Implementing Real Options in Engineering Projects

A conceptual framework to adopt Real Options

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Executive summary

Problem: No overview of required efforts exists to adopt Real Options in Large Engineering Projects

There is an abundance of ROA literature present on valuation analyses in many specific cases, and books assessing the real options methodology. Most literature in this field is limited to solely valuation assessments and techniques. Little literature assesses implementation issues for real options in (large engineering) projects.

The concept of real options analysis poses significant opportunities to exploit uncertainty in projects and enhancing the project payoff. However, current practices for real options in project organizations find slow adoption. The reason for the slow adoption is mainly found in the reason for its complex valuation and distance to actual project management practices. Managers treat real options as black boxes, as it goes beyond their understanding. Real Options Analysis clashes with standard project management practice where uncertainty and flexibility are minimized into manageable levels, considered acceptable or bearable by the project owner. The lack of a comprehensive overview of required efforts to adopt real options in projects can reframe project owners from adopting this approach.

The conducted research focused on providing an overview of factors affecting real options implementation in large engineering projects. This is carried out by an extensive literature review on the real options discipline, the project management discipline and the found literature assessing the integration of both disciplines. Resulting from that analysis, a conceptual design is proposed to adopt real options in projects and its organization.

Placing real options in projects

Real options can be implemented in projects to prepare the project for foreseeable project scope changes. The project scope change is widened and multiple project end-states are considered. Adopting real options entails that these can be exercised and implemented without an intermediate scope change. Through this way, the cost of the initial scope widening can be earned back by saving on later project scope changes. Also, the project performs better in an uncertain environment as it can adapt more to this by exercising options. A clear project scope definition must be maintained to be able to maintain grip on the project progress. A clear real option design is required to avoid that a ill-defined project scope is adopted.

Results 1: List of factors influencing real options implementation in project organizations

A number of factors have been identified throughout the conducted literature review. These factors play a role concerning the adoption of real options in a project organization and implementation in projects. It entails a new set of tradeoffs which the project owner is faced with.

- Risks in RO. Adopting RO in a project does not result in a risk-free project nor RO. Unique project risks remain, resulting in a time-dependent risk discount factor and additional assessment.
- Experience with RO and portfolios of RO. Cumulative build-up and exchange of experience is required to learn from RO adoption. Most projects are eligible for a multitude of RO, careful balancing is required not to stress the project owners organization too much.
Financial health of the project owner. RO places a burden on the project owner's financial reserves. The viability of the project owner may set boundaries to the budget for RO and may vary over time.

Monitoring RO. RO need to be monitored and reassessed to determine whether they should be exercised. An approach may lead to a bias to exercise or abandon RO prematurely. Resources are required during the RO active lifetimes to keep the RO 'alive' and valid and determine the right time to exercise the option.

Cost of waiting. The required time to implement an option can result in loss of revenues. A choice exists between upfront implementation or at the moment of exercise. This results in a tradeoff between upfront versus exercise efforts, the required implementation time with loss of revenues for longer implementation times, and the flexibility for the options assets.

Project contract changes. The degree of uncertainty which is exploited by the RO, can initiate a rethinking the project contracts. When learning effects are to be maximized, flexible contracts may be preferred.

Specialized resources. These may be required for executing tasks in the implementation of a real option. These may need to be booked some time in advance, or bought against substantial higher cost.

Permits, EIA and regulation. Depending on size and activities for the option, permits, EIA or regulation may apply. This needs to be known upfront, as these could be combined with the activities upfront. Changes in permits or regulation can influence the option characteristics.

Technological developments. New developments may alter the expected uncertainty evolution. Thus changing the option characteristics.

External actor alignment. RO with long lifetimes require another actor alignment at the time of option exercise. This requires additional efforts, resources and implementation time to align the actors compared to a traditional approach. PR-activities concerning the active RO in a project over time is required to facilitate RO implementation.

Results 2: A conceptual design to adopt real options in projects and its organizations

The project plan in standard project management practice is extended with a project options plan. This document is used in the upfront phases where the design of a project is created and the Final Investment Decision is taken. Two plans are advised to be created, to enable a comparative basis between a standard and real options approach in the project. The project options plan should include the valuation assessment of the proposed real options and a first version of the implementation plan. This includes a technical design of the RO, the impact of implementation, a proposed monitoring approach and analysis of required resources, permits and project contract assessment. Other included elements are the options value, valuation method, assumptions, assumed and analyzed uncertainty and expectations regarding the uncertainty evolution over time.

The tasks considering the identification, assessment and implementation of real options show similarities with the objectives of tasks in project risk management. Though the methods are different, real options management approach can be combined with project risk management. Integrating both approaches creates synergies and reduces organizational costs. It also reduces a bias towards exercising or abandoning real options at a wrong moment. Resources could be reallocated within this department to other options or risks in the same department. Real options are documented throughout the PLC and are to be updated over time.
The efforts over time to enable real options implementation in projects are summed in a new factor called $m$, representing the cumulative expenses to enable real options implementation in projects. $m$ can be designed by varying in the intensity of upfront, variable and implementation efforts. This is represented in an options implementation approach which is developed in the project options plan. It is developed to enable optimal or satisfying implementation of the adopted real options in the project. Such an approach consists out of three elements: real options management planning, monitoring & control and decision rules. It contains the options characteristics, implementation plan and exercise criteria, and proposes how the monitoring & control should take place. Three different implementation approaches have been designed in this research:

- An upfront approach, where as many tasks and factors are executed upfront with intensive monitoring & control. Leading to quick implementation but against higher opportunity expenses. This approach fits for options with a high chance on exercising or of strategic importance to the project owner.

- A lean approach, minimal effort is put upfront, but prior to the moment of exercise. Resulting in lower cost, but a large reassessment before implementing the option, resulting in a longer implementation time. This approach fits for small options with a low chance on exercising or a small impact on the project.

- A mixed approach, where maximal benefit is sought for exploiting economies of scale and an 'average' between the first two approaches.

**Results 3: Impact of opportunity expenses on the real option**

Over time, uncertainty is resolved, leading to a lower spread and shifts in the real option value. Based on reassessments, an assigned options owner can advise the project owner or manager either to wait, exercise or abandon the option. Reassessments are carried out to check the options validity. Evolvement of uncertainty may not always result in the expected range of developments assumed or found in earlier analyses. Thus, the options value and characteristics may change over time. Not reassessing a real option can lead to a wrong exercise or abandonment decision.

The cumulative expenses made to keep the real option alive may enforce a renewed maturity date, where the options payoffs do not cover the expenses made anymore. This only holds for settings where the options maturity date is set when the option will definitely turn into losses for the project. This is presented in the figure on the next page. Additional demands can be stated for a correction factor to justify the real expenses made versus the potential value of the unexercised option. Example: for one million of real expenses, several times of potential value must be available at the option exercise moment.

**Illustration: Syngas production facility in port of Rotterdam**

A flexible syngas production facility in the port of Rotterdam is used as an illustrational case in this research. A flexible plant is valued with a range of real options as phased investments or as growth options. These are compared to a non-flexible plant configuration. A simulation approach is used to value the real options, while multiple price uncertainties are taken along in the analysis. The flexible plant shows significant improvements over a non-flexible configurations. The expected NPVs of the configuration are presented in the figure on the next page. Despite adopting a flexible approach, the overall expected NPVs remain negative.

The options implementation time for 1 or 2 gasifiers is taken at 2 years of implementation, due to the requirements of permits and environmental assessments. There is a considerable cost of waiting in-
involved (over EUR 6.7 million in 95% of the cases) which favors the adoption of a mixed approach over a lean approach. Executing tasks upfront reduces the options implementation time and improves the project returns.

The cumulative expenses involved to keep the options alive in terms of reassessments, permits and monitoring & control, are in this case of a marginal character. The average options payoff can reach up to EUR 200 million. The maturity date is reset for a couple of months, which shows a relatively small impact on a total lifetime of 20 years.

Concluding: message to project owners

This research aimed towards presenting a bundled overview for potential and required effort to adopt real options in project organizations and implement these in projects. The identified factors and presented implementation approaches, summarized in $m$, present a better balanced decision moment for project owners to adopt real options or stick to a conventional approach. The distance for real options integration in projects is surprisingly not that far from standard practices in project risk management.
Preface

After starting my bachelors SEPAM education in September 2004, I quickly turned into the energy & industry domain specialization as my main interest was at energy and chemistry. During my education, the emphasis has been put on the integration of different perspectives, from a systems point of view and actor point of view. The latter posed a new and interesting way for me at the start of my education. The need for policy and assessment from an actor point of view to allow proper implementation of (large) technical systems surprised me in the beginning. It posed a serious added value for my education. Meanwhile, I took additional electives in business economics and financial management, project and technology management as I continued to have broad interests.

The integration of these different electives and subjects into a graduation project immediately caught my attention as I passed by at Rob's office for an informal chat about graduation possibilities at the section Energy & Industry. The range of freedom in choosing the topic of my graduation project gave me a great opportunity to learn more of the real options perspective. A simple sentence posed by Rob showed me a 'light' where economics, a flavor of finance with technology and project management could be integrated in one subject. However, providing a setting for the graduation project proved not that simple, as I could not find a company willing to facilitate me with this topic. At that point, it was proposed that I do my project at the faculty TPM. Though it could give a certain difficulty in data analysis and a case illustration, the theory part could be exploited more optimally. Considering the low implementation adoption of real options in practice, this proved a good alternative. In September 2009, I kicked off. Filled with confidence in further exploring the topic of real options, project management and how these could be combined. I can honestly say I learned a lot along the ride concerning both fields of research and not to forget, the integration of both.

Though the product of any graduation project is a product made by a sole person, that person could not have accomplished this without support of nearby people. At first, I wish to thank the graduation committee for taking efforts in guiding me and feeding me with discussions on topics and ideas created along the way. I'd like to thank them also for providing the possibility to go overseas for some intense learning moments for real options analysis and applications. Second, I wish to thank prof. Neufville and his PhD-candidate Michel, for dedicating time to teach and support a graduation student with limited knowledge of flexibility in systems. A special thanks to Rob, my first supervisor, for various discussion and guide moments which proved necessary on more than one occasion, but also moments to pull me out of my 'safe modeling corner' and pushing me to set deadlines.

Support also came from beloved ones in my direct surroundings. Friends who were available for discussions on this topic and giving counterweight sometimes. My parents for their love and support wherever they could provide some to lighten burdens on my graduation project. And not least, my girlfriend Henriëtte who had to deal with sometimes a frustrated and saggy boyfriend, forcing me back on my chair and get to work. Thank you to all.

Finally, as promised, a thank you to Ramon, the morning shift guard, for the many times he walked with me to open an office for me at some early hours, to continue my work.
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1. Introduction

The implementation of flexibility in projects by the use of real options (RO) currently knows limited applications. Real Options Analysis (ROA) proposes a new array of valuation tools for projects of all kind. Though the methodology has been subjected to continuous developments in academic literature and attempts towards practitioners, RO hardly find their way into real projects (Borison 2003). RO valuation tools are abundantly present for specific case studies in academic literature. But little literature focuses 'bringing RO to the market'. There is no overview or assessment of indirect factors and effort that are associated with real RO.

This is, in short, the main reason for the initiating this research. In this report the field of implementing RO in engineering projects will be analyzed and a conceptual design is presented to adopt RO in a project organization and implement RO in projects. This chapter will elaborate on the research gap between ROA and the Project Management discipline, to lay out a basis for the thesis report.

In pursuit of future corporate success, managers have to deal with choices how to invest in projects today. In the recent decades, market places have become increasingly dynamic. This forces companies to become more agile in order to respond to changes in the market. The choices that need to be made today, in order to secure future revenues, are characterized by uncertainty and dynamics in the market conditions.

Under uncertainty, taking decisions becomes more difficult: the certainty that the payoff will justify the investment decreases, while the importance of acquiring a strategic advantage to the competition becomes increasingly important. Flexibility becomes an increasingly important issue for companies to 'stay in the game' (Yeo and Qiu 2003). Or to put it in another perspective: investors should aim to benefit from uncertainty (Cardin, Nuttall et al. 2007), rather than reducing uncertainty towards 'manageable levels' in standard practices (Perminova, Gustafsson et al. 2008).

Managers commit to investments, which are carried out to ensure future corporate success. Developing a detailed long-term strategic plan and fully committing to this without any intermediate changes, is considered to be unlikely in competitive markets (Yeo and Qiu 2003). Being able to alter a strategy on the way in order to enhance market benefits, holds value. Being and remaining flexible in uncertain and competitive markets, creates a potential to extract value against lower cost.

In the context of uncertain and competitive markets, uncertainty needs to be managed in an increasingly beneficial way for managers undertaking projects to safeguard their corporate future. The field of Real Options, emerged from discontent with conventional investment valuation methods, provides a new set of tools to value an investment while taking flexibility into account (Amran and Kulatilaka 1999).

This thesis will assess the theory of ROA and its integration with engineering projects. The main focus is not to assess the validity of the ROA theory. The asset valuation discipline is a well-known area, whereas the implementation of RO is not. There is a lack of literature considering the implementation possibilities how to implement these in projects. Section 1.1 elaborates on the two most important practices for this research, which leads to the identification of the research gap and the purpose of this research in section 1.2. An outline of this document is provided in section 1.3. A list of abbreviations used in this document can be found in Annex 1.
1.1 Problem statement
In this section, the Real Option concept is introduced in section 1.1.1, followed by a first view on Project Management in section 1.1.2. These two concepts form the main base for the research gap and the conducted research and design thereafter. The tension between both concepts is illustrated in paragraph 1.1.3.

1.1.1 Real Options
Though this concept is subject to more detailed explanation further in the report, a basic introduction of the concept is required for the research gap and goal of the conducted research.

The field of Real Options Analysis (ROA), as mentioned in the introduction section, has emerged from a discontent with conventional investment valuation tools, such as discounted cash flow techniques as the Net Present Value (NPV). The method presents a 'now or never' approach to any investment to be undertaken. The method ‘began’ its development in the 1970’s. Real Options, a term once coined by MIT Sloan Professor Myers in 1977, introduced a new perspective how to deal with uncertainty and volatility in investments. This methodology focuses on exploiting uncertainty rather than eliminating it (Park and Herath 2000), by converting an investment into different elements which can be (irreversibly) committed to at a variable moment. By doing so, more flexibility is created in the investment including the consequences for the potential investment payoff. This opposes to full commitment based on a single value as with conventional discounted cash flow models (Neufville 2003).

The goal of ROA is to value flexibility in investments, aiming to enhance the investment returns. The method acknowledges that a manager retains possibilities to actively intervene in the committed investments. Currently, a wide selection of academic research is available on Real Options and specific analyses in cases where flexibility might add value to a certain projects, investments or business initiatives 1.

Different types of projects can be related to real options. In this thesis, the focus is set on Large Engineering Projects (LEPs), based on developing technological related knowledge or (technical) facilities which belong to an engineering project. Real options in non-technical related environments, or in knowledge related projects are not considered.

1.1.2 Project Management
Projects can be found in virtually any professional field. The project management discipline, developed since the 1950’s, has an array of tools to initiate and execute projects as efficiently and effectively as possible. However, standard practice aims to minimize flexibility and uncertainty, as it endangers the efficiency of project execution.

A project, meaning a “temporary endeavor undertaken to create a unique product, service, or result” (PMI 2004), is undertaken to create certain benefits for the project owner(s) and/or project user(s). A project often requires an investment and allocation of resources. Classic project management practice dictates that an initial design for an artifact is proposed, which is executed according to as effectively and efficiently possible within the constraints of budget, time, quality and scope (Turner 1993).

1 See the literature section for a number of examples in this field.
1.1.3 Implementing Real Options in Project Management

Briefly stated in the first sentences of this chapter, the integration of both practices is hardly discussed within the literature. Some literature acknowledge the potential of RO, Miller & Lessard (2000) for example. They see potential of applying RO within projects, mainly as a competitive advantage. However, they rather focus on late locking as a mean to incorporate the maximum amount of flexibility in projects. Thus, they stick to a conventional approach. The choice to adopt RO within a project organization becomes a lock-in, and it potentially influences relationships with external actors. Common literature solely focuses on the value RO can add to the investment value, but do not consider any implementation issues (Luehrman 1998; Yeo and Qiu 2003; Copeland and Tufano 2004; Brealey, Myers et al. 2006; Hahn and Dyer 2008).

When a first view is given to both practices, they are contradictory. ROA focuses on exploiting uncertainty, while standard practice in project management aims to minimize uncertainty and flexibility during project execution phases. While the literature on the analysis and valuation of options is wide-spread, mainly under academic institutions, the implementation of real options is lacking (Borison 2003). 25 years after the introduction of the term by Myers, the method has a very limited structured application in practice. The low availability of literature concerning factors, effort and issues concerning the implementation of RO, create a gap in the current literature of Real Options.

A standpoint is taken that this gap potentially limits the adoption of RO in practice. Project owners and managers do not know how to cope with contradictory issues regarding uncertainty and flexibility. Thus, they stick to 'what they know and what has already worked before'.

This leads to the following research gap, which is considered central in this thesis:

*There is a currently a lack of knowledge regarding the indirect associated factors, trade-offs and effort required to enable real options implementation in engineering projects.*

1.2 Research & Design Goal

This thesis aims to serve both a research goal, and originating from the found results, propose a conceptual design to adopt Real Options in project organizations and implementation in LEPs.

The research consists of an extensive literature review assessing the fields of real options analysis, the project management discipline and the integration of both fields. Thus, the aim is conduct a qualitative assessment of RO and PM, and review earlier published research concerning 'putting RO to work'. The goal is that a comprehensive overview of factors is presented which affect the adoption of RO in project organizations and implementation in projects.

The identified factors are used as an input to propose a conceptual design how project owners can adopt RO in a project organization and how the factors influence the implementation of RO. The indirect factors are likely to have an effect on the choices which have to be made by the project owner to take RO along or to 'stick' to a conventional approach.

The contribution of this research and design is that project owners have a better view on the required efforts to consider and adopt RO in LEPs. The organizational and implementation efforts of RO are presented together. Overall creating a better decision moment for a project owner whether to take a RO approach or conventional approach to realizing the LEP. And how RO can be adopted in the organization to implement the RO.
To illustrate the proposed concepts, a case study is included. This case can be used to illustrate the value of flexibility by using RO, and how (a number of) factors affect the implementation of RO and the project performance. The case is based on literature and historical data, but is theoretical.

1.3 Research Questions & Report Outline
The identified research gap can be translated into the following main research question:

What factors affect the implementation of Real Options in engineering projects and how can these be handled?

