a large degree (7).

The company’s cash position also influences its credit rating. This credit rating impacts the financing and procurement conditions that the company can negotiate in general and for the project (all companies).

In some cases other financing options can such as debt or equity lending can be available (9). But despite attractive options such as risk sharing the deal conditions (e.g. higher capital costs) will not be as favorable compared to the own balance sheet (9). These notions indicate the basic trade-off that has to be made.

In conclusion, there are several considerations important for cash position consideration, in this context maintaining an acceptable credit rating is an important goal (all companies).

**Meeting strategic goals**

The level to which the project adds to goals set by the strategic top of the company is used as a criterion in every part of the investment process by all companies (1, 2, 4, 5, 6).

This goal can be mistaken to be (only) a collection of the other drivers. However it also has another unique function: the executive board has to be able to explain the rationale behind investments to all kinds of parties (e.g. owners, environmental groups) (10). It is also a check to ensure that companywide goals are not superseded by alternative goals (all companies). This will be elaborated on in the intra-organizational section.

All companies use this criterion at the start of the investment process: will the project add value to the company’s strategic goals? This is a first means of removing infeasible options.

Frequently this is a qualitative measurement of the formal missions stated on the companies’ communication channels. This is part of the prescribed documentation in the gate reviews of the investment process.

**Meeting sustainability criteria**

All companies state that meeting the (sustainability) regulations is a driver of the investment process direction. In this section it should be seen in the form of compliance (i.e. as a constraint) and not of maximizing this goal. That goal is treated in sub section 0.

Environmental policy is taken in to account with regard to its ‘carbon exposure’ effects. For renewables, the subsidy schemes are also crucial (4, 5, 6). Furthermore the power plants should adhere to all formal health,
safety and environment regulations. Getting the level of compliance documented for permits is a large aspect of the cost of the investment process (development expenditure or ‘Devex’).

Next to stating these compliance motives, all companies state publicly that they wish to minimize environmental effects (in their strategic mission statements). But the common coping strategy focuses on being compliant.

Alternative drivers with less emphasis
Several drivers were stated less often or with less emphasis.

- For banks investment projects are interesting when the `RAROC´ (risk adjusted return on capital) is higher than the bank’s other options for supplying financing. A high `debt service ratio´ is attractive because it indicates lower risks in fulfilling debt obligations (9).
- Goal reasoning was frequently stated as being a driver: developing the project becomes the goal (4, 7). The large amount of work performed, social desirable behavior, the desire to “outperform” competing departments and other intra-organizational dynamics play a role (7, 10). Also political influence can play a role at companies with governmental shareholders (5, 6, 7).
- The analysts desire for the investment process to `instill trust` can influence the actual investment process, e.g. through changes in data representation or smart timing. This is stated to happen frequently during investment processes (7).

Information processing
Information processing in the investment processes is divided into common bounded rationality categories. These are explained in detail in section 3.3 and 3.4.

Firstly a summary is given of the processing aspects stated in many interviews (or emphasized as a key driver in several interviews). Secondly a short overview of other alternative processing aspects that received less emphasis (or stated not to be a key driver) is given per category (if present).

Decomposition between departments
Information processing is divided between several departments: all companies have strategy, business development, technical development, production and trading departments (2,5,10).

Every department receives specialized tasks and frequently should also handle the risks (4). An example is ‘tolling’ within one company, where the production handles technical risks and trading handles market risks (4).

In many cases the business development department is responsible for the integral investment process (2).

Decomposition in stages
All companies split up their information processing in stages (1, 2, 4, 6, 10).

The stages have different names and sometimes the main stages are split up into sub-stages (2). The stages are all closed by gate reviews. The gate reviews are all performed by investment committees with a diverse group of members to minimize issues such as group think, bias and lack of knowledge (1, 2, 4, 6, 10).

Common stages include:

- Before the specific investment process takes place companywide strategic goals are set and usually a scenario analysis is performed which lead to possible future paths (1, 2, 4, 6, 10). Common
uncertainty axes in these analyses are ‘macro economic development’ and ‘public perception with regard to environmental sustainability’.

- In most cases, the following portfolio analysis phase precedes three main front end loading stages. In this stage the main choices are made for a region’s technology capacity and capacity indication (10).
- During the “scanning” or “business development” phase initial market opportunities are explored. These are usually based on portfolio considerations (2,5).
- During the “scouting” or “scoping” phase a specific market opportunity is specified (1,2,4,6,10).
- During the “design” or “definition” phase the power plant project is detailed to such a degree that it can be financed and constructed (this happens in the front end loading phase and is closed by the final investment process) (1,2,4,6,10).

**Decomposition in hierarchy**

Similar to other corporate environments, the information processing and decision making is distributed in different hierarchical positions (both for banks as well as power companies). Key groups are portfolio managers, analysts, business development heads, investment comities and executive board members (at power companies). Several issues are relevant with regard to hierarchies (1, 2, 10):

- Projects with a high Capex tend to travel ‘top-down’, while some smaller projects can originate ‘bottom-up’ (10). This is especially true for larger international companies, where the number of hierarchical levels is larger (10).
- Attention of higher hierarchical layers tends to intensify in later stages of the investment process (10).
- Attention of higher hierarchical layers tends to intensify with higher Capex projects (1).

**Decomposition by outsourcing**

Outsourcing to engineering firms, law firms and strategic consultants happens at all companies. The level of outsourcing will intensify at later stages due to the considerable costs involved and the level of detailed knowledge required (1). Acquiring all documentation for formal procedures such as permit approval and external financing consumes a large part of the Devex budget (1). However the outcomes of these formal procedures (e.g. the building permit) in these phases add much financial value to the projects (1).

**Uncertainty editing**

Several companies indicate their methodology resembles the scenario methodology developed by Royal Dutch Shell which selects a limited number of uncertainty axis (2,4). This is elaborated in further detail in the following sub section ‘dealing with uncertainty’. Differences in the organizations also exist, these are stated at section 4.3.

**Company goal editing**

Many goals can be stated throughout the organization: they differ between different persons, departments et cetera (2, 5).

The goals are simplified to strategic goals set by the executive board. These goals are simplified by portfolio managers to a preliminary choice in geographic region, conversion technology and capacity indication (1, 2, 4, 10). Plant modifications and lifetime extensions are also indicated when necessary (10). The goals of the investment process teams are simplified to the investment guide goals and “project promises” for gate reviews (1, 2, 4, 5, 9).
**Risk editing**

Risks are assessed according to investment guides (all companies). Companies focus primarily on well-known risks with perceived high impacts (1,4,6,7). Risks that are given much attention are:

- building permit risks (key risk for all)
- power price volatility (key risk for all)
- land lease risks (key risk for all)
- subsidy risks (key risk for renewables)
- natural resource availability risk (such as wind speed yield risk; key risk for renewables)
- technical risks in the power plant
- grid connection risks
- construction and risks
- fuel price risk
- carbon exposure risk
- risks in partnering

Outcomes of the risk assessment are frequently simplified to potential impact and its chance distributions (2,7). These are often based on past experience saved in historical data sets (7). All parties take distributions of the main risks on their financial models into account (different per future scenario) (all companies).

Power price risk receives much attention. All companies use elaborate forecast models based on long term future merit orders expectations, fuel price assumptions and demand assumptions (6). The models give estimates for power prices in different timeframes, for up to 40 years (2, 6, 7). The merit orders are based on assumptions regarding changes such as: decommissioning of plants, interconnection changes and new investments (6,7). These are large, confidential models. The outcomes are revised periodically or when major changes occur. Power price projections are strongly based on market future prices (4).

Systemic risks are frequently simplified to the `Beta` in CAPM`s. The weighted cost of capital is usually supplied by the financial department. This data is sensitive to competition and is revised periodically (2, 7). Risks in climate policy are mainly simplified to carbon exposure cost distributions (7).

**Technical design editing**

Technical design is simplified to combining commercially available components (4). For power plants a very limited number of suppliers of key components are available (such as Alstom, General Electric, Mitsui and Siemens) (7). Specialized engineering firms (such as Jacobs and ABB) are hired to deal with detailed technical design issues when there are knowledge gaps (7).

Location choice is simplified by regarding locations within the bounds of cooling water, permit issues, availability and sometimes feedstock supply via waterways (mainly for coal and biomass) (4). Often the `lessons learnt` from previous projects are also used for quick scans of suitable locations and setup (4).

**Editing in time**

Simplification are decreased throughout the investment process. More detail is added along the way (all companies).
First strategic choices and portfolio choices are made. After these choices locations can be reviewed in greater detail. This is done for a specific technology, region and power capacity range (4,6). The reviews are confined to a limited number of future paths (form the scenario analysis outcomes).

After location choice the investment proposal will become more detailed in time with declining bandwidths of estimates. ‘Knock-out criteria’ are assessed in the initial phase to identify unfeasible projects in the early stage (2, 5). Examples are strategic fit, land lease options, financing options (5). An effort is made to delay activities consuming large “Devex” budgets to the final stages of the investment process. Examples are detailed design and permit applications (5, 7). The bandwidth of the financial outcomes are expected to decrease considerably among all companies (e.g. from 30% to less than 10% (5)).

**Heuristics: reduce knowledge uncertainty and deal with risks**

As stated previously in ‘decomposition in stages’, knowledge gathering is structured to come to an efficient investment process. Choices that reduce much degrees of freedom are taken early in the process to aid in this process (e.g. location choice, technology choice).

At many companies, allocation of resources is frequently coupled to the perceived degree of uncertainty and the potential impact on the project deliverables. Important, high impact issues receive more resources (2,6).

**Heuristics: Seek technical and social validity in risk and knowledge uncertainty**

Several companies use these tactics to reduce knowledge uncertainty on the validity of assumptions. Sessions are held for analyses such risk assessments and scenario analysis (2, 6).

In certain cases, the participants are selected from different departments (e.g. comprising of business developers but also constructors or asset operators)(1). This is done to keep ‘tension on assumptions’.

In addition, separate ‘value assurance teams’ are also seen during this activity (1).

**Heuristics: Couple budget allocation to value creation**

In order to avoid unnecessary waste of Devex budgets it is common practice to allocate budgets according to the value creation in the stage (1, 5). The expensive aspects of the investment process are usually set at the end of FED if possible (to prevent avoidable Devex costs and financial reasons).

**Framing: dimensions of the problem**

Investment processes typically have to take a host of dimensions into account. Dimensions include regulatory, financial, technical, political, organization, legal and strategic elements (all companies).

**Framing: Information required**

Investment processes for (non-nuclear) power plants can take 2 to 5 years, but up to 10 years (2,4). Information changes during this timeframe. Information requirements also change (2,4). The companies update the information throughout, although often periodically due to the processing effort required and the fact that information comes from different departments or organizations. For instance power price forecasts in time will typically be updated by a strategy department periodically. Or updates will occur when major changes in the sector occur (7).

A large diversity of information needs to be collected throughout several departments and several organizations (consultants, public administrations) (all companies). The main focus of gathering this information is on factors that are stated in the investment guides (all companies). This includes aspects that have proven important in past investment processes (4).
Dealing with uncertainty

Dealing with uncertainty has already been indicated to some degree in ‘editing uncertainty’.

All companies simplify exogenous uncertainty in a methodology which chooses a limited number of determinants (or “axis”) of uncertainty as a basis for indicating possible futures and their outcomes. Frequently stated focal areas contain (2, 4):

- uncertainty in macro economic development
- uncertainty in public policy (regulation, subsidies, carbon exposure)
- uncertainty in consumers’ environmental sustainability focus (e.g. coal to gas ratios)
- uncertainty in technologic development
- uncertainty in sector structure (capacity markets, interconnection)

Differences between the companies exist in who performs the scenario analysis (e.g. ‘make or buy’) these are elaborated on in the section 4.3. The scenarios are constructed to indicate likely future paths. These outcomes are often a starting point for the modeling assumptions during the investment processes (1).

Another way of dealing with uncertainty is reducing knowledge uncertainty. This is a key focus of all power companies and two main options were stated:

- buying specialist services (e.g. lawyers, engineers, political specialist).
- performing extensive sensitivity analysis.

All companies take the outcomes of these scenario analyses as a starting point for the investment process. Other uncertainties are left out of the consideration (2, 4).

Conclusions for ‘common coping strategies’

The outcomes stated above will form an essential starting point for the analysis in chapter 5 and 6. Firstly they will be used to indicate validity of the first proposition (stated in section 3.4). Secondly the results are combined in an investment concept stated in section 5.4. Specific coping strategies from the common coping strategies are selected for the ABM investment module in section 6.3.

To keep the information of all common coping strategies comprehensible an overview is stated below with main conclusions. This table will be elaborated on in the following chapters.

<table>
<thead>
<tr>
<th>Proposition</th>
<th>#</th>
<th>Empirical results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proposition 1: common coping strategies</strong></td>
<td>#</td>
<td><strong>Common amongst respondents</strong></td>
</tr>
<tr>
<td>- Satisficing goals (see par.4.2.1.)</td>
<td>1</td>
<td>meet sufficient level of trust in business case</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>meeting hurdle rate</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>acceptable residual risk outcomes</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>minimize avoidable opportunity costs</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>maintain healthy cash position</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>meet strategic goals of executive board to sufficient extent</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>meeting sustainability criteria</td>
</tr>
<tr>
<td>- Information processing by</td>
<td>8</td>
<td>divide processing between departments</td>
</tr>
<tr>
<td><strong>decomposition (see par.4.2.2.)</strong></td>
<td><strong>9</strong></td>
<td>stage-gated decision processes</td>
</tr>
<tr>
<td></td>
<td><strong>10</strong></td>
<td>decision leading to proposition distributed to different hierarchical layers</td>
</tr>
<tr>
<td></td>
<td><strong>11</strong></td>
<td>outsourcing to engineering firms, law firms, consultants et cetera</td>
</tr>
<tr>
<td><strong>- Information processing by editing (see par.4.2.2.)</strong></td>
<td><strong>12</strong></td>
<td>simplify all uncertainty to limited number of uncertainty axis in scenario analyses</td>
</tr>
<tr>
<td></td>
<td><strong>13</strong></td>
<td>diversity of local goals is simplified to strategic goals set by executive board for processing</td>
</tr>
<tr>
<td></td>
<td><strong>14</strong></td>
<td>simplify real-life risks to (treatment and analysis) of perceived high-impact risks</td>
</tr>
<tr>
<td></td>
<td><strong>15</strong></td>
<td>simplify risks to (outcomes of analysis to) functions of cost and income</td>
</tr>
<tr>
<td></td>
<td><strong>16</strong></td>
<td>simplify systemic risks with CAPM to outcomes in functions of cost and income</td>
</tr>
<tr>
<td></td>
<td><strong>17</strong></td>
<td>simplify technical design to portfolio requirement and limit to local options</td>
</tr>
<tr>
<td></td>
<td><strong>18</strong></td>
<td>Increase level of detail in analysis throughout stage-gates.</td>
</tr>
<tr>
<td><strong>- Information processing by heuristics (see par.4.2.2.)</strong></td>
<td><strong>19</strong></td>
<td>reduce knowledge uncertainties</td>
</tr>
<tr>
<td></td>
<td><strong>20</strong></td>
<td>seeking technical and social validity of assumptions</td>
</tr>
<tr>
<td></td>
<td><strong>21</strong></td>
<td>couple search cost budget (in Devex) to value creation. Delay expensive actions to last stages of the FED when possible.</td>
</tr>
<tr>
<td><strong>- Information processing by framing (see par.4.2.2.)</strong></td>
<td><strong>22</strong></td>
<td>gather sufficient strategic information to come to a DCF valuation</td>
</tr>
<tr>
<td></td>
<td><strong>23</strong></td>
<td>take all relevant dimensions of problem into account in valuation (legal, technical et cetera)</td>
</tr>
<tr>
<td></td>
<td><strong>24</strong></td>
<td>follow investment guide guidelines to gather and process information</td>
</tr>
<tr>
<td><strong>- Dealing with uncertainty (see par.4.2.3.)</strong></td>
<td><strong>25</strong></td>
<td>select limited number of uncertainties as a basis for likely future paths (scenario analysis). Ignore others or use them only in qualitative form during gate reviews. Reduce knowledge uncertainty by outsourcing to specialists and also perform extensive sensitivity analysis.</td>
</tr>
</tbody>
</table>

Table 5 Overview of common coping strategies; stated by power plant investment experts in section 4.2.

This table concludes the empirical results in common coping strategies. The following section states the diverging coping strategies.

### 4.3. Diverging coping strategies

Differences between investment processes are organized in the same categories as used in section 4.2. For every investment process difference, reasons stated by the expert are included\(^{22}\). An effort has been made here to focus only on the descriptive statements of the experts. Normative statements led to interesting discussions however they should be left out of the main results and analysis. This section follows the setup used in section 4.3. Differences are stated for goals, information processing and dealing with uncertainty. The section concludes with an overview of diverging coping strategies as a key outcome.

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\(^{22}\) These causes are the differences between organizations that the experts hold responsible for the decision making constraint. Figure 7 states the theoretical framework.
Goal differences
First, key differences in the drivers for investment companies at different companies are stated. Secondly, goals that received less emphasis (or stated not to be a key driver) are briefly indicated.

Differences in financial valuation methods
Minor differences in financial valuation methods were present. Power companies use similar valuation methods such as NPV (-margin)(4,5,6,7,10) and IRR(1,2). All methods are based on discounted cash flows. Banks tend to use RAROC (9). All companies use the figures to compare to a financial hurdle rate set on a strategic level.

Companies rarely stated rarely using “real option valuation”- or “irreversible investment theory” methods (2). These analyses can be costly and experts stated that it is more difficult to explain outcomes throughout the organization since the methods are not yet commonplace.

Banks have to look at power plant investments differently than power companies. This is due to the fact that banks (also) operate in the financial sector. Banks need make money on the capital they have lent to power companies and have to earn back costs: Euribor interest, funding costs and return on risk margins(9). In their sector risks such as currency risk and country risk require more attention from banks in comparison (9).

The power companies have not stated reasons for their choice in valuation tools. However causes are explored in chapter 5 to explain the difference.

Difference in risk seeking
A frequently stated powerful goal of the investment decision was “not to do worse than the competition” (2, 7).

The reason for the power of this goal is quite simple and has to do with the preference of the shareholders or owner. For these parties relative losses (compared to sector performance) are much more painful than relative gains (compared to sector performance). Executive boards and heads of business development are quite aware of this phenomenon and tend to ‘mirror the market’ in their portfolio (2). This decreases the chance of doing worse than the competition. Another reason was also stated: there is more information throughout the sector than in one organization so that would make “herding behavior” attractive.

However one company did not acknowledge this goal and tries to gets good performance by differentiating its risk seeking from the competition. The expert states that this has to do with the company’s ownership (not all stock is publicly traded on the stock exchange) and their strong trading desk (6). With these enabling characteristics, risk seeking could have a higher financial gain due to the widely spread risk averse goal in the sector of “not doing worse than the competition”.

Portfolio value addition
The level of influence that the portfolio consideration has on the investment process will differ according to several differences between companies (1, 6, 10):

- In markets where companies have a very large generation share, introducing a new power plant in the merit order can result in a relatively small value addition (compared to a market with a limited market share) (10). A cannibalizing effect can occur on the company’s own old power plants in ‘conquered markets’ because of the merit order changes. This only applies for very high market shares in generation (10).
- Smaller companies or companies with a light asset base will simply have less degrees of freedom of combining power plants to add portfolio value (10).
- Vertically integrated companies can derive more benefits in portfolio value addition considerations (10). Their influence in connected parts of the supply chain gives them more degrees of freedom in choices that can influence to portfolio value addition.

Differences in sustainability goals
In section 4.2 all companies stated environmental sustainability criteria to be influencing the investment process. Several companies not only wish to comply with sector regulation. They use environmental sustainability as a goal on itself. This difference is explained by company owners (usually government shareholders), mindset of the chief executive officer and board, lack of experience in conventional power plants and overall company culture (4,7,10). The effects on the investment process can be considerable.

This group of companies does not review power plant types perceived to be less environmentally friendly in their portfolio consideration. Experts state that hard coal, lignite (and sometimes nuclear) into consideration in their investment processes (4, 5, 6).

Expanding experience with unknown technology
Companies may wish to improve their knowledge level on using technology that is new\(^{23}\) or unknown to the company (4). New technology often includes renewable energy for the power companies. Unknown technology can also be thermal power plants for companies with a light asset base (4).

A desire for learning about the implementation of new or unknown technology could be a positive argument during the final investment decision (4). However the novelty factor will also influence the financial influence of development risks (1, 5).

Alternate differences in goals with less emphasis
- Local employment can be a driver for choices in the investment process (5). This effect will be much larger when more municipalities are influential shareholders (5).
- A “budget-culture” is still stated to present to some degree, especially at power companies with a public administration history before privatization (1,6, 7). A budget-culture could lead to the goal of making sure budgets are fully utilized during investment processes. This can lead to higher Devex budgets which can diminish the chance of a investment option reaching the final investment decision because the ‘search costs’ are larger than the value creation during the investment process stages.
- The wish of “outperforming” other power plant investment opportunities can affect an investment process (10). A motive can appear for ‘window dressing’ (improving appearance of performance). An example is changing the data representations that are shown to the executive decision maker (to indicate a ‘prettier picture’). This is not uncommon in the industry (7). If the company size increases usually more options are considered giving more ground for this kind of behavior (10).