This research question can be subdivided into several sub-questions, which address the main research question in achieving the goals stated in the previous paragraph.

1. What are the indirect factors of real options concerning implementation?
2. How do these indirect factors compare to a conventional project approach?
3. What effects does adopting real options have on the design and implementation of an engineering project?
4. What barriers can be identified when real options are taken along in the design phases?
5. How can real options be integrated into large engineering projects?
6. What impact do the factors have on the adopted real options in a project?
7. What additional value does a flexible synthesis gas production facility in the Rotterdam port area have over a lumpy investment alternative, and how are the options affected by the proposed implementation systems?

Sub-questions 1 to 3 involve the earlier mentioned literature analysis of ROA and PM. The main concepts and results from this analysis are presented in chapters 2 to 4. Chapter 2 elaborates upon important concepts of the PM discipline. Chapter 3 provides an introduction in the RO concepts. Quantitative aspects are not evaded, but are of marginal importance in describing the concepts and principles which matter for this research. The case does use a quantitative approach of the real options methodology. Chapter 4 discusses the identified factors for integrating both disciplines. The real options methodology is mainly assessed from a qualitative point of view.

Sub-questions 4 to 6 involve integrating the results from the literature review into a design how RO can be adopted in a project. Chapter 5 proposes a conceptual design to adopt RO in a project organization to enable implementation. Chapter 6 elaborates upon implementation approaches and how factors affect the real option characteristics.

Sub-question 7 involves the proposed theoretical case. Although this question and the case have no direct ties with main research question and its gap, it provides an illustration of the real option value and concepts of implementation. Chapter 7 discusses the model, set-up and results from a RO analysis.

Finally, chapter 8 presents the conclusions and reflects upon the performed research and proposed design.
2. **Project Management Discipline**

In this chapter a number of key aspects of the Project Management (PM) discipline are explained which are considered important in this research. Based on a literature review, a number of concepts are elaborated and discussed. First, in this paragraph the definition of a project and the PM discipline are given, as well as a brief elaboration of the project life cycle. This is followed by a brief elaboration on project scope management (section 2.1) and project risk management (2.2). Section 2.3 will elaborate on the concept of project plans and 2.4 will dive deeper into PM and flexibility in projects.

The Project Management Institute (PMI) defines a project as “A temporary endeavor undertaken to create a unique product or service”. Temporary is defined in such way that each project can be marked with a definite begin and a (pre-determined) end, when a project is completed (PMI 2000). A wide definition is provided in literature, because projects are carried out in virtually any discipline. A second important definition is also taken from the Project Management Institute (2000), concerning PM itself: “Project Management is the application of knowledge, skills, tools and techniques to project activities to meet project requirements”. Both definitions of a project and project management will be adopted in this thesis. Project based management is composed of a number of key tasks to control a project and to deliver the project within specifications, on time and on budget, with the ultimate goal of achieving project success. The definition of project success is ambiguous. The type of project partly determines how project success is interpreted: delivering a project within time, budget and constraints is not always the measurement for project success. This also depends on other factors such as project complexity and the chosen technology (Shenhar, Dvir et al. 2001).

Virtually all projects undergo a common set of phases, such as initiation phases as design and start-up of the project. Intermediate phases as project execution & operation phases. Followed by final phases as shutdown or demolishing of the project assets. These phases are referred to as the project life cycle (PLC) (PMI 2004). Annex 2 provides an elaboration on the PLC concept.

### 2.1 Project Scope Management

The final deliverable and the beneficial change set the project scope. The scope guides the project through its activities, thereby setting its aim. The definition as handled in this report is given by PMI (2004): "The work that needs to be accomplished to deliver a product, service, or result with the specified features and functions". Each project needs to have a well defined scope, in order to keep focus on the project and its deliverables. A project scope should describe, amongst others, the boundaries and constraints of the project. Together with the project organization, the project scope determines the balance between project quality, time and costs. These form the five key functions of project-based management (Turner 1993). This is also shown in figure 1 below. A more elaborate description of Project Scope Management (PSM) is given in Annex 2.

The definition of a project scope needs to be clear. An ill-defined project scope is often cause for schedule and budget overruns. A project scope that does not match the environment of the project execution, will lead to wrong deliverables or wrong timing of a project. Scope control throughout the different project lifetime phases remains important.
Project scope changes can be initiated over the project lifetime to realign the project with its environment and the deliverables. A dynamic project environment or long lead times of projects can enhance the chance of needing a project scope change. Three types of reasons for project scope changes can be identified:

- Technical requirements. A scope change is necessary in order to secure proper technical functioning of the project deliverables.
- Legal requirements. Changing regulations can enforce a different approach towards project in order to be allowed or able to implement the deliverables.
- Financial incentives. A change in the environment can provide incentives to initiate a scope change in order to enhance the project (and/or the deliverables) financial performance.

The result of a project scope change is alteration of the path how the final deliverables are created and/or alteration of the deliverables themselves. Project scope changes often occur at the expense of project efficiency, next to schedule and budget performance (staying within or on the set constraints) (Miller and Lessard 2000; Olsson 2008). Cooper & Reichelt (2004) investigated project changes, resulting in the advice to implement changes as fast as possible to reduce cost increases, and a multitude of changes have an disproportional impact on the project performance.

Due to a dynamic project environment, a clear defined project scope can become ill-defined over time. Thus, scope control remains necessary. Change requests in the project scope are to be documented, irrelevant of actual implementation.

2.2 Project Risk Management

Project Risk Management (PRM) has evolved over time to an integral part in the project management discipline. Risk management forms an important and integral part of projects. Virtually any engineering project knows risks of some sort (Miller and Lessard 2000). Despite the existence of multiple definitions for risk, often associated with ‘risk = chance * effect’, a more nuanced definition is used in literature (PMI 2000; Ward and Chapman 2003; PMI 2004; Perminova, Gustafsson et al. 2008; Verbraeck 2009). The definition of risk used in this report is based on UK PRAM 2nd edition 2004 from Verbraeck (2009) and Ward & Chapman (2003): “A risk is an uncertain event or set of events which, should it occur, will have an effect on the achievement of objectives. Risk consists of a combination of the probability of occurrence of a perceived threat or opportunity, and the magnitude of its impact on objectives”. Though risk is often interpreted with threats to achieving project

![Figure 1 - Five key functions of project-based management (Turner 1993)](image)
deliverables (the product) or the road towards project completion (the process). However, risk also entails opportunities as these pass by, that can enhance the deliverables or process. However, these are often neglected within projects. Some literature favors to explicitly focus more towards exploiting opportunities as well in projects, and turn project risk management into project uncertainty management (Ward and Chapman 2003; Perminova, Gustafsson et al. 2008).

A brief explanation of a common project risk management approach is discussed here. Annex 2 provides a more elaborate view on the approach of project risk, as presented in the PMBoK 2004 edition (PMI 2004).

- Risk Management Planning: identification how risk will be dealt with throughout the project phases
- Risk Identification: searching for risks that affect the project, and document identified risks for further assessment
- Qualitative Risk Analysis: prioritization of risks by qualitatively assessing their likelihood and impact
- Quantitative Risk Analysis: considerable risks are subjected to a more thorough analysis by quantifying the risk where possible and its impact on the project
- Risk Response Planning: development of mitigation plans
- Risk Monitoring & Control: reassessment of risk identification and analyses over time to monitor developments through project including response plans.

This is an iterative process, repeating itself as risks must be reassessed over time and adjusted on the renewed project environment. Figure 2 shows a simplified flow scheme. A response plan to a risk can influence the project. Risks and their approach need to be documented. The project may need to be changed to cope with the identified risks and approaches: The response plan may need a change request to realign the project key tasks with this risk. During the risk monitoring & control phases preventive & corrective actions can be proposed. Approved change requests are to be documented in the project database, possibly resulting in an updated project management plan. These updates initiate new rounds, because changes can lead to identification (and required assessment) of new risks.

All identified risks in a project can be documented. Such system, a risk register, can serve as a central database to list the identified options, prioritize them, and link response plans to them. On top of that, risks can be assigned to a certain owner, who is responsible for assessing the risk and the response plan when necessary. Correct documentation of these risks is important, as well as any approved change request in the project. Approved change request can cause the initiation of project scope changes, depending on the risk.
2.3 Project Plan

Projects need guidance and active management to create their deliverables (Turner 1993). In the initial phases of the PLC, a project plan is commonly created which can shape this management. This section will enlighten the concept of this project plan.

A project plan can serve as support item for the project owner or management for taking the Final Investment Decision (FID). After that point, the project is committed to by the project owner for further development or advancement throughout the PLC. It contains a variety of analyses, integrated into one document to form a "consistent and coherent document that can be used to guide both project execution and project control" (PMI 2000). Companies can have frameworks for project plans to standardize formats. Usually, project plans for projects show common ingredients. Annex 3 contains a list for project plan elements, but the most important aspects are that the project scope, approach, background and costs are assessed. The motivation for commitment to the project is reflected, usually in the project charter. A first assessment of the risks and benefits is included. It should be noted that a project plan is not a necessity, but will provide a more structured view for taking the FID. In this thesis it is assumed that, especially for larger engineering projects, project plans are common practice in project management. The document is commonly intended to be short and to the point.
An adequate project plan should create a structured view on the project’s cost, necessity and potential benefits. Although it is not explicitly stated in the PMBoK editions of 2000 and 2004, a financial analysis can be important. A financial analysis, such as a Discounted Cash Flow (DCF) analysis, can be used to justify the initiation of a project by mapping the cash flows (and profits from the project). The project plan’s primary function on the short term is to guide the project execution and control phases, while the financial analysis focuses on the entire lifetime of the project.

The position of the project plan within the PLC can be multi-fold. It can be used and reassessed multiple times in the initial phases of a project: at the project start, after the conceptual design, and after a detailed design, prior to execution phases of a project. This document is revised over these phases of the project, again to support the project owner in taking decisions regarding project continuation.

Another use for a project plan is to align a project with the project owner’s strategy and firm (strategic) vision and ‘culture’. A company can have certain preferences regarding the level of risk it is willing to take and able to bear. A project deviating too far from the owner’s vision or strategy can cause a loose project scope, possibly resulting in budget and schedule overruns. Thus, a project plan can serve to identify whether the project fits in a company portfolio.

2.4 Flexibility in projects
This section will review current literature assessing flexibility in projects and how this can change the view on projects and their management. Flexibility is an important interrelating component between the fields of RO application and PM practice.

Flexibility in projects is generally not conceived as desirable in the PM discipline. Projects usually request a stable and controlled environment to enable efficient execution (Olsson 2008). Efficient project execution is often measured in terms of meeting time, cost and specification settings for the project. In that sense, uncertainty and flexibility are to be minimized (PMI 2004). This contradicts with the statement made regarding real options in the introduction chapter: uncertainty holds value, and introducing more flexibility into projects can allow a higher extraction of value. An uncertain and dynamic world full of new developments requires a different approach in order to successfully stay in the market for companies operating in such environments.

Strategic management states that flexibility is placed as an instrument to manage uncertainty (Mintzberg 2006). Flexibility is linked with uncertainty: if no uncertainty exists, the returns of any initiative would be certain. Therefore, no incentive would exist to implement flexibility. It would imply additional efforts without any increase in the benefits. If the returns of a project are already known and certain, then there is no variability. In practice however, there is always a certain degree of uncertainty present. Depending on the level of uncertainty, the implementation of flexibility in a project can become beneficial.

Multiple forms of flexibility in projects exist, which can have a different impact on the PLC. All phases in the PLC can be affected by introducing flexibility into projects. A number of different flexibility concepts are elaborated in this section: internal & external flexibility and flexibility in the product and process. The impact of these types of flexibilities on project management perspectives are enlightened.
2.4.1 Internal & external flexibility

Internal and external flexibility refer to different elements of flexibility in projects. Internal flexibility refers to how project requirements are to be met, while external flexibility aims to define what requirements are to be met within a project (Olsson 2008). External flexibility refers to the definition and management of the project scope. In this sense, internal and external flexibility interact with each other.

Internal flexibility refers to a project's efficiency. The issue how requirements and objectives will be met is determined by the project organization and the level of constraints put on the resources for allocation over the different project tasks.

External flexibility relates to project effectiveness. The common objective of a project is to increase the value for the project owner. Due to shifts in business and/or project objectives, flexibility in the project can be desirable. The value of this type of flexibility is the primary field for real options applications in projects (Amran and Kulatilaka 1999).

The level of interaction between internal and external flexibility can differ from a stakeholder viewpoint. Actors in the execution of a project may interpret the different types of flexibility in another way (Olsson 2008). However, for all actor positions in a project setting the external flexibility defines the boundaries for the internal flexibility. The scope of a project determines its management: the identification of the project scope, control and changes. Scope changes are determined by these levels of flexibility. The degree of 'free movement' within the project scope determines the degree of internal flexibility. An example can be given for resource allocation: the less restrictions on how use of resources are to be used, the better optimization can be applied. This in turn may result in less conflict situations during the PLC. Another small example is the change of delivery date for materials, which may be a change within the project scope for the project manager, but an external scope change for a supplier.

Generally, in the front-end phases of projects (setting the requirements and forming the design of the project deliverables) flexibility is not undesirable. Often, flexibility is encouraged in these phases. In the early project phases there is plenty of room for maneuvering in order to capture uncertainty and 'set' the project (deliverables). But after the project has been approved and the FID is passed, the room for external flexibility strongly diminishes. The focus turns to execution of the project in a 'controlled environment' (Olsson 2006b). As the project progresses, the room to maneuver becomes smaller. Changes in later project phases come with significant cost increases. This is graphically represented in figure 3 below.
This intuitively makes sense: when a project is in its execution phases, changing the project scope or activities comes with significant more effort compared to upfront phases. Thus, standard PM practice aims to limit the external flexibility during later project phases. The room for maneuvering during later project phases is mainly embodied by the possibilities shaped by the internal flexibility. Hence, the potential to make use of external flexibility (thus to implement project scope changes as efficiently as possible) diminishes over time. The decreasing potential to maneuver can provide a conflict area. In later stages of projects, room to maneuver can be desirable by project owners or users. New information can arise which can enable project owners to add value to their project (Miller and Waller 2003), thus initiating a scope change. The importance of internal flexibility grows over time. A higher degree of internal flexibility can allow more efficient project execution, as the activities can be continued as they were intended within the set boundaries in earlier project phases. The internal flexibility during initiating phases of a project are only marginal. But the front-end phases shape the internal flexibility, thereby partly determining how efficient a project can be executed (assumed that the conditions do not significantly alter during the PLC). This concept is represented in figure 4 below, where the relative share of external and internal flexibility are represented.

Olsson (2008) links the internal and external flexibility with internal and contextual uncertainty. Internal uncertainty would refer to the unknown events or variability within the project scope, while contextual uncertainty refers to unknown events outside the stakeholders manageability. Contextual uncertainty implies adaptations of the project or within the project depending on developments outside the influence of the stakeholder. See figure 5 below for an overview of these combinations.

<table>
<thead>
<tr>
<th>Internal flexibility</th>
<th>Contextual uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustment of plans due to new internal project information</td>
<td>Adjustment of plans due to new prerequisites</td>
</tr>
<tr>
<td>Scope adjustments due to new internal project information</td>
<td>Scope adjustments due to new prerequisites</td>
</tr>
</tbody>
</table>

Resolving uncertainty can lead to new information. Internal uncertainty elements will generate new information regarding project elements within the scope (for example task durations). This may lead to internal adjustments (such as the plan in case the new duration is not on a critical path) or to an adjustment in scope (delivery date adjustment or search for another subcontractor which can do the
job). The same holds for contextual uncertainty. New prerequisites can be formed due to new information, which can enforce a change in the project progress. If the new prerequisites can be processed within the current project scope, the issue can be resolved making use of internal flexibility. If not, a scope change is necessary to cope with these changes. New prerequisites derived from contextual uncertainty are not always undesired. These can add value to a project. When a scope change in a project is needed, this does incur additional cost and effort, as the current approach needs to be altered.

2.4.2 Flexibility in product & process
Flexibility can be applied in different phases throughout the project and in different ways. The project deliverables or product can hold a certain degree of flexibility, as well as the process towards setting the project objectives.

A flexible approach in the project process is difficult to manage. Flexibility can be used to diversify the design process of developing and setting requirements for the project deliverables. Deadlines can be difficult to establish when a flexible approach is adopted, since a higher degree of flexibility entails fewer restrictions on the planning scheme. Especially when a project owner is operating in a complex setting with many external actors. These actors may not have aligned interests. A 'standard' PM approach is likely to lead to adverse results. Deadlines set in a project, where negotiations need to take place, can provoke strategic behavior of significant actors who's commitment is considered necessary. A process design can facilitate decision-making to align actors for a project, but the overall project deliverables are hard to determine upfront. Instead, the result is likely to be a compromise of a series of solutions, possible for multiple problems. It should be noted that adopting such a flexible (soft) approach demands time (Bruijn and Heuvelhof 2004). A process approach can be used to create a strategy between the actors to hear opinions, adjust the project deliverables or how the project is executed. In the end, resulting in more efficient execution of the project because resistance is lowered. Late locking of different project requirements or the process is preferred by Miller and Lessard (2000) as method for dealing with uncertainty and flexibility. This approach towards flexibility in process is aimed to deal with possible strategic behavior from external actors.

When the project initiator does not depend on external actors (with different interests), building more flexibility in the process is likely to be easier. As less actors are involved, combined with the state of mind of these actors, cooperation is easier to establish. Increasing flexibility in the process partly entails less restrictions on the planning process. This creates a higher degree of agility for the involved project members to complete the project. Olsson (2008) advocates that less restrictions in resource allocations allows a higher degree of flexibility for managers to use their resources optimally. This lowers the probability that conflicts cannot be solved within the 'playing field' of the manager. Less restrictions do not necessarily lead to loss of control over the project. However, project documentation is and remains important. All deviations and occurrences have to be documented in case evaluation is requested. General, it can be expected that more intensive communication is needed within the institution taking on the project. Less restrictions results in a higher degree of freedom to allocate resources (equipment and personnel), which have to be informed and consulted. These resources (especially human assets) need more guidance by the project manager in order to be matched with tasks in the project. When different actors are involved in a process involving less restrictions, more intensive cooperation is desirable to prevent mismatches. The relation between different direct involved parties within the development and
execution of projects are laid down in project contracts. Annex 2 and the PMBoK (PMI 2004) provide an overview of various types of contracts. The type of contract defines what kind of cooperation is desirable (or not). For example, turn-key contracts in project allow flexibility towards the (sub)contractor(s) to fulfill their requirements regarding project deliverables. But these types of contracts work best on low-tech projects where there is less uncertainty involved. Reimbursement contracts propose more intensive cooperation between project owner, manager and contractor(s).

The product is defined as the result of a project, which is usual a physical artifact. Flexibility in the product relates to the ability to adapt the project deliverable(s) to the surrounding (potentially changing) environment. This is where real options can be applied. This type of flexibility can refer to expanding or cutting capacity by shutting down sites, or investing in an additional production chain. Flexibility in operation modes is another example.

Both types these flexibilities can be combined in designs, as they can interact with each other. The type of flexibility desired in the product is to be investigated and laid down in the requirements for the project during the design phases. This is the primary responsibility for the project owner (assuming that the project owner initiates the project to make use of it during operation). A flexible manufacturing process can be proposed, where the management has the ability to lower production capacity if markets develop downwards, while options are built into the project to expand the production capacity in case of favorable market developments.

Flexibility in a product generally requires an additional investment in the project design. By doing so, the project owner reduces its costs of altering strategy during the projects life in case this is deemed necessary, or shows potential to extract additional profit (Miller and Waller 2003).

2.4.3 Flexibility & scope
Regardless whether flexibility is consciously prepared for in a project, it is often used in some way. In the front-end phases of projects, flexibility is least discussed and even encouraged. It can enhance the design process towards a satisfying design meeting the requirements (Miller and Waller 2003; Olsson 2006a). Though the general aim is to minimize flexibility in execution and operation phases, it does not entail that the inclusion of flexibility is always negative for projects.

Expanding internal flexibility shows potential to reduce costs in a project. An increase in internal flexibility is often acquired by reducing the number of restrictions, but more intensive communication is necessary. This depends on the number of tasks and the project complexity. Due to this higher agility given to the manager, reductions in cost can be achieved. Olsson (2008) reports that high internal flexibility can induce cost reductions of around 10% due to optimizing resource allocation in construction management, as well as cost reductions achieved by lean project implementation. However, the potential of cost savings by more internal flexibility is relatively small compared to possibilities originating from external flexibility.

External flexibility concerns the effectiveness of the project. Contextual uncertainty developments can lead to new premises. This can trigger project participants (the project users and/or owners) to implement another strategy for the project. This requires a project scope change if the current one cannot comply with this demand. Changing the project scope in later project phases (after the project has been approved) shows significant rising cost (see figure 3).
The number of scope changes likely depends on the complexity grade of the project, the technologies used and the uncertainty surrounding the project. The initiators for external flexibility see potential in changing the project in order to benefit from a better usability of the project during later phases. Reducing the number of scope changes can increase the reliability of the budget estimations. Hence, increasing the financial reliability of the project.

When a 'low-tech' project is executed, the number of scope changes the project participants expect will be lower and the expectations that the project will be delivered on time, budget and specifications is larger than a 'high-tech' project where the technology for application is brand new. Next to this, the size of the change is a contributing factor as it increases the effort to cope with change in a disproportionate way (Cooper and Reichelt 2004). The best way to cope with project changes is to implement the change (if considered necessary) as fast as possible to minimize cost increases. This does not exclude the possibility that the increased effectiveness resulting from the scope change pays itself back during the operational phases of the project.

Project members can prepare for scope changes up to a certain degree. The project organization can build elements into their scheme to cope with changes during the PLC. Project scope management is an important part in all phases, as it determines the focus and what is outside the boundaries for the project. Possibilities exist to prepare for certain project changes.

An adequate assessment of the project scope is necessary to ensure a scope tight enough to guarantee the projects effectiveness and efficiency. This includes an important trade-off. A project scope which is vaguely defined, can lead to ill-defined project activities without clear purposes. However, a higher level of internal flexibility can be created by providing a wider project scope. Thus more agility for the project members to execute the project in a flexible way (both in the process and the product). But implementing flexibility in projects has costs: effort, time and resources, next to the direct related cost for options (see chapters 4 and 5 for a more elaborate illustration on this principle). There is a trade-off between setting a tight project scope to ensure project effective and efficient implementation. More flexibility can come at higher cost and effort, but can (not necessarily) heighten project payoffs and implementation success. But too much flexibility will cause a loose project scope and projects without vision.

The opposite can suffer from the same illness: providing a too narrow defined project scope will neglect the projects changing environment, requiring more scope adjustments over time. Next to this, neglecting flexibility could make a difference: added value, reduced cost and/or risk or even not initiating a project. Thus, running into (unanticipated) cost increases the chance on project failure.

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2 Low-tech refers to using well established techniques which have been proven multiple times in practice.
3. Real Options Methodology

The field of real options (RO) is the other main topic of research within this thesis. Based on an extensive literature review, the concepts of real options thinking and application are elaborated in this chapter. The review provides the basis for comparing and integrating real option applications in projects and its management in later chapters in this report.

The concept ideas behind real options are briefly presented in 3.1. Next, the method is compared with other, more traditional, investment (e)valuation techniques in section 3.2. Section 3.3 elaborates on different types of real options. Different general valuation techniques are discussed in section 3.4. The chapter is concluded with an overview of direct hurdles that are brought into the setting by RO. RO applications are mainly discussed using relatively simple examples and qualitative assessment of the RO theory. The focus is not to discuss the entire real options literature, where the methodology has been fine-tuned on many individual cases present in academic literature databases. Rather, the discussion of the concept of RO is included to introduce the reader into the purpose of the conducted research. An illustrative case study is used for a more elaborate example with a number of real options in chapter 7.

3.1 The Real Options concept

The definition of a real option is given as ‘the right, but not the obligation to take an action at a predetermined cost for a predetermined period of time’ (Copeland and Antikarov 2003). This concept will be explained in this paragraph, starting by briefly explaining the history of real options, followed by its application purpose and implications in investments.

3.1.1 The roots of the real options methodology

The roots of the real options methodology can be found in the financial stock options pricing. Financial stock options are contracts that are sold against a certain premium, where the buyer obtains the right, but not the obligation, to buy a stock against a predetermined price. A stock price can deviate in value, and when the option is ‘in-the-money’, the owner can exercise his option, buying the stock against the predetermined price instead of the actual market price at that moment. Annex 4A presents a short and simplified example of this principle.

Two types of financial options are generally traded: put and call options. Call options allow the owner of the contract the right to buy a stock at a predetermined price within at a predetermined time. A put option is the opposite: the owner holds to right to sell a stock against a predetermined price at a predetermined time. This holds for European types of financial options. Different types of financial options exist. European options are types of options that can only be exercised at their maturity date. American options can be exercised any time within obtaining the contract and the maturity date. This changes the possibility for the owner of the contract to exercise his option between the date of obtaining the contract and the maturity date (the date that the option expires).

A breakthrough happened in 1973, when Black & Scholes published their model. They constructed a model capable of valuing financial options in a closed form formula. This work was awarded with a Nobel Prize in 1997. Their equation was able to quantify the value of an European financial option.

The model assumes a risk-neutral world, where the equations are as given below (Yeo and Qiu 2003):

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3 A ‘funny’ side note is that the European stock markets merely trade in American stock options.
\[ c = SN(d_1) - Xe^{-r(T-t)}N(d_2) \]

With \( d_1 \) and \( d_2 \) as:
\[
d_1 = \frac{\ln \left( \frac{S}{X} \right) + \left( r + \frac{\sigma^2}{2} \right)(T-t)}{\sigma \sqrt{T-t}}
\]
\[
d_2 = d_1 - \sigma \sqrt{T-t}
\]

See the table below for the explanation of the variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Represents</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c )</td>
<td>Price of a European call option</td>
</tr>
<tr>
<td>( S )</td>
<td>The stock price</td>
</tr>
<tr>
<td>( r )</td>
<td>Risk free rate of return</td>
</tr>
<tr>
<td>( X )</td>
<td>Strike price (exercise price) of the option</td>
</tr>
<tr>
<td>( T )</td>
<td>Expiry date of the option</td>
</tr>
<tr>
<td>( N(x) )</td>
<td>Cumulative probability distribution for the standard normal distribution</td>
</tr>
</tbody>
</table>

Table 1 - Variables in the Black-Scholes formula

Over time, this framework was extended, and the theory was 'tried' to evaluate flexibility associated with physical investments (Yeo and Qiu 2003). The thought behind these applications is that current valuation tools for investment fail to capture a crucial element for managers, which is the possibility to intervene in a project when considered necessary or desirable. The link between the financial and real options can be explained using the Black-Scholes formula 'where it all began'. The variables listed in the table above can be linked with variables which compare to those of an investment. Luehrman (1998) lists these in an overview, which is given in the figure below.

A change in the variables will change the value of the option in the investment. A longer time to maturity, or expiration, of the option will enable the option a longer period to reach a desired value (for example higher). A higher present value will increase the option, while a higher expenditure will lower the option value. An increased risk profile, or increased uncertainty, will resolve in a higher
volatility rate for the option, thus resulting in potential higher values to be achieved and thereby increase the options value. Finally, the time value of money will affect the present value of the project assets, thereby: a higher rate will lower the option value (Amran and Kulatilaka 1999).

3.1.2 Flexibility as a choice

Taking real options in consideration for an investment or project is a choice, to be made by the decision makers in charge of the investment. This is the project owner and/or the users. Olsson (2006a) found that these involved project members are least averse for flexibility in projects. Adopting RO is a choice, not a necessity. This paragraph will elaborate on this choice.

Traditional valuation tools for investments assume one single line of developments, such as discounted cash flow (DCF) techniques, for example the net present value (NPV), or internal rate of return (IRR). Depending on the decision rule, set by the decision makers of the investment, the investment will be rejected or committed to. These methods assume full commitment to the entire project, irrelevant to all intermediate developments which might happen after the FID. Real options recognize the flexibility management retains to alter the course of their investments after the FID, but values this as well. By taking options along, more flexibility is taken along in the investment. Uncertainty is a very important element in the decision to consider real options in a project. Increased uncertainty will positively influence the options value, because it allows a higher potential value of the assets. A higher volatility means that larger deviations from the average value is possible, both upwards and downwards. If the option is not ‘in-the-money’ it will not be exercised, thereby limiting its impact on the project. If the option is exercised (when it is ‘in-the-money’), it will increase the project value and positively affect the project.

Each project or investment can take along different options (see section 3.3 for types of real options). This sets the amount of flexibility in the project for the management to maneuver. Each option which is taken into consideration, is assessed on its value. Since each project is by definition unique, different (combinations of) options can be considered. Each option is valued and thereby decided whether it should be taken along. When an option does not increase the value of the project, the option is excluded from the valuation analyses, because it holds no value to take the option along in the project (under the assumptions and conditions of the analysis). Therefore, it would be unwise to dedicate effort to the analysis of RO if it negatively affects the project. This can be represented by an expression for the real option (Cardin, Nuttall et al. 2007):

$$V_{flexibility} = MAX[0, NPV_{flex} - NPV_{non-flex}]$$

As can be determined from the formula above, the real options approach is to be considered as an extension to current investment valuation tools. Traditional methods as the NPV will continue to provide the basis for investment evaluation. Rewriting the formula gives the ‘conventional’ formula for obtaining the value of flexibility or the value for the option(s) (Yeo and Qiu 2003):

$$NPV_{active} = NPV_{passive} + c$$

Where the $NPV_{active}$ is the strategic NPV with the value of the flexibility (represented by c). Figure 7 shows an application of a real options approach on an investment valuation result. By taking a RO approach, downside risks are reduced while upside potential is enhanced. This way, the investment
gives better returns, as corrective actions (which are prepared for by taking the specific real options along in the investment) alters the expected outcome of the investment.

Generally, RO are considered when a project is to be initiated while faced with significant levels of uncertainty. In these situations, RO can increase the projects value. In Annex 4B, a simple illustration is given how flexibility can help increase a projects potential value.

Besides the existence of sufficient uncertainty, it is important that the addition of flexibility has a beneficial impact on the project. When an investment valuation shows that the project has a very strong positive value, adding flexibility can increase the potential, but will not be crucial for the investment decision. Increasing the level of flexibility results in putting more effort into the project, which will not pay off in a change of the decision. The impact of a real options approach is generally at best when the passive NPV shows a value near zero or slightly negative. Adding flexibility at this point can enhance decision making whether and how to invest. This does not withdraw the potential to include additional flexibility to enhance the (expected) project returns even further if the value is already positive.

So, applying ROA to value investments in advance can be advantageous when sufficient levels of uncertainty exist and a classic NPV is (slightly) negative or zero. The choice to apply ROA to an investment does come with a different mind-set compared to traditional investment analysis (Amran and Kulatilaka 1999): flexibility is no longer minimized. The focus shifts towards exploiting uncertainty instead of minimizing. The approach of risk within projects changes. In a conventional approach towards project valuation and acceptance, risks and uncertainty are treated as undesirable and are reduced to 'manageable levels' (Perminova, Gustafsson et al. 2008). ROA tends to be more pro-active in the approach towards risk: focusing on reward maximization by exploiting uncertainty and risks (Neufville 2003). This is represented in figure 8. Since risk can also pose opportunities for investment returns, ROA can be placed as an attempt to actively use risks to enhance the investment returns.

Figure 7 - Schematic representation of the impact of including flexibility in project valuation (Yeo and Qiu 2003)
When no or little uncertainty is identified in a project, the returns are also less volatile. Thus, a lower risk-adjusted discount rate can be chosen (Brealey, Myers et al. 2006). The assurance that these cash flows are indeed ‘collected’ after the investment has been made, is larger than with projects that do have inherent high levels of uncertainty. Because the uncertainty is lower, the volatility of the project’s underlying assets will change less dramatically over time, thus limiting the spread of the present value. Conducting a real options approach towards such project will show that building options on a project have a lower value. In fact, without sufficient uncertainty, it would more likely be a waste of effort and resources.

3.1.3 Real Options are never optimal.

With the gift of hindsight, options are never necessary. When there is no uncertainty concerning the investment or any project, taking options along in the project is unwise as it reduces project efficiency. In other words: options are never optimal. Consider an example for car insurance.\(^4\) Insuring a car involves paying a premium to cover for the potential crash the driver could get involved in for the coming year. There is a chance to get involved, but there is also a considerable chance that the driver will not be involved in any traffic accident. When the car is insured, and the driver does not experience any accident with damage as a consequence, he will leave his 'option' unexercised. Therefore, he wouldn’t have needed the option and would have been more efficient not to insure the car. However, in the event the driver does get involved, and the car is not insured, the situation is not optimal either. Paying for the full damage is less optimal than when he had insured the car, paid the premium and exercised the option to let the insurance pay for the damage. There is a possibility that the driver will not get involved and did not insure his car. This event is optimal, but the driver has not taken along the option. However, considering the risk the driver could get involved, the 'robust' way would be to insure the car. Or one could say the way of 'least regret'.

Concluding, RO will not focus on achieving efficiency of the implementation for an artifact. Rather, it aims to enhance the effectiveness or 'least regret' to an artifact. A successful application of ROA to an investment will result in higher payoffs, but more importantly: an artifact that suits multiple end-states in the face of uncertainty. The higher payoff is a result of the given flexibility to the artifact to adapt into a changing, uncertain environment. Important to note is the upfront recognition of these impacts, since ROA focuses on providing a number to support decision makers in taking the FID.

3.2 NPV, Decision Tree Analysis & Real Options compared

This section will compare this ROA methodology with other forms of investment and decision analysis commonly used. The differences in the approaches are highlighted. It also sheds some light on the applicability of these techniques in practice. First, the NPV is compared with ROA, followed by

\(^4\) This is again a simplified example, removing the demand that car insurance is not mandatory by the authorities.
the comparison of Decision Tree Analysis (DTA) with ROA. The use of this comparison is placing ROA in perspective with other valuation techniques for application and use.

As mentioned in chapter 1, the adoption of ROA in real investments is proceeding in a slow pace. However, it would be unfair to neglect the fact that a number of companies do use Real Options in their valuation assessments. Consider the following overview, for 205 companies out of the Fortune 500 in 2002/2003 (Copeland 2008):

- 96% use NPV
- 67% use Scenario Analysis
- 11% use Real Options Analysis

11% is a rather low adoption rate for a valuation which exists for over 20 years. Yet, ROA is still developing new applications and models. Next to this, there is a considerable amount of companies who gave up at real options analysis after they considered it: 32%, contrary to 11% abandonment for other valuation techniques (Copeland and Tufano 2004). Lander & Pinches (1998) devote that the required assumptions to mathematically enable RO applications limit the scope of applicability.

### 3.2.1 Net Present Value

The most common applied investment valuation technique is the Net Present value (NPV). The NPV is a form of a discounted cash flow (DCF) valuation. This tool compares the required investment cost with the revenues (either cash inflows or savings) it will generate. Next to this, the time value of money is taken along. Currency now is worth more than later. The cash inflows and outflows are corrected for the inflation rate or opportunity cost plus an adjustment for the risk associated. A method to determine the risk-adjusted rate on an investment, is the Capital Asset Pricing Model, or CAPM. This model allows to compare a risk free rate plus a risk-adjustment rate for the risk profile of the investment. The risk profile is determined by the market (Brealey, Myers et al. 2006). Thus, the method returns a figure for the investor. Commonly, when NPV > 0, the investment should be taken along. The total payoff, discounted for the time value of money and risk, shows a positive result. In practice, when the NPV shows around zero, an investor will take a closer look before in investing or rejecting a project.

However, there are some flaws in this method. The conceptual flaw of the DCF methods, such as the NPV or Internal Rate of Return, is that these ‘assume a single line of development for a project’ (Neufville 2003), based on averages. In uncertain worlds, the resulting cash flows can’t be determined accurately, but rather form a distribution of possible cash flows in the future of the investment, depending on the (market) development in that same period. A mechanical flaw in the DCF-techniques is that the discount rate is set once for a project. However, the technology used in the project can change throughout time, causing the associated risks profile to change as well. Setting a risk premium to obtain an appropriate discount rate is difficult in advance, and may change over time (Brealey, Myers et al. 2006). This implies that the value of the specific exercisable option(s) of the associated asset are subject to changes as well. Another flaw is that the NPV assumes that an average input results in an average output. However, in general project payoffs are asymmetric. In other words, the flaw of the averages applies (Neufville 2003). These characteristics lead to the failure to value flexibility that managers have in their projects. Real options allows some level of intervention for managers and to value these actions upfront. Thus, it results in a better approximation of the project value, rather than assuming one line of development, and full
commitment regardless future events. Guthrie (2009) categorizes static DCF analysis as limited to situations where managers do not have to commit to follow-up investments which influence incremental cash flows. These situations can be captured better by using DTA and ROA.