\(^{23}\) New is used to indicate the novelty of actually implementing commercially mature renewable technology on a large scale (e.g. windmills and biomass have been around for decades).
**Information processing differences**

**Differences in outsourcing**

Section 3.2. states that all companies outsource information processing activities. However there are differences in outsourcing for several activities.

Smaller firms typically tend to outsource expensive strategic analysis (power price forecasts and strategic scenario analysis) (4,5). Larger companies can afford to have more specialized departments, enabling them to perform their own scenario analyses and power price forecasting (2,10).

**Capital structure differences**

Power companies embarking on individual projects are less likely to take on (equity or debt) lending compared to smaller parties such as project developers (9). Usually the larger power companies can handle the large capital expenditure requirements on their balance sheet for well-known markets and plant types (10).

Options such as project finance are more common at higher risk projects undertaken by smaller companies (9). Companies usually attract external capital for new unknown markets and also high risk projects. This happens more frequently for renewable projects due to the uncertainties in the sector (10).

**Differences in simplifying risks at power companies**

Differences exist in how companies simplify risks in their models. Here we will focus primarily on the simplification of price risks distributions in the financial models.

As stated in the section 4.2, all companies work with outcomes of strategic scenario analysis. These scenarios are used to come to context for the risk assessments for the specific project at hand (all companies).

The outcomes can be retained as full distributions in the model or point estimates can be used.

By using full distributions in the financial models more information is taken into account. All large (and most smaller) companies indicate that simulation methods are used, the ‘Monte Carlo’- type was stated frequently (1,2,4,5,10). However these calculations are relatively expensive and complicated compared to using fixed numerical values. In addition and they require more information to be available compared to simpler variants (7). These downsides will increase the Devex and complicated models are often found to be less transparent in communicating the key findings throughout the organization (1, 4, 5, 7).

An alternative is to use point estimations that have a certain confidence level. For instance a P90 value for power price would indicate that there is 90% certainty that the actual outcome of the power price will be higher. Using these kinds of values allows for much simpler calculations but much distribution information is lost. This option is sometimes used at smaller power companies.

Depending on the risk aversion level, analysts can provide and use values such as a P50 or P90 values. In certain cases the volatility currently seen in the power sector has changed the use from P50 to P90 values in response (5,7).

In the final stages of the investment process most power companies use Monte Carlo simulations (1, 2, 4, 5, 10). However there are two aspects stated to influence the decision to use such elaborate models or not:

- The stated downsides of Monte Carlo simulations will weigh heavier on power companies that are relatively small (4, 5).
In this geographic region, the added value of Monte Carlo simulations is perceived to be smaller for renewable plants without feedstock (such as wind parks) (1, 4, 5, 7). Their favorable merit order position and lack of dependence on feedstock price (such as found at natural gas power plants) reduces focus on the effect of the distributions in the financial model.

**Difference in risk focus of banks**

Banks will perform own risk assessment processes before supplying capital (9). The risks assessed by power companies will also be reviewed at the banks.

However banks will normally focus more on risks common in the financial sector. Important risks that are reviewed are: currency risk, refinancing risk, payment default risk, interest risk and country risk (9).

**Heuristics**

*No differences were stated in the use of heuristics.*

**Differences in access to information framing**

Companies not only have different means of processing information, they also have different levels of access to information. Stated determinants on this level of access are the size and characteristics of the current asset base (4) and also the size of the company (4). Companies with a high level of vertical integration will have more access to information (4). Experience in the lifecycle of their current power plants supplies data and insights (“lessons learnt” (4). The size of the company enables specialized desks not only processing but also gathering information (such as desks that can perform strategic scenario analysis or power price forecasting) (2,10).

**Differences for dealing with uncertainty**

**Buying or performing scenario analysis**

Sub section 0 already introduced scenario analysis as a common coping strategy to deal with uncertainty. Differences exist in the way these analyses are acquired. Larger power companies tend to perform an elaborate scenario analysis within the company. Smaller companies tend to purchase the analysis outcomes from specialized consultants (2, 8, 10).

**Assessing flexibility by using real options analysis**

The use of real options differs in the use of real options analysis. Some companies sporadic use of the analysis in the financial forecasting. While other companies report no use of real options analysis at all. Drivers for the differences can originate in technology specific risks and uncertainties; larger projects or projects with large flexibility value are more interesting for this analysis (2). Also company size was stated as a driver; larger companies have more means to perform these demanding analysis (2,6,10).

**Overview of main outcomes for different coping strategies**

The outcomes stated in section 4.3 will form a special part of the analyses in chapter 5 and 6. They will be used in several ways. Firstly, they will be used to check to which level the second proposition set coincides with actual investment practice. The second proposition set was (also) stated in section 3.4. This analysis indicates a level of representation of this proposition set. Insights in this level of representation will be helpful in coming to an ABM investment module with a higher level of fidelity. Secondly, to enable actual heterogeneous modelling, the explanations for differences will be analyzed in chapter 5.

In order to keep the information comprehensible an overview is stated below. This table will be elaborated on in the following chapters.
Proposition 2: different strategies

Differences amongst respondents in:

- Satisficing goals (see par 4.3.1)
  26 financial valuation method: NPV, IRR, RAROC,
  27 risk seeking when ensuring continuity (seeking risk vs. Mirroring the market)
  28 Taking "portfolio value addition" in account or not
  29 Sustainability goals
  30 Expanding experience with unknown technology
  31 Relevance of local employment effects
  32 Spending budgets (at budget cultured companies)

- Information processing by decomposition (see par.4.3.2.)
  33 Level of outsourcing (of expensive strategic analyses)
  34 Capital structure options

- Information processing by editing (see par.4.3.2.)
  35 Ways of simplifying risks
  36 Focus on particular risks

- Information processing by heuristics (see par.4.3.2.)
  37 -no differences stated-

- Information processing by framing (see par.4.3.2.)
  38 Access to information sources (e.g. Technical or political issues)

- Dealing with uncertainty (see par.4.3.3.)
  39 Using real option analysis or not. Buying or performing scenario analysis.

Table 6 Overview of differences in coping strategies stated by power plan investment experts.

4.4. Expert review of bounded rationality perspective

In addition to the normal interviews, one review was performed in order to review the premises of bounded rationality stated by Simon (Simon, 1982; p.163-176).

After the initial interview on the investment processes, a highly placed executive was asked to review these premises. The expert has international experience in portfolio analysis, investment gate reviews, and business development tasks (11).

The expert’s review of bounded rationality premises

- Imperfect information: agreed, ‘deep uncertainties’ seem especially difficult.
- Limited information processing capacity: agreed to some extent. E.g. Outcomes such as NPV’s can be calculated (under simplifications) but full real options or irreversible investment theory is not yet used. One reason is their complicated forms and difficulties in communicating their characteristics.
- time constraints: agreed to some degree (the group can postpone in certain cases)

The expert stated bounded rationality to be an applicable model for portfolio analysis and business development. Bounded rationality was compared by the expert to the main characteristics of ‘incrementalism’ (explained as small changes in steps often linked to political processes) and ‘rationality’ (explained as options displayed in utility functions, tested on requirements) or ‘mixed scanning’ (stated below).
Aspects of all models are stated to be present throughout by the expert. But bounded rationality seems to be most applicable (even when compared to “mixed scanning”). Mixed scanning was explained as a combination of incrementalism and rational aspects such as indicated in (Etzioni, 1989). For specific aspects, it could be applied well too. The expert stated examples of this kind of mixed scanning when making strategic choices on levels of vertical integration (e.g. acquire strategic positions in hard coal mining or not).

The expert stated his view of the investment processes to change throughout the last decades with regard to the types of decision making used at the company (-group). Discussions were more incremental (and also informal) in the old regulated industry setting compared to the new setting (e.g. stage gates, formal criteria, external investment committees). There is a definite trend toward more use aspects of analytical methods to come to solutions.

4.5. Use of the empirical analysis in further analysis
Several empirical outcomes are used in the following chapters. A key outcome of section 4.1 is that the participants represented companies which own more than half of all generation capacity in the Netherlands. A key outcome in section 4.2 is Table 6. This table states common coping strategies used by all consulted power plant investors. The table will be used to indicate if the first proposition holds for power plant investment practice (in section 5.2). Table 6 is a key outcome in section 4.3. This table will be used to indicate a level of representation for the diverging coping strategies (in chapter 5).

The reasons for differences in coping strategies will be used to come to properties that can specify investment processes of actors according to relevant differentiators. These properties will allow for an initial review of the path towards construction of heterogeneous representations of agents in the ABM (in chapter 6). Lastly, the separate bounded rationality expert review (in section 4.4.) shows some encouraging results on the use of bounded rationality and also states ‘mixed scanning’ as a possible representation form of strategic considerations in choices on the level of vertical integration in the supply chain. This collection of outcomes is the basis for the analysis of empirical results in the following chapter.
5. Analysis of empirical results

This chapter states the analyses performed on the empirical outcomes and their results stated in chapter 4. This is done to come to an integral concept of the investment process and to assess the validity of using the bounded rationality perspective to represent investment processes in the Netherlands.

To this end, firstly the (rationale behind) methods used in the analysis are stated in section 5.1. Secondly the propositions (stated in section 3.4.) are confronted with the empirical outcomes common between all respondents (stated in section 4.2.). These confrontations lead to indications of validity levels of the propositions in section 5.2. Thirdly the differences in investment processes are analyzed based on the reasons stated by the respondents. This is done in section 5.3. This is done to come to propositions for heterogeneous representation of the agents in the ABM. The chapter is concluded with an overview of main results and recommendations for the conceptual model of the investment processes.

5.1. Analyses

In chapter 3, the review of key notions in project management and corporate finance led to the necessity of propositions that explain deviations from prescribed methods by actors. A review of the bounded rationality-perspective has lead to two main proposition sets in section 3.4.

The first proposition focuses on the use of bounded rationality coping strategies in order to represent investor behavior. For this proposition it will be essential to gain some insight in the proposition’s level of representation when confronted with empirical results. The second proposition focuses on the role of investor differentiation on investor coping strategies (through decision process constraints). For this proposition it will be essential to gain insight in the effects of investor differentiations on the investor’s coping strategies. The analyses used to enhancing these insights are stated below per proposition.

Analysis of the first proposition

The first proposition was formed in section 3.4:

“Bounded rationality coping strategies can be used to represent power plant investor behavior (given decision constraints).”

This will be reviewed through confronting the theoretical characteristics of bounded rationality coping strategies (stated in section 3.4.) with the actual outcomes (represented by the table stated in section 4.2.). The outcome will consist of a review per coping strategy. This will indicate to what extent the proposition holds for the measurement performed with the investment experts.

Analysis of the second proposition

The second proposition was also formed in section 3.4:

“Investment process differentiators (e.g. company size difference) will change the decision process constraints and consecutively the investors’ coping strategies”.

Certain diverging coping strategies held high relevance for the experts. The background of these differences in coping strategies was already stated in sub section 4.3. Several investment process differentiations were stated by the experts to indicate the differences per coping strategy. These limited set of reasons include logical explanations like differences in an investor’s company size, ownership and asset
base. When stated as reasons for coping strategy differences, these differentiators are added to a set of separate columns in the original database. The (construction of the) database is stated in Appendix 8. This original database holds an overview of all the coping strategies retrieved from the interview summaries which were stated multiple times or stated to be of key relevance by the investment experts.

This action allows for a simple yet effective way to indicate which differentiators influence which coping strategies. These can be seen by looking at the checked cells under the columns of investor differentiations. A simplified concept is shown below.

Figure 8 Basic concept of analysis to come to initial connections needed for explaining investor behavior differences.

The resulting specified overview is stated in section 5.3. These results should not be viewed as an exhaustive concept explaining all diverging investor behavior. But rather as a starting point for future research that can enhance understanding of diverging investor behavior. The overview can also be used to indicate if the second proposition holds for power plant investment practice. Resulting insights allows for a preliminary check of the path towards the future investor module formalization. This is performed in chapter six.

5.2. Bounded rationality vis-à-vis empirical outcomes

Bounded rationality aspects of goals
During this research the focus of bounded rationality with regards to goals has been on satisficing elements. The satisficing element of goals (vis-à-vis maximizing) was already stated in section 3.3. The most important difference between the two was stated to be in the aspects of sensitivity to “relative scores”
(maximizing) versus sensitivity in ‘reaching certain targets’ (satisficing). All common goals stated in Table 5 are now reviewed on these sensitivities;

1. The goal of ‘meeting a sufficient level of trust in a good business case’ is very sensitive to ‘reaching a goal level’ and much less to ‘relative scores’. Regardless of other investment options this level of trust needs be high enough. Therefore can be regarded as a satisficing goal.

2. The goal of ‘meeting a hurdle rate’ can have both maximizing as well as satisficing goal aspects depending on context. The goal can be maximizing when the hurdle rate is very dependent on alternative options. It is expected that this is more relevant for larger, more internationally oriented organizations. The goal can be satisficing when the hurdle rate is seen more as a given inside the organization. This was frequently stated in the interviews.

3. The goal of ‘acceptable residual risk outcomes’ can be assumed to be satisficing. A certain limit (with regard to impacts and their chances of occurrence) needs to be held in the project. Regardless of financial discounting. This is a separate consideration, isolated (in this research) from the discounting of risks in the financial forecast results. In this discounting of risks, relative performance would be higher. However in this case the goal is defined as a separate criterion for decision makers.

4. The goal of ‘minimizing avoidable opportunity costs’ is sensitive to relative performance. Shareholders will expect the senior management of power companies to get the best returns for their shares. If other options perform better they should be chosen (when only regarding this goal in isolation). This reasoning indicates that this goal has heavy weighing optimizing aspects. The satisficing aspects are present to a lesser degree.

5. ‘Maintaining a healthy position’ can have both maximizing as well as satisficing goal aspects. It The investment options will be compared to each other with regard to effects on the company’s cash position. However the interviews revealed that the focus lies mainly on maintaining a good credit rating and room to maneuver. Therefore the satisficing aspect weighs more heavily here.

6. Meeting strategic goals can have maximizing as well as satisficing goal aspects. The added value to all strategic goals will be compared between options by senior management. However the interviews clearly indicated that this goal was seen more as a threshold in the early stages of the investment process. That is why it was formulated with the inclusion of ‘to a sufficient extent’. The question of “will the option add value to company strategic goals” is a threshold which was often built in the very first gate reviews at many power companies. In this sense it is a goal with clear satisficing aspects.

7. ‘Meeting sustainability criteria’ seems much more sensitive to reaching a goal level than outperforming other options (in this formulation). Some power companies clearly have ‘green’ strategy which has more relative performance aspects but this is a separate goal stated at the diverging coping strategies. So in this definition ‘meeting sustainable criteria’ is a satisficing goal.

These outcomes lead to the table stated below.

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Goals)</th>
<th>Sensitivity to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Common goals amongst respondents</td>
<td>relative performance</td>
</tr>
<tr>
<td>1</td>
<td>meet sufficient level of trust in business case</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>meeting hurdle rate</td>
<td>Low-medium</td>
</tr>
<tr>
<td>3</td>
<td>acceptable residual risk outcomes</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>minimize avoidable opportunity costs</td>
<td>High</td>
</tr>
</tbody>
</table>
It is concluded that most goals feature satisficing aspects. This adds to the validity of the bounded rationality framework stated in Figure 1 for representing power plant investment processes. However it should also be concluded that maximizing aspects are also present at some of the goals (especially avoiding avoidable opportunity costs). This review applies to the common goals of investment processes stated by investment experts.

**Bounded rationality aspects of information processing**

The bounded rationality level of information processing aspects (but only those common amongst all organizations) will be treated per processing coping strategy. These have all been introduced in section 3.3. Key aspects of each coping strategy are elaborated on in the sections stated below. The resemblance of the (theoretical) coping strategies with the empirical results is reviewed in tables. These reviews leads to a level of validity of the investment processes’ bounded rationality propositions. The tables are elaborated on where necessary.

**Decomposition**

March (1994) states that the assumption behind this coping strategy is that solving all component parts of a problem leads to an “acceptable solution to the global problem” (March, 1994; p.12). March (1994) also states that a close interdependency between components can lead to complications since the basic assumption will not hold in this case.

The review will focus the key decomposition aspect. This is the level to which the empirical results resemble coming to ‘components of the problem’. When interdependence- or other issues arise they will be stated.

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Decomposition)</th>
<th>Applicability in order to attain:</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>divide processing between departments</td>
<td>High; distribution of components in- and outside the power company</td>
</tr>
<tr>
<td>9</td>
<td>stage-gated decision processes</td>
<td>High; splitting up of components in time</td>
</tr>
<tr>
<td>10</td>
<td>decision leading to proposition distributed to different hierarchical layers</td>
<td>High; linked to “decentralization and “hierarchy” stated in (March, 1994; p.13)</td>
</tr>
<tr>
<td>11</td>
<td>outsourcing to engineering firms, law firms, consultants et cetera</td>
<td>High; reduction through buying knowledge, linked to “division of labor” and “specialization” (March, 1994; p.13)</td>
</tr>
</tbody>
</table>

In the empirical results, the experts frequently state the high relevance of managing the information flows between all the information processing parties necessary in the information process (e.g. in interview (2)). These statements seem to indicate interdependency is an important factor in the investment processes. This indication can be combined with the statement on `components` stated above. With expected interdependency it is likely that an increasing amount information processing units will also increase the chance of complications. This resembles the statements on project complexity made in section 2.3.
For decomposition, it is concluded from table 7 that the proposition displays a high level of validity with the empirical results. Also there seems to be a relevant level of interdependence between components.

**Editing (simplifying and editing problems)**

March (1994) states that simplifying and editing problems can be done in several ways. Two ways are firstly to “discard some available information” or secondly to limit the “amount of processing done on the information” (March, 1994; p.12). In the review stated below editing’s defining aspects are assumed to be ‘discarding information’ and ‘limiting processing’.

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Editing)</th>
<th>Applicability for</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>simplify all uncertainty to limited number of uncertainty axis in scenario analyses</td>
<td>high; no other uncertainty axis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high; only relevant outcomes</td>
</tr>
<tr>
<td>13</td>
<td>diversity of local goals is simplified to strategic goals set by executive board for processing</td>
<td>high; all informal goals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high; only use these goals for trade-offs</td>
</tr>
<tr>
<td>14</td>
<td>simplify real-life risks to (treatment and analysis) of perceived high-impact risks</td>
<td>high; e.g. no ‘black swan risks’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high; only use distributions</td>
</tr>
<tr>
<td>15</td>
<td>simplify risks to (outcomes of analysis to) functions of cost and income</td>
<td>high; no informal effects, no external effects</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high; only use distributions</td>
</tr>
<tr>
<td>16</td>
<td>simplify systemic risks with CAPM to outcomes in functions of cost and income</td>
<td>high; e.g. Limit world to ‘systemic risks’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high; only use point estimates</td>
</tr>
<tr>
<td>17</td>
<td>simplify technical design to portfolio requirement and limit to local options</td>
<td>high; discards all options except portfolio fitting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high; e.g. limit detailed design to industry options</td>
</tr>
<tr>
<td>18</td>
<td>increase level of detail in analysis throughout stage-gates.</td>
<td>high; reducing info as soon as possible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high; ”choice dimensions sequentially” (March, 1994; p.12)</td>
</tr>
</tbody>
</table>

Table 9 Review of bounded rationality aspects of editing stated by experts

For editing, it is concluded from table 8 that the proposition displays a high level of validity with the empirical results.

**Heuristics (applying rules of behavior based on pattern recognition)**

March (1994) summarizes from expertise studies that experts “substitute recognition of familiar situations and rule following for calculations” (March, 1994; p.12). Both ‘situation recognition’ and ‘rule following’ is reviewed with the empirical outcomes. The table stated below states the results.

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Heuristics)</th>
<th>Applicability in order to attain:</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>reduce knowledge uncertainties</td>
<td>Mixed; the substance of the uncertainties will be unknown by definition. The form of reducing uncertainties is prescribed by the rule (e.g. addressing high impact uncertainties with priority)</td>
</tr>
</tbody>
</table>

Table 9 Review of bounded rationality aspects of editing stated by experts
seeking technical and social validity of assumptions

Low; combining resources does not seem to resemble rule following or situation recognition. A point could be made that other might recognize patterns (but this is not the focus here)

couple search cost budget (in Devex) to value creation

High; also see table 2 in section 3.1. for project stage ‘situation recognition’. And the Devex budget can be regarded as a (search cost) rule to be followed

From these outcomes it is concluded that the bounded rationality proposition for heuristics do not fully resemble empirical results

Framing (by problem definition, information requirement and dimensions)

Framing (by problem definition, information requirement and dimensions) March (1994) states that the this coping strategy allows decision makers to “direct attention and simplify analysis” (March, 1994; p.14). These elements of ‘directing and simplifying’ are used to indicate the level of framing used in the investment processes.

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Framing)</th>
<th>Applicability in order to attain:</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>gather sufficient strategic information to come to a DCF valuation</td>
<td>High; focused on coming to strategic financial forecast in fixed methods</td>
</tr>
<tr>
<td>23</td>
<td>take all relevant dimensions of problem into account in valuation (legal, technical et cetera)</td>
<td>Low; taking all these into account can make direction and simplification cumbersome</td>
</tr>
<tr>
<td>24</td>
<td>follow investment guide guidelines to gather and process information</td>
<td>High: guides stipulate focal points and prescribes form for analysis</td>
</tr>
</tbody>
</table>

For framing, we conclude from table 9 that its proposition displays a mixed level of validity with the empirical results. Measures such as investment guides and NPV method use do resemble framing characteristics but the multidisciplinary does not seem to do so.