It should be noted that ROA remains based on DCF methods. Valuing investments through the use of real options still requires to discount the cash flows over time. However, it is considered that the use of options alters the investments risk profile, thereby allowing for a lower discount rate. By recognizing options and taking them along in the valuation, the risk profile is altered. Thus allowing a correction in the discount rate. Often, ROA assumes a risk-free setting for the option valuation, often labeled as valuation in a risk-neutral world. See section 3.4 for more on this topic.

3.2.2 Decision Tree Analysis

Decision Tree Analysis (DTA) extends on the NPV method. The basic method is the same, while it acknowledges a certain degree of uncertainty that is inherent in the project. Often, DTA is used as a form of scenario analysis for projects. This relative simple extension to the NPV allows to compare multiple scenario’s, depending on a (limited) number of external developments. The manager can choose the best alternative to invest in. Using this method, there are two important elements in the analysis: event nodes and decision nodes. Annex 4B shows the potential added value when it is recognized that managers have the ability to alter the project in later stages.

The benefit of this method is that the impact of decisions is mapped in a clear way. Sufficient knowledge is required to determine identified possible future states. Each alternative is valued, usually with a constant discount rate. When all alternatives are valued, they can be represented in a tree. By working backwards through the tree, the best action to take at each point can be determined, to work a way through the tree towards the most optimal end-state of the investment. Regarding the element that sufficient knowledge is required: the method assumes that all possible end states can be assessed. The uncertainties need to be translated towards probabilities. This is not always possible (Guthrie 2009). There is also limited possibility to include flexibility in point where decisions can be made. In other words: it is assumed that there is one point, pre-determined in time and with pre-known possibilities, with a certain static value representing the payoff of those choices.

The main disadvantage of DTA lies in the limitation of the amount of decisions that can be modeled, without the tree becoming bushy and difficult to analyze. Thus, a window where a decision can be taken, either upfront or later on, becomes difficult to analyze. This is a problem which can be overcome using RO. Taking a decision alters the project risk profile, which would require an adjustment in the risk-adjusted discount rate (De Reyck, Degraeve et al. 2008). If this is not carried out, DTA would violate the law of one price (Copeland and Antikarov 2003). However, it is possible to value certain options through the use of DTA. De Reyck et al (2008) developed a method to value options by analytical calculations.

3.3 Types of Real Options

Each project shows unique characteristics. By applying more flexibility in a project, thus, the flexibility would be of a unique character as well. However, a number of categories for options can be identified, showing that a limited number of flexibility topics cover most issues. Section 3.3.1 lists a number of option types and explains these. This is followed by another type of distinction in the real options practice.
3.3.1 Categories of Real Options

There is a distinction to be made between 'simple' options and 'compound' or 'complex' options. Simple RO consist of the valuation of solely one real option taken along in a project. Whereas the opposite, 'compound' or 'complex' options, are created by a combination of different types of options (Trigeorgis 2005). The valuation of a simple real option in a project is more straightforward, as there is only one valuation assessment to be carried out. When a combination of (different types of) RO are taken along in a project, each with its own characteristics, the value of the options may interact with each other (Benaroch 2001). Thus, that would make the assessment of the (individual) options value more difficult. Interaction effects prohibit to calculate the sum of the options assessed as 'simple' options (Trigeorgis 2005; Brosch 2008). Brosch (2008) has developed a methodology to analytically assess real option portfolios in order to acquire the appropriate value while not ignoring their interaction effects.

Overall, seven categories of simple RO exist (Amran and Kulatilaka 1999; Benaroch 2001; Yeo and Qiu 2003; Guthrie 2009). These are listed and explained below:

1. Option to defer
   Postponing an investment to allow learning can increase the value of a project. More uncertainty about the project outcomes can be resolved. The investor can be given better insight about future financial flows and allow a better decision for commitment to the investment. This is the most common discussed real option throughout academic literature.

2. Growth options
   A company can invest into initially loss-making business, paving the way for possibly multiple valuable follow-up investments in order to turn the assets into a profitable investment. When markets are marginal, a modest set-up can be preferred. If the market develops towards favorable conditions in the future, follow-up investments can be made to increase the production capacity.

3. Staging options
   If a project remains uncertain, the project can be broken into several ‘sub-projects’. This allows intermediate abandonment of the project in case results are not as expected, while maintaining the options to continue development of the project.

4. Exit options
   A project can be abandoned if the market conditions severely change to the worse. A project or assets can be sold against salvage value or (if possible) used for other purposes. These options can be valuable in order to minimize losses.

5. Learning options
   A pilot plant or project can be initiated, which will result in losses, but can enhance the technology and performance. In case the market favors or technology gains are acquired, the technology can be brought to the market with increased speed.

6. Business Scope options
   A company can have the choice of expanding or contracting its business activities at sites, depending on the market situation. An example is to build in initial over-capacity to expand activities in case market demand increases, or to (temporarily) shut down certain plants in case of an economical crisis causing significant drops in demand. The example of mothballing a plant or site is an example for this option.
7. **Sourcing options**

A company can choose to invest into more flexible inputs, where can be changed in case demand favors a switch between possible inputs. An example is the choice for a power plant with a flexible burner to switch from oil to coal during operation stages.

It is likely that many projects are eligible for multiple types of options described above. For sake of simplicity for (inexperienced) managers and for maintaining efficiency in projects, the question arises what composition of options would be optimal in projects. That is, if the company wishes to follow a flexible strategy by using options. Applying a single option can allow a more easy, transparent valuation, but may not require ‘enough flexibility’ for an investment to justify commitment of the company. Incorporating more options can make valuation more tricky, and imposes a heavier impact on the RO monitoring and implementation processes. This is the main topic of discussion throughout chapters 4 and 6.

### 3.3.2 Real Options ‘on’ and ‘in’ projects

That the field of real options remains in development, is shown by Wang & De Neufville (2005; 2006). They found that different types of real options concerning projects exist. These are divided in real options ‘on’ projects or real options ‘in’ projects. The field of options development in their vision is represented in the figure 9 below.

Real Options ‘on’ projects can be seen as financial options taken on technical projects or investments. The technology itself is treated as a black box model and not affected. Real Options ‘in’ projects involve alternating the initial design towards the inclusion of more flexibility in the future. The latter type of Real Options are more difficult to identify and assess, as the specific project determines the possible set of options, and technology itself can be affected if implementation of real options is desired. Real options in projects are more difficult to identify, because in-depth knowledge of the specific technology is required to identify and assess such real options, besides that the possible options strongly depend on the specific project.
By shifting the borders of real options, a new area of possibilities is unlocked for incorporating real options as creating flexibility in projects. By 'opening' the design space of an artifact, the number of possibilities for options increase enormously. It however does not change much concerning the categories of RO defined in the previous paragraph. It does imply that the level of technological understanding increases to successfully incorporate real options. Further, it is recommended to use a structured analysis method to assess a design on robustness and analysis where flexibility can be implemented as efficiently as possible. Screening tools are proposed to identify and assess options (Wang and Neufville 2005; Wang and Neufville 2006; Cardin, Nuttall et al. 2007).

3.4 Valuation methods for Real Options
A brief review of common applied valuation methods is presented in this section. Discussion of these methods increase the understanding of how the valuation of RO relates to implementation issues in project management.

This section will not go into detail of the many valuation methods known in the literature. Merely the principles will be discussed here. Extensive examples of RO valuation can be found in journal publications for specific cases. Also, a number of books explicitly discusses valuation methods. Books which are especially helpful in gaining grip on real options valuation are Copeland & Antikarov (2003), Dixit & Pindyck (1994) and Guthrie (2009). Brosch (2008) explicitly focuses on the valuation of portfolios of real options, thus valuing the interactions and path dependency of options in an analytical way. The reader is referred to these books for a more comprehensive understanding in these RO valuation methods. Based on RO valuation analyses, decision rules can be obtained when an option should be exercised, given the knowledge and uncertainty at the time of valuation. These decision rules aim to extract the optimal amount of value from the flexibility in the RO presented in the investment.

However, all these books show a shortcoming, as they all merely assess options 'on' projects, and disregard the identifications of options 'in' a project. There is a general 'denial' that the technological system of an engineering project can enhance applications of RO. This can hold consequences for the valuation, because the initial investment is altered.

First, the numerical examples of real options are enlightened, with the direct application of the Black Scholes formula, followed by a replicating portfolio approach. This construction can also be applied in a binomial lattice. The binomial lattice valuation method is the most popular method, thus it will receive the most attention. This section concludes with RO valuation using Monte Carlo simulation.

3.4.1 Black Scholes
A first direct application would be the straight-forward application of the Black-Scholes formula. However, though this may deliver an option value, there are a few assumptions in this method. First, it assumes that the option can only be exercised at the maturity date, on a non-dividend paying asset. It would thus include that the asset does not pay any returns, but only increases or decreases in its intrinsic value.

These elements prevent a wide application of Black-Scholes for RO valuation. Extensions of their model have been developed in the literature to value American type of RO. But the resulting numerical value presents itself quite often as a black-box to managers. Thus, a more pragmatic approach is often desired. Park and Herath (2000) present a clear discussion on this issue.
3.4.2 Replicating portfolio approach
A method which heavily relies on the no arbitrage principle is the replicating portfolio approach. Annex 4D explains this principle. This method is commonly applied in combination with the binomial lattice (discussed in 3.4.3), but can be used on a stand-alone basis. That way, it produces a single numerical value for the RO, much like a direct application of the Black-Scholes formula.

For the Real Option, a counter investment is created using a combination of risk-free investment opportunities. Commonly government bonds are used to create such counter investment portfolio. Government bonds are considered to be risk-free investments, as the likelihood that a nation will go bankrupt is very small, and often not accepted in the international community. Thus, the payoff of these government bonds is considered as a risk-free payoff, as the investment in these bonds are assumed to be risk-free.

For the option payoff, a portfolio of bonds can be created. This portfolio will be created such that it will match the exact payoff of the option, using a certain (tailor made) hedging ratio. Because both payoffs are the same, the value of the investment must be the same. Therefore, the option can be valued by creating a replication portfolio. Copeland et al (2003, 2004) and Brealey et al (2006) explain the concept explicitly in the way to value an option. Often, this method is combined with steps up-and downwards, thus creating a lattice to value the option payoff. This is based on the volatility rate of the assets.

The proposed main advantage is that the investor need not worry more about the choice of an appropriate discount rate, as the perfect created hedge poses a risk-free payoff, so a risk-adjusted rate of discounting is no longer required. This relates also to another valuation method: Risk-Neutral valuation. Here the key feature is that it is assumed that investors are indifferent concerning risks, thus valuing the option without any preferences of the investor. The reader is referred to Brealey (2006, p 567 & chapter 9) for more on this topic. Both methods commonly result in the same option value.

3.4.3 Binomial lattice
The most applied method in valuation of real options is the binomial lattice. This method has the advantage of being relatively simple, robust and can be represented visually, thus showing the manager of the option a clear layout of future developments (Hahn and Dyer 2008). Generally, the lattice model assumes that the underlying asset cash flows can be modeled using a geometric Brownian motion (GBM) model. Annex 4D presents elaboration of this type of model, including extensions as Mean Reversion processes. These types of models are required to construct a binomial lattice. A lognormal distribution is assumed for the payoffs, because prices cannot assume negative values. By increasing the number of time steps, the probability distribution of the different end-states converges to such a lognormal distribution. Depending on the use of a replicating portfolio, it also assumes an arbitrage-free environment. However, this need not be the case to perform an option analysis and continue to use a risk-adjusted discount for an investment. This model is a form of dynamic programming where alternatives between different moments of option exercise can be compared to each other. So in other words, both American and European types of options can be valued and shown for optimal moments to exercise given the decision rule(s).

The binomial model is a good analytical approximation of the stochastic variable in an investment. The model assumes that the asset can revert to two different values per time step: up and down. The
size of the time step can be determined by the analyst. The limitation of the model is that too many time steps will make the analysis more time and resource consuming, whereas the total payoff may be limited. A lattice approach is often taken as binomial with recombining points, but can be modeled as trinomial or larger and not recombining. Both Copeland & Antikarov (2003) and Guthrie (2009) elaborate on these approaches. The valuation principles remain the same, thus the binomial lattice is used for further elaboration.

The upward and downward movements are usually modeled as recombining events:

\[ u = e^{\sigma \sqrt{T}} \]
\[ d = e^{-\sigma \sqrt{T}} \]

\( u \) represents the move upwards, whereas \( d \) represents the movement downwards of the commodity price. The chance for up and down movements can either be estimated subjectively or based on historical data, or constructed using the risk-neutral approach, thus resulting in (Park and Herath 2000):

\[ p = (e^{\gamma \Delta t} - d)/(u - d) \]

Where \( p \) represents the chance on an upward movement. The general lattice layout is shown in figure 10 below for the first two time steps.

![Figure 10 - A general layout of a binomial lattice model for the first two time steps](image)

Each box represents a price 'scenario'. At \( t=0 \), the current price or starting price is shown. \( t=1 \) shows two different states, where the price has increased, or moved down. At \( t=2 \), three price scenarios are possible, and so on. The number of time steps can be increased to as many steps as is desired in the analysis. All developments (so up to \( t=n \), where \( n \) is the assumed to be the final time for exercising the option, or in other words: the options maturity date) are laid out in the model. Therefore, it is likely that it will have more than just two time steps. Practically all models take more than just the two steps shown in the figure, but the illustrational part is clear.

If the boxes can be labeled as a scenario, all scenarios have to be laid out. Thus, by knowing the chance of an upwards and downwards movement, the chance that a certain end-state is reached,
can be calculated or estimated. From this way, the way backwards can be calculated for the investment cash flows, and the option cash flows.

At each point, the options value can be calculated by comparing the present value (the payoff at that point) with the exercise cost, and comparing this with the set decision rule when to exercise the option. This can be when the options value reaches a certain threshold (for example, >0 or >1 million EUR), to justify the effort of exercising the option at those conditions. If the decision rule is not met, the option will not be exercised at that moment. Leuhrman (1998) and Park et al (2000) contain some elaborate examples. However, most books concerning real options valuation elaborate extensively on this method.

The decision rule is an important element. By calculating the different payoffs of the option in all modeled scenarios, an optimal point of exercise can be determined. The decision rule can be set at this level. Other decision rules can be set as well, as long as it satisfies investors demand. For example, for a quick introduction into the market, not the optimal value can be important, but merely a positive result. The investor could wait longer with exercising awaiting a higher option payoff, but could result that a competitor beats the investor to the market. Thus, the decision rule can be set by the analysis or by the investor, which conditions have to be satisfied to exercise an option.

The method does have problems dealing with path dependency issues, as it can only model one option. When multiple options come into existence, the model will become complex and quickly quite 'bushy'. To solve this issue, time steps have to be limited, but this also loses refinement in the approach and thus a less reliable valuation of the option and its exercise moments (Wang and Neufville 2005). Extensions of this model also exist into multinomial and non-recombining models for valuing RO. These models however leave the 'simplicity' issue and quickly become harder to understand. Guthrie (2009) and Copeland & Antikarov (2003) present some examples in their work.

3.4.4 Monte Carlo Simulation
Simulation for real option applications can be adopted for multiple reasons. First, if the price of the uncertain variable cannot be modeled using GBM, it can be difficult to construct a lattice approach. For example, MRP models are more easy to be analyzed using Monte Carlo Simulation. A follow-up step can be to convert the resulting distribution to a binomial lattice involving multiple time steps. Also, Monte Carlo simulation approaches can be explicitly helpful in assessing multiple uncertainties to value an option. Also, Monte Carlo Simulation can deal with multiple RO in its analysis, showing their respected outcomes. Thus, portfolios of RO can be modeled using simulations.

Most analyses for options valuation consider one uncertainty, and assume no other uncertainties or set these as deterministic. Thus, these analyses show limited validity with a real situation. Copeland & Antikarov (2003) present a ‘consolidated approach’ dealing with multiple uncertainties (see Annex 4C for a brief review or their book, chapter 9). Whereas Amran & Kulatilaka (1999) disfavor this approach, because it lacks structure in the analysis. This is not shared by Copeland & Antikarov (2003) and considering the amount of journal articles using Monte Carlo simulation in their RO valuation process. The consolidated approach presents a well-laid down process to combine uncertainties and model the project payoffs, then resetting this distribution (commonly as a lognormal distribution) into a binomial lattice. Hence, the valuation of options can take place. When this approach is not adopted, the decision rules need to be stated in a clear sense, as well as the used
parameters and stochastic models. This would represent the structure of the model, but the analysis itself will be less structured in overview, because the iterations are computationally calculated. The results can show final distributions however, which can be combined with the intuitive approach from options valuation in lattices. So in order to use Monte Carlo Simulation for valuation, it is important to at least have some degree of understanding in the lattice valuation of RO.

Simulation approaches can help clarify complex analytical analyses into simple steps and show variations during the different iterations. This is more intuitive for investors and (project) managers less familiar with valuation techniques. Another benefit is that Monte Carlo simulation can provide numerous side statistics on how many iterations showed the options exercise, and different levels of uncertainties can quickly be assessed. However, this depends on the model being programmed, and which software is used. Often, Microsoft Excel plug-ins such as Crystal Ball or @Risk are used.

There is some difficulty in all methods, but especially simulation is sensitive for the 'garbage in = garbage out' principle (Wang and Neufville 2005). Slightly wrong chosen parameters will result in a useless and possibly misleading model. However, using simulation is considered the preferred approach as it intuitively can deal with multiple uncertainties and multiple distribution configurations at the same time. Next to this, multiple RO can be presented in a same model, and distributions of the value or payoffs can be shown throughout the analyses, allowing managers to get a feeling how the options value is constructed and where its added potential in the investment can be found. Thus, presenting a number of same benefits as with the binomial lattice approach. However, there is less published concerning options valuation using real options. Some sources can be explicitly helpful in setting up such an approach besides the earlier mentioned Copeland & Antikarov (2003); the reader is referred to (Wang and Neufville 2005; Laurikka 2006; Roques, Nuttall et al. 2006; Hahn and Dyer 2008).

### 3.5 Real Options valuation difficulties

A number of difficulties arise when an attempt is taken to value RO. These are listed in this section based on the conducted literature review. Real options analysis finds its roots in the financial options theory. Finance literature poses opportunities to promote real options, but also notice the boundaries and identifies issues when attempting the use of RO to value flexibility. The difficulties are listed below.

- The volatility of assets may not always be known. Estimates based on historical data may lack future predictions, or may be absent (Copeland and Tufano 2004). Estimating volatile events by subjective management can pose a solution (Copeland and Antikarov 2003), but can result in a shift in the range of expected value of options.

- The basics of financial stock options theory can be used to explain the methodology and its application. But this also forms a disadvantage. Financial options refer to intangible assets and are commonly traded via standard contracts. For real options, real assets are commonly involved. There is almost never a standard contract available for these assets. By treating technology or assets as a black box, the possibility is created to compare these options with financial investments in securities. Valuation through the use of the replicating portfolio method allows this (Copeland and Tufano 2004; Wang and Neufville 2006). However, it may not be possible to construct a hedging portfolio for a proposed real option, which makes valuation a difficult task. Other numerical methods, such as direct valuation using the Black-
Scholes formula, is only applicable for simple European types of options: options which can only be exercised at the maturity date.

- Real options approaches can quickly become very complex. Valuing options can demand high ‘analytical and computational horsepower’. Managers will regard such item more quickly as a black box tool, thereby losing confidence in the technique. The consequence is that managers abandon the technique and return to the simpler valuation models (Copeland and Tufano 2004). An approximating answer can be sufficient in most cases, and can even be better as it requires less resources to provide answers to the posed investment questions (Brealey, Myers et al. 2006).

- Real options may lack in structuring the problem. Real options are based on real assets, which may be hard, maybe even impossible to quantify because real projects often are less transparent than the options traded on financial markets. Exercise prices and maturity dates may be difficult to explicitly specify for a real option in an uncertain world. Assumptions may still have to be made (Brealey, Myers et al. 2006). Both the exercise price and the present value of real options are not pre-determined and are subject to market developments. For financial options the exercise cost is already known and certain (which is the premium to obtain the option) (Yeo and Qiu 2003)

- Financial options are quite commonly short-lived. The maturity date for financial options is commonly less than 1 year. For Real Options, the lead times of options is quite longer, and it may be possible that there is no maturity date (Yeo and Qiu 2003).

- Competitors in a market also have real options methodologies at their disposal (Brealey, Myers et al. 2006). This can have a dramatic impact on the value of specific options of a company, which may interact with real options held by its competitors. An option to defer because of its value (analyzed on a single setting), may suddenly become worthless if one or more competitors jump onto the possibility in the market. An appropriate valuation of these interactions with options is very difficult, if not impossible considering unpredictable (strategic) behavior of actors. These uncertainties can require an early commitment prior to the competition. A balance between these uncertainties of (ir)rational behavior and value of flexibility is required (Yeo and Qiu 2003).

The points listed above are generally applicable to all types of real options: both ‘in’ and ‘on’ projects. However, there is an additional difficulty in valuing real options ‘in’ projects, as the actual technical design of the investment is altered. This implies a more sophisticated activity to compare the value of the real option(s) with a reference design, especially when also the specific technology ‘in’ the project is used (for example a coal gasifier instead of a pulverized coal furnace). In more complex projects many design variables and parameters can be affected by allowing this. Another difficulty is the project’s characteristics that these often show complex path-dependencies and interdependencies which cannot be addressed in the same way real options on projects are addressed (Wang and Neufville 2006).
4. Integrating Project Management & Real Options Analysis

After the literature review for PM and ROA, the integration of both disciplines is not straightforward. These differ in their principles: PM aims to minimize uncertainty and flexibility, whereas ROA aims to recognize and exploit uncertainty.

This chapter aims to elaborate on factors and tensions that exist concerning the integration of RO in a PM approach. This is an intermediate step to create a conceptual design towards the adoption of RO in project organizations and implementation in projects.

Section 4.1 elaborates upon the used method to identify factors, gaps and tensions and its limitations. Section 4.2 elaborates upon RO to initiate flexibility in projects. Section 4.3 discusses the identified factors from the literature review. These are summarized in section 4.4 and in 4.5 applied to different organizational levels. These serve as basis for chapters 5 and 6 to propose a conceptual design for adopting RO in project organizations and implementation in projects.

4.1 Scanning for factors

This section elaborates upon the used method to scan the different assessed literature resources for identifying gaps and tensions for the integration of RO within LEPs. Paragraph 4.1.1 will elaborate upon the used method. Paragraph 4.1.2 discusses the weakness entailed in this analysis. Finally, paragraph 4.1.3 tries to provide an answer for the limited amount of literature concerning the integration of ROA in PM.

4.1.1 Method to identify factors

Three classes or literature are assessed: literature focusing solely on ROA, PM or aiming to discuss factors integrating both disciplines (labeled as integration literature). Factors are defined as topics which play a role when ROA is integrated in a PM approach.

The literature review is conducted with a perspective to scan for factors in each discipline that are required to enable RO adoption and implementation in projects. Factors can be discussed in PM literature, but not in ROA literature or integration literature. These factors are listed and categorized to the degree they discuss the topic. Three categories are used in this chapter:

1. Factors that have been properly reviewed and assessed in literature in such way, that these can be taken along in the assessment for adopting RO in projects. These factors thus do not form a problem concerning RO adoption in projects.
2. Factors that have been mentioned in literature, but not thoroughly assessed or missing a point. These factors are labeled as ‘tension fields’. Further assessment and alignment is necessary to enable RO adoption into projects.
3. Factors that have not been assessed or merely been assessed by literature, but are expected to play a role concerning RO implementation. These are labeled as gaps.

This is input for an iterative process to scan and identify factors and categorize these. These can be put into an overview which assigns a ‘value’ to these. This framework is showed in table 2.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type of literature</th>
<th>ROA</th>
<th>PM</th>
<th>Integration literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor A</td>
<td></td>
<td>1</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Factor B</td>
<td></td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td>2</td>
<td>-</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2 - Categorizing identified factors in literature, the numbers are examples
Blank spots represent that a factor is not found to be discussed in the type of literature. This does not mean that it is a gap. PM literature for example does not develop a gap concerning RO identification for example. It can discuss a certain factor which also becomes relevant for adopting ROA. Thus, a factor is identified and adopted in this analysis. This factor is scanned in other literature for assessment and categorized.

This way, a set of factors is identified throughout the PM, ROA and integration literature and discussed in sections 4.2 and 4.3.

4.1.2 Weaknesses in the used approach
The used approach to identify and analyze factors knows drawbacks. This paragraph briefly elaborates upon these.

First, the analysis is limited to the assessed literature. A 'helicopter view' is maintained as long as possible, to oversee and assess a wide variety of literature in the identified categories. The abundance of literature assessing PM and ROA limits the range of the search. Likely, issues can be discussed in literature not assessed in this work. Factors could have been left out or wrongfully assigned in a wrong category. However, time and scope requirements in this project did not allow to these activities to sufficiently conducted. Besides, validation of these factors is difficult because RO adoption remains fairly low. Experts on ROA and PM can be used to validate these factors and bring input towards a discussion concerning the importance and impact of these factors on the adoption and implementation perspectives of RO in LEPs.

The used categories are subjective of nature. One can discuss when a factor is labeled as a gap or tension field.

4.1.3 Limited integration literature
Remarkably little literature deliberately focuses on the implementation of RO proposed at a certain investment. Much of the literature assessing RO value strategic investments which are important to the project owners continuity, but do not refer to implementation of these RO in practice. This is partly due to the case sensitivity of each project in every setting. Often it is advocated that the added value for the project of RO justifies the additional effort to value RO, but leave it to that. Adner & Levinthal (2004b) refer that the decision to take a RO approach must be a matter decided on strategic level, and is not an issue on implementation level. However, they acknowledge that 'RO management efforts' are required, but do not elaborate on the impacts of RO on an implementation level.

The explanation behind the relatively little literature is because of the low adoption rate. The use of theoretical cases do not offer the build-up and exchange of experience. Even if RO are applied in certain cases, such approaches can be kept confidential or use tailor-made valuation models and not openly discuss the implementation. Thus, the amount of cumulative experience build-up is marginal concerning RO adoption and implementation. Literature that does assess implementation issues of RO, have been adopted within this report as much as possible.

4.2 Real Options to initiate flexibility in projects
An important notion is to question what real options should enable in projects. RO generally focus on improving project effectiveness. Miller & Waller (2003) create a clear notion: "By making an initial investment in flexibility, the company reduces the cost of altering its strategy". The project scope is
widened, so that the adopted RO can be implemented without an intermediate project scope change. Or to put in other words: The adopted RO in the project deal with foreseeable changes in the project, thus creating the possibility to change the strategy of the project (or company) by exercising the option (Gil 2009).

Compared to traditional PM practice, real options would hence result in a reduced chance that scope change would occur. The adoption of RO, formed in widening the project scope, introduces more costs. A wider project scope reduces project efficiency, but increases the project effectiveness. It can prove to be money well spent when a traditional approach results in a project scope change half-way in the project. However, this is hard to validate and quantify in cost. Virtually any type of RO is aimed to increase project effectiveness, as it sets the strategic aim of the project deliverables. In some way, RO are opportunities. Thus, the cost of implementing an opportunity (in the form of an adopted RO) is reduced compared to when the project owner would not be prepared. In theory, it should lead more quickly to a project acceptance (as the flexibility shows that the project has a positive value, see chapter 2, Yeo & Qui 2003, Park & Herath 2000) or support in strategic decision making (Brealey, Myers et al. 2006).

In chapter 2 it is discussed that the project scope shapes the internal flexibility. Assuming that the uncertainty does not resolve itself other than expected, it can be assumed that no incentive exists to initiate new external flexibility. When a real option is adopted in a project, the internal flexibility is enhanced at the expense of external flexibility. External flexibility is shaped by uncertainty, which can be contextual or internal but what cannot be coped within the project scope at the specific moment (see paragraph 2.4.1). Figure 11 shows this in a schematic layout. Uncertainty can initiate new external flexibility, but also internal when the project can be adjusted without a scope change.

The enhancement of project performance requires another stance, other than minimizing flexibility and uncertainty. However, a solid project scope definition remains important. RO can increase flexibility, but need not make a project more vague. If the option is defined well, and the field of involved actors knows sufficient information (and support this approach), RO need not endanger a

![Figure 11 - Effect of increasing internal flexibility by taking real options along in a project, at the cost of external flexibility](image-url)
fuzzy scope definition. Flexibility within PM can be enhanced by in-house development and execution with the project owner, because of reduced reluctance of internal project members (Olsson 2006a). This is difficult for LEPs, but could be solved by redefining project relations. These issues are addressed later in this chapter.

Real options can increase the level of internal flexibility at the cost of external flexibility, under the premise that uncertainty resolves as expected over time. Relations between the different involved project members, such as owner, user(s), manager and contractor(s) are of vital importance for the degree of reluctance against flexibility. A clear scope definition of the project remains important: incorporating real options need not make a project more vague, as long as is clear which options are taken along, what the effects on the projects are (and will be after exercising one or multiple options).

4.3 Factors influencing the integration of Real Options in Projects
Identified factors from the literature review and brainstorm are discussed in this section. Each paragraph will discuss a factor and elaborate upon the literature that discusses this element and its contribution to RO implementation. Resulting in an overview of work carried out to put RO into practice, and discussion of factors which have not been given the full appropriate attention.

The primary reason to implement real options is clear: additional flexibility can enhance the project value and thus performance. There is some recognition in literature that the impact of RO depends on the management approach: PM approach interacts with the value of a real option (Nembhard, Aktan et al. 2002; Miller and Waller 2003; Bhargav 2004; Adner and Levinthal 2004a). However, the implementation of RO remains a relatively unexplored area.

Eschenbach et al (2007; 2009) try to highlight a number to highlight losses of revenues that fail to be caught in standard asset valuation analyses, however acknowledge the importance of the methodology for projects in a 'near zero NPV area'. They mainly focused their efforts in uncovering the cost of waiting, which will be discussed in 4.3.5. Coff & Laverty (2007) name the importance of organizational issues on the value of options, but mainly focus on a bias to either exercise or kill the option depending on the organization. In 4.3.1 this will be topic of further discussion. Miller & Waller (2003) and Adner & Levinthal (2004b) conclude that RO create a necessity for monitoring, which will be discussed in 4.2.2. Miller & Lessard (2000) leave it to the notion that the real options methodology is likely to work in disadvantage of LEPs, because it can provoke critical stakeholders (both external and internal) to show strategic behavior against locking into options. Flexibility towards irreversible commitment in projects can best be carried out by late locking of requirements. However, they do not elaborate on the topic of flexibility in the project deliverables. Boute et al (2004) solely focus on the benefits of flexibility and advocates that ROA should be the preferred approach in project management. But they ignore all factors concerning implementation of these options. In short, a very small proportion of the assessed literature pays attention to any implementation part concerning RO. Thus, it leaves a 'dark page' for this methodology to place it into reality and more importantly, convincing a project owner that flexibility by adopting RO in LEPs can very well be beneficial.

A number of factors are mentioned which are based on PM literature assessing aspects of the PM discipline. When this factor is considered relevant for integration purposes, the factor is taken along in the analysis. Thus, literature is used to select factors and apply a scan on other types of literature. Different literature sources on finance, real options and project management, have been used to
identify and discuss these factors. The main sources are (Turner 1993; Amran and Kulatilaka 1999; Miller and Lessard 2000; Benaroch 2001; Copeland and Antikarov 2003; Neufville 2003; Boute, Demeulemeester et al. 2004; PMI 2004; Wang and Neufville 2005; Brealey, Myers et al. 2006; Meredith and Mantel 2006; Guthrie 2009). Where other sources have been consulted, the reference is given at the specific paragraph.

4.3.1 Organizational bias to real options

Coff & Laverty (2007) presented a welcome addition in the field of RO implementation. They assessed the ROA methodology with organizational theory and practices. Though not focused on implementation within engineering projects, they present an interesting insight on a bias toward RO adoption in organizations.

There are different ways how real options can be taken along in projects. The project owner has different organizational choices at his disposal how adopt RO implementation. Two extremes are discussed concerning the organizational impact of implementation: an integrated approach and an isolated approach. Their conclusions are briefly discussed below.

The integrated approach focuses keeping the adopted RO strictly aligned with the main organization. Thus requires costs to keep the option alive. They argue that this creates a bias towards RO implementation while the conditions may not be satisfied, because of social reasons. Cost and effort already put into the RO become a sunk cost for RO exercise. Not implementing the option will result in losses. Thus, it creates a bias to exercise the option.

Besides the costs, there are social biases in favor to exercise the option:

- People involved in the assessment and integration of the options, including the managers, evolve over time. Persistent uncertainty whether the exercise circumstances of an option will be reached, can lead to a desire to continue the investment in the option(s). Social networks evolve over time around the affected options, pushing towards continued investment by using the influence they have within the organization or project.
- Other divisions and departments can, next to direct affected resources, lobby for continued investment, as a way to avoid change. Abandoning an option cause stress on working relations between the different departments, creating an environment that other managers continue to support further investing.
- Directly responsible managers for the option can become reluctant to abandoning the option, due to the implicit contracts or promises with other individuals.

Ultimately, escalation of commitment to RO can happen in a project. An option is kept alive too long, or exercised under false premises, leading to sub-optimal payoffs or even losses instead of profit. In this sense, escalation of commitment can be a significant risk in organizations.

The opposite, an isolated approach, focuses on minimal cost an effort dedicated to keeping the RO within the organization. The RO is left alone and reintegrated with the organization when the initial exercise conditions are met. This creates integration efforts. Over time, a real option can become further detached from an organization, resulting in higher required efforts to realign the option. The increasing integration costs create a bias to abandon or kill the real option, because this is added on the exercise costs of the RO.
Besides the integration cost moment, social bias towards abandoning the RO exist:

- Managers who develop and control the RO, have limited social ties to the main project organization due to the isolation. There is no regular interaction or routines which link the options. This reduces the influence to continue investing in the option throughout the time the option is active (not yet expired).
- The decision-makers of the project feel less committed with the options. Therefore, they are less committed in keeping options alive and fulfilling implicit promises made to other involved people in option(s) department(s).
- Due to isolation of options, options which require substantial change when exercised, are likely to be lobbied against. This is an indirect consequence of the two points above. Systems do not co-evolve and limited knowledge transfer happens, thus leading to managers lobbying against option(s) even though they may hold promising results for the future.

Coff & Laverty (2007) propose a balanced approach to cancel out bias, they see this as their main objective for integrating an options approach in organizational management. They see monitoring as a key element in implementation of RO. It creates a requirement for integrating ROA in PM organizations, which can be labeled as follows:

**Requirement:** Integrating real options in PM organizations must result in a minimization of biases to exercise or abandon a real option outside the defined criteria throughout the PLC.

### 4.3.2 Monitoring of Real Options

Monitoring of RO for implementation purposes is important for multiple reasons. Uncertainty is present and exploited in adopting RO, this needs to be monitored to know when to take the exercise decision. Using deterministic tools to model uncertainty is a common pitfall in many analyses (Christiansen and Wallace 1998). By conducting a RO valuation analysis, a proposed layout is presented for resolving uncertainty over time. At this point, a deterministic approach is used for resolving the uncertainty. It can occur that developments walk another path than anticipated upon in earlier analyses. Very little literature elaborate upon this aspect except for a short notification by Miller and Waller (2003). Special resources can be assigned to carry out these tasks. Monitoring is required to address the issues whether the real option is still valid with the new (possibly different) situation. Adner & Levinthal (2004a; 2004b) merely label that a ‘RO management aspect’ is to be considered at the strategic level to enable implementation. Thus, the factor is known, but not thoroughly assessed in the authors opinion.

PM literature advocates in the monitoring & control of various aspects such as quality, risk, scope and cost. The essence of monitoring and impact of these tasks on projects have been assessed more extensively than for RO.

However, all reviewed literature do not elaborate on the cumulative impact of these monitoring duties. Thus, the impact of these tasks are unknown to the project owner and no approach exists to integrate RO in PM practice. It results in a tension field for implementing RO.

**Tension field:** Monitoring of RO is required, but no approach currently exists how to implement a monitoring approach.

**Requirement:** A structured monitoring framework applicable for all types of RO must be included to enable effective RO implementation.
4.3.3 Impact of cumulative opportunity expenses for real options
The consideration made in RO valuation literature is that sufficient uncertainty needs to be present to include a RO approach. It is recognized that this value is required to justify the effort of a valuation assessment. Monitoring tasks are carried out on a continuous basis. Other costs such as identification and valuation are present as well: no real option 'comes for free'. Though monitoring is acknowledged, there is no approach present in the assessed literature to map these cumulative opportunity efforts. Impact and budgets for cumulative risk approaches in standard PM practice have not been considered, as this is assumed as mandatory in LEPs. This creates another tension field and requirement for a design to adopt RO.