Dealing with uncertainty

The expectations for dealing with uncertainty stated section 0 are met to a high degree. A short review is stated below;

- ‘Many uncertainties are not taken into account in the consideration’; empirical results confirmed selection of a limited number of uncertainty axis in scenario analysis.
- ‘Decision makers try to remove uncertainties that arise specifically from knowledge gaps’; empirical results confirmed this by the use of outsourcing to specialists, the processes used in scenario analysis, and extensive sensitivity analysis.
- ‘Decision makers also try to remove certain uncertainties that result from incomplete contracting’; the added value (and costs in Devex) of service providers such as lawyers to minimize issues with contracting was stated by many investment experts.

It is concluded here that the theoretical expectation has a high fit with the empirical measurement.
Concluding: validity of the first proposition

It is concluded from section 5.2 that investment practice shows many bounded rationality characteristics but to a varying degree for different bounded rationality categories. For the features of the bounded rationality categories of ‘satisficing goals’, ‘decomposition’ and ‘editing’ a high level of validity is shown (based on the reviewed statements). For the bounded rationality categories of ‘heuristics’ and ‘framing’, this level of validity is lower. Formulations and context of the coping strategies stated by investors are relevant when assessing validity of the investor concept.

5.3. Differences in investment process

In section 5.1, a concise method was proposed for coming to ‘a starting point for understanding differences in investment behavior’. The results of these analysis methods are investment process differentiators (and their effect on coping strategies). The connections between these differentiators and coping strategies are stated in this section. The results allow for a review of the second proposition (formed in section 4.4). The investor differentiators and their effects also lead to a proposed concept of the investment processes (in section 5.4.).

Formal company characteristics

Company size

Company size was frequently stated as a reason for different choices in investment processes. When the experts spoke of company size their focus was primarily based on the financial value of the power company’s asset base.

Experts stated that company size influences the investment processes in several ways: in changing emphasis of goals, information processing and dealing with uncertainty. Several goals are influenced by company size:

The goal of maintaining a healthy cash position is shared amongst all companies. However the relative effect of the Capex requirements for a new plant on cash position will be smaller when the balance sheet of the company is much larger. Therefore the goal will be more important for smaller companies.

A department’s goal of outperforming the other investment options within the company can be larger when more investment options are reviewed. Given search costs these will normally be the larger companies. So the goal can become more important at larger companies.

Company size also effects on information processing in various ways. Larger companies will usually have:

- More specialized departments to gather and process information. This allows them to perform more elaborate analyses (such as power price forecasting, strategic scenario analysis and Monte Carlo type simulations. Smaller companies will have to outsource this kind of analysis or simplify their models (e.g. use P90-values in the financial forecast instead of distributions).
- Less need for external capital supply such as debt or equity financing compared to smaller (for the reason stated above).
- More of the preceding portfolio analysis (and the following portfolio choices) is done at corporate headquarters. At smaller companies the number of management layers will usually be smaller and the information processing capacity is more limited. Therefore, business development managers within smaller companies will usually have more influence in the portfolio consideration.
More data and insights derived from previous projects. This is since larger companies tend to have more power plants. Smaller companies will have to buy this information (if it is available) or focus more on specific technologies.

A larger degree of formalization of their investment process (to enable comparison between a multitude of problems and because the executives will need to spread attention across more projects).

Finally, company size also influences the way the companies deal with uncertainty. Larger companies will usually have:

- The possibility to develop own strategic scenarios that indicate possible futures. Such projects can be to elaborate for smaller power companies. In this case generic scenario analysis will have to be procured from external sources.
- More means to influence policy uncertainty. “Lobbying” will be easier for large companies compared to smaller companies (they have more influence on local economic conditions and can afford to attract lobbyists).
- The possibility to use more flexible analysis methods such as real options analysis. The larger companies make more use of this kind of tools. One reason is the costs and specialist knowledge involved.
- The possibility to diversify more between countries, the supply chain and the generation portfolio (for large vertically integrated multinational companies).

When these considerations are confronted with proposition 2 the results are stated below:

![Figure 9 Overview of results of company size on differences in coping strategies](image-url)
Ownership
Company ownership is based on the distribution of the equity. It influences the investment processes in several ways: in changing emphasis of goals, to a limited degree in information processing and in a limited way in dealing with uncertainty. Several goals are influenced by a company’s ownership;

The goal of not doing worse than competition: this goal is present at all power companies. However the power companies that are traded on the stock exchanges will have more pressure to show good performance in comparison to companies with owners such as municipalities and federal governments. Municipalities and federal governments can afford a focus on long term goals (such as environmentally sustainable production) compared to private shareholders.

The goal of sustainable generation portfolios: within the companies reviewed, companies with a large ratio of municipality or state ownership will not tolerate the use of hard coal, lignite and in some cases nuclear. This is a very influential factor in the investment behavior.

The goal of enhancing local employment: for obvious reasons this goal will receive much more emphasis when municipalities are hold a large ratio of the power company’s ownership. In some cases this provided a considerable driver in the location choice for the power plant investment option.

Ownership also effects the information processing with regard to decomposition.

- State owned companies will have different access to capital compared to publicly owned companies. In certain cases it was stated that the state could withhold a large ratio of the company’s dividend. For new power plant investment options the state would provide funding.
- Sometimes state or municipality owned companies can afford a less risk adverse profile due to the relatively high financial robustness of the owners. Certain companies actively use this strategy of risk seeking as a competitive advantage compared to publicly owned companies. Similar considerations apply for dealing with uncertainty.

When these considerations are confronted with proposition 2 the results are stated below:

<table>
<thead>
<tr>
<th>Ownership</th>
<th>Decision process constraints</th>
<th>Decision process coping strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance of short term performance</td>
<td>Information process capacity</td>
<td>△ Risk seeking</td>
</tr>
<tr>
<td>Focus on env. sustainable development</td>
<td>Information access</td>
<td>△ Sustainability as a key goal</td>
</tr>
<tr>
<td>Local employment relevance</td>
<td>Uncertainty in power sector</td>
<td>△ Goal of local employment</td>
</tr>
<tr>
<td>Risk appetite</td>
<td>Ambiguity in preferences</td>
<td>△ Capital structure options</td>
</tr>
</tbody>
</table>

Figure 10 Overview of results of ownership on differences in coping strategies

Vertical integration
In this research, vertical integration is seen as the level to which the company holds positions in the supply chain (the power supply chain was stated in section 2.1.).
Experts stated in section 4.3 that vertical integration influences the investment processes in several ways: in changing the emphasis of one goal, to a limited degree in information processing and to an important degree in dealing with uncertainty.

The level of vertical integration influences the investment process goals through the goal of portfolio value addition. The consideration will be more important in cases where there is a high level of vertical integration throughout the supply chain (such as combined positions in natural gas, generators and trading). More interaction effects need to be considered in such a case.

The level of vertical integration also influences information processing: a company with a high level of vertical integration will have more access to information compared to a company without vertical integration. Positions throughout the supply chain can supply vital information such as fuel price expectations from feedstock positions or market inform via traders.

Vertical integration can also give companies options in dealing with uncertainty. The different positions in the supply chain give more flexibility. This flexibility can be used to outperform competitors. One example could be using the option to store fuel supplies in order to add robustness to deal with uncertainty in the fuel price. When these considerations are confronted with proposition 2 the results are stated below:

<table>
<thead>
<tr>
<th>Vertical integration</th>
<th>Decision process constraints</th>
<th>Decision process coping strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction effects in supply chain</td>
<td>Information process capacity</td>
<td>Δ Portfolio value addition</td>
</tr>
<tr>
<td>Information sharing in supply chain</td>
<td>Information access</td>
<td>Δ Accessing information sources</td>
</tr>
<tr>
<td>Flexibility in operations</td>
<td>Uncertainty in power sector</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ambiguity in preferences</td>
<td></td>
</tr>
</tbody>
</table>

Figure 11 Overview of results of vertical integration on differences in coping strategies

Geographic focus

Geographic focus is most apparent in the national, European or global focus of the power companies.

Geographic focus influences information processing, management of risk and dealing with uncertainty in the investment process.

For companies with a broader geographic focus (e.g. not being confined to one country) it becomes important to change editing in the investment process. Separate risks such as country risk and currency risk will have to be taken into account, e.g. to compare between power plant investment options.

Geographic focus will also change the options of dealing with risks in the investment process. Companies with a broader geographic focus can diversify their business more which gives risk management options (e.g. diversifying of generation capacity across nations to minimize aggregated country risks). This can lead to changes in information access and uncertainty in the power sector (e.g. global company can even choose continents with other levels of risk in the power sector).
Geographic focus also gives the option of dealing with uncertainty: it can enable “shopping” for favorable subsidy characteristics between countries in time. This is not possible for power companies with a national focus. When these considerations are confronted with proposition 2 the results are stated below:

Figure 12 Overview of results of geographic focus on differences in coping strategies

**Current generation portfolio**

In this research, the current generation portfolio is seen as the number and kind of power plants that the company already owns. Experts stated that the current generation portfolio influences one goal and one information processing aspects of the investment process;

The current asset base influences the goal of gaining insight in unknown or new technology. When a company possesses many assets in a certain technology type the goal will receive less attention in the investment process compared to `unknown territory´.

Access to information is different for larger or smaller asset bases. With a larger asset base more information can be derived from the existing power plants to process in the investment process.

Lastly the specific generation portfolio will change the goals (e.g. certain generation portfolios will increase the value of the portfolio value as a goal). When these considerations are confronted with proposition 2 the results are stated below:
Conclusions for formal characteristics and the second proposition

The reviews of the formal company characteristics leading to Figure 9 through to Figure 13 have proven the usefulness of the second proposition in representing differences in coping strategies seen in the investment practice. Several characteristics of the connections stated in the figures need to be specified more in order to allow for proper use of the theoretical framework. Recommendations are stated in section 7.2. However, the review stated above shows that the second proposition holds for the formal company characteristics (based on reviews based on expert statements).

The use of the theoretical framework for representing technology specific risk and uncertainties and the intra-organizational dynamics poses difficulties. Technology specific risk and uncertainties lead to different coping strategies for investment processes. But they cannot specify a particular power company. This means that the framework is of less use for this differentiator. The intra-organizational dynamics can specify a particular power company but the differentiator is much too ambiguous for use of the theoretical framework.

It is concluded that the framework can be used for the formal company characteristics after the research recommendations have been performed. The intra-organizational dynamics should be specified before the proposition can be reviewed there. The proposition does not hold for technology specific risks and uncertainties.

Technology specific risks and uncertainties

In this research, the most obvious distinction stated by experts was between renewable and conventional power plants. Their differences in technology specific risk and uncertainties lead to several changes in decision making constraints and resulting coping strategies stated by the experts:

- The decision making constraint of uncertainty in the sector is larger for renewable power plants due to technology specific risk and uncertainties. This leads to capital structures with more equity or debt lending for renewables compared to conventional plants. In this way the power company changes its risk exposure (risks are distributed among and between the investors). Another reason is because they try to attract more information processing capacity and information access from external financial partners that supply part of the capital.

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24 This also applies for the setup of agents in chapter 6.
The technology specific risks and uncertainties can lead to less information processing capacity for renewables. The added value of taking distributions of risks into account in the financial forecasting was stated to be smaller compared to conventional plants, so the budgets are also made smaller for this aspect of the investment process. Conventional plants such as natural gas plants are much exposed to (uncertain) connections through power markets (e.g. ‘being in the money’) and feedstock markets. So these receive larger Devex budgets for more elaborate modeling.

The technology specific risks and uncertainties can lead to focus on different risks. For renewables risks in permit approvals, energy sourcing (e.g. wind profiles) and subsidy allocation were stated to be very relevant. For conventional plants, power price and volume risk, carbon exposure risk and fuel cost risk receive more attention. These different risks can also lead to different levels of outsourcing between.

**Intra-organizational dynamics**

In this research intra-organizational dynamics are expected to play a role in the investment processes. Their workings can be a study of considerable size in other scientific disciplines. Research constraints lead to the choice of stating only a limited number of intra-organizational dynamics that were stated by the experts:

- The final decision makers (executive boards) are accountable to owners, such as shareholders or a limited number of municipalities. The executives will take the anticipated results of owners of their actions into account in managerial decisions. One effect can be ‘herding’ in the sector since the position of executives is compromized when the company behaves much worse than the sector as a whole.
- Analysts will often take the anticipated results of executive decision makers into account when making investment process choices.
- Mergers and acquisitions between power companies have occurred in the last decade: its culture, access to information, ability to process information and decision rules can change when a company is acquired or merged. Naturally it will also change formal company characteristics (e.g. size or geographic focus).
- Power play in company politics was a frequently described dynamic by experts. It was stated to happen by owners to executives and also down the formal company hierarchy.
- Social behavior within the company can occur and this can lead to motivated (‘goal’) reasoning. One example can be window dressing by analyst since many people have worked hard on a project.
- Personal motives were frequently stated for many different positions in the company. The workforce and decision makers are frequently well aware of the personal effects of a power plant being built or not. Examples are getting real life experience in implementation, having a job continuity or enjoying prestige linked to large projects.
- Spending the budgets can become a goal when budget cultures appear. One rational stated by the experts is that employees are used to ‘use up’ the budgets to avoid future cutbacks. A connection to a history of state or municipal ownership is stated in particular by experts.
- The use of different financial decision rules (e.g. NPV, IRR) was stated to come from intra-organizational events in the past. Personal preferences and experience in use of the rules by employees can influence this coping strategy.

The effects of intra-organizational dynamics on the investment process can be diverging. This investor differentiator can lead to a multitude of decision making constraints in a multitude of ways. Currently,

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25 This does not mean that other risks such as represented in wind profiles and subsidy risks assessment will not receive more budgets for information access and processing.
information is lacking in the form of a proper organization of intra-organizational dynamics as well as sufficient insights in specific aspects and their relevance. So an unequivocal explanation cannot be supplied in this review. However one trend is stated to indicate polarity. A large degree of any of these dynamics increase the chance that the decision process shifts away from analytical type decision making towards decision making with political aspects.

5.4. Representation of differences in investment process

The results stated in section 5.3 and the analysis stated in Appendix 8 has led to an overview of the connections in the table stated below. It connects differences between the coping strategies to seven investor differentiations. The structure of this table follows the approach stated in section 5.1. (This resulted in Figure 8).

In this overview, the connection for differing investment process strategies can be traced to their introduction (in section 4.3.) and the interview numbers in which they were initially stated by experts. The actual (references to) interviews are stated in the confidential Appendix.

The table indicates which coping strategies are likely to be affected by an investor differentiation. For instance, investor difference of ´company ownership´ is likely to affect risk seeking strategies, sustainability goals, relevance of local employment and capital structure options.

The outcomes are stated below;

<table>
<thead>
<tr>
<th>Proposition 2: investor differentiations - diverging strategies</th>
<th>#</th>
<th>Differences amongst respondents (incl. stated link)</th>
<th>Stated link</th>
<th>Stated link</th>
<th>Stated link</th>
<th>Stated link</th>
<th>Stated link</th>
<th>Stated link</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Satisficing goals (4.3.1)</td>
<td>25</td>
<td>Financial evaluation methods: NPV, IRR, NAVIC,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4, 5, 6, 7, 9, 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Risk seeking when ensuring continuity (回避 vs. monitoring the market)</td>
<td>27</td>
<td></td>
<td>2, 7</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Taking “portfolio value addition” in account or net</td>
<td>29</td>
<td></td>
<td>1, 6, 10</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Sustainability goals</td>
<td>29</td>
<td></td>
<td>4, 7, 10</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Expanding experience with unknown technology</td>
<td>30</td>
<td></td>
<td></td>
<td>stated link</td>
<td>stated link</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Relevance of local employment effects</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Spreading budget (or budget controls) companies</td>
<td>32</td>
<td></td>
<td>1, 6, 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Processing by decomposition</td>
<td>33</td>
<td>Level of outsourcing (e.g. expensive strategy analyses)</td>
<td>0, 7</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Processing by adding (par.4.2.1.)</td>
<td>34</td>
<td>Capital structure options</td>
<td>9, 10</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Processing by adding (par.4.2.2.)</td>
<td>35</td>
<td>Ways of simplifying risks</td>
<td>3, 6, 7, 10</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Focus on particular risks</td>
<td>36</td>
<td></td>
<td>1, 2</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Processing by heuristics</td>
<td>37</td>
<td>No differences stated</td>
<td>4, 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Processing by framing (par.4.3.1.)</td>
<td>38</td>
<td>Changing access to information sources (e.g. Technical or political issues)</td>
<td>2, 4</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Dealing with uncertainty (par.4.3.2.)</td>
<td>39</td>
<td>Scenario analysis</td>
<td>2, 6, 10</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12 Initial connections between differences in coping strategies and the reasons for these differences stated by experts

This table gives initial insights in the factors that lead to differences in coping strategies. For the ABM this
means that (through this new insight), the difference in characteristics can lead to certain differences between their investment processes (modeled in the investment module).

In line with the example of ownership, an ABM modeler can expect differences between a municipalities (or state) owned company vis-à-vis a publicly owned company:

- Risk seeking strategy: ‘more room for a risk seeking strategy’ vis-à-vis ‘the necessity to not to do much worse than other publicly owned power companies’.
- Sustainability goals: ‘the sustainability goals are a key goal on itself’ vis-à-vis ‘an acceptable sustainability level should be reached’.
- Relevance of local employment: ‘local employment is an important goal for the owners and thus management’ vis-à-vis local employment is not a critical goal on itself’.
- Capital structure options: ‘commercial options plus options available only to the public sector’ vis-à-vis ‘options available to the commercial sector’.

This group of links for diverging strategies can be specified for each individual agent in the ABM for all investor differentiations. This leads to a ‘customized’ set of coping strategies for each individual investor.

This customized set can be augmented with the strategies common for all investor (reviewed in sections 4.2. and 5.2.). Together, this set of strategies supplies a more detailed representation of power plant investor decision making with an increased level of validity.

Figure 14 Conceptual representation of power plant investment processes.

This concept still holds several issues that have to be addressed before the concept can be used. The issues in coming to a formalized module in the ABM are discussed separately in chapter six. Several issues regarding the investment concept are stated below:

- Several knowledge gaps still exist:
  - Confidential but crucial figures (such as the investor’s weighted average cost of capital) could not yet be procured from the investment experts.
  - Crucial insights are not yet available from the different fuel and power price forecast models used at power plant investors. However, in interview number [4], it was indicated
that the outcomes can be approximated by the futures prices of power-prices and fuel prices.
  
  o It is uncertain how the investment processes will change due to the current bad market conditions seen in the power sector.

- The method of interviewing has its downsides:
  
  o The interview summaries are in effect summaries of perception measurements. This can lead to a diversity of issues. For instance, it is unclear which effect (potential) perverting motives might have on the validity of the statements. One example of this can be an expert who might opt to conceal certain competitive advantages (in order to protect their own position).

The analysis from chapter five have led to an investment concept and a set of issues. However the final recommendations for coming to an upgraded ABM concept are still missing.

In chapter six, first ABM characteristics will be introduced. This allows for a confrontation of the investment concept with the ABM characteristics. This analysis leads to the final recommendations for coming to an upgraded ABM concept.

**5.5. Conclusions of the outcomes of analyses on empirical results**

The starting points of the analyses in this chapter were two propositions that are based on a literature review in chapter three.

For the first proposition, the review of the empirical coping strategies with bounded rationality characteristics has shown that power plant investment processes have varying degrees of bounded rationality characteristics. The concept is of bounded rationality turned out to be especially useful for representation of goals, decomposition and editing. Here, the fit with the empirical results was high.

The measurements on which the outcomes rely are perception measurements representing one quarter to three quarters of the Dutch power plant owners. These measurements hold translation steps in making (accorded) summaries, formulating the categories and analyzing to an investment concept. It was stated in section 5.2 that formulations and context of the empirical results are relevant for the proposition results. Therefore it is recommended to also review the original formulations (stated in the confidential summary Appendices) during ABM translation efforts.

For the second proposition, the review has shown that several investor differentiations can give initial insights on how the investment process changes. These differentiations are:

- company size
- company ownership
- level of vertical integration
- geographic focus
- current generation portfolio
- technology specific risks and uncertainties
- intra organizational dynamics

Specific connections to coping strategies are stated in table 10. In further research it would be interesting to add more information to these connections. As of yet it is apparent that they exist, however questions remain regarding issues such as their (level of):
- general applicability (do they apply to all power companies)
- completeness (are these all the relevant links)
- specific characteristics of the connections (do they interact in a simple way or is there more to it)
- interaction effects (i.e. if certain combinations of investor differentiators produce different results than their unique outcomes combined)
- ambiguity (this is especially relevant to the consolidated notion of ‘intra organizational dynamics’)
- potential issues when using them in ABM modeling.

These issues are recommendations for future research. However the potential issues for ABM modeling will be reviewed in the following chapter.
6. Improvements to the Agent-based model

Chapter five has led to a new power plant investment concept. The ABM could benefit from the added value that this concept offers. However this requires selection and translation of parts of the investment concept for use in the ABM. This is performed in this chapter.

Several relevant issues in translating the investment process concept are reviewed to this end (stated in section 5.4 and 5.5). This review was performed without consideration to existing investment modules in the ABM. The main outcomes are concrete implementation recommendations for ABM researchers. These outcomes are augmented with conclusions and reflections.

To these ends, first an overview of relevant literature is stated in section 6.1. This indicates the context of the current ABM research. Secondly, a concise description of key characteristics of Agent-based modeling is stated in section 6.2. Thirdly, the investment concept stated in chapter 5 is confronted with the key characteristics that resulted from section 6.2. This confrontation is performed in section 0. Section 0 results in modeling recommendations for ABM researchers. Lastly, conclusions and reflections are drawn in section 6.3.

6.1. Agent-based model literature

Several literature sources were used in order to come to a review of key notions in ABM’s. These sources are mostly directed on the replication of ‘complex socio technical systems’ by ABM’s. This perspective of ‘complex socio technical systems’ was introduced in section 1.1. Key social and technical elements used in the power system are stated in chapter 2.

More information on modelling ABM’s in order to represent socio technical systems is stated in Van Dam’s PhD thesis ‘Capturing socio-technical systems with agent-based modelling’ (K.H. Van Dam, 2009). A high aggregation level review of modelling techniques for simulating complex supply chain systems is stated in (Behdani, 2012).

An specific, elaborate overview of a wider but related range of power sector simulation methods can be found in Chappin’s PhD thesis ‘simulating energy transitions’ (Chappin, 2011; p.57). Alternative methods (such as computational general equilibrium models or system dynamics models) are introduced by Chappin. These can serve as a basis for understanding the unique added value of ABM’s vis-à-vis other simulation methods. A frequently cited work by Bonabeau (2002) discusses the basic principles and main applications of agent-based models.

This research will focus solely on Agent-based modeling given the research objective. A summary of ABM’s which are focused on modelling power markets is stated in Chappin’s PhD thesis (Chappin, 2011; p.58). An elaborate overview of ABM research in the (broader) energy domain is stated in (K.H. Van Dam, 2009; p.169).

26 If the existing investment module of the ABM would be taken into consideration, this could to lead to several issues. Firstly basing considerations on the current structure could lead to a sub optimal investment module (e.g. relevant elements are left out of consideration because they cannot to the current ABM structure). Secondly, the consideration requires in-depth knowledge of the ABM that is only available at the ABM modelers.
A key source of information used in this research is the book ‘Agent-based modelling of socio-technical systems’ by Van Dam, Nikolic and Lukszo (2012). This book gives an introduction in modelling ABM’s with similar characteristics as the system reviewed in this research. The second chapter of this book in particular is of key importance for the ABM recommendations. It states the basic Agent-based modeling steps. Another frequently cited source for ABM modelling is Gilbert’s book ‘agent-based models’ (Gilbert, 2008).

Next to these generic ABM modelling literature sources there are several literature sources of the ABM in this research. These are built to represent (specific aspects of) power sectors. De Vries and Chappin (2011) propose the ABM for replicating emergent power market behavior due to policy interventions. One example of a policy intervention is installing price floors for carbon markets connected to the power sector. The effects of such policy interventions on power market behavior are reviewed in the ABM in (Richstein et al., 2012). This research is used as a basis to come to recommendations for ABM investment module upgrades in section 6.3.

The ABM allows the research stated above to take intertemporal effects into effect. These effects are normally lost in other simulations such as equilibrium based models. Therefore this is one of the key advantages of using the ABM vis-à-vis other simulation methods. The intertemporal effects are deemed relevant due to the power sector characteristic of ‘path dependency’ (Laurens J De Vries & Chappin, 2011; p.1). Path dependency was already introduced in section 2.1.

Advantages like the ability to deal with intertemporal effect make the ABM a promising tool to simulate power sector behavior. However, to grasp key characteristics of this ABM it is necessary to understand the basics of Agent-based modeling first. These are introduced in the following section.

6.2. Agent-based modeling fundamentals

Agents have several characteristics that are of key importance for explaining the concept of ABM’s (K H Van Dam et al., 2012; p.58). These are introduced first. Next, the notions of ‘states’, ‘actions’, ‘rules’ and ‘environment’ are introduced. Examples for these notions based on the power sector are also stated. Next these notions are combined in a visual representation of Agent-based modeling by Van Dam et al (2012). This Agent-based modeling structure is then used to explain how implementation of investment concept improvements can lead to ABM validity and fidelity improvements. Next, the focus this research with regard to the Agent-based modeling cycle is indicated. The delineations allow for coming to a method of selection of investment concept coping strategies. The selection is based on problem formulations of the ABM. These are reviewed next. The review is completed with a selection of implementation requirements for Agent-based modeling. The main outcomes are stated in this section’s conclusions.

Agent characteristics

Agents are essential in any ABM. To introduce the basic structure of Agent-based modeling, its key notions need to be specified more. This will be used as a basis for notions in consecutive sub sections. Agents and actors were already introduced in section 1.1. And clearly, differences exist between the two.

It was stated that actors in general can be seen as real-life “entities” that influence some part of the real world through the decisions they make (K.H. Van Dam, 2009; p.4). The representation of actors in an ABM calls for some level of abstraction. Actors need to be translated toward the formalized concept of agents in some way.
Agents are essentially pieces of software code that are written to represent only certain parts of the actor’s behavior in real life to some degree (K.H. Van Dam, 2009; p.4). The agent is the smallest whole unit to which the complex socio technical system is decomposed in at ABM’s.

Van Dam et al (2012) have summarized agent characteristics based on an article by Jennings (2000). Exact phrases used by Van Dam et al are quoted in the list stated below (K H Van Dam et al., 2012; p.58). Agents in the ABM have the following characteristics:

- **“Encapsulated”:**
  The power plant investors can be clearly distinguished from other parts of the power sector\(^{27}\) (such as transmission or regulators). The same goes for their interactions with surroundings (such as a selling power on a power exchange).

- **“Situated in a particular environment”:**
  The investors receive information from their environment through various ways such as political connections (“sensors”) and have ways of acting on this information (“effectors”). Examples of acting could be lobbying by power companies for changes to policy interventions in areas such as carbon taxes.

- **“Capable of flexible action”:**
  For instance, the power plant owners could “proactively” adjust their investment strategy in anticipation of policy interventions. Or they can react to changes in regulations (by changing the detailed technical design and the financial forecast during the FED-phase).

- **“Autonomous”:**
  Investors control their own behavior and also their own “internal state” (this internal state will be stated below). E.g. a power company can choose to invest in a power plant, thus expanding their production portfolio (but also diminishing their cash position).

- **“Designed to meet objectives”:**
  These can be simplified variants of the investor’s goals stated in chapter four (such as meeting a financial hurdle rate) given the ABM researcher.

The condition of agents with these characteristics can be expressed in ‘states’ in Agent-based modeling.

**States**

The state is a crucial notion in ABM’s. According to Van Dam et al (2012), in the (ideal typical world of an) ABM the agent is wholly defined by this state. To understand the ABM modelling paradigm states need to be elaborated on in more detail. The agent’s state can be “internal”, “local” or “global” in their orientation (K H Van Dam et al., 2012; p.58). These orientations can be cumbersome to grasp at first glance. Therefore examples are given for every state:

- **“Internal states”:** parameters which are unique for this agent (these parameters in turn can be “private, public or a mixture”) (K H Van Dam et al., 2012; p.58). Examples of these are:
  - Private state: e.g. a power companies ‘weighted average cost of capital’ (explained in section 3.2). Such information holds highly sensitive information that a power company will not share with competitors.
  - Public state: e.g. the current set of power plants operated by this unique power company will be known to all competitors in the power sector.

\(^{27}\) This characteristic is a crucial link to the broader ‘systems approach’ frequently used at TPM. Ryan (2008) explains this systems approach. He cites W. Ross Ashby who states that a system can be seen as “a set of variables sufficiently isolated to stay discussable while we discuss it” (Ryan, 2008; p.27).
Mixture of states: in theory, an example would be one power company’s building plans for a new power plant. These can be unknown to most other companies in the sector. But if the power company shares resources with partners these will be informed of the building plans.

- “Local states”: all the information of the internal state augmented with all information of other interacting actors that can be observed by this agent (K H Van Dam et al., 2012; p.58). An example could be the total production portfolio of all power companies in one power market. All power companies can observe which power plants are present in the power sector.
- “Global states”: all the information of the local state augmented with all information in the ABM ‘environment’ of the agent. The ‘environment’ will be defined later on in this section. Van Dam et al state a focus on the ability of the environment to observe and/or influence agents states (K H Van Dam et al., 2012; p.59). A example for this research could be the following (hypothetical) situation:
  ‘The unexpected addition of many coal fired power plants in the Netherlands lead to a higher national carbon footprint of the power sector. Local action groups respond with a campaign to show the downsides of coal fired plants\(^{28}\). An unexpected change in public attitude follows. The national government responds by issuing a carbon tax. This was not expected by the power companies. This external incentive changes the power plant investment behavior of the power company.’

So these states represent parameters relevant for the agents. And they are organized to the orientation of the way their information is shared in the power sector. States can change due to ‘actions’ performed by the agents.

Actions

Actions are derived from “mechanical decision rules or transformation rules” in the ABM (K H Van Dam et al., 2012; p.59). These ‘rules’ can be static or dynamic and can be dependent on any of the three main states described above. So these actions can be based on information derived from any of the three states. Here the value of the states becomes clear. One example will clarify this; A power company will not share all parts of their investment strategy with competitors. So the other agents in the ABM do not have access to that information and cannot use the information in their rules.

Van Dam et al state frequently used ABM rule types (K H Van Dam et al., 2012; p.59):

- “multi criteria decision making”\(^{29}\): e.g. to choose which power plant to invest in, the agent makes a trade-off based on the expected financial value additions, carbon footprints and required capital investments for several power plants. The highest scoring power plant will be built.
- “Inference engines”: e.g. agents base the power plant investment decision on available factsheets and ‘lessons learnt’ in previous power plant projects.
- “Evolutionary computing’ and ‘machine learning” are explained in more detail by Van Dam et al (2012) but hold less relevance here given the current phase of the ABM research.

So rules depend on the access to information (described by the states). And they can be programmed in different ways in the ABM. These rules have to process information (in order to come to a decision). The previous example and the power sector uncertainties stated in section 2.3 show that this information will

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\(^{28}\) The coal plants are assumed to be coal plants without carbon capture and storage in this example.

\(^{29}\) This method is explained in section 1.1
be incomplete in real life. A number of the power sector uncertainties are frequently seen in the
‘environment’ of the agents.

**Environment**

In ABM’s, the environment is the place where the interactions between agents and external parameters can be structured in a diversity of ways (K H Van Dam et al., 2012; p.61-64). The parameters are external because they are not owned by any of the agents.

One example is a change in power companies’ environment due to rising power prices and falling coal prices. These depend to a large degree on factors that the agents do not control or own. Under certain circumstances, these two environmental circumstances could improve the NPV of a coal fired power plant option. The company earns more money on the power produced and pays less for the fuel. Given the frequently stated goal of creating value by the power companies, the NPV rule could lead to a action in the ABM (i.e. building the coal fired plant in this example). So the environment can affect the actions of agents in the ABM.

This action of building a coal fired plant would change the internal state of the agent. Actions can be directed at creating change in any of the agent’s possible states (K H Van Dam et al., 2012). So for this example these actions can change an agent’s:

- **internal state:** e.g. a power company’s ‘weighted average cost of capital’ changes due to changes in their cash position, which in turn affects alternative financing options.
- **local state:** e.g. a power market’s entire collection of power plants will change. The new coal fired plant competes on the power market. This changes competitive interaction with competitors.
- **global state:** e.g. a coal tax can be imposed by policy makers, after they observe that the carbon footprint of the current production portfolio is not diminishing.

**Modeling structure of Agent-based models**

The basic structure of ABM’s is derived from the notions stated above. This structure was visualized by Van Dam et al (2012). Their visualization is stated below. Here the notions of states, rules, actions and the environment are combined in ABM modeling structure. The interactions between agents and also the environment become clear here.
Van Dam et al (2012) regard all the combined actions and state changes of one agent to be its 'behavior' (Van Dam et al., 2012; p.60). This definition of behavior links the ABM translation of the investment concept to the research question stated in section 1.3. This link is explained in the next sub section.

**Improvements in validity and fidelity**

An improved investment module can lead to several improvements in the representation of investor behavior in the ABM. The representation can improve in two different ways:

Firstly the use of more realistic information in the ABM’s investment module could improve the *validity* of the ABM. The line of reasoning is indicated the figure stated below. It shows how improvements can ‘travel’ through the ABM based on the Agent-based modeling structure stated above.

The figure indicates how improvements based on the investment concept in chapter 5 could make the ‘rules’ (and resulting ‘actions’ of the agents) in the ABM more realistic. In turn, these realistic actions in the ABM also lead to more realistic changes of states. Figure 16 already showed that these states and actions interact. The resulting changes of this interaction imply that the representation of investment behavior of agents can become more realistic (for investments in power plants). In this line of reasoning more realistic behavior in the investment module can improve the *validity* of the ABM.

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**Figure 15** "Structure of an Agent-based model" stated in (K H Van Dam et al., 2012; p.57)

**Figure 16** How improvements of the investment concept can lead to improved validity of the ABM.
Secondly, the investment module can also lead to more detailed information in the ABM investment module. This would allow the ABM to represent a larger part of the power sector it represents. A similar line of reasoning (as used for validity) is stated below. This could lead to a higher level of model fidelity for the ABM. This is shown in the figure stated below.

![Diagram showing the relationship between improved investment concept and improved fidelity of the ABM.](image)

Figure 17 How improvements of the investment concept can lead to improved fidelity of the ABM.

An example is given of how incorporated details of the investment concept can lead to fidelity improvement of the ABM based on the figure stated above: In sub section 0 it became clear that the ‘power plant investment decision’ is actually split up in several ‘gate review’ decision moments in real life. Currently the investment module does not represent this part of the dynamics of the power sector. But nevertheless, the current choice is a valid representation if the focus of the ABM is more limited. Empirical outcomes in section 0 show that power companies have this final investment decision (FID) at the end of the FED-phase.

However adding multiple decisions points (in time) to the ABM would add the dynamics of the actual investment process to the representation. With this investment module expansion the ABM would replicate a larger part of the power sector it represents. So investment module expansions like this would improve modeling fidelity.

Both outcomes indicate options to improve the ABM’s representation of reality. This representation would be more realistic and a larger part of the power sector would be represented by the ABM. The outlook of these improvements begs the question of which improvements are most relevant for the ABM investment module.

**Focus in modeling cycle**

To indicate which improvements are most relevant for the ABM investment module more delineation is required first. This is due to the consideration that integral revision of the existing ABM module is a comprehensive task. It does not lie in the scope of this research to revise the entire model through to the actual model use. However initial steps of the ABM modeling cycle should be reviewed to come to recommendations in this chapter.

Van Dam et al (2012; p.74) state the following basic modelling steps for constructing an ABM. Firstly a “problem formulation” specifies the problem to be studied. Secondly, a “system identification and decomposition” is performed in order to come to a description of the system under review. Thirdly “concept formalization” is performed to come to a specified system description. This is due to necessity of coming to a concept without “ambiguity and context dependence” for the ABM (K H Van Dam et al., 2012; p.83). It is convenient to address these kinds of issues before starting with coding. Fourthly, the formalized concept is transformed into code. This is the limit of the scope of this research. The following steps five to ten are stated below in the figure and are elaborated on in (K H Van Dam et al., 2012).
This research focuses on the initial problem formulations stated by the ABM researchers. The ‘problem formulation’ step is crucial for the analysis and determines the main outcomes in section 1.1.

Selecting coping strategies based on problem formulation

The problem formulation allows for effective selection of relevant coping strategies from the investment concept for use in an investment module upgrade. The coping strategies are most ‘relevant’ when they contribute to solving the problem that the ABM researchers actually want to solve in their research.

This allows for a ‘quick scan’ of the investment concept stated in chapter 5. This investment concept is too comprehensive for complete implementation in the ABM investment module. Not all of the coping strategies in the investment concept will have great value for solving the problems that the ABM researchers actually want to address. This means that the recommendations in section 6.3 can be more focused.

However it should be stated here that this also means that the recommendations for the ABM investment model are dependent on the problem formulation of the research. So the ABM recommendations can be different for other ABM research. Appropriate steps should be taken for research with other problem formulations. These are stated in the reflection in section 6.3.

A short review of the problem formulation is needed to perform the selection. This is performed in the following sub section.

Problem formulation of the ABM

For the problem formulation of the ABM this research bases the formulation on two sources.

Firstly the main source of information are the publications at TPM (Laurens J De Vries & Chappin, 2011; Richstein et al., 2012). Secondly a meeting with the first author of this research took place (ir. J.C.Richstein, on 24 April 2013). During this meeting the original formulation was augmented with future directions for likely problem formulations.

For clarity it is essential to differentiate between uses of research notions of this research and the ABM research. Otherwise it would be confusing to have separate research notions of this thesis versus those used in the ABM research. Therefore, research notions used by the ABM researchers receive the addition ‘of the ABM research’. Research notions originating from this thesis do not have these additions.

A specific problem formulation of the ABM research is introduced in (Richstein et al., 2012; p.1):
“The recent low of CO2 prices in the European Union Emission Trading Scheme have triggered a renewed discussion, whether the introduction of a CO2 price floor would lower investor uncertainty and thus trigger more investment in low-carbon electricity generation”.

This paper focuses on one type of policy interventions (CO2 price floors). For this research the choice is made to base the relevance on a wider array of policy interventions: carbon based policies (e.g. Carbon taxing, price floors) as well as renewable energy policy (e.g. feed-in tariffs). This is based on the meeting outcomes and the second paper at (Laurens J De Vries & Chappin, 2011; p.1).

The behaviors that the ABM researcher want to replicate are also summarized (focused on Western Europe):

- “investment in low-carbon electricity generation” (Richstein et al., 2012; p.1)
- “understanding complex market behavior” of “isolated” as well as “interconnected” power markets (Laurens J De Vries & Chappin, 2011; p.1)

Understanding the effects of the policy interventions on this behavior is used as a summary of the problem formulations in the analysis.

Implementation issues

The problem formulations of the ABM research stated above allows for selection of coping strategies based on relevance. The selection results in a concise set of coping strategies in section 4.2. The selection is a crucial step in coming to recommendations for ABM researchers.

However implementing these selected coping strategies might still pose problems for the ABM researchers. The researchers need to be able to translate this selection to ABM code in the consecutive modeling steps. This poses the question of which requirements Agent-based modeling holds for implementing coping strategies in the ABM. This question needs to be answered in order to complete the recommendations for the ABM research. This will allow for statements of expected modeling issues when translating of the investment concept selection into actual code in the ABM.

The requirements are found be reviewing the ABM modeling steps 2-4. The actual review is stated in Appendix 9. This review resulted in two main Agent-based modeling requirements stated in (K H Van Dam et al., 2012; p.77-83):

- “ambiguity” (notions should have one meaning in the ABM)
- “context dependence” (meaning of notions do not change in a different surrounding)

This is a goal-oriented selection of all requirements stated in Van Dam et al (2012). Notions such ‘environmental information availability’ and ‘being code able’ are not taken into account here (stated in Appendix 9. This means that this set of requirements cannot be used in other research. It is only used to indicate initial issues in translating certain coping strategies in the ABM investment module. Additionally, the requirements are derived solely from modeling steps two and three. Requirements of consecutive modeling steps should be investigated in follow-up research.

The two ABM requirements stated above will be addressed at the selected coping strategies when applicable. This will allow (only) for initial discussion on the translations towards the ABM.
Conclusions of this review

The review of Agent-based modeling fundamentals lead to several conclusions for the approach in section 6.3.

Firstly Agent-based modeling of the power sector can be visualized by the modeling structure stated in Figure 15. Key notions in this structure are states, rules, actions and the environment. Secondly the review showed how model validity and fidelity improvements of the ABM can result from the new investment concept (Figure 16 and Figure 17). Thirdly it was shown which ABM problem formulations can be used for selection of the most relevant coping strategies. Lastly, three ABM requirements were stated in order to review initial implementation issues of the investment concept selection. These requirements are (only) an initial basis for review.

These conclusions lead to the selection and review of coping strategies in the following section.

6.3. Results for the ABM

Among others, the previous sections lead to problem formulations and the analysis method stated above. In this section two steps are undertaken to come to ABM recommendations.

Firstly, the problem formulations of the ABM research are used to make a selection of relevant coping strategies. These coping strategies are derived from sections 4.2 and 4.3. Secondly the selected coping strategies will be reviewed in more detail on their added value as well as their potential issues.

Selection of coping strategies

The selection of the coping strategies is stated below. The original coping strategies from sections 4.2 and 4.3 are used in these tables. These coping strategies are valued according to the perceived added value to the ABM research at TPM. Implementation issues or connection options to the existing ABM are not taken into account here yet. However these will be discussed later on in this section for selected strategies when necessary.

In order to keep the selection transparent, separate explanations are added for high scoring coping strategies. A limited number of ‘kick-out’ criteria are also used for indicating the reason why other coping strategies hold less value to the ABM problem formulation. These are the following criteria:

1. No high added value addition expected in due to small effects on both ’representing low carbon generation investment behavior’ as well as ’explaining complex power market behavior as a whole’.
2. No high impact changes expected in these coping strategies due to policy interventions.