**Tension field:** There is currently no approach that assesses the cumulative impact of opportunity expenses to enable RO adoption and implementation.

**Requirement:** RO must be assessed on their expected cumulative efforts required to keep the option alive over its presumed lifetime.

4.3.4 Balancing portfolios of real options in organizations
Most LEPs are eligible for multiple RO: the amount of possible configurations can be immense. Especially with RO 'in' projects there is an enormous increase in the design space. However, incorporating 'unlimited flexibility' will ultimately result in disadvantages: loss of scope and project control. Thus increased risk on schedule & budget overruns. Neufville & Scholtes (2010) discuss that a few implications of flexibility can significantly enhance performance. Screening models aim to search optimal points where flexibility will have the largest potentials of performance enhancement and integration into the design (Wang and Neufville 2005; Cardin, Nuttall et al. 2007).

Combinations of multiple RO within an investment are labeled as a portfolio (Anand, Oriani et al. 2007; Brosch 2008). Anand et al (2007) conclude that a portfolio of RO consists of a well-balanced set of growth and switch options. This enables the possibility for an investment to adapt in a dynamic and uncertain environment. Brosch (2008) proposes the valuation perspectives for interacting portfolio's of RO on a numerical basis.

Valuing a portfolio of RO quickly becomes complicated. Interaction effects and path dependency issues prohibit a simple analysis. A higher amount of RO increasingly complicates the valuation, but also implementation as more effort is required to control the project and the RO throughout the PLC.

The amount of (in-house) experience of the investing company and other project member is important to understanding the potential added value of options (Amran and Kulatilaka 1999). Inexperienced managers with options and flexibility in projects are likely to be more averse to more 'sophisticated applications' of options: more options parallel and sequential in the analysis. By having expertise in-house concerning options implementation, the project owner has able support to analyze and take decisions. Especially in the face of multiple RO, interaction & exclusivity issues and a dynamic environment, expert support is required. Another issue is to overcome the 'black box' experience of managers concerning option implementation. This is a temporary issue that can be overcome in time, as cumulative experience concerning RO adoption can build up. Along with confidence in the methodology.
Balancing a portfolio of RO is important, as too many RO cloud a project scope and deliverables. It also places a more heavy burden on project owners to deal with higher degrees of flexibility which they are not used to. This can endanger tight project schedules. This creates a gap:

**Gap:** Project owners adopting RO need to accumulate experience and places stress on the organization.

**Requirement:** RO approaches must be able to be documented and reviewed to allow cumulative experience build-up.

### 4.3.5 Cost of waiting

Eschenbach et al (2007; 2009) assess RO within the view of engineering projects. Their main contribution is placing facing RO with its cost in delay to implement in projects. They rightfully conclude that cost of waiting is widely ignored within the ROA literature field. Amran & Kulatilaka (1999) notices a potential 'leakage of value', but do not extensively treat the issue. Copeland & Antikarov (2003) completely ignores this issue. The implementation time is of significant impact on the RO valuation process and implementation. Ignoring the implementation time of a RO causes overvaluation of real option(s) (Nembhard, Aktan et al. 2002).

Different impacts of these costs are possible. This holds when the project is not up for consideration to be lengthened in its lifetime. First, a real option can have a limited time span compared to the total lifetime of the project. When the RO is exercised when the options lifetime is less than the remaining (operational) lifetime of the project, no losses needs to be incurred. When the RO lifetime is higher than the projects remaining lifetime, loss of costs occur. The automatically holds for assets in options that generate revenues for the remainder of the projects lifetime. A later implementation will result in lower revenues. The other main impact is the option implementation time: this period could have been used to generate (positive) revenues for the project, but is spent on exercising and implementing the RO (Eschenbach, Lewis et al. 2009).

Another point of interest for RO costs is the value of a strategic advantage (Yeo and Qiu 2003; Brealey, Myers et al. 2006; Maritan and Alessandri 2007). In LEPs it is possible that only one type of artifact is necessary to jump onto an opportunity in the market. Thus, in an environment with competitors, the advantage of being first needs to be considered. Waiting with exercising the RO with rational thinking can cause a competitor to quickly fill the gap, resulting in major costs of lost revenues for the project owner holding the RO.

It creates a tension field between the fields of ROA and PM. The project owner has to assess the importance of fast implementation and lost revenues to determine the impact of the option on the project performance. Thus, creating a requirement:

**Requirement:** Each adopted real option must be assessed on the possible costs of waiting or loss of revenues due to the implementation time and be compared to the project performance.

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Assuming a project is temporary of nature. It is possible to assess the value of this option combined with lengthening the project lifetime, likely resulting in a higher combined option value because payoffs can be generated over longer periods of time.
4.3.6 Project owners culture & financial health

The project owners culture, vision & mission reflects its preferences towards taking and treating risk. Project initiation can also be limited by availability of (skilled) resources, budget or financial reserves. It limits the amount of flexibility a project owner can bare. A project owner can initiate a project and have a limited budget available to implement RO along the way. This budget can vary over time, depending on the company's performance.

A project owner can only execute a limited number of projects at once, balanced in its project program. A balanced set of project with associated risks is required to guarantee the projects owner continuity. Each project will put a burden his financial reserves and resources. Committing to investments or exercising a RO are irreversible events. Depending on the risk-profiles of its projects, a project can drag the project owner into financial problems. A large project will pose a heavier burden on a company, resulting in less allowance of risk considering the chance of endangering the project owners continuity. A project owner is willing to change its perception when the risk of project failure is easily bearable. When a project poses a high burden, a less volatile approach can be preferred. Minimizing uncertainty and risk can make a project bearable for a project owner. Marginal projects which are of a size vital for the continuity of the investing company, are likely to be dismissed as too risky, as the allocation of resources towards the project can better be allocated to a less uncertain project (i.e. one with a higher certainty & expected NPV). However, when a project poses little burdens on the company results, it is more easily allowed to take real options into account as uncertainty can be exploited better.

Considering LEPs, RO can have long active times before they mature. When the RO is not yet exercised in the PLC, the project owner is 'stuck' with the money reserved for implementing RO. He cannot allocate this money into other assets or other projects, as it will kill the option(s). Unless the project owner has sufficient financial reserves that these costs can be bared with ease. Economical developments could turn for worse in case of RO exercise in economic crises. A project owner preparing exercising a RO, but if the exercise cost cannot be paid, the RO cannot be implemented. Banks may not always be willing to grant loans (depending on the level of risk and solvability of the project owner). Thus, there is a constraint to the amount of flexibility a company can bare.

The relative size of the adopted RO in a project also matter. Based upon the relative impact on the project performance, it can be given a more or less 'prominent' position. An option which can double the project performance, can be given higher priority within the organization.

Important aspects are in short:

- The financial health of the project owner & ability to exercise RO over project lifetime
- The relative size and possible threat a project can be for the investors continuity
- The risk averseness or entrepreneurial characteristics of the project owner

**Tension field:** Adopting RO will place a burden on the project owners financial reserves.

**Requirement:** The adoption of RO must remain within bearable limits to the project owner.
4.3.7 Risk approach
The payoff of RO is often not a straightforward linear function. The creation of a hedging portfolio of bonds for valuation of a RO is difficult in real projects, if not impossible (Wang and Neufville 2005). But more importantly is the assumption of a risk-neutral and risk-free valuation. The valuation of real options consider a risk-neutral investor and world, where the cash flows can be discounted against a risk-free rate.

Despite the fact that a RO will be exercised over time when uncertainty is resolved, and the actual payoff of the RO will create additional benefits for the project, this does not stroke with PRM. There are a variety of different risks (see annex 2), which can impossibly be resolved in total. Other risks can surround the implementation of the option, not solely in its payoffs as assumed in ROA. These can be labeled as project risks, rather than market risks. Thus, not all risk is eliminated. From the Capital Asset Pricing Model (CAPM) point of view, a risk-free discount rate should not be used (Brealey, Myers et al. 2006). The notion of a risk-free world for RO valuation is nice, but unrealistic. A risk-adjusted rate will remain important. Though RO applications result in a reduction of risks by actively managing the project to its environment (Alesii 2005), unique project risks still require a risk-adjusted discount rate (De Reyck, Degraeve et al. 2008). Thus, a lower discount rate can be appropriate, but assessment remains necessary.

**Tension field:** Adopted RO remain faced with unique project risks, thus unable to be valued using risk-free discounting.

**Requirement:** RO must be assessed at the project start and over time on the faced unique project risks to set an adequate discount rate.

4.3.8 Permits, EIA, legal procedures
Depending on the RO, permits, impact assessments or certain legal procedures have to be carried out prior to exercise. This depends on the type and size of the activities and assets. An environmental impact assessment (EIA) may be required when significant activities are included in the option. The requirements are usually laid down in a law for Member States of the EU. These requirements have an impact on the RO implementation time, thus the period over which is can start generating revenues and the flexibility a RO poses. Generally, permits or conducting an EIA can take from a number of weeks up to multiple years. LEPs generally have long operational lifetimes, but the impact of permits can be significant.

Over time, these regulations, permit and/or EIA requirements can change. Thresholds to acquire a permit or conducting assessments can be altered, leading to more or less work over time to exercise a RO. Changes in regulation can also pose new opportunities. In that case though, these should be recognized and assessed in advance of the project start.

In a conventional PM approach, the project owner would only have to assess this once at the project start. Adopting a RO approach, can oblige him to carry out assessments multiple times when he exercises a RO of significant size. Resulting in higher cost and effort, longer lead times and therefore less revenues. This has to be assessed when RO are considered. However, literature considering RO in strategically large projects seem to neglect these issues.
**Gap:** Permits, EIA and regulations assessments are not considered in RO applications, but can impact on RO validity and value.

**Requirement:** RO must be assessed on permits, regulations or EIA compliances at the point of adoption.

4.3.9 Technological developments

New technologies and/or improvements can enhance potential of an asset in a later period. The ROA concepts is partly based on this principle. Especially learning RO are an example of this. A project owner can benefit from these developments by setting his options open over the projects lifetime. There is a catch, which is the (deterministic) expectation of technological developments. ‘Known unknowns’ or ‘unknowns unknowns’ can pose a difficult task to value and take along in a project. An estimation or learning curve could be introduced to some aspect, but it inherently assumes developments over time to go according to the ‘proposed’ plan at the project start. This is rather unlikely.

Especially LEPs with a long projected operational phase can be confronted with this type of uncertainty. A way to cope with these uncertainties is to use existing (relatively proven) alternative technologies to value and use as option(s) in the project, when possible. It brings an additional set of requirements which the new technology has to fit in, substituting the current technology which would otherwise be used. The new technology should be ‘backwards compatible’ as an additional new requirement.

**Tension field:** Technological developments may hamper valuation and implementation of RO, despite that the type of uncertainty heightens the value.

**Requirement:** Technological developments must have a degree of reliability and tractability to adopt RO in LEPs.

4.3.10 Availability of specialized resources

Exercising RO often refers to realizing tangible assets. Especially call-type of RO. In LEPs, large specialized resources can be required to execute tasks in a project. Examples are specialized welders, heavy lifting equipment, specialized demolition teams. Specialized equipment can be booked for several years in advance, what can hamper the flexibility of exercising an option. There is significant cost involved to acquire these specialized resources on a short notice for example exercising a RO. Thus, by this increase of exercise cost (on short notice) the RO total payoff becomes less. Solutions to this issue are always case specific, but partly depend on external market conditions. When specialized resources are available in-house, there is generally more insight on the available slots. This can ‘limit’ the loss of flexibility, as well as the cost involved.

**Gap:** Necessity of specialized resources may hamper the flexibility of implementing the option and its payoff.

**Requirement:** Adopted RO need to have a clear upfront design and list of required resources to implement these.

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6 External market conditions could be the state of the worldwide economy. In growth periods, it is likely that more material is booked further ahead in time. In times or crises, it is likely to be easier to book a short period in advance and against lower cost for specialized equipment and staff.
4.3.11 Project contracts & relations
Project contracts describe the relations between different internal project members: the project owner, manager, users and (sub)contractors. The type of contract which can best be used depends on the type and level of uncertainty. Different types of project contracts exist (Shenhar, Dvir et al. 2001; PMI 2004). The best type of contract is linked with the project complexity (and the type of technology used and the actor environment\(^7\)). Project contracts can facilitate or endanger relations. Turn-key or lump sum type of project contracts will only function when the degree of uncertainty is within manageable levels and fairly well-known. Reimbursement types of project contracts are likely to suffer less from very high levels of uncertainty. The choice of a contract is of vital importance to achieve cooperation and decreasing the likelihood of conflicts between internal actors. Thus, increasing the aim for project success.

Adopting RO results in new (widened) boundaries. By increased levels of uncertainty, it can become more difficult to provide a complete contract between the project members. The payoffs, the technology and exercise price may be uncertain at the time the project contract is defined. Only an incomplete contract can be written between the project owner and the contractor. The choice of the project contract is important for the option implementation. Key factor is the RO design: is the option well-defined with all information available regarding payoffs and exercise price, technology application known? Then a turn-key or lump sum contract can be used. Depending on the degree of incompleteness of a contract, more cooperation needs to be sought between the different actors in order to minimize total cost (Groenewegen 2005). Reimbursable contracts can be preferred due to the uncertainty or incompleteness of the knowledge concerning the project and the contract.

The project owner also has a choice not to incorporate the adopted RO within the contract. A new contract bidding round can be initiated when the owner wishes to exercise the RO according to the intended options (technical) design. It does however lengthen the implementation time of the RO. Project contracts can be avoided by fully development and execution of projects in-house. But in the case of LEPs, it is considered unlikely that a project owner has full knowledge and resources at his disposal. Executing a LEP virtually always require use of external resources.

\textcolor{blue}{\textbf{Gap:}} New uncertainty boundaries may require rethinking the project contracts, as a less complete contract may be written, which is not assessed by literature.

\textcolor{blue}{\textbf{Requirement:}} Adopting RO requires a clear view on the uncertainty to be exploited and allow review of project contracts.

4.3.12 The actor ‘playing field’
Virtually all LEPs have to deal with external actors, who in some way will be involved in the project (Miller and Lessard 2000). An actor analysis will be carried out to identify them and their interests in the project. Actors can have powers at their disposal, being able to delay or even block activities. Actors can be ‘critical’, meaning that their support is necessary in order to carry out the project (Bruijn and Heuvelhof 2004). These critical actors possess sufficient means to delay or block the

\footnote{\textsuperscript{7} Meaning the actors which the project members have to deal with in order to execute the project. Such as environmental pressure groups, citizens, municipalities, governments and unions.}
project from completion or execution. Actors can have interests which are not aligned with each other.

In the conventional approach, the alignment of actors had to be conducted only once. After the process has been (successfully) carried out, the project owner can execute his project. The external actors know what to expect, as there is one possible end-state of the project and the deliverables are clearly stated by the project organization. The adoption of RO in LEPs can difficult this approach. RO can have long active lifetimes and actor arenas are dynamic of character (Bruijn and Heuvelhof 2004). Interests of actors can change over time, actors can leave, and new actors can come into the picture. Besides, multiple project end-states are now possible. This can ‘scare’ the external actors. RO can have long active times which these can be exercised. Keeping external actors actively committed over a long period is difficult, and can create a counter incentive to block the ‘uncertainty’ towards the external stakeholders. Upfront involvement of actors and a degree of openness is required in the early phases regarding the RO and different end-states a project might be in. This can create a ‘relaxed’ ambiance regarding the new (flexible) approach of the project members. However, a balance may be required due to competition and not unlocking incentives for strategic behavior.

A non-option related issue is the reputation of the direct involved project members. A bad reputation more quickly creates a suspicion regarding the adoption of RO: something that harms their interests. A trustworthy reputation is required to reduce this element. A new process approach is to be initiated prior exercising a RO of significant size, that may impact the interests of external stakeholders. A high level of suspicion due to bad reputation is likely to more quickly generate negative associations with exercising options to alter the initial project design.

The importance of aligning the actors should be given adequate attention. A delay caused by actors can derail the relations between the direct involved project members and their surroundings, creating an environment of distrust. Any other change (within or without anticipation with the use of RO) can be confronted with opposing actors trying to block any deviation from the plan that was originally intended. The cost of these delays can be significant, as the implementation time of options increase, generating revenues at a later point and possibly reducing the remaining planned operational time (Cooper and Reichelt 2004; Eschenbach, Lewis et al. 2009).

There are attempts to integrate multiple actors in real option valuation context (Smit and Trigeorgis 2007). However, these do not focus on the implementation of real options with more than 3 actors, and more towards valuation rather than implementation of real options.

**Gap:** Adopting RO will likely result in additional required time and efforts to align external actors at RO implementation.

**Requirement:** Adopting RO should include a concept process approach to implement in the LEP.

### 4.4 Overview of factors, tension fields and gaps

A list of identified factors is presented here, based upon the assessed literature and expected factors that play a role. Table 3 presents the factors in the overview of the proposed method in 4.1.1. Each factor is discussed somewhere in literature. PM literature is also used as a ‘supply source’ for
scanning factors which are expected to be relevant. These mainly resulted into gaps, because RO and integration literature have not of merely assessed these factors.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type of literature</th>
<th>ROA</th>
<th>PM</th>
<th>Integration literature</th>
<th>Results in</th>
<th>Discussed in paragraph</th>
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<td>3</td>
<td>3</td>
<td>Gap</td>
<td>4.3.4</td>
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<td>-</td>
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<td>-</td>
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<td>3</td>
<td>3</td>
<td>Gap</td>
<td>4.3.8</td>
</tr>
<tr>
<td>Technological developments</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>Tension field</td>
<td>4.3.9</td>
</tr>
<tr>
<td>Specialized resources</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>Gap</td>
<td>4.3.10</td>
</tr>
<tr>
<td>Project relations &amp; contracts</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>Gap</td>
<td>4.3.11</td>
</tr>
<tr>
<td>Dealing with external stakeholders</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>Gap</td>
<td>4.3.12</td>
</tr>
</tbody>
</table>

Table 3 - Factors which need to be assessed to enable RO adoption in projects and project organizations. The literature references where the factors are based upon are given in the stated paragraphs.

The identified gaps, tension fields and requirements are briefly summed up below.