Explanations are given when deemed necessary. These considerations lead to the following selection for the common coping strategies:

<table>
<thead>
<tr>
<th>#</th>
<th>Common amongst respondents</th>
<th>Added Value</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>meet sufficient level of trust in business case</td>
<td>High</td>
<td>Crucial goal stated by experts, deviation of analytical perspective</td>
</tr>
</tbody>
</table>

30 The reasons were already stated in (the footnote of) the introduction of this chapter.
31 These were stated in section 6.2
<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>meeting hurdle rate</td>
<td>High</td>
<td>Adds satisficing aspect vs. Preceding optimizing goals</td>
</tr>
<tr>
<td>3</td>
<td>acceptable residual risk outcomes</td>
<td>disputed</td>
<td>[1], this added value is smaller only because integral risk considerations are already taken into account in coping strategy #2. And residual risk is already a key issue in coping strategy #1. The added value of the separate argument is present but loses much of its impact for the problem formulation.</td>
</tr>
<tr>
<td>4</td>
<td>minimize avoidable opportunity costs</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>5</td>
<td>maintain healthy cash position</td>
<td>High</td>
<td>Adds to investment uncertainty issues vs. the current financial crisis</td>
</tr>
<tr>
<td>6</td>
<td>meet strategic goals of executive board to sufficient extent</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>7</td>
<td>meeting sustainability criteria</td>
<td>High</td>
<td>Policy intervention focus</td>
</tr>
<tr>
<td>8</td>
<td>divide processing between departments</td>
<td>Low</td>
<td>[1]</td>
</tr>
<tr>
<td>9</td>
<td>stage-gated decision processes</td>
<td>High</td>
<td>Adds timeline of decision process</td>
</tr>
<tr>
<td>10</td>
<td>decision leading to proposition distributed to different hierarchical layers</td>
<td>Low</td>
<td>[1], [2]</td>
</tr>
<tr>
<td>11</td>
<td>outsourcing to engineering firms, law firms, consultants et cetera</td>
<td>Low</td>
<td>[1], [2]</td>
</tr>
<tr>
<td>12</td>
<td>simplify all uncertainty to limited number of uncertainty axis in scenario analyses</td>
<td>High</td>
<td>Impact of uncertainty, ABM focus on long term behavior</td>
</tr>
<tr>
<td>13</td>
<td>diversity of local goals is simplified to strategic goals set by executive board for processing</td>
<td>Low</td>
<td>[1], [2]</td>
</tr>
<tr>
<td>14</td>
<td>simplify real-life risks to (treatment and analysis) of perceived high-impact risks</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>15</td>
<td>simplify risks to (outcomes of analysis to) functions of cost and income</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>16</td>
<td>simplify systemic risks with CAPM to outcomes in functions of cost and income</td>
<td>Low</td>
<td>[2], and also taken into account in coping strategy #2</td>
</tr>
<tr>
<td>17</td>
<td>simplify technical design to portfolio requirement and limit to local options</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>18</td>
<td>increase level of detail in analysis throughout stage-gates.</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>19</td>
<td>reduce knowledge uncertainties</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>20</td>
<td>seeking technical and social validity of assumptions</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>21</td>
<td>couple search cost budget (in Devex) to value creation</td>
<td>High</td>
<td>Could influence low carbon generator options</td>
</tr>
<tr>
<td>22</td>
<td>gather sufficient strategic information to come to a DCF valuation</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>23</td>
<td>take all relevant dimensions of problem into account in valuation (legal, technical et cetera)</td>
<td>Low</td>
<td>[2]</td>
</tr>
<tr>
<td>24</td>
<td>follow investment guide guidelines to gather and process information</td>
<td>Low</td>
<td>[1], [2]</td>
</tr>
</tbody>
</table>
select limited number of uncertainties as a basis for likely future paths (scenario analysis). Ignore others or use them only in qualitative form during gate reviews. Reduce knowledge uncertainty by outsourcing to specialists and also perform extensive sensitivity analysis.

Table 13 Added value of common coping strategy addition for the ABM research; kick-out criteria [1] and [2] are stated above.

The results in the table do not mean that the coping strategies have no added value whatsoever. The highly relevant common coping strategies will be reviewed in the following sub section.

Secondly the selection for the *diverging* coping strategies is stated below. These will have to be customized for different agents in the ABM where applicable;

Table 14 Added value of diverging coping strategies to the ABM research; kick-out criteria [1] and [2] are stated above.

Only the highly relevant coping strategies in the tables stated above are selected. Three aspects of these strategies are reviewed:
Their added value to the ABM research (based on the ABM problem formulations stated in section 6.2).

Potential issues (when implementing in the ABM investment module).

Modeling recommendations (where possible).

They are reviewed in the following sub section in this fashion.

Review of relevant coping strategies

Meet sufficient level of trust in business case (coping strategy 1)
It was already stated in section 4.2 that this is a frequently stated, important notion at the power plant investors. It is a very loosely defined investment consideration. But it tends to include some combination of attractive financial forecasts and trustworthy, favorable risk assessments.

Implementing this strategy in an ABM would add aspects of financial outcomes and risk assessments but also informal judgment to behavior simulations. It was also indicated in section 3.4 and 5.2 that this is more realistic option compared to a purely analytical perspective on the investment decision (e.g. an isolated NPV-rule).

However considerable implementation issues can be expected when translating this coping strategy to any ABM. This coping strategy is highly ambiguous and is context dependent. To give one example of potential issues in this regard; ‘trust’ can imply informal judgment at the boardroom table to one investor or ‘P95-confidence intervals’ to another investor. This strategy is too ambiguous for translations by any ABM researcher at present. It is concluded that the coping strategy is not suited for ABM implementation in its present form. However given its heavy influence stated by investors, further investigation of this coping strategy is recommended for future research.

Meeting the hurdle rate (coping strategy 2)
Implementing this coping strategy would add very relevant aspects of investment processes to the ABM:

- Hurdle rates are based on the DCF method. In section 3.2 it was stated that this method is the principal financial decision method at power companies (though several rules are used such as NPV, IRR, or RAROC). The method is elaborated in section 3.2. One example is given here: use of this type of method would explain a focus of agents on short term results above long term results (long term results simply have less financial influence due to discount rates32).

- This goal has a satisficing element (i.e. sensitive to reaching the absolute value which is set by executives). This type of decision rule is more plausible than ‘picking the best option’ (e.g. the highest NPV). This statement is based on the decision process limitations stated in section 3.4. The hurdle rate also explains that investment projects compete with other options for funding. This allows for inclusion of financial markets, power company credit ratings and scarce resources within the company to explain power sector behavior.

- The required DCF method requires predictions of future cash flows. These in turn require assessments of the key aspects of risks and uncertainties in the power sector (stated in section 2.3.

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32 The use of discount rates is stated in section Error! Reference source not found.. Its use inherently implies that long term performance of a power plant will always be less important compared to the first years of the power plant’s lifecycle. The decline of the financial effects of costs and benefits on the present value is exponential in time.
\[\begin{itemize}
\item The DCF method allows for inclusion of the time value of capital and risks in the consideration. Both could be crucial in reviewing how power markets react in time on policy interventions (dynamic behavior).
\end{itemize}\]

This coping strategy is well defined in financial literature and holds few ambiguities in its (formal) definition. It should be the principal rule that decides the agent’s actions of investing in power plants. This is based on its widespread use and its considerable usefulness in predicting reactions on policy interventions on the power markets. It should be noted that the DCF model is dependent on subjective assessments (with regard to validity).

**Maintain healthy cash position (coping strategy 5)**
Implementing this coping strategy would add crucial behavioral aspects of agents to the ABM:

\[\begin{itemize}
\item The strategy prevents investments when the agent does not have adequate financial room for investment (after including debt and equity financing options). Without this coping strategy, bankrupt agents in the ABM could still invest (if their hurdle rate was met). This option would decrease model validity greatly.
\item The empirical outcomes showed that agents need to watch their cash positions because their credit ratings could be decreased by rating agencies. These decreases can cause all kinds of effects that influence the agent’s states. Examples are as higher capital costs or difficulties or more expensive equipment suppliers. These resulting state changes can decrease the valuation of power plant projects, leading to changes in investment behavior. Another chain of events could also occur: the investor might choose not to invest in order to keep credit rating (buffers) high.
\end{itemize}\]

Given these added values it is very important to implement this coping strategy in the ABM. Cash position is well defined in financial theory. The ambiguous notion of what is ‘healthy’ can be addressed by referring to credit rating categories. The agent rule should at least force hard constraints for the investment decision (i.e. no financing options means no investment regardless of the forecast). In time this rule could be expanded with other aspects such as credit rating effects considerations stated above.

**Meeting sustainability criteria (coping strategy 7)**
Implementing this coping criteria is essential for the ABM research:

The ABM problem formulations are focused on assessing effects of carbon or renewable policy interventions. Without implementing this coping strategy in some form, agents would have no direct connection to policy interventions that are issued by the researchers in the ABM. This coping strategy can be seen as an environmental given in the eyes of ABM modelers (e.g. as a hard constraint and not a rule). But with this choice, potential behavioral elements are lost. One of the ABM modelers stated two (hypothetical) examples of this. One example is risking fines when the payoffs of ‘not playing by the rules’ are considerable. Another is the agent’s motive to fulfill more informal policy goals of governments in fear of other interventions these might apply if they do not comply. This type of ‘wheeling and dealing’ could not be represented when seeing this coping strategy as part of the environment.

This coping strategy holds little ambiguity or context dependence in its initial form. The formal rules are usually the same for all agents and they are clearly specified by policy makers. However the informal rules used in the example might be a very different story! This might be an interesting issue for future research.

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33 Of course, policy interventions that influence states such as the market price would influence the outcomes of the investment module. But this is an indirect effect.

34 However the informal rules used in the example might be a very different story! This might be an interesting issue for future research.
ABM can be shaped *initially* in the form of a hard constraint in the agent’s rules in the investment module. Regardless of outcomes of other rules that the agents have, agents must be in compliance with the minimal environmental and market regulations in this initial concept. In time additions to this basic rule might include the payoffs of cheating by agents or some kind of form to represent informal ‘wheeling and dealing’ between power companies and policy makers. Sensitivity analysis would be an interesting exercise when these kinds of rule variations would be feasible for the ABM modelers.

**Stage-gated decision processes (coping strategy 9)**

This coping strategies can contribute to the ABM research by adding the dynamics of the investment process itself. Decisions made at one point in time are changed into a recurring decision process. Unique added value for the ABM would be:

- Realistic representation of the effects of the investment process itself on the power sector behavior. Section 4.2 shows that investment processes can take up to ten years. Shorter time spans are possible but these kinds of time spans will delay any investment decision of any agent.
- The option for ABM researchers of reviewing value growth of power plant options in time during the investment process. This can be particularly interesting for evaluating power plant options with a costly investment process or that have a long lead time.
- The option to add other coping strategies later on (given that some are inherently linked to the concept of stages in the investment processes).
- The influence that the agent’s investment process already has on the other agents connected to its local state *during the investment process*. For instance, when one power company buys land for a power plant (years before its final investment decision). This action will limit site options for other power companies. But more importantly, it will also signal building plans to all other agents that can access that information. This might change their investment behavior due to the competitive interaction aspects they use in their power price forecasting. The states of other agents can affect this agent in similar ways.

This means implementing this coping strategy can expand the research options for ABM researchers greatly when compared to decisions made at one point in time. The stages (stated in section 6.2) can be used to run the recurring set of rules of agents to replicate ‘gate-reviews’. These are linked to the states of the agent at that time. Options for changes in the recurring rules are:

- *Rules change per gate*: for instance the financial forecast outcome bandwidths used in ‘meeting hurdle rate’ should decrease in time. This can be set as a constraint in order to move the option to consecutive stages.
- Changing *emphasis* of rules per gate: e.g. the initial gates can have a larger emphasis on ‘maintaining a healthy cash position’ of initial assessments in ‘meeting sustainability criteria’ while later gates have more emphasis on ‘meeting hurdle rates’, ‘sufficient trust in the business case’ and very detailed assessments of ‘meeting sustainability criteria’. It should be stated here that

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35 This notion is explained in section 2.2.
36 Experts stated in section 4.2 that without more precise estimates (in time) the investment options will not pass to consecutive stages. So if they cannot improve insight in uncertainties for the project along the way, it will not proceed and will never be able to reach the final investment decision. This might even stop very lucrative power plant options due to the gate review requirements!
37 This sounds plausible given the requirement of decreasing bandwidths of financial forecast outcomes per gate. That would make a hurdle rate rule much more interesting in later stages (they become more precise and plausible). Also the experts frequently stated use of investment ‘kick-out criteria’ in section 4.2. One candidate for such a kick-out criterion is the realistic potential to fulfill local regulations in the first place (linked to the assessment of ‘meeting
none of the rules should be taken out for certain gates (one option is to change their weights in time when a MCDA\textsuperscript{38} is used in the ABM).

**Simplify all uncertainty to limited number of uncertainty axis in scenario analyses (coping strategy\textsuperscript{12})**

This coping strategy enables the representation of how agents deal with uncertainty in the power sector. The added value would be that the addition of the coping strategy allows the ABM to:

- Take managerial uncertainty considerations in account in the ABM. This addition adds to the effects that uncertainty already has on internal states. These latter types of effects are already represented through implementing the ‘hurdle rate’ coping strategy. An example of such an effect of uncertainty is a change in the WACC which could change the outcome of a DCF based rule.
- Show the effects on the power sector of the fact that agents base their rules only on selected uncertainties while rejecting all other uncertainty information (in the states) of the power sector.

Ideally, all agents would base all their rules only on the states that resemble the simplified information that originates from scenario analyses. This would be a key starting point for all investment considerations of agents. Other information in the environment is not used in the rules of agents. This represents a strong limitation to information access comparable to the real power sector.

The selection of the uncertainty axis and other substantial issues in scenario analysis can be disputed. And not all of these outcomes will be readily supplied by power companies due to their strategic interests. A starting point from the empirical review is the main perceived uncertainties stated in section 4.2.

Implementing this type of simplification to the internal state of every agent could offer many insights to the ABM research. Information access can be disputed. However it would be feasible to perform sensitivity analysis in the ABM based on several options in dealing with uncertainty (e.g. varying choices of uncertainty axis through changing states).

\textsuperscript{38} Defined in chapter 1
Couple search cost budget (in Devex) to value creation (coping strategy 21)

This coping strategies can contribute to the ABM research by adding several aspects seen in the power sector:

- It enables the research to take the value of options to continue with a power plant project into account (per decision gate)\(^{39}\). This enhances the representation of the ABM compared to representing only the final investment rule of agents. E.g. if perceived value creation of the project is ‘lagging’ in time compared to the Devex costs the project needs, it can occur that even excellent power plant options might never reach the final investment rule. They would need too much investment in Devex budgets long before they actually become valuable enough.
- It enables more realistic variation in information access for agents. E.g. agents can have larger Devex budgets for projects that have higher value during that gate.

Implementing this strategy could be initiated by adding a rule that ‘rations’ access of agents to all three states per decision gate. Devex cost but also information access grows to an exponential degree during FED stages. The increases in Devex budgets are stated in the interviews and section 4.2 in more detail. In the interviews, experts already stated that (among others) Devex costs for the FED are very dependent on generation technology\(^{40}\). Outcomes in chapter 4 indicated that the value creation is particularly dependent on acquiring the land-lease agreement, the granting of building (and associated) permissions and lastly the allocation of subsidies (for renewables). These can be used to create an information access rule. For instance, information ‘access rationing’ per gate is based on the ratio of (total Devex costs up until this gate/ the entire Devex budget for this FED).

"Portfolio value addition" differences (coping strategy 28)

This coping strategy implementation can contribute to the ABM research by adding novel behavioral aspects:

- The investment algorithm would take the agent’s path dependency into account (e.g. his current power plant portfolio). The existing power plants of the agent will influence current or future choices with this rule. This is a principal difference compared to assessing a novel power plant project’s value in isolation. There the ‘old’ generation park has no influences on the new decision. This can interesting for ABM research because it can change long term behavioral dynamics.
- This would help to explain why only a selection of all agents will invest in power plant projects that do not have an attractive (isolated) valuation. Those agents base their choice on the increase on the integral portfolio value of their generation park. Many agents will not use the portfolio rule (e.g. their park is too small for relevance of the rule, or the consideration is deemed too expensive for them). These agents would only invest given isolated (positive) valuations.
- It would help to explain the divergence in generator type investments. In portfolio thinking, this divergence allows for smarter operations of the agents generation park. Different generators have different added values linked to the power markets (e.g. their power generation cost profiles). This

\(^{39}\) These are all the projects that are in the state gates that have not yet reached the final investment decision and are feasible (but only potential) projects. These have a value of an ‘option’: the right but not the obligation to build the plant at a particular site (e.g. building permit approval or a land lease agreement improve this type of value). The agent that possesses the option (e.g. a land lease agreement) will shield other agents from building the same plant at the same location.

\(^{40}\) E.g. experts state that nuclear power requires huge upfront Devex budgets compared to building a natural gas turbine.
could prove to be very interesting for behavior regarding novel low carbon generator types (which are a focal point in the ABM research).

Implementing this strategy could take place in the form of a rule that is only applied to agents that use portfolio value addition. This rule could be based on the difference between the agent’s generation park valuation with or without the novel power plant option. This difference indicates portfolio value addition.

Implementing this rule has interesting academic merits. But actual use in the ABM would also require considerable computational resources. For the applicable agents, the ABM would have to calculate the valuations of all power plants in its generation park. In conclusion it is recommended to ABM researchers to review the feasibility of implementing this coping strategy in the ABM.

**Sustainability goal differences (coping strategy 29)**

This coping strategy implementation can contribute to the ABM research by adding novel behavioral aspects: it limits the options that (a selection of all) agents actually consider in their investment process. In section 4.3 it became apparent that is a hard constraint for those agents. And it can result in a key influence on the investment behavior. This is a relevant strategy given the ABM research focus on low carbon generation investments.

Implementation of this strategy could be in the form of a simple rule specified only for applicable agents. Based on section 4.3 these agents will not take certain generation options into account. ABM researchers could state that this rule should be able to change in time. This sounds reasonable given the ABM research focus on long term behavior and changing perceptions in low carbon generation investment. The rule is not likely to change in a few years but it should be able to change in decades. This issue could be dealt with by making assumptions on a certain lifetime of this rule. It will not be used by the agent after this time. Another option would be to perform a sensitivity analysis regarding the implementation of this rule.

**Overview of ABM recommendations**

A summary of the relevant coping strategies review leads to the table stated below. It states the selected coping strategies, their unique added value and suggestions for formalization.

<table>
<thead>
<tr>
<th>#</th>
<th>Coping strategy</th>
<th>Added value for representation</th>
<th>Model suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Meet sufficient level of trust in business case</td>
<td>informal judgments</td>
<td>Improve the concept first</td>
</tr>
<tr>
<td></td>
<td></td>
<td>financial considerations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>risk assessments</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Meeting the hurdle rate</td>
<td>DCF modeling &amp; linked notions</td>
<td>Introduce as rule</td>
</tr>
<tr>
<td></td>
<td></td>
<td>satisficing elements</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>involves risks &amp; uncertainties</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>includes time value of capital</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Meeting sustainability criteria</td>
<td>direct connection to interventions</td>
<td>Introduce as rule</td>
</tr>
<tr>
<td>9</td>
<td>Stage-gated decision processes</td>
<td>effects of investment process</td>
<td>Recurring rules (gates)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>value growth in FED</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>allows gate-related strategies</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Simplify to limited number of</td>
<td>managerial considerations</td>
<td>Sensitivity analyses</td>
</tr>
</tbody>
</table>

41 The outcomes stated that the following generation options are sometimes excluded from investment consideration: Nuclear, coal-fired plants and lignite-plants.
102

<table>
<thead>
<tr>
<th>uncertainty axis</th>
<th>specify information access in states</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 Couple search cost budget to value creation</td>
<td>option values of plants in FED realistic information access for agents Introduce as rule</td>
</tr>
<tr>
<td>28 Portfolio value addition</td>
<td>path dependency inclusion valuations in broader context explains divergences in investment Review feasibility</td>
</tr>
<tr>
<td>29 Sustainability goal differences</td>
<td>realistic exclusion of coal, nuclear etc Sensitivity analyses</td>
</tr>
</tbody>
</table>

Table 15 Overview of coping strategies for use in the ABM

This table is a key outcome of the Agent-based modeling review. The following section states the main conclusions of this chapter. Reflection on the analysis in this chapter is also included.

6.4. Outcomes in ABM translations

The analyses in this chapter show how implementing relevant parts of the investment concept from chapter 5 to the ABM can lead to improvements in model validity and fidelity for the ABM. Firstly, the investment concept can be used for realistic improvements of rules (the agents’ formal rules as well as their access to the agent’s states). Eventually, this can lead to behavioral replications of the ABM which approximates the selection of real world behavior to a higher degree. Secondly, the investment concept can be also used for model fidelity improvements of the ABM. The insights that the investment concept deliver allow for efficient selection of coping strategies. This selection can be based on their added value in a representing a larger part of the power sector. A trade-off needs to be made since the ABM cannot include all coping strategies.

To these ends, a selection and review of coping strategies is summarized in Table 15. This table is a key outcome of this chapter. The review and table are based on the problem formulations of TPM research. They should be revised for other problem formulations. These insights answer sub question 4 in section 1.3.

One part of the investment concept is not yet taken account in this chapter. The investment concept stated common and diverging coping strategies. It also stated initial connections between stated determinants and the diverging coping strategies. In most cases, these initial links currently lack the quality needed for proper use in ABM translations. Improvements on this part of the investment concept were already stated in section 5.5. For the ABM translation alone, it is recommended to consult power plant investors for the relevance of the diverging coping strategies in section 6.3. This could deliver case specific connections to states for each agent (on which the rules are based).

The proposed improvements are based on a static perception measurement at investment experts. This necessitates several critical observations:

- The option of perverting motives of experts cannot be ruled out in their answers (and in consecutive steps throughout this research). This can influence model validity of the ABM.
- The perceptions of investment experts do not have to be shared by all in the organization. This can influence model validity of the ABM.
This research cannot comment on how the current investment processes under review will evolve in time. One example is a ‘no coal/no nuclear’ decision rule for certain agents. It was already stated in section 6.3 that it is not certain that these rules will evaporate or change over time. This is a critical point for the research, especially given the TPM perspective of ‘complex adaptive systems’. Future research could be performed on how the investment processes are expected to change. Sensitivity analyses on rules in the ABM are also an option to see what might be likely changes (i.e. if such an analysis points out very positive outcomes for an agent under certain circumstances in rules or states it is likely that the agents will change their investment processes in similar ways).

Recommendations for ABM modelers have been made in section 7.2.
7. Conclusions and recommendations

7.1. Conclusions

This research was performed in order to improve the representation of investment behavior in large power plants in the Netherlands by an Agent-based model. The main research question is:

‘What is the most fit for purpose way of representing investment behavior in power plants in an Agent-based model?’

Two propositions (based on literature reviews) were analyzed to indicate validity for representing investment behavior. These led to the following outcomes:

Proposition 1: Bounded rationality coping strategies can be used to represent power plant investor behavior (given decision constraints). A review of empirical outcomes indicated that the bounded rationality perspective is highly valid for the decision making categories of ´Goals’, ´Editing’, ´Decomposition´ and ´Dealing with uncertainty´. The decision making categories of ´Framing´ and ´Heuristics´ are valid to a lesser degree. Overall the perspective proves to be very useful.

Proposition 2: Investment differentiators will change the investor’s decision process constraints which in turn change the investors’ coping strategies. This proposition holds for the differentiators of all ´formal company characteristics´ but not for ´technology specific risks and uncertainties´. The differentiator ´Intra-organizational dynamics´ needs more specification first given its current ambiguous aspects. These answers and analyses on Agent-based modeling lead to the main answer to the research question:

A limited set of proposed coping strategies can be used as a basis for coding an investment module in the Agent-based model. This set of strategies allows for replication of power sector behavior given realistic decision making constraints. The set is selected according to added value to the Agent-based model problem formulations. Insight in the added values of each coping strategy with regard to model fidelity and validity are stated below. The answer only applies for mature technology power plant investments (larger than €50 million) in the Netherlands.

Resulting recommendations are stated in section 7.2. Reflections on this research are stated in chapter 8. Detailed outcomes are stated below to answer the initial four sub-questions;

How are defining aspects of power plant investment processes described in scientific literature?
A literature review led to a limited number of models. The way of organizing the investment process is mainly structured by project based approaches (more specifically ´front end development’-prescriptions in project management literature)(Bosch-Rekveldt, 2011). Project management prescribes strategies for coming to a sufficient amount of information on which to base a power plant’s ‘final investment decision’; given resource scarcity in the initial phases of a project (until the start of construction of the power plant).

The process’s final investment decision is mainly structured by use of corporate finance theories(Brealey & Myers, 2003). These prescribe ways of coming to a capital investment decision (choosing between investment options) and also financing decisions (how to organize the capital structure). An important aspect of investment is stated in discounting the expected future cash flows of the power plants. The ´discounting´ of these cash flows allows for representation of the time value of money as well the risks that are perceived given the project specifics. This allows for investment options to be compared to other investment options.
The deviations from these methods seen in real life can be explained by means of several theories in decision science. The theory of ‘bounded rationality’ was found to be most applicable for this research (Simon, 1982). This is based on the investment processes’ focus on information processing combined with real life limitations to decision making stated by experts and literature. Some of these real life limitations are time constraints, limited development expenditure budgets and limited access to information. Bounded rationality states the use of ‘coping strategies’ categorized in goals, information processing and dealing with uncertainty. These strategies allow for representation of deviations to a purely analytical decision making perspective. Resulting recommendations are stated in section 7.2.

How are power plant investment processes performed in the Western European power sector? Empirical data collection was performed through interviews and the results were analyzed in tables. The outcomes are threefold. Firstly two sets of decision making coping strategies were found. The first set contains strategies common for all companies and the other contains diverging strategies. The common coping strategies are stated below;

<table>
<thead>
<tr>
<th>Proposition</th>
<th>#</th>
<th>Empirical results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proposition 1: common coping strategies</strong></td>
<td></td>
<td><strong>Common amongst respondents</strong></td>
</tr>
<tr>
<td>- Satisficing goals (see par.4.2.1.)</td>
<td>1</td>
<td>meet sufficient level of trust in business case</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>meeting hurdle rate</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>acceptable residual risk outcomes</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>minimize avoidable opportunity costs</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>maintain healthy cash position</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>meet strategic goals of executive board to sufficient extent</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>meeting sustainability criteria</td>
</tr>
<tr>
<td>- Information processing by decomposition (see par.4.2.2.)</td>
<td>8</td>
<td>divide processing between departments</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>stage-gated decision processes</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>decision leading to proposition distributed to different hierarchical layers</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>outsourcing to engineering firms, law firms, consultants et cetera</td>
</tr>
<tr>
<td>- Information processing by editing (see par.4.2.2.)</td>
<td>12</td>
<td>simplify all uncertainty to limited number of uncertainty axis in scenario analyses</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>diversity of local goals is simplified to strategic goals set by executive board for processing</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>simplify real-life risks to (treatment and analysis) of perceived high-impact risks</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>simplify risks to (outcomes of analysis to) functions of cost and income</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>simplify systemic risks with CAPM to outcomes in functions of cost and income</td>
</tr>
</tbody>
</table>

The diverging strategies are stated in the answer to the following sub question.
simplify technical design to portfolio requirement and limit to local options
Increase level of detail in analysis throughout stage-gates.

- Information processing by heuristics (see par. 4.2.2.)
  
  17. reduce knowledge uncertainties
  
  18. seeking technical and social validity of assumptions
  
  couple search cost budget (in Devex) to value creation. Delay expensive actions to last stages of the FED when possible.

- Information processing by framing (see par. 4.2.2.)
  
  20. gather sufficient strategic information to come to a DCF valuation
  
  22. take all relevant dimensions of problem into account in valuation (legal, technical et cetera)
  
  23. follow investment guide guidelines to gather and process information
  
- Dealing with uncertainty (see par. 4.2.3.)
  
  24. select limited number of uncertainties as a basis for likely future paths (scenario analysis). Ignore others or use them only in qualitative form during gate reviews. Reduce knowledge uncertainty by outsourcing to specialists and also perform extensive sensitivity analysis.

Table 16 Overview of common coping strategies; stated by power plant investment experts in section 4.2.

Secondly it was concluded that the investment practice in the Netherlands has many bounded rationality characteristics (but to a varying degree for different decision making categories). Thirdly a set of reasons was found that indicate differences between power plant investment processes.

From these results it is concluded that investment processes performed in the Dutch power sector can be represented by stating the common coping strategies stated above. These should be augmented with diverging coping strategies based on investment process differentiations (stated below). Resulting recommendations are stated in section 7.2.

Which insights explain the similarities and diversities between power plant investment processes seen in Western European power sector?
For the differences in coping strategies several reasons were stated by experts (as ‘investment process differentiators’). A review led to a preliminary overview of stated connections between the coping
strategies and the investor differentiations;

<table>
<thead>
<tr>
<th>Proposition 2: Investor differentiations &gt; diverging strategies</th>
<th>#</th>
<th>Differences amongst respondents by</th>
<th>Measured in</th>
<th>Corporate culture</th>
<th>Company history</th>
<th>Level of best practice integration</th>
<th>Geographic factors</th>
<th>General investment portfolio</th>
<th>Technology specific risks and opportunities</th>
<th>Risk strategies and capital structure</th>
<th>Stated link</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>Financial valuation method: NPV, IRR, ROIC</td>
<td>4,5,6,7,9,10</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Risk seeking when ensuring continuity (seeking risk vs.</td>
<td>1.7</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Taking “portfolio value addition” in account or not</td>
<td>1.6,10</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Sustainability goals</td>
<td>4,7,10</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Expanding experience with unknown technology</td>
<td>4</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Relevance of local employment effects</td>
<td>3</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Spending budgets (at budget controlled companies)</td>
<td>1,6,7</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Level of outsourcing (e.g. expensive strategic analyses)</td>
<td>4.7</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Capital structure options</td>
<td>9.10</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Ways of simplifying risks</td>
<td>5.6,7,10</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Focus on particular risks</td>
<td>1.2</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>No differences stated</td>
<td>4.7</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Changing access to information sources (e.g. technical or political issues)</td>
<td>2.4</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Scenario analysis</td>
<td>2.8,10</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td>Stated link</td>
<td></td>
</tr>
</tbody>
</table>

Table 17 Initial connections between differences in coping strategies and the reasons for these differences stated by experts

These specific connections are a first step in understanding investment process differences but they leave much to be desired before application is possible. These recommendations are stated in section 7.2.

Which considerations have to be made in order to translate the power plant investment processes concept into an Agent-based model in a fit-for-purpose way?

In order to translate the investment concept into an Agent-based model several steps are necessary. Firstly coping strategies need to be selected (for model parsimony). This selection is based on the problem formulations stated by the ABM modelers. Key aspects in the formulations were the changes of carbon based policies (e.g. Carbon taxing, price floors) as well as renewable energy policy (e.g. feed-in tariffs). These changes result in unknown behavior: “investment in low-carbon electricity generation” (Richstein et al., 2012; p.1) as well as “understanding complex market behavior” (Laurens J De Vries & Chappin, 2011; p.1). A selection of all coping strategies was made based on two criteria. Firstly unique added value in explaining the behavior stated above and secondly the impact of the policy interventions on the coping strategies. The result was a fit for purpose selection of coping strategies. These were treated on specific added values in representing the required power sector behavior. Recommendations were made for ABM modelers based on Agent-based modeling structures used in (K H Van Dam et al., 2012);

<table>
<thead>
<tr>
<th>#</th>
<th>Selected coping strategy</th>
<th>Added value for representation</th>
<th>Model suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Meet sufficient level of trust in business case</td>
<td>informal judgments, financial considerations, risk assessments</td>
<td>Improve the concept first</td>
</tr>
<tr>
<td>5</td>
<td>Meeting the hurdle rate</td>
<td>DCF modeling &amp; linked notions satisfying elements</td>
<td>Introduce as rule</td>
</tr>
</tbody>
</table>
Table 18 Overview of coping strategies for use in the ABM

<table>
<thead>
<tr>
<th></th>
<th>involves risks &amp; uncertainties</th>
<th>includes time value of capital</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Meeting sustainability criteria</td>
<td>direct connection to interventions</td>
<td>Introduce as rule</td>
</tr>
<tr>
<td>9</td>
<td>Stage-gated decision processes</td>
<td>effects of investment process</td>
<td>Recurring rules (gates)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>value growth in FED</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Simplify to limited number of uncertainty axis</td>
<td>managerial considerations</td>
<td>Sensitivity analyses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>specify information access in states</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Couple search cost budget to value creation</td>
<td>option values of plants in FED</td>
<td>Introduce as rule</td>
</tr>
<tr>
<td></td>
<td></td>
<td>realistic information access for agents</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Portfolio value addition</td>
<td>path dependency inclusion</td>
<td>Review feasibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>valuations in broader context</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Sustainability goal differences</td>
<td>realistic exclusion of coal, nuclear etc</td>
<td>Sensitivity analyses</td>
</tr>
</tbody>
</table>

Including these coping strategies make the rules in the investment module more realistic. This leads to more realistic (interacting) action and changes in the ABM. This can lead to improved model validity for investment behavior replication. Including these coping strategies can also give the investment module a higher degree of representation through more representative rules. This leads to more representative (interacting) actions and changes in the ABM. This can lead to improved model fidelity of investment behavior replication. Recommendations in the use of these outcomes are stated in section 7.2.

### 7.2. Recommendations

**Investment concept**

The investment concept can only be used for large investment processes in the Netherlands (mature technologies with an investment size of over €50 million).

Due to practical limitations, the resulting investment concept could not be verified by independent investment process experts. Resulting outcomes of such a review would enhance insights in applicability of the integral concept (as well as its potential shortcomings).

Several knowledge gaps still need to be addressed. These content related issues are stated in section 5.5.

For the differences in investment processes, the connections between investor differentiations and resulting coping strategies pose questions which need to be addressed. These are regarding issues in the investment concept’s (level of):

- **General applicability** (do the stated connections apply for all power companies in the power sector). Participants in the interviews represented a majority of the Dutch generator companies in the sector as a sample. But not all power companies participated and the measurement was based on individual perceptions (not the organization as a whole).
- **Completeness** (are these all the relevant connections to explain differences in behavior?).
- **Specific setup each connection** between investor differentiations, the resulting decision making constraints and the resulting coping strategies (do they always influence the consecutive step in a simple way or is this connection more complicated).
- **Interaction effects** (i.e. if certain combinations of investor differentiators can produce different results than their unique outcomes combined).
- **Ambiguity** of differentiators (this is especially relevant to the consolidated notion of ‘intra organizational dynamics’).
- **Use of the differentiator** “technology specific risks and uncertainties”; this is a technology specific differentiator and not an actor-specific differentiator.
- Potential issues when implementing a selection of concepts in ABM modeling (treated in the section stated below).

**Investment module in the Agent-based model**

A set of recommendations is specified based on problem formulations of Agent-based modelers at TPM. Table 15 summarizes these results. This is a key outcome for this research. It should be revised for different problem formulations.

In addition to using these recommendations, it would also be useful to base specific formulation and coding on the original statements stated in the confidential Appendix. This gives the ABM modelers the most amount of information possible. References are stated in the empirical chapter.

**Additional recommendations for further research**

The investment concept was created based on the characteristics of the Dutch power sector. However it can be expected that several other sectors can draw lessons from the concept, given that they have similar sector contexts and decision making constraints. Examples of these can be:

- Similar power sectors outside the Netherlands
- Other large scale asset based companies that have to deal with high uncertainty and long term investment horizons (such as transmission operators or petrochemical companies).

It would be interesting to find out if aspects of the proposed investment concept could also apply on these kinds of sectors (and if so, under which conditions and with which differences).

- In Agent-based modeling, one crucial paradigm is that of the “complex adaptive system’. It would be interesting to gain insight in how the power companies are changing their actual power plant investment processes. This can be expected in reaction to the negative outcomes of recent power plant investments stated by the experts in reviews and also the increased dynamicity of the power sector environment as a whole.

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43 Much effort was put in to reviewing these interviews in the best way possible. But incidents can occur where information stated in the interviews sometimes had to be left out of the main report when summarizing the key findings.
8. Reflection

8.1 Reflection on research

This research was based on a critical viewpoint on investment process representations by Agent-based modelers at the TPM. The research indicates that this critical viewpoint was justified based on the review of empirical analysis. Investment processes undeniably have bounded rationality characteristics. However, the research outcomes appear to lead to many more questions. In essence a simplified concept of investments has been confronted with the empirical descriptions of experts.

The added value of this research lies especially in the unique insights that it gives researchers in the former ‘black box’ of power plant investments processes. This allows for more valid representations of investment processes in the ABM (after the recommendations are met). It also allows for selecting realistic investment process elements in a transparent way, based on the unique added value of coping strategies to the ABM problem formulations. This is a novel option for ABM modelers. It can lead to model validity improvements and also allow a qualitative trade-off in model fidelity versus model parsimony. The existing ABM investment module was deliberately held out of the considerations but ABM modelers stated the added possibilities of the ABM modeling recommendations. Specifically for using ‘Stage-gated decision processes’ and ‘Coupling search cost budgets to value creation’.

Very little external empirical information on these investment processes was found before and during this research. No readily made investment framework was available. The research supplies a well founded decision science framework (bounded rationality) based on elaborate arguments in power sector uncertainty, project management and corporate finance. The empirical information was based on employees of many power companies in the Dutch power sector. The measurement took a broad perspective by also interviewing bankers and consultants. The arguments to select this framework are well founded. Consecutive steps allowed for explorative research given heavy constraints (stated in section 1.4.). But these pragmatic solution led to problems in indicating reliability (and potentially unknown shortcomings due to the novel method). However some methodological issues can be stated in consecutive steps (stated in section 8.2). This research has led to several academic products:

- A novel overview of changes, resulting uncertainties and resulting power plant risks.
- Empirical data supplied by investment experts that is publicly available to other researchers.
- Summary of this data in two practical coping strategy overviews that broaden the view of investment process from an analytical DCF exercise toward an integral, multidisciplinary perspective.
- Initial indications of connections between differences and investor differentiators. Allowing for or directed search in future research.
- Recommendations for improvements of the investment module in the Agent-based models.
- Insight in how these can lead to model fidelity and validity improvements.

8.2 Reflection on approach

This research encountered practical limitations due to the nature of investment processes (stated more elaborately in section 1.4). This resulted in not being able to use formal methods such as ‘case studies’ or ‘grounded theory approach’. Such well-founded research methods also have well documented

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A host of investment behavior analyses were found but few defined the actual investment processes.
methodological weaknesses. In this research such existing insights cannot be used. However a critical reflection is stated for the modeling steps. In particular the modeling steps after the propositions;

- **The propositions only stated the general form of the decision making framework and did not (ex ante) state specific coping strategies for investment practice.** So the use of the perspective can be valid for representing common coping strategies and ‘formal company characteristics’ for different coping strategies. But the validity of their specific coping strategies for the entire population is not yet assessed. So in order to be of use for general applicable in representing the population, this requires further research in the form of e.g. expert reviews.

- **There are unknown effects on reliability of the coping strategies** due to the fact that the sample measurement is:
  
  - Static (does not indicate changes which can be expected in complex adaptive systems)
  - Limited within the organization (individual perception measurement, and potentially susceptible to perverting motives).
  - A limited part of the total population (companies not represented might behave differently)
  - Susceptible to potential influence by the interviewer (influencing participants or using specific formulations of the interview outcomes for own benefits)
  - Not performed by using well known methods such as case studies or grounded-theory approach. These are designed to indicate the reliability and shortcomings of outcomes.
  - Unknown levels of influence of coping strategies on the investment behavior. And no knowledge on interaction effects between coping strategies.

- **Similar effects exist with regards to indicating reliability levels for the use of the differentiators.**

- **The current investment module has not been taken into account.** This has good reasons\(^{45}\). But is also means that it is not possible to state the added value of the new ABM investment module proposal vis-à-vis the existing module. When the novel module would be coded, the differences in behavior in the ABM would be most interesting.

8.3. Reflection on research process

In hindsight it took a long type for me to come to the key notions and methods in this research. The object of research is truly multidisciplinary and the information overflow I allowed was considerable in the beginning. The lesson I learnt was to ‘stay as high as you can for as long as you can’. And to focus all attention on the key analysis steps. Selecting the essential aspects took much time. However I am pleased to know much more about such useful subjects as stated in the research.

The option of using formal methods would have been great (perhaps keeping me on track to a larger extent). But I still believe that other options would not have succeeded.

One approach conceived in advance was most successful. This was the plan I had made for maximizing participation of participants. The great help of Laurens de Vries, Bas Groot, Tijs Groot, Phillippe Heidendal and the anonymous strategist in approaching experts also helped considerably. It would be good for TPM to remain in contact with the experts in future research.

A final lesson was also learnt on January 5th 2013; Speed skating can cause serious brain trauma (leading to serious delays in research, bad headaches and attention deficit).

\(^{45}\) An effort was made not to be dependent on the current modeling structure to come to the best possible results regardless of modeling structure.
References


Appendix (non-confidential)

Appendix 1. Scientific paper

KEY FINDINGS

- Real life power plant investment processes have bounded rationality characteristics.
- The bounded rationality framework allows for explaining how differences in investors’ characteristics create differences in their investment process (coping strategies).

Note to graduation committee:

Setup of this article has been chosen in accordance with:

- Journal selection: was elaborated on in the green light version .pdf
- Prescriptions of “Journal of Economic behavior and Organization” (Elsevier website)
An initial review of empirical results on power plant investment processes by using the bounded rationality perspective.

Joris Groot
Faculty of Technology, Policy and Management at the Delft University of Technology

Abstract
This paper reviews how power plant investors organize their investment processes. This research is focused on large scale power plant investments in the Netherlands. The objective of this research is to enhance the validity of the representation of investment decisions for use in academic research such as simulation models. An initial expert consultation and literature review have lead to propositions based on the ‘bounded rationality’ perspective of decision making (Simon, 1982). These propositions were the basis for a set of semi-structured interviews with investment experts and subsequent analysis. Four categories of limitations to purely analytical investment decision making in the power sector have been found. These limitations lead to a set of decision making ‘coping strategies’ in the form of goals with satisficing aspects, bounded information processing and ways of dealing with uncertainties. Bounded rationality characteristics were observed in all aspects of decision making. Preliminary differentiators between investors’ decision making processes were stated by experts. These are: company size, ownership, level of vertical integration in supply chain, geographic focus, current asset base and intra-organizational dynamics. These can be used for heterogeneous representation of power plant investors. The results of this research have knowledge gaps due to information sensitivities and the previous lack of an existing investment process framework. Discussion remains on the specific formulation of coping strategies as well as several methodological issues. It is recommended to review the outcomes as initial empirically founded concepts. Separate concept validation and concept improvements are also recommended.