**Gaps:**
- Project owners adopting RO need to accumulate experience concerning RO valuation and implementation and places additional stress on the organization.
- Permits, EIA and regulations assessments are not considered in RO applications, but can impact on RO validity, implementation time and value.
- Necessity of specialized resources may hamper the flexibility of implementing the option and its payoff, often considered in PM, but not in ROA or integration literature.
- New uncertainty boundaries may require rethinking the project contracts, as a less complete contract may be written, which is not assessed by ROA or integration literature.
- Adopting RO will likely result in additional required time and efforts to align external actors at RO implementation compared to a traditional approach.

**Tension fields:**
- Monitoring of RO is required, but no approach currently exists how to implement a monitoring approach.
- There is currently no approach that assesses the cumulative impact of opportunity expenses to enable RO adoption and implementation.
- Adopting RO will place a burden on the project owners financial reserves.
- Adopted RO remain faced with unique project risks, thus unable to be valued using risk-free discounting.
- Technological developments may hamper valuation and implementation of RO, despite that of uncertainty increases option value.

**Requirements:**
• Integrating real options in PM organizations must result in a minimization of biases to exercise or abandon a real option outside the defined criteria throughout the PLC.

• A structured monitoring framework applicable for all types of RO must be included to enable effective RO implementation.

• RO must be assessed on their expected cumulative efforts required to keep the option alive over its presumed lifetime.

• RO approaches must be able to be documented and reviewed to allow cumulative experience build-up.

• Each adopted real option must be assessed on the possible costs of waiting or loss of revenues due to the implementation time and be compared to the project performance.

• The adoption of RO must remain within bearable limits to the project owner.

• RO must be assessed at the project start and over time on the faced unique project risks to set an adequate discount rate.

• RO must be assessed on permits, regulations or EIA compliances at the point of adoption.

• Technological developments must have a degree of reliability and tractability to adopt RO in LEPs.

• Adopted RO need to have a clear upfront design and list of required resources to implement these.

• Adopting RO requires a clear view on the uncertainty to be exploited and allow review of project contracts.

• Adopting RO should include a concept process approach to implement in the project.

Concluding from this summation, is that quite some assessment needs to be carried out upfront, and do not hold connection to the valuation assessment of the RO itself. It does impact the decision of the project owner whether or not to adopt RO.

4.5 Adopting Real Options introduces new tradeoffs
This section concludes the chapter. It further elaborates upon the identified factors in the previous paragraphs. The factors can be assigned different 'levels': on the RO level, project level and on the organizational level of the project owner. These levels are assumed to create a better categorization of different factors. These are not validated or based on literature. However, it forms a logical segmentation. It further discusses the impact of these factors when RO are adopted.

4.5.1 Factors on the Real Options level
Per real option, a number of indirect factors or tension fields apply when these RO are considered to be adopted in a project. Here, the classifications of RO is used as presented in paragraph 3.3. The factors are marked in **bold** to highlight these, and will be provided in bullets to give the required tensions. It elaborates upon required attention from the project owner when such type of option is considered.

**Defer options**

• Postponing an investment in total is one of the simplest and most researched RO. Eschenbach et al (2009) found that the **cost of waiting** is too often not involved in real option valuations, but may have considerable impact on the project performance.

• A **monitoring** element is required to enable implementation when the exercise criteria are met. Also, the decision rule (with respect to the market and technology) needs to be
reassessed from time to time in order check the validity of the decision rule (Miller and Waller 2003), when to invest and when to defer.

- Deferring will also lie a burden on the required specialized resources. These need to be available at the new point of investment in the project. It may seriously alter the required investment cost in acquiring the assets (reducing the RO total value).
- Permits, EIA or legal procedures will need to be revised, as validity may be time dependent. Changes in the regulation can place restrictions on the initial project design. Redoing procedures can increase implementation time of the RO or even the entire project.

**Growth options & option to stage investment**

These categories of RO generally face the same factors. Therefore, they are combined below. Where applicable, differences are highlighted.

- Monitoring is required to assess whether the right conditions are met for exercise the RO or initiating a new phase.
- There can be a cost of waiting involved, as late implementation will reduce the operational phase of the assets, thus generating less revenues.
- Depending on the size of the RO, permits, EIA or other regulation can be required, also having an impact on the implementation time of the RO. Also changes within this area can alter the value and/or existence of the RO.
- Depending on the RO nature, technological developments can be important, as a project can aim for the implementation of a new technology which may not be available yet. For phased investments, the development of a new technology can initiate a new phase of the total investment.
- Specialized resources can be necessary to acquire the assets of the growth or phased investment option.

**Learning options**

- Explicitly this RO focuses on facilitating technological developments. It involves a pilot, discovery or exploring aspects of technology or market. LEPs often require tailor-developed technologies, thus an important aspect.
- Learning, referring to something that is unknown, may require fulfillment to a permit, EIA or legal regulation. Depends on the type of activities and the size of the RO.
- Project contract selection is an important element in this type of RO, as the amount of uncertainty is explicitly large. Designing a contract should aim towards maximum learning potential.

**Exit options**

- An option to shutdown a project prematurely will require monitoring to assess the conditions whether shutdown is desired. Important in the analysis is the threshold value, and the expected longer term developments. Temporary bad market conditions do not immediately favor shutdown.
- Legal requirements can be an important item if a project is to be shutdown other than anticipated upon. Two small examples: social plans for the labor force can be required by law, or the requirement to continue producing spare parts for customer protection.
**Business scope options**

- A skilled monitoring team is required to assess the optimal operation mode for the plant, and initial built-in capacity. Implementing operational flexibility within existent assets is fairly common. Here, mainly the upfront scope in the design phase is important. This especially holds for RO ‘in’ a project, referring to increased effort and alteration of the technical design.

- Loss of revenues is not in the picture when operational flexibility is adjusted to the market conditions. Considering the constraints of the operating flexibility, this would be adjusted to create optimal revenues for the project.

**Sourcing options**

- Monitoring of the developments is required to determine the optimal switch point between inputs. This is determined by the decision rule for the option, as usually switching costs are involved.

- A permit may be required in order to use certain inputs. Governmental tax programs can also work in favor or disfavor for certain switch flexibility.

**4.5.2 Factors on the project level**

A number of tensions identified refer to the project level of adopting RO. These are highlighted in this section.

**Project Contracts**

Depending on the portfolio of RO and the type and degree of uncertainty, a redesign of project contracts can be required. This needs to be carried out on the project level. A project owner will have a new choice to include his adopted RO within one project contract, or restart a new contracting phase when the real option is to be exercised. This does however have its implication on the implementation time of the real option, which can cause a loss of revenues.

In the case of market uncertainty and fully developed technology, less incentive for internal or extensive cooperation exists. When a project is relatively complex, involving technology developments for example, a relation towards mutual trust and cooperation can be desirable. This allows better fine-tuning of resources. Thus, the type and level of uncertainty can be used to help a project owner choosing a contract form. This is presented in the figure below.

<table>
<thead>
<tr>
<th>Market uncertainty</th>
<th>Technological uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low degree of uncertainty</td>
<td>Low incentive for cooperation</td>
</tr>
<tr>
<td>High degree of uncertainty</td>
<td>Medium incentive for cooperation</td>
</tr>
</tbody>
</table>

**Figure 12 - Incentives to select a project contract form in the face of uncertainty**

A higher incentive to introduce cooperation would turn to reimbursable types of project contracts. With relatively low degrees of uncertainty, a RO approach presents less value. It also holds smaller chances on project changes. Thus less incentive for cooperation and learning. For market uncertainty, the time-to-market element becomes important as soon as project deliverables become
viable. In the face of technological uncertainty, learning becomes more important to implement new technologies. Thus, a higher incentive for cooperation between the project owner and (sub)contractors. Reimbursable contracts tend to set relations more as in-house environment. And in-house execution propose a better environment for collaboration and a reduction in resistance for the implementation of more flexibility (Olsson 2006a).

**Cumulative opportunity efforts**

On a project level, the project owner and manager have to construct an approach to assess the adopted RO in the project. They need to be monitored, reassessed over time and realigned with the main project design and phases over time. This requires effort. Effort to keep the options alive. If this is not carried out, the RO becomes 'detached' from the main project environment. Monitoring is necessary to ensure proper implementation of the adopted ROA project owner and manager need to set budgets and boundaries how monitoring should be organized to cope with the adopted RO within the project environment.

**Actor environment**

Increased effort and a change in approach towards dealing with external actors is required. Multiple project end-states are adopted with the integration of RO. This is required both on the project level, but organizational level as well. Because organizations are usually involved in multiple projects simultaneously, the reputation of the project owner granted in one project can influence others.

A renewed approach should be based on more continuous effort to deal with actors. Because project stated can intermediately change, it opens up multiple opportunities for external (critical) actors to form delays or block implementation of RO. A trustworthy relationship, balance of openness and interaction is required. Compared to a traditional approach, multiple processes may have to be conducted over the project lifetime, at the base design and prior to RO exercise. Sufficient time and effort is required prior to exercising the RO to conduct a process approach (Bruijn and Heuvelhof 2004). This however presents tensions within on the project level, as a quick implementation is preferred, with a faster beneficial result for the project.

**Physical plant layout**

Though not mentioned earlier, but needs to be taken along. The physical lay-out of the project needs to be reconsidered. Options may require space in the project, as it affects real assets. For example, a flexible plant requires additional space for placement of pipes, equipment and additional safety features. However, this tradeoff is part of the direct exercise cost and not so much for indirect factors along the way, though it can have a reflection a company options policy.

**Implementation time, cost & flexibility of the real option**

The impact of a RO implementation time in known in some literature (Nembhard, Aktan et al. 2002; Guthrie 2009), though often not taken along in the analysis. Neglecting the impact of the implementation time can cause overvaluing the RO adopted in a project.

The project owner often has a choice in the design how a RO is to be implemented. It can be possible to shorten the RO implementation time by adjusting the base design: by conducting more preparations for the RO implementation in technical aspects. This way, less tasks have to be carried out in order to implement the RO. Another possibility is that the tasks are carried out within a
shorter time span, but likely against disproportional higher exercise cost. It could allow a quicker generation of revenues by the RO for the total project performance.

This influences the physical amount of flexibility which RO can bring to the project. By carrying out option tasks upfront, the amount of flexibility which can be applied in the real option becomes smaller. In other words, the degrees of freedom within the real option assets diminish and more specifications for the assets are generated. This need not be a problem when the technological (RO) design is fully developed and ready. But in the case of technological uncertainty, it may limit the choice of assets over time for the RO: new equipment may not be compatible. This tradeoff is presented in figure 13 below.

Another important issue is the cost. If more cost for the RO implementation is carried out upfront, sunk cost appear for the real option. Because when the real option is not exercised, it will provide a cost which cannot be reallocated to some other project asset. This can also be categorized under the disposal cost. It also creates a bias towards exercising the real option within the project, because more effort has already been carried out.

![Diagram](image.png)

Figure 13 - Tradeoff between cost & effort upfront or at the moment of option exercise with the impact on the option

The importance of 'time-to-market' is a relevant factor to take along in the tradeoff. The strategic importance of 'being first on the market' can be important from an innovation perspective. The standards for a market can be set, or obtaining a large market share. Beating the competition to the market, thus gaining a strategic advantage (Ortt and Smits 2006). These aspects may be difficult to quantify, but such value can be estimated in a qualitative assessment.

Proper upfront analysis is required to see what the implications of these possibilities are. Screening models for options can assist where and what real options can bring to the project. Also, the likelihood that the option will be exercised can help in assessing the tradeoff whether preparations can be done in advance (at $t=0$, or prior to the decision of exercising an option). More effort can be put upfront into a business scope option if its beneficial for the project to operate on a flexible basis. This justifies cost upfront, rather than adjusting the project scope in later phases, introducing higher total project costs.
4.5.3 Factors at the organizational level
This section elaborates upon the identified tension fields which play on an organizational level. A project owner is immediately faced when initiating his project with the very first decision: whether to adopt RO. When RO are considered, an assessment should be carried out in the early design phases where flexibility can ‘make a difference’ in the project. Screening models can assist in this phase as there is a wide area of real option packages possible.

Balancing portfolios in the project owner organization
The choice to incorporate RO is an example for a strategic tradeoff, and not a simple manner of implementation (Adner and Levinthal 2004b). This is an important distinction, but it lacks recognizing that there are tradeoffs concerning the implementation of RO.

Most projects can include more than one real option. Portfolios can amplify or cancel out certain effects of flexibility in LEPs. But considering the contribution of this chapter, it also entails effort to recognize, analyze and implement these RO. A multitude of RO will introduce interaction effects, whereas the organization costs for RO (per option) lower, as synergies in the organization can be created. However, the number of interactions increase disproportionately at some point. This brings along serious heightened valuation cost and expects to introduce significant higher implementation efforts. Thus, there is an optimal point for RO integration in a project. The increase of value per added real option lowers, as a limited number of options can capture sufficient amounts of flexibility. Adding more options will substitute other options, leading to marginal additional values for the project. This concept is graphically presented in figure 14.

![Figure 14 - Impression of assessment cost for interactions between real options](image)

The selection and adoption of RO within projects for the project owner creates a burden on the company's resources. A company can only carry a finite amount of flexibility. Exercising RO creates expenses over a project lifetime. A project owner needs to have a sufficient reserve of resources to pay these expenses, or have a sufficient health to attract resources (i.e. debt capital) to finance the exercise. This can create a limit to the amount of flexibility which a project owner can give to its project(s). A preference can also be applied from the project owner, limiting the impact of flexibility on the total project returns, to keep a project within certain manageable boundaries. This is a

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8 Based on a same principle as scaling up processes: the cost per unit decreases
function depending on preferences for risk avoidance/tolerance, company profile, resource (capital) health and potentials of the options (compared to the volatility of the assets and expected developments on both short and long terms). Compared to the traditional approach, there is a reopening of the design space with real options, but with different new boundaries set to it. The boundary can be set in terms of maximum additional cost for the (direct technical) project cost, the number of options or the total impact of options (for example: as a percentage how options minimally need to enhance the expected returns compared to a traditional design of the same project).

Adopting portfolios of RO within a project alters the risk profile of the project owners organization. Commonly, project owners and managers are involved in multiple projects at the same time. A balanced program in the project management organizations aims to create a diversified portfolio of projects. Adopting RO will change the risk profile. Thus, not all projects can be included with RO portfolios, as it will burden the project owner too heavy. Thus, adopting RO can heighten the risk profile, which may need to be compensated by more lower risk projects (with a conventional approach). This is case specific and depends on the projects owner viability.

**Approach towards risk & experience with real options**

The attitude of the project manager and project owner towards risk is to be changed. Maximizing reward is aimed for with the adoption of RO (Neufville 2003), but lack of experience with RO may hamper the implementation of RO, as management and the project owner treat RO as a black box (Amran and Kulatilaka 1999; Brealey, Myers et al. 2006). This is a temporal bridge to overcome, but nonetheless a tension field. Deviating from a trusted and developed approach is tricky for project owners. Especially because a sense is initiated that the risk profile of a company is heightened when a project is initiated with a negative value with 'classic' DCF valuation and positive with an options approach. Cumulative experience build-up can break this circle, but requires effort and skilled resources to deal with this tension field.

**Monitoring bias & cumulative impact**

Partly connected with the points mentioned above. Monitoring can partly compensate the sense of heightening the risk. A wrong RO implementation could turn out for the worse. Thus, it is in the interest of the project owner organization to cancel out bias of RO exercise or abandonment. This can result to suboptimal payoffs or even turn projects into losses. Strict monitoring and reassessments can prevent this up to a certain degree. Section 5.4 and chapter 6 will continue on this topic.
5. **Adopting Real Options in a Project Management organization**

This chapter proposes a conceptual design how RO can be integrated in a PM organization. This approach should present project owners an approach how they can adopt RO. The factors and tension fields from chapter 4 serve as a basis for developing the here proposed design.

A structured approach to RO adoption in PM organizations is important, because actions from the PM influence the value of adopted RO (Bhargav 2004). Quick responses towards the changing conditions, result in higher value extraction rates. Currently, no conceptual framework exists for the adoption of RO in PM organizations. Without a structured approach, RO implementation can lead to suboptimal results or even losses.

A PLC will serve as the basis for the adoption method proposed below. First, the initial phases of a project are highlighted and the role that RO will play in these project phases. This is followed by the execution of the approach, building a real options department within a PM organization. In section 5.3, implementation elements for RO within project organizations are discussed.

**5.1 Converting Design Options into Real Options: Project Options Plan**

In the design of virtually any artifact, there is an immense design space where options are present in overwhelming numbers. This however does not entitle these as RO. This paragraph briefly enlightens the formation of RO in the early design phases of a project.

**5.1.2 From Design Options into Real Options**

In the conventional PM approach, a project is initiated for the cause of a beneficial change. In the conceptual phases, the design space is explored and mapped. This is followed by narrowing the design, creating requirements and objectives for the project deliverables. One project design is created, which is generally selected as robust and aimed to generate a positive end value in multiple and most likely environments (Christiansen and Wallace 1998). The design options are pinned down into one conceptual project design. This is refined into a detailed design. After these phases, the project faces the FID: the Final Investment Decision. In section 2.3 the concept of a project plan is discussed. Throughout these initial phases, the project plan is used to 'guide' the project at the project decisions to continue or abort the project. Intermediate there are a number of milestones and/or moments to assess the project design progress.

The RO approach is different to the conventional approach. RO are to be adopted in the project design phases, otherwise they cannot be valued in the investment. In that sense, a RO is a conscious action in the design and configuration phases of a project.

Design options can be turned into RO during these initial phases. Same as the conventional approach, the design space is explored. But rather than creating one design, a flexible design is proposed. Multiple end-states are assumed possible. Multiple design option(s) can be retained in the form of a (portfolio of) real option(s). These RO can alter the project end-state over the project lifetime. That
is, if the RO is exercised. If the RO matures within the project lifetime, it cannot be exercised anymore. See figure 15 for a representation of the approach in these early project phases.

Figure 15 - Comparing an approach of real options in project management with traditional practice

The figure holds a couple of simplifications. First, does not show intermediate go/no-go decision moments. These are likely to be present. Second, it ignores external influences from experts or external actors in both the conceptual and detailed design phases.

The RO approach, a conceptual design includes a first can of design options into a conceptual 'base' design of the project and a general 'RO package'. This package represents a set of design options, integrated with the base design, how flexibility can be included in the project. In these phases, screening models and valuation models can enhance the use of real options within the project. Further along in the design phases, the RO are split into RO 'in' and 'on' a project (see section 3.3 for an elaboration on these classifications). Both types of options interrelate with the base design of a project. However, RO 'on' a project do not alter the technological design, only the size and configuration. RO 'in' a project do alter the technological design, preparing for the implementation of flexibility by altering technological components. In this sense, RO 'in' projects are more tightly integrated with the actual base design. In these phases, a project owner can have a choice how to design the RO and adopt these within a project.