Keywords: power plant; investment processes; bounded rationality;

1. Introduction
The Dutch power sector is an important sector to its policy makers and citizens (European Commission, 2006; Ministerie van Economische Zaken, 2005). A diversity of developments (such as liberalization, public perception and R&D) drive the transition of this sector toward new and unknown ‘states’ (European monitoring centre on change, 2008).

The power sector consists of many crucial elements (e.g. infrastructure, regulators, power companies) that often interact in complicated ways (Correljé & Vries, 2006). One way of analyzing this power sector is through a systems perspective (Bar-Yam, 2003). In this research perspective, a system is seen as “a regularly interacting or interdependent group of components forming a unified whole” (Nikolic, 2009; p.3). When regarding the power sectors large number of elements and the complicated way in which they interact, it can be described as a ‘complex system’ (Simon, 1962).

46 E-mail address of the author: dtgroot@gmail.com, telephone number: +31(0)-6 41058368.
47 Concept scientific article for thesis at the Delft University of Technology; reviewed by Prof.dr.ir. P.M. Herder, Dr.ir. L.J. de Vries, Dr. M.L.C. de Bruijne.
So from this perspective, the power sector has a high level of complexity and it is faced with many internal but also exogenous changes to the system (or ‘dynamics’). Examples of these dynamics are an increasing number of power companies due to liberalization (internal) and unexpected macro-economic developments (exogenous). This combination of complexity dynamics make it difficult for policy makers to determine how desirable changes in this sector could best be reached. Effects of their policy interventions are hard to predict due to the complexity and the current dynamics of the sector.

Dealing with this complexity and dynamics would allow for effective ‘transition management’ of the power sector towards their desired future states (based on policy goals) (Chappin, 2011). Effective transition management in turn would allow for avoidance of avoidable supply chain vulnerabilities and societal costs (NGI, 2012).

One crucial component in the value chain of the power sector is power generation. When a new power plant is introduced in a power sector this changes the system’s characteristics for all of its power producers and it can affect system behavior. One example is the issues known as “competitive interaction” (Murto, 2003; p.3). Power companies are linked via the power markets and can behave strategically in response. It becomes apparent from these kinds of effects that understanding how power generation addition is performed is essential for effective transition management. To represent power generation addition in the system, a clear concept needs to be available that can represent power plant investment choices in the sector. This is the key research issue in this research.

Power plant investment decisions are set in a broader context of the integral ‘investment process’. Several ways of representing the investment process have been used in the past. Previously the focus tended to be on representation through the analytical perspective of ‘rational’ decision making (W. Edwards, 1954). This rational decision making is based assumptions which do not seem plausible for the power plant investment processes (Conlisk, 1996). This means that more insight in the way in which real life investment decisions are made could add to the validity of a representation of investment processes. These insights lead to an improved ‘investment concept’.

Gaining the required insights is challenging due to several expected issues (stated in the ‘methods’ section). Therefore, initial insights were sought by means of a literature review leading to propositions on deviations of the rational decision making. These are based on ‘bounded rationality’ decision making (March, 1994; Simon, 1982). Empirical information was gathered by means of semi structured interviews. These outcomes were confronted with the propositions to indicate their validity.

The remainder of this paper is organized as follows. Section 2 reviews the (choices in) methods used for this research. Section 3 describes and concludes the results of the research. Section 4 states discussion points for further research and this research.

## 2. Methods

In this section the data-collection and analyses methods are described in the research in chronological order. The methods stated were preceded by an initial expert consultation and a preliminary literature scan in order to perform effective research. These indicated that the research had to deal with information sensitivity, resource scarcity and the multidisciplinary nature of power plant design.
During the preliminary literature scan, no empirical descriptions of power plant investment processes were found\textsuperscript{48}. This meant a theoretical basis had to be created first. The preliminary expert consultation indicated the heavy use of project management and financial theory in the investment practice. These theories form the starting point of the literature review. Corporate finance theory was chosen due to its well suited separation of management and ownership for this research. Relevant literature was accumulated through searching standard works indicated in the courses of the TPM curriculum as well as searches in the scientific database ‘Scopus’ (using search terms such ‘investment process’ and ‘power plant’) (Berk & DeMarzo, 2011; Bosch-Rekveldt, 2011; Groenleer, 2012).

Decision theory was chosen as a starting point for the investment concept due to its capability to deal with multidisciplinary subjects and also to explain deviations from financial decision making. These are not related to power sector substance which makes them suitable for exploratory data collection.

Gathering empirical data posed numerous challenges. The number of experts is scarce and the issues stated above had to be dealt with. The data should enable the testing of the bounded rationality perspective and add as much substance as possible within the constraints. Semi-structured interviews (based on decision aspects) offered the best, feasible way of collecting data. A diversity of experts has been interviewed from a diversity of companies to maximize representative value. All interviews were summarized and accorded by the experts. Issues stated frequently of stated to be of key importance were included in a database.

The outcomes in the database were categorized and these categories were confronted with bounded rationality characteristics to indicate level of fit. Reasons stated by experts were stated separately and analyzed to come to investment process differentiators.

3. Results

3.1. Literature review

Project management

The literature review of project management is based on a limited number of literature sources (Bosch-Rekveldt, 2011; Meredith & Mantel Jr., 2006; PMI, 2008). For this research the focus was on the front-end development (‘FED’) phases of traditional project management. A definition of FED is stated by the construction industry institute in Gibson et al (Gibson et al., 2006):

\begin{quote}
the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project
\end{quote}

This means in projects there is a necessity to deal with information gathering and processing, probabilities of outcomes, uncertainty and reaching goals given scarcity of resources.

During the FED-phases several inherent project attributes have to be dealt with in all projects. A selection relevant to this research was selected from a broader overview stated in (Meredith & Mantel Jr., 2006; p.9-11). Influential project attributes to the investment processes are “interdependencies”, “uniqueness”, “resource limitations” and “finite due dates”. These project attributes will result in certain:

- limits to information processing capacity (e.g. budget and time constraints)

\textsuperscript{48} The review was primarily performed via use of the scientific journal database ‘Scopus’. The review was primarily performed via use of the scientific journal database ‘Scopus’. Many sources describe investment in the power sector from a analytical perspective or in macro-level evaluations such as (Gerhardt & Blaney, 2010; Gross et al., 2007; Paap, 2012). However no model was found that can explain why similarities and differences between investors exist in their real world investment behavior.
- limits to information access (e.g. information gathering budgets are limited)

These two outcomes are relevant for the assumptions on rational decision making. This will be indicated in the decision science review. Other outcomes that affect these assumptions on rational decision making are derived from a corporate finance review.

**Corporate finance**

The literature review of corporate finance was based primarily on standard works of corporate finance (Berk & DeMarzo, 2011; Brealey & Myers, 2003; Goetzmann, 2012). An important characteristic for corporate finance is its focus on corporations. All the reviewed power plant investors are corporations. Corporations distinguish themselves by being “a legally defined, artificial being (a judicial person or legal entity), separate from its owners” (Berk & DeMarzo, 2011 p.5). This separation indicates the possibility of goal conflicts due to the separation of ownership and management, frequently called ‘agency problems’ (Brealey & Myers, 2003; p.9). Another issue arises when regarding capital investment decisions. Valuation methods require assessments of risks and uncertainty (in order to compare the investment option to alternatives). This requires subjective assessment given the uncertainties in the power sector (Fraser, 2003; Gerhardt & Blaney, 2010; Gross et al., 2007). Therefore the use of corporate finance also has effects on decision making:

- uncertainty in power sector (e.g. regarding carbon taxes or capacity markets)
- ambiguity in preferences (e.g. difference in management’s versus the owners’ goals)

It is concluded from these two literature reviews that the investment processes are focused on information processing. However there are considerable limitations to decision making. This begs the question of how decisions are made given these limitations. This is reviewed in the following section.

**Decision science**

A review of decision science was performed based on several literature sources (W. Edwards, 1954; Groenleer, 2012; Kahneman & Tversky, 1979; March, 1994; Simon, 1982). These sources indicate a range of decision theories which can be applicable depending on the decision content and research goal. This range is frequently stated between extremes of the analytical versus the political perspective (Groenleer, 2012; March, 1994). The focus in information processing indicates added value of using theories with elements of the analytical perspective. However given the decision making limitations stated above, a form of rational decision making limited to these real life issues seems more valid for representing investment processes.

Therefore the theory of “bounded rationality”, first introduced by Simon (1955) is used to come to propositions on an investment concept. With bounded rationality Simon sought to “replace the global rationality of man with a kind of rational behavior that is compatible with the access to information and the computational capacities that are actually possessed by organisms” (Simon, 1955; p.101). In his work “a primer on decision making”, James G. March (1994) supplies a useful organization of the real life strategies for deciding under the limitations stated above. These elements shall be referred to as ‘coping strategies’. March states coping strategies organized in goals, (four ways of) processing information and dealing with uncertainty (March, 1994; p.12-14). These are defined and specific examples are stated for the power sector;
- Satisficing goals: goals are based on reaching a reaching a minimal level (e.g. the NPV should be positive).
- Information processing by decomposition: aspects of the problem are split up in smaller parts to allow for decision making (e.g. distributing responsibilities between departments, or setting decision stages for investment processes).
- Information processing by editing: aspects of the problem are not taken into consideration (e.g. simplifying project risks to distributions of their cost and income functions in a financial model).
- Information processing by framing: decisions are framed by adopting a certain perspective in making the consideration (e.g. simplifying investment processes to a corporate finance approach such as a ‘discounted cash flow method’ with a focus on the final capital investment decision).
- Information processing by heuristics: “decision makers recognize patterns (...)and apply rules of appropriate behavior” (March, 1994; p.13) (e.g. use rules of thumb based on previous “lessons learnt” during previous power plant projects).
- Reducing uncertainty (e.g. removing knowledge by using “diligence and imagination”, contracting or ignoring uncertainties) (March, 1994; p.13).

**Framework and propositions**

These strategies serve as a basic theoretical framework for propositions on the investment processes, which are visualized in the figure stated below;

<table>
<thead>
<tr>
<th>Investor differentiations</th>
<th>Decision process constraints</th>
<th>Decision process coping strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasons stated for different coping strategies stated by experts (e.g. Aspects of their company culture or Their strategic positions in the sector)</td>
<td>Information process capacity</td>
<td>Satisficing goals</td>
</tr>
<tr>
<td></td>
<td>Information access</td>
<td>Information processing by decomposition</td>
</tr>
<tr>
<td></td>
<td>Uncertainty in power sector</td>
<td>Information processing by editing</td>
</tr>
<tr>
<td></td>
<td>Ambiguity in preferences</td>
<td>Information processing by framing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Information processing by heuristics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reducing uncertainty</td>
</tr>
</tbody>
</table>

Figure 19 Basis for the propositions on heterogeneous power plant investment processes based on bounded rationality

The model has three distinct elements. Firstly ‘investor differentiations’, which represent differences that exist in the real world between organizations (e.g. company size differences). Currently this is visualized as a cloud because they are still unknown. These can affect the organization’s ‘decision process constraints’ (e.g. information processing capacity). In turn these decision process constraints result in ‘decision process coping strategies’ (e.g. information processing by editing). The model can allow for differences but also similarities in investment processes. When organizations have no differences in investor differentiations
they are faced with similar decision process constraints which lead to similar coping strategies.

This theoretical framework leads to two propositions for review in this research:

**Proposition 1:**
Bounded rationality coping strategies can be used to represent power plant investor behavior (given decision constraints in the power plant investment processes).

**Proposition 2:**
Investor differentiation (e.g. company size difference) will change the decision process constraints and consecutively the investors’ coping strategies. This means that certain investor differentiators lead to insights that can improve representations of differences in decision making in real life.

These propositions were confronted with empirical outcomes derived from semi-structured interviews. The outcomes are discussed in the following section.

### 3.2. Empirical review

**Review of common coping strategies and the first proposition**
The data was collected by interviewing investment experts in 2012. The key outcomes are selected based on stated relevance by the investment experts. This resulted in a large amount of specific coping strategies in investment process practice. The coping strategies were summarized in Table 19 and Table 26. Firstly a summary was made for coping strategies common amongst corporations. These are categorized by using the coping strategy categories defined for use in section 3.3. The subjoined table shows the results of the interviews;

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49 The interviews were performed in 2012 by the author. These were held at one specialized bank, one valuation consultant and five power companies. The companies represent a quarter to three quarters of the total Dutch generation capacity ownership (Enipedia, 2012). The respondents held positions in key places such as business development departments, vice presidents, business analysts and one former CEO.

50 Limited to aspects stated to be of key interest or stated multiple times.
### Proposition 1: Common coping strategies

<table>
<thead>
<tr>
<th>Proposition</th>
<th>#</th>
<th>Empirical results</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Satisfying goals</td>
<td>1</td>
<td>Meet sufficient level of trust in business case</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Meeting hurdle rate</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Acceptable residual risk outcomes</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Minimize avoidable opportunity costs</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Maintain healthy cash position</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Meet strategic goals of executive board to sufficient extent</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Meeting sustainability criteria</td>
</tr>
<tr>
<td>- Information processing by decomposition (see)</td>
<td>8</td>
<td>Divide processing between departments</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Stage-gated decision processes</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Decision leading to proposition distributed to different hierarchical layers</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Outsourcing to engineering firms, law firms, consultants etcetera</td>
</tr>
<tr>
<td>- Information processing by editing</td>
<td>12</td>
<td>Simplify all uncertainty to limited number of uncertainty axes in scenario analyses</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Diversity of local goals simplified to strategic goals set by executive board for processing</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Simplify real-life risks to (treatment and analysis) of perceived high-impact risks</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Simplify risks to (outcomes of analysis) functions of cost and income</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Simplify systemic risks with CAPN to outcomes in functions of cost and income</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>Simplify technical design to portfolio requirement and limit to local options</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Increase level of detail in analysis throughout stage-gate.</td>
</tr>
<tr>
<td>- Information processing by heuristics</td>
<td>19</td>
<td>Reduce knowledge uncertainties</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Seeking technical and social validity of assumptions</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Couple search cost/budget in Deves to value creation</td>
</tr>
<tr>
<td>- Information processing by framing</td>
<td>22</td>
<td>Gathering sufficient strategic information to come to a DCF valuation</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>Take all relevant dimensions of problem into account in valuation (legal, technical etcetera)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>Follow investment guide guidelines to gather and process information</td>
</tr>
<tr>
<td>- Dealing with uncertainty</td>
<td>25</td>
<td>Select limited number of uncertainties as abasis for likely future paths (scenario analysis); Ignore other or use them only in qualitative form during gate reviews. Reduce knowledge uncertainty by outsourcing to specialists and also perform extensive sensitivity analysis.</td>
</tr>
</tbody>
</table>

**Table 19 Overview of common coping strategies; stated by power plant investment experts.**

Some of the coping strategies stated above require elaboration here. ‘Meeting sufficient level of trust in the business case’ was stated as the key consideration for the final investment process. The business case comprises of a financial forecast outcome combined with a qualitative risk assessment. The goal of ‘meeting sustainable criteria’ has to be seen in the context of being in compliance with regulations (and not in maximizing environmental sustainability goals). Key activities used in ‘Reducing knowledge uncertainties’ were hiring specialists, performing extensive contracting with partners and performing extensive sensitivity analysis.

In order to evaluate the first proposition, the empirical results are reviewed for their level of fit with the bounded rationality-framework. The results are stated below for the decision process coping strategies stated in Figure 19. The levels of fit are all based on criteria stated in (March, 1994). Firstly the goals are reviewed in Table 20:
Table 20 Review of empirical goals for bounded rationality fit

From table two it can be concluded that the current empirical results show a high level of fit for all but one of the goals with regard to the bounded rationality perspective\(^{51}\).

Next, information processing is reviewed in Table 22 through to Table 24. After stating the tables, these results are concluded in a combined review for information processing.

Table 21 Review of decompositions for bounded rationality fit

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Decomposition)</th>
<th>Applicability in order to attain:</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>divide processing between departments</td>
<td>High; distribution in/outside organization</td>
</tr>
<tr>
<td>9</td>
<td>stage-gated decision processes</td>
<td>High; splitting up tasks over time</td>
</tr>
<tr>
<td>10</td>
<td>decision leading to proposition distributed to different hierarchical layers</td>
<td>High; distribution mainly inside organization</td>
</tr>
<tr>
<td>11</td>
<td>outsourcing to engineering firms, law firms, consultants et cetera</td>
<td>High; reduction through buying knowledge</td>
</tr>
</tbody>
</table>

Table 22 Review of editing for bounded rationality fit

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Editing)</th>
<th>Applicability for</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>simplify all uncertainty to limited number of uncertainty axis in scenario analysis</td>
<td>high; no other uncertainty axis; high; only relevant outcomes</td>
</tr>
<tr>
<td>13</td>
<td>diversity of local goals is simplified to strategic goals set by executive board for processing</td>
<td>high; all informal goals; high; only use these goals for trade-offs</td>
</tr>
<tr>
<td>14</td>
<td>simplify real-life risks to (treatment &amp; analysis) of perceived high-impact risks</td>
<td>high; e.g. no ‘black swan risks’; high; only use distributions</td>
</tr>
<tr>
<td>15</td>
<td>simplify risks to (outcomes of analysis to) functions of cost and income</td>
<td>high; no informal effects; no external effects; high; only use distributions</td>
</tr>
<tr>
<td>16</td>
<td>simplify systemic risks with CAPM to outcomes in functions of cost and income</td>
<td>high; e.g. Limit world to ‘systemic risks’; high; only use point estimates</td>
</tr>
<tr>
<td>17</td>
<td>simplify technical design to portfolio requirement and limit to local options</td>
<td>high; discards all options except portfolio fitting; high; e.g. limits detailed design to industry options</td>
</tr>
<tr>
<td>18</td>
<td>increase level of detail in analysis throughout stage-gates</td>
<td>high; reducing info as soon as possible; high; “choice dimensions sequentially” (March, 1994; p.12)</td>
</tr>
</tbody>
</table>

\(^{51}\) March (1994) reviews work by Herbert Simon to conclude that satisficing goals can be identified by their sensitivity to reaching a certain minimal level (March, 1994; p.21).
Table 23 Review of framing for bounded rationality fit

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Framing)</th>
<th>Applicability in order to attain:</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>gather sufficient strategic information to come to a DCF valuation</td>
<td>High; focused on coming to strategic financial forecast in fixed methods</td>
</tr>
<tr>
<td>23</td>
<td>take all relevant dimensions of problem into account in valuation (legal, technical et cetera)</td>
<td>Low; taking all these into account can make direction and simplification cumbersome</td>
</tr>
<tr>
<td>24</td>
<td>follow investment guide guidelines to gather and process information</td>
<td>High; guides stipulate focal points and prescribes form</td>
</tr>
</tbody>
</table>

Table 24 Review of heuristics for bounded rationality fit

<table>
<thead>
<tr>
<th>#</th>
<th>Empirical results (Heuristics)</th>
<th>‘situation recognition’ and ‘rule following’</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>reduce knowledge uncertainties</td>
<td>Mixed; the substance of the uncertainties will be unknown by definition. The form of reducing uncertainties is prescribed by the rule (e.g. addressing high impact uncertainties with priority)</td>
</tr>
<tr>
<td>20</td>
<td>seeking technical and social validity of assumptions</td>
<td>Low; combining resources does not seem to resemble rule following or situation recognition. A point could be made that other might recognize patterns (but this is not the focus here)</td>
</tr>
<tr>
<td>21</td>
<td>couple search cost budget (in Devex) to value creation</td>
<td>High; e.g. The FED budget can be regarded as a (search cost) rule to be followed</td>
</tr>
</tbody>
</table>

From Table 22 through to Table 24 it can be concluded that the current empirical results show a varying level of fit for use of the bounded rationality perspective. The outcomes in decomposition and editing show a high level of fit with the bounded rationality perspective. These levels of fit are lower for (and show more variation within) heuristics and framing.

This leaves the category of ‘dealing with uncertainty’. The expectations for dealing with uncertainty are met completely. A short review is stated below in Table 25.

<table>
<thead>
<tr>
<th>Expectation in bounded rationality</th>
<th>Empirical outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>many uncertainties are not taken into account in the considerations</td>
<td>empirical results confirmed selection of a limited number of uncertainty axis in scenario analysis.</td>
</tr>
<tr>
<td>decision makers try to remove uncertainties that arise specifically from knowledge gaps</td>
<td>empirical results confirmed this by the use of outsourcing to specialists, the processes used in scenario analysis, and extensive sensitivity analysis.</td>
</tr>
<tr>
<td>decision makers also try to remove certain uncertainties that result from ‘incomplete contracting’</td>
<td>the added value (and costs in the FED) of service providers such as lawyers to minimize issues with contracting was stated by many investment experts.</td>
</tr>
</tbody>
</table>

Table 25 Review of dealing with uncertainty for bounded rationality fit.

The review first showed that the proposed bounded rationality strategies can be used to represent empirical outcomes Table 19. Separate reviews indicated that proposition 1 holds to a high degree for
goals, editing, decomposing and uncertainty. The proposition holds to a varying extent for framing an heuristics.

**Review of different coping strategies and the second proposition**

In addition to the common concepts, the results that were different between corporations were also stated in coping strategies. Table 26 shows the resulting differences in coping strategies;

<table>
<thead>
<tr>
<th>Proposition 2: diverging strategies</th>
<th># Differences amongst respondents in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Satisficing goals</td>
<td>26 financial valuation method: NPV, IRR, RAROC,</td>
</tr>
<tr>
<td></td>
<td>risk seeking when ensuring continuity (seeking risk vs. Mirroring the market)</td>
</tr>
<tr>
<td></td>
<td>28 Taking &quot;portfolio value addition&quot; in account or not</td>
</tr>
<tr>
<td></td>
<td>29 Sustainability goals</td>
</tr>
<tr>
<td></td>
<td>30 Expanding experience with unknown technology</td>
</tr>
<tr>
<td></td>
<td>31 Relevance of local employment effects</td>
</tr>
<tr>
<td></td>
<td>32 Spending budgets (at budget cultured companies)</td>
</tr>
<tr>
<td></td>
<td>33 Level of outsourcing (of expensive strategic analyses)</td>
</tr>
<tr>
<td></td>
<td>34 Capital structure options</td>
</tr>
<tr>
<td></td>
<td>35 Ways of simplifying risks</td>
</tr>
<tr>
<td></td>
<td>36 Focus on particular risks</td>
</tr>
<tr>
<td></td>
<td>37 - no differences stated -</td>
</tr>
<tr>
<td>- Information processing by</td>
<td>38 Access to information sources (e.g. Technical or political issues)</td>
</tr>
<tr>
<td>- Information processing by editing</td>
<td>39 Using real option analysis or not. Buying or performing scenario analysis.</td>
</tr>
<tr>
<td>- Information processing by heuristics</td>
<td></td>
</tr>
<tr>
<td>- Information processing by framing</td>
<td></td>
</tr>
<tr>
<td>- Dealing with uncertainty</td>
<td>39 Using real option analysis or not. Buying or performing scenario analysis.</td>
</tr>
</tbody>
</table>

Table 26 Differences in coping strategies

One coping strategies requires elaboration. The coping strategy ‘ways of simplifying risks’ is most clearly shown in the level of simplification of the risk distribution functions.52

When asked about differences in coping strategies, the investment experts stated reasons for the differences. Analysis has led to an overview of investor differentiation categories in Table 27.53

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company size</td>
<td>E.g. RWE versus Delta (or Eneco)</td>
</tr>
<tr>
<td>Ownership of company</td>
<td>Type of prevalent shareholders (e.g. public stock, municipalities)</td>
</tr>
<tr>
<td>Level of vertical integration</td>
<td>Positions in feedstock, production, networks, trading, retailing</td>
</tr>
<tr>
<td>Geographic focus</td>
<td>National vs. European vs. Global orientation</td>
</tr>
<tr>
<td>Current generation portfolio</td>
<td>E.g. Coal, nuclear, renewables</td>
</tr>
<tr>
<td>Technology specific risks and uncertainties</td>
<td>Particularly those in renewables vs. Conventional power plants</td>
</tr>
<tr>
<td>Intra organizational dynamics</td>
<td>Umbrella notion used for issues in e.g. Company culture, power play, personal motives</td>
</tr>
</tbody>
</table>

Table 27 Initial overview of investor differentiations; resulting from empirical outcome analysis.

52 E.g. using a ‘P95’ confidence interval vs. using full distributions in the financial forecasting.

53 This is first review of these type of determinants and much work remains to be done. Especially in specifying ‘intra organizational dynamics’ (however it was a very important factor so it has been stated here in the preliminary version. In addition, future research should include a review on the level of completeness of this set of determinants. The ones stated here were derived from the differences in coping strategies but others could be relevant for the framework.
It should be noted here that especially ‘intra-organizational dynamics’ requires attention in future research. Stated connections between coping strategies and these investment differentiations are indicated in Table 28.

Table 28 Stated connections between investor differentiations and coping strategies

Table 27 and Table 28 indicate the link between investor differentiations and the coping strategies. However that does not yet prove that this due to the decision making constraints stated in Figure 19. To this end, an example is stated for every one of the decision making constraints;

- **Information processing capacity**: experts from smaller companies indicate that resources needed for scenario analysis are only practical for large companies. This limits information processing capacity as a constraint which means they do not perform proprietary scenario analysis on their own in their coping strategies\(^\text{54}\).

- **Information access**: experts stated that incumbent (nationally focused) companies frequently have better access to insights on local political dynamics due to their local heritage. This changes the way in which those companies simplify risks in their assessments. The can perform in-depth risk assessments because they have better information access.

- **Uncertainty in power sector**: Experts have stated that due to their (state) ownership, they take on a different level of *effects of uncertainty* in their decision process compared to publicly owned companies. This changes their risk appetite.

- **Ambiguity in preferences**: Municipal ownership can lead to a more ambiguous focus on the goals of the power company managers\(^\text{55}\). This can result in satisficing goal additions such as ‘relevant local employment effects’.

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\(^{54}\) However, these companies can buy power sector scenarios from specialized consultants.

\(^{55}\) These are taken into consideration by managers at the power company. They expect municipal owners not to be pleased with projects that do not add to their local employment. This changes goal ambiguity.
These considerations lead to the answer to the second proposition. Using the framework enables the explanation of many of the coping strategy differences by means of differentiation and constraints. But not all coping strategy differences are explained at present.\textsuperscript{56} Specific examples prove that the concept is useful in explaining investment process characteristics, but many of the connections need to be studied in more detail. The determinant of “intra-organizational dynamics” is a crucial notion in investment practice but it needs specification for valid use in the theoretical framework. Analysis of the empirical reviews has led to issues for future discussion stated in the following chapter.

4. Discussion

Applicability of decision science theories
The theory of bounded rationality has proven useful in explaining investment process characteristics. The framework can be used but it should be noted that the empirical fit with information processing by ‘framing’ and ‘heuristics’ was varying. Also the usefulness does not mean other theories do not have added value in gaining insights in investment processes. One expert reviewed the premises of bounded rationality to be valid for investment practice in a separate review. But he also indicated that making strategic choices on levels of vertical integration in the company have many characteristics in common with decision making through ‘mixed scanning’ (Etzioni, 1989).\textsuperscript{57}

Reflection on the data collection and analysis method
This research is based on a perception measurement by interviewing a limited number of experts. Among others potential downsides can be found in:

- Unknown effects of perverting motives or worldviews at experts leading to measurement errors.
- Unknown levels of representation of the individual expert’s insights to indicate his organizational processes as a whole.
- Limited insight in the loss of fidelity due to translations in interviews, their summaries, the analysis methods and the resulting outcomes. The method is particularly sensitive in summarizing of empirical results toward concisely stated coping strategies.
- Knowledge gaps in the model.\textsuperscript{58}
- The lack of insight in how these processes change in time.\textsuperscript{59}

It is recommended to validate the concept separately at different power plant investors and address the residual knowledge gaps stated above. The concept should be reviewed as an initial, empirically founded framework as a basis for further improvement and validation.

\textsuperscript{56} E.g. Different choices in financial rules were not explained yet.
\textsuperscript{57} This is a theory of decision making that is based on mixed use of political an analytical decision. The theory is elaborated on in (Etzioni, 1989).
\textsuperscript{58} E.g. the weight of the coping strategies in the model (in their effect on investment behavior). Another example is the specific setup of ‘intra-organizational dynamics’. The last key issue is in explaining and validating the causal links shown in Figure 19 for all coping strategies. Now only connections are indicated as a starting point.
\textsuperscript{59} This is particularly relevant due to the current expensive lessons due to the current power sector uncertainty impacts stated by the experts.
5. Reference


Appendix 2. Initial consultation with power company strategist

The consultations with an anonymous power company strategist were used to gain a first indication of in main elements of an investment process in the period July and August 2012. The strategist is known to the review committee. Stated below is a summary of these discussions:

- **Sensitive information that the agents will not share due to competition considerations:**
  - Weighted cost of capital
  - Predictions of price curves
  - Overhead
  - Costs of “buying” increased certainty such as permits, measuring costs, construction quotes

- **Power companies make their investment considerations according to several criteria.**

- **Different parties are involved** such as valuation consultants, technical experts from different departments and decision makers from external investors and the power company’s director’s. Several parties decide during several stages. Project management and corporate finance play key roles.

- **Invariably financial valuation is a key issue** for the power company. The main process can be described as forecasting future cash flows from converting fuel into electricity with a certain level of efficiency. The profits should be adjusted for subsidies, fiscal regulations and carbon emission rights. It involves subjective assessments but also analytical elements.

- **Discounted cash flows calculations (NPV, IRR) are commonplace.**

- **However many real life issues make the financial evaluation more complicated:**
  - There is not a fixed profit margin but rather a **spread** (“dark spread” for coal, “spark spread” for natural gas and the addition of “clean” indicating CO₂ compensation inclusion.
  - **Timescales.** This spread should be a means to “earn back” a certain Capital Expenditure. However the prices are varying on different timescales (days, years, long-term until plant decommissioning).
  - **Ramp-up costs** of the power plant should also be included in this financial evaluation.
  - **Merit orders** (order indicating cost pattern and first to last ram-up hierarchy) should be included in the consideration. The change of physical generation “landscape” (e.g. new plants or old plant being decommissioned) is difficult to forecast over the next 20 years. Merit order is a key point for the financial evaluation: it leads to an indication of running time and capacity requirement.
  - **Corporate strategy** regarding merit orders; At this point inter corporation strategy also starts to play its part. In line with heavy competition, competitors in the power sector can attain benefits in “blurring” the actual chain of events they will undertake towards the outside world. This is only one example of strategic motives to make information ambiguous within the sector.
  - **There are currently three major issues linked to merit orders** which make PIP’s very challenging: 1> changing merit orders, 2> low carbon generators that have priority merit (“pushing a merit order curve to the right”) and 3> demand diminishing due to macro economic factors and decentralized power generation (e.g. Domestic Photovoltaic).
• **Dealing with systemic uncertainty** is often simplified cost of equity tools to a capital asset pricing model.

**Appendix 3. Energy efficiency and Dutch power generation characteristics**

Given the large diversity of energy concepts used in the power sector a definition of energy efficiency used in this research is stated first. The definition is based on the research scope (e.g. not taking heat as a valuable product into consideration). In further research this should be an interesting topic given the economic value of residual heat (for instance in cooling water).

Energy efficiency:

\[
\text{electrical power supplied by the power plant} \quad \frac{\text{the energy content of the converted fuels or sourced energy}}{} (60)
\]

The electrical power that is supplied to the grid is supplied by a variety of power plant types. The figure stated below gives some sense of scale of energy feedstock (or sourcing) types.

![Figure 20 Overview of Dutch generators by size and type (Enipedia, 2012).](image)

The demand that these power plants have to meet cannot be forecast fully deterministically. However the

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(60) For all fuel converting power plants the lower heating value of the energy content of the fuels is used.
demand profiles do have common characteristics. Important causes for the stereotypical demand curve have been stated below by the Dutch TSO ‘Tennet’.

Figure 21 Overview of average daily power consumption in the Netherlands (Tennet, 2012b).

Appendix 4. Power sector risks linked to power plant characteristics

Exposure to power sector risks varies for different generation options. The figure stated below gives another indication of the risk exposure for the most common non-renewable base load plants by Fraser and Blaney (2010). It is concluded that investment processes have to be adapted to different types of power plants.

![Figure 22 Major base load generation investment risks for several power plant types in the USA, adopted from (Gerhardt & Blaney, 2010; p.42)](image-url)
Appendix 5. Power market design variables

Stated below is a table copied from Correlje and De Vries’ work on ‘hybrid electricity markets’ (Correljé & Vries, 2006; p.10). It indicates main market design variables for power markets. This allows for an efficient characterization of the Dutch power market in section 2.2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of market opening</td>
<td>Corporatization of a state monopoly, single buyer, wholesale market and competition in the retail market allow for an increasing degree of competition, but involve increasing transaction costs and requirements as regards the economic and institutional structure.</td>
</tr>
<tr>
<td>Pace of market opening</td>
<td>Being a leader or a follower vis-à-vis neighboring countries/states, or lagging (EU, USA Federal) policy.</td>
</tr>
<tr>
<td>Integrated versus decentralized market</td>
<td>Integrated markets with mandatory pools, reduce transaction costs, but combine both economic and physical control over the system in the hands of a single party, potentially facilitating governance.</td>
</tr>
<tr>
<td>Public versus private ownership</td>
<td>Public ownership provides a means for direct control but entails policy capture, may impede effective regulation and limits financial resources. Private ownership requires political and institutional stability and regulatory commitment.</td>
</tr>
<tr>
<td>Competition policy and horizontal unbundling</td>
<td>Influences the competitiveness in market segments, trading off economics of scale and scope.</td>
</tr>
<tr>
<td>Network unbundling</td>
<td>Unbundling influences the independence of network managers and their interest in providing equal conditions for all network users.</td>
</tr>
<tr>
<td>Network regulation of network tariffs and access conditions</td>
<td>Influence the conditions for competition and the pressure upon network managers to work efficiently.</td>
</tr>
<tr>
<td>Congestion management method</td>
<td>Affects trade opportunities between regions.</td>
</tr>
<tr>
<td>Arrangements with neighboring networks and interconnector congestion management</td>
<td>Market integration may enhance the competitiveness but may also cause higher prices in the exporting country.</td>
</tr>
<tr>
<td>Balancing mechanism (in decentralized markets)</td>
<td>Balancing mechanisms affect cost and revenues of types generation, especially for intermittent sources and influence entry.</td>
</tr>
<tr>
<td>Wholesale and end user price regulation</td>
<td>Protects consumers, at the expense of investment stimuli to the industry.</td>
</tr>
<tr>
<td>Capacity mechanism</td>
<td>Different types of capacity mechanisms exist in order to stimulate investment in capacity.</td>
</tr>
<tr>
<td>Position of regulator</td>
<td>Ex ante or ex post regulation.</td>
</tr>
</tbody>
</table>

Figure 23 Power market design variables and consequences copied from (Correljé & Vries, 2006; p.10).

Many of these variables are described in (Haas et al., 2006) for European power markets. Stated below a table is included which indicates similarities and differences for European power markets. The combination of these tables gives a wealth of information when explaining investor attractiveness between nations.
Appendix 6. Expert’s opinions on current power sector investment behavior

The opinions stated below were stated by the experts throughout the interviews. Representation level and other background information is found in section 4.1. The methods used to come to these outcomes are found in chapter 1.4.

Portfolio value vis-à-vis project value

All companies stated that the portfolio value addition was considered to a limited degree. One expert stated that an indication of value addition to the integral portfolio should actually become the primary financial valuation method (6). The argument would be that currently all companies use a project based valuation, however they actually want to add value to the company as a whole.

Using such a valuation with wider scope is already used frequently. But using it as the key performance indicator would add interaction effects of the company’s assets (compared to current project evaluation) (4,6).

Reasons for perceived over-investment in the Netherlands

Experts state that they expect no large differences between investment processes in the industry.

It is often stated that events like the blow out in Fukushima cannot be taken into consideration (7). A complete overview of all events capable influencing the European power sector is not expected to be feasible by any of the experts. The consequences of the Fukushima event (such as accelerated nuclear phase-out in Germany) were not foreseen by any of the experts.
Other possible events were considered (such as a small demand decreases) but other effects have been underestimated. One clear example stated by many experts is the large expansion of German PV power generation capacity. Merit order changes were expected but not to this degree (7).

Experts give several (contested) explanations (6,7):

- Free CO₂ rights improved the financial status of power companies
- The profit margins were very attractive in the last decade
- There were several old power plants, which might lead to the idea that they required renewal
- Power companies held a very good cash position and had to put this capital to use somehow
- The level of actual investment by competitors was higher than expected
- Interconnection capacity is growing faster than expected
- There is less decommissioning than expected
- It appears the European Commission has been unexpectedly successful in decreasing market imperfections; this in turn has lead to lower prices.

Several experts expect that systematic changes are inevitable. A frequently stated option is implementation of capacity markets.

**Appendix 8. Overview of database (-method) with interview outcomes**

A table is stated below which indicates the main outcomes from the interviews with energy investment experts.

The table is organized as follows (based on columns from left to right):

- The first columns state the bounded rationality coping strategies from the propositions:
  - Goals
  - Information processing divided into: editing/decomposition/heuristics/framing
  - Dealing with uncertainty
- These are the main categories to organize the interview outcomes (other categories were stated below to these initial categories for use throughout the thesis- but not in this analysis)
- Next to the categories are the actual investment strategies stated by the experts, followed by reference numbers to allow for traceability.
- These are followed by columns of reasons stated by experts in order to indicate why these differences exist (investor differentiators. Special comments are addressed in the following columns.

The stated investment strategies by experts are processed as follows:

- Separate strategies were identified in the interview summaries. Notions stated multiple times or stated to have high relevance for the expert were taken into account in the database stated below.
- These strategies are allocated to initial location at of the categories of goals/ information processing/dealing with uncertainty
- Their origins (interview reference numbers) were also stated
- Green indicates similar strategies and red indicates differences in strategies.
- For the relevant, different strategies (see red colored strategies below), reasons where consolidated. The reasons for differences were linked to the strategies.
- This lead to the table stated below, which is used as a basis for structuring chapter four and as a basis for analysis in chapter five.
- This table is situated in the analysis excel file (tab ’22.’)
Figure 25 24 Indication of all coping strategies and their reasons stated by investment process experts.
Appendix 9. Critical issues in ABM modeling steps

This appendix reviews modeling steps two and three to come to key issues that should be addressed when coming to ABM recommendations. The results are used in section 6.2 and 6.3.

Modeling steps 4-10 are not taken into account here due to research scope. However these should be reviewed in future research.

Modeling steps two and three will be reviewed shortly. Only aspects that allow for coming to key issues are reviewed here. Van Dam et al (2012) can be a more consulted for a more elaborate description.

System identification and decomposition
In this modeling step, the system which is under review is split up into its component parts (‘decomposition’). Van Dam et al (2012; p.77) state that for Agent-based modeling these are always the potential agents and their interactions. They propose two phases within modeling step two: “inventory” and “structuring” (K H Van Dam et al., 2012; p.77);

Inventory
The inventory phase should lead to an overview of (among others) ‘relevant’ notions such as concepts, actors, behaviors et cetera. From this phase we conclude that it needs to be possible to indicate a ‘level of relevance’ of the notions in the investment module. This can give Agent-based modelers some grasp of which notions to take into account or not. So possibility to indicate the ‘level of relevance’ of aspects of the investment concept is one essential evaluation criterion for these steps.

Structuring
The next phase is “structuring” which is the key phase of system identification. According to Van Dam et al (2012), it should lead to a clear view on the (relations between) agents all three stages named in the previous section (internal, local and global). To come to an explicit model throughout this phase (and following phases), it becomes apparent that the existing concept should be unambiguous (i.e. notions should have one meaning) and not dependent on context (the meaning of notions should not change in different surroundings). These two criteria of “ambiguity” and “context dependence” are also stated for modeling step three and will be taking into account as evaluation criteria in the following section (K H Van Dam et al., 2012; p.83).

One sub-phase of structuring is “environment”. In this sub-phase Van Dam et al (2012) focus on the exogenous variables (however “extremely slow processes” are also allocated to this environment van Van Dam et al) (K H Van Dam et al., 2012; p.80). To include all relevant information, this research will use the term “environmental information” (K H Van Dam et al., 2012; p.80).

Since the key focus of this research is the investment module it is relevant to ask whether the formalization of the investment concept can ‘connect’ to all the environmental information in the ABM. For instance, if the exogenous variables needed for the new investment module are not available in the ABM this will create issues. For instance the goal of ‘creating local employment’ will be impossible to code in the ABM if there is no exogenous variable regarding employment in the ABM. Therefore the ‘availability of essential environmental information’ is used a key issue for recommendations.

Concept formalization
In this phase the goal is to come to a concept which is “explicit, formal and computer-understandable” by means of a “software data structure” or “ontology” (K H Van Dam et al., 2012; p.83).

The criteria of ‘ambiguity’ and ‘context dependence’ are very important notions in this phase but have already been stated in the section 6.2.4. However the notion of “computer-understandable” is novel. A notion can be explicit and formal but not (yet) “computer-understandable”. For this to be so, Van Dam et al state that the element of the investment concept should be able to be connected to the computer language used (K H Van Dam et al., 2012; p.83).

For this research, there are issues in assessing the criterion of being “computer-understandable” in this research. For this criterion to be assessed in depth more research resources are needed. Firstly knowledge of the actual computer language is essential. Secondly, a selection of the aspects in the investment concept is needed given that this is a cumbersome activity. Lastly the criterion seems to be more suitable for “software data structures” than “ontology”.

Therefore, this criterion falls outside the scope of this research. However it is a recommendation for further research to evaluate the investment concept aspects when the preceding modeling steps are undertaken by an ABM researcher.

Conclusion

Concluding from this section, several key issues should be assessed in the ABM consideration:

- ‘ambiguity’ (notions should have one meaning)
- ‘context dependence’ (meaning of notions do not change in a different surrounding)
- ‘availability of essential environmental information’

ABM modelers suggested not to take the current model into account in order to come to the best investment module possible. Therefore environmental information is not taken into consideration in the main analyses stated in chapter 6.