After the detailed design phase, the project is presented for the FID. If the FID is passed, the project will be executed. In this approach, the project end-state is not fully clear. Adopted RO can be exercised, abandoned, or they can mature when these are not exercised nor abandoned. It may not always be possible upfront to determine a maturity date for a real option (Yeo and Qiu 2003). The portfolio of RO determines the number of end-states a project can reach within the set project scope at that moment. A multitude of RO can amplify each other or cancel each other out. Generally, if
there are $n$ real options, $(n! + 1)$ different end-states can be possible at maximum if all RO can be exercised independently of each other.

By choosing an appropriate valuation method, it is possible to show some additional statistics, such as the chance an option is implemented. Examples of valuation methods are Monte Carlo Simulation or a lattice approach. This can pose an additional help for the project owner to ‘design’ the RO within the project. This way, the tradeoff can be given direction to carry out more tasks upfront for example (if there is a large chance that an option is implemented). Or to obtain permits already at the project start, rather just prior to the RO exercise moment.

5.1.2 Project Options Plan
Taking the FID, a clear and consistent project plan should be presented to the decision-makers. It creates a better decision environment towards committing to a project. By adopting RO, this process need not change. A difference between the conventional PM approach is that management is likely to be more skeptic towards the adoption of RO within projects. It places a larger burden on the project organization, while the adopted projects show lower payoffs with conventional valuation methods (such as a NPV) compared to a RO approach. This suspicion is supported by Brealey et al (2006) and Amran & Kulatilaka (1999), which elaborate on reduced trust as ROA can be treated as a black box.

The concept of a project plan can be extended: including the considered RO and the approach how these RO can be implemented. The traditional project plan describes, amongst others, items as the project scope, time, cost, quality and risk management plans next to the project charter. This project charter section can demonstrate why RO should be adopted. Most likely, a valuation analysis shows the potential of added value for the RO in the project. To provide a comparative environment for the project options plan, a conventional project plan can be presented as well. The conventional project plan focuses upon one project end-state. The project options plan refers to the same project, altered with the adoption of identified and assessed RO in the earlier (design) phases. It provides a fair basis for the decision maker to compare both project approaches and the required effort to adopt and implement the RO. A level of synergy exist in creating the plans because they treat the same project.

A clear and understandable valuation assessment is required to overcome the issue of black box treatment. In that sense, the analysis can focus on providing more statistics and ranges rather than just one figure concerning the added value: the choice of valuation method and presentation of the results is important. The project members are aware of presence of uncertainty and the impact. So provide overviews how RO can enhance results and focus upon reduction in downside risks.

A project options plan includes a first scan of the required effort how to deal with the required efforts to enable RO, like many factors in chapter 4. The project options plan should include the following items:

- Valuation results:
  - The RO value, payoffs and benefits for the (total) project
  - The analyzed exercise conditions, statistics when to implement and when not under which conditions
  - The conducted analysis method and assumptions
  - The RO (presumed) maturity date
  - **Risk analysis for required discount rates** of the proposed RO
• The technical design of the RO, including a list of required resources and planning
• Expected future technical developments concerning the proposed RO
• In case of a mutual interaction between the base design and the RO design: the changes and interrelations with the real option design and the main project design
• Interaction effects with other adopted RO in the project
• Assessment of change in risk profile for the project owner due to the presented portfolio
• Analysis of required permits, EIA or regulation and expected developments over time
• First plan towards RO implementation policy (further discussed in 5.3)

The project options plan needs to contain both benefits and efforts of adopting a RO approach in the project. Thus, it should include a first approach how the RO are to be implemented, the regulations or permits which may be required and the assumed development path over time at the moment of analysis. The renewed plan focuses on creating a balanced decision environment at the FID.

Derived from chapter 2, the adoption of RO implies that the project scope is widened to deal with the implementation of these RO without an intermediate project scope change. Miller & Lessard (2000) found that a clear and concise scope definition is a key contributor to project success. This presents an additional requirement to the adoption of RO: the project scope can still be adequately defined and controlled. RO for adoption in the project should be analyzed and mapped thoroughly, with a plan to implement these in the project. The focus of adopting RO in a project is to increase the project effectiveness rather than efficiency. As discussed in chapter 3, RO are never optimal: the inclusion of plans to adopt RO introduces a chance that these efforts are futile, as the options are not exercised. This should be compromised by a improved project returns the adopted RO allow.

5.2 Linking Project Risk Management and Real Options

In an attempt to link the integration of the real options within a PM practice, a peek has been taken to link the RO approach with PRM. The reason to analyze these fields in order to combine these is provided below.

The concept of ROA focuses on exploiting uncertainty, and maximizing rewards from risk (Neufville 2003). The definition used for risks in this thesis is given in section 2.2. However, risk is often associated with downside events, threatening the project from reaching the set deliverables within the constraints, it also poses opportunities. In some ways, RO show similarities with risks. RO can be labeled opportunities within projects, defined upfront, to alter the strategy. Thereby aiming to increase the project effectiveness. But the concept of opportunities with real options poses a way to address both concepts.

Another element which presented a 'suggestion' to link PRM and RO implementation is the call for reforming PRM. Some literature advocates a change in the PRM approach. By widening PRM, the focus shifts also towards benefits of opportunities in projects. Terms as project uncertainty management are preferred towards risk management (Ward and Chapman 2003; Perminova, Gustafsson et al. 2008). This new approach should lead to a better utilization of opportunities which are discovered upfront and during the project. RO fits into this picture, as it exploits opportunities derived from uncertainty in the project environment.

Both PRM and adoption of RO require a structured, organized approach. Inadequate treatment of risks leads to an increased impact of firing risks on the project. Similar for RO: inadequate exercise of
RO hampers optimal extraction of value. A second element which is important for both fields is the continuous effort for monitoring and control.

Based upon the PRM flow scheme in the PMBoK 2004 edition (see figure 2 and PMI, 2004), a flow scheme is developed how real options can be assessed and adopted in projects. This scheme is presented in figure 16. However, the order of tasks is somewhat different than from PRM. The identification and assessment of risks is carried out by setting up a risk management planning. This describes how risks are identified, assessed and documented throughout a project. This differs from a RO approach. For RO, uncertainty is the main focus of the assessment. This allows a qualitative scan for RO. After this, a quantitative valuation of the RO is conducted if an option shows sufficient potential. Screening models (see section 3.3) can be convenient to identify and assess RO where these can enhance a project. These tasks are carried out upfront at the project design phases before the FID, and are largely presented in the project options plan as well. In the upfront phases, flexibility is commonly encouraged (Olsson 2006a).

![Diagram](image)

**Figure 16 - Scheme for assessing real options implementation in LEPs. The blue boxes indicate analysis and implementation of real options, whereas the boxes at the right are linked with project management tasks.**

After the first valuation assessment, a RO management planning is set up. This describes the implementation strategy of the proposed set of RO, similar to a Risk Management Planning in PRM. In the RO management planning, the same issues as in a project options plan concerning the adopted RO should be included. Along with:
• RO owner, manager and responsibilities
• RO implementation plan (further discussed in chapter 6)
• Review procedures for RO monitoring and reassessments to allow experience build-up

In a sense, the proposed documentation system can be compared with a risk register. RO are listed, prioritized, assessed (when these are considered valuable) and documented. An owner or manager of a certain RO can be appointed, responsible for the development and updating of the assigned RO. A comparable approach exists in PRM (PMI 2004). Section 6.3 will discuss the implications for these roles on the minimization of a bias towards exercising or killing the appointed RO.

Based upon the documentation, an implementation plan can be created per option. How will the RO be adopted throughout the PLC during its active lifetime. The procedures to exercise or abandon the option are presented here. As well as an approach to monitor, reassess and control the RO.

The final task is the actual monitoring of the adopted RO throughout the PLC until the RO matures, is abandoned or exercised. In other words, the actual implementation of the adopted RO. Chapter 6 elaborates upon these topics of a monitoring approach, costs and efforts and the importance of monitoring. This includes RO reassessments, these are necessary over time to keep track on the validity of the real option. A pillar of the RO methodology is exploiting uncertainty. However, the uncertainty around a project changes over time, due to new insights, new research, commodity price developments, or discontinuous events. These can be different to the expected uncertainty evolvement in the valuation analysis. This requires reassessing adopted RO from time to time to check the value and validity of the RO. Dedicating effort to monitoring an option which no longer holds value for a project is useless. Revising the options plan after a reassessment can require a new valuation assessment.

This approach is an iterative process. The adoption of a (portfolio of) real option(s) leads to a change in the project scope. This can have a renewed impact on the RO management planning which may be adjusted due to a shifted project focus. Reassessments may require new valuation approaches.

In a certain point of time in the PLC, all adopted RO have been exercised, abandoned or matured. Thus, there is no incentive to continue monitoring activities. However, this can create a bias from the staff to strategically keep RO open to prevent shutting down the department. This is inefficient for the project owner. To prevent the formation of such bias, staff reallocation within the organization needs to be ensured. A possibility for this is to link the here proposed ‘Project Real Options Management’ (PROM) approach with PRM. Or, some level of external control should supervise the PROM department. Such external element should be considered as neutral or independent towards the project environment. By combining both approaches, staff and other resources can be reallocated within the project or organization on other RO, new opportunities or risks that needs attention.

An important distinction between ‘regular’ opportunities and RO in this context is that RO are identified and assessed before the FID. Both threats and opportunities may present their selves during later project phases and are to be utilized. It is possible to transform certain opportunities, deriving from uncovered uncertainty, into new options in a project. However, these cannot be valued at the point of the investment decision. It is impossible to value RO in the area of ‘unknown-unknowns’. Though these cannot be valued, they can pose benefits for a project. Allocated resources
become better trained over time to deal with these opportunities and integrate these (if allowed by management).

Though ROA and PRM have some difference in the methodologies to identify and assess their tasks, there is a degree of similarity. Methods in PRM aims to reduce uncertainty, while ROA methods aims exploiting a degree of uncertainty. Thus, methods differ how to perform tasks regarding identification and assessment of both risks and RO, and the implementation of RO. The latter one can be compared with risk response planning in terms of contingency plans, which have a similar impact. Integrating both approaches can lead to reduced cost due to synergies in this task.

5.3 Real Options Implementation Planning in a Project Organization

This paragraph elaborates on the concept of implementing RO in a project organization. Here, a number of identified factors in the previous chapter are placed into a perspective of a project owner who is faced with the adoption of RO within a project. A conceptual design towards an implementation system is presented. The goal is to provide a structure for the project owner how a number of gaps and tradeoffs presented in the previous chapter can be handled.

There is enormous freedom how RO can be implemented within projects. So far, no structured approach has been presented in the literature. Based upon the analysis of chapter 4, three components are assumed which can summarize and relate the identified gaps into an implementation approach. Their relations and contents are assessed in this paragraph, resulting from the analysis, discussion and findings from previous chapters in this report.

Within a project organization, the project scope and the project management plan define the project path throughout its PLC. Or: project paths, because multiple project end-states are assumed with RO. Another contributing factor is the company profile. It determines the companies policy towards identification, valuation and adopting RO. The approach and actions of a company and stance towards uncertainty influence the value and characteristics of real options (Amran and Kulatilaka 1999; Bhargav 2004). Thus, the company profile defines a perspective towards the (renewed) stance risk & uncertainty. The company's financial health (as discussed in section 4.3.6): the adoption of RO must remain bearable for the project owner. These factors, the project scope definition and PM plan form the boundaries in which an implementation approach for RO can be designed. The three components involved are the RO management planning, decision rules and RO monitoring & control. All elements will be discussed in this paragraph. An overview of the relations is provided in figure 17. In the next paragraphs, the role of these components in the implementation of RO are discussed.

5.3.1 Real Options Management planning

Introduced in section 5.2, the RO management planning shapes the strategy towards adopting and implementing RO in the project organization. The boundaries for the management planning are provided by the company profile. The company profile sets a financial limit to the budget for flexibility and the range of impact which the RO can have on the total project. The RO management planning elements are based upon identified requirements in chapter 4.

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⁹ Here, the company reflects the project owner, or the investor. It need not represent the project manager.
Figure 17 - Elements for a Real Options implementation system in projects and its relation, a simplified view

**Stance towards risk & uncertainty**

The company profile states the (financial) health of the company towards the project. This element sets boundaries to the impact of adopted RO that a project owner can bare. If a project owner has significant financial reserves at its disposal, he may be willing to adopt a higher impact of RO on the project performance (were the value of c represents a higher part of the total investment value).

During later project phases, the companies health should be reassessed over time, along with the RO. The financial health can change over time, especially in LEPs with long projected lifetimes. The analysis can show whether the (not exercised) RO pose an increasing burden for the project owner. The opposite effect is also possible: altering the RO because the improved position can allow higher option payoffs by revising their design.

Market dynamics strongly determine the level of risk a project owner is ‘willing’ to take. When operating in a rapid changing environment, a project owner will be forced to take a higher level of risk or exploit deeper levels of uncertainty to stay in the market\(^\text{10}\).

**Interaction of management planning with Real Option value**

There is an interaction relationship with the real options of a project, especially during the initial exploring and design phases. There is a limitation to the amount of flexibility a company can bear, and it stance towards risk also influences its value in practice. Hence, the RO which can be identified in-and outside the regular policy field of the project owner, can create a counter incentive to adjust the policy to cope with certain options to enhance the project return. Policy can be changed so that a certain real option can be adopted.

**External Actors & Real Options**

The company profile states the required knowledge and specialized resources that are present in-house. In-house implementation of flexibility in the project generally results in less resistance (Olsson 2008), but LEPs are virtually always dependant on external project members. If in-house expertise or specialized resources are available, the utilization of these resources should be maximized to minimize the resistance (and cost) of flexibility implementation.

Adopting RO need not compromise the actor relationships. A clear design of adopted RO and

\(^{10}\) The concept of a strategic advantage plays an important role. Learning options are a good example.
openness concerning the (limited amount of) possible project end-states. Generally put though, the adoption of RO will require more effort towards actor commitment.

In section 4.3.12, a gap between ROA and PM is identified concerning actor commitment. In LEPs, project owners and managers have to deal with (critical) external actors. A **process approach is to be adopted** to involve actors with the proposed project. A clear project charter is a prerequisite to generate support under the actors. If the project owner shows a 'vague business plan', the actors do not know what to expect and may provoke suspicion. A trustworthy image of the project members is important to minimize the chance and impact. There are different points in the PLC where surrounding actors should be given additional attention (compared to a conventional approach).

A process approach is to be initiated by the project owner at the project start to identify and assess the actors interests. This process should lead to a satisfying project design and RO package with sufficient support under the (both critical and non-critical) actors. Over the PLC, RO can become more interesting to exercise. These RO can alter the project strategy at some point, so therefore it is important to inform the actors again. However, RO having long active times, are likely to 'tire' external actors, as these do not wish to be actively bothered with the project owners potential actions. However, actor arenas are dynamic of character: actors themselves and their interests can change over time (Bruijn and Heuvelhof 2004).

The decision rules when to exercise an option is taken by the project owner. But the effects of exercising the options can be discussed with the actors. Resistance and ideas with external partners to a flexible project can be reduced or exploited, which will reduce the chance on delays due to hinder of blocking actions from actors. When a real option becomes 'more active', that it tends to meet its exercise criteria within a short time frame, a new process can be initiated to inform and commit actors. So at the project start and prior to the real option exercise, a process approach should enable a more smooth implementation of the project and its adopted RO.

It is important to remain active on the background: actors seeking information in time between must be answered, thus a PR-team should be in place. However, usually LEPs already have a range of PR-activities to inform and involve actors within the set project environment. It thus introduces marginal additional costs.

**Project Contracts**
The choice of a project contract is made at the project start. Standard PM practice refers to the complexity of a project and the definition of project success for the choice of a project contract. A **reconsideration of the project contracts** can be required with the adoption of RO. This depends on the degree of uncertainty that will be exploited, and the required resources to acquire the assets involved in a real option. Sections 4.3.11 and 4.5.2 elaborate on the choice of project contract, depending on the type and degree of uncertainty to be exploited. A larger degree of (technological) uncertainty favors more cooperation between internal project members, thus reimbursable types of project contracts. This allows better learning and fine-tuning incentives for the project members.

A project owner has the choice to integrate the main project and its adopted RO into one contract, or separate these. When a real option is considered to be exercised, a new contracting round is initiated. This is a choice to the project owner which has to be made at the start of the project. It allows the use of 'package deals', but has an impact on the RO implementation time.
Permits & regulations

In the first assessment of the RO at the project start, an analysis is to be carried out whether the size and activities associated with the RO require permits, an EIA or compliance with other regulation.

Two things are important to deal with RO and placement of these tasks in the implementation. First, the relations between the different adopted RO. These must be known upfront for the designers, because these influence each other. Consider a project with 3 growth options: A1, A2 and B. A1 and A2 are compound real options: A2 can be exercised after A1. Option A1 and B cancel each other after exercise. If all options would require a (different) permit, it would be inefficient to obtain both permits at the project start. The management team would want to know the chance that, given the conducted analysis (and assumptions), different RO are exercised. If option A1 has a higher change of implementation throughout the project, it would make sense that the project owner would focus on this permit. Thus, a choice presents to the project owner whether the permits are to be obtained in front or prior to the exercise moment, presenting the second thing: when should the project owner obtain the permits? Important considerations would be:

- How fast should the option be implemented (or is a longer implementation time crucial)?
- What is the cost of delay if the permit procedure would take longer than expected, i.e. less and later generation of revenues?
- And are the permit requirements expected to change over time, and how long will the permit be valid to for the associated real option?

Answering these questions can help the project owner setting his mind when he want to obtain permits for his RO: at the start of the project, or at the moment of exercise. The likelihood that a real option is exercised can help determine when he should carry out this task in the PLC.

5.3.2 Monitoring & control

Monitoring of RO during the project shows similarities in approach with PRM (see 5.2). It is a continuous, ongoing process. This holds for the adopted RO until all options are exercised, abandoned or matured.

The task of monitoring & control is to facilitate the path towards the moment of options exercise or abandonment. Its goal is to minimize or eliminate wrong exercise moments and minimizing wrong abandonment of options. These effects can result in suboptimal option payoffs or even losses. Meanwhile, there should be no bias to sustain monitoring all adopted RO are matured, exercised or abandoned. By integrating these tasks with PRM, this bias can be reduced: staff could be reallocated to monitor and solve other risks (or opportunities) identified in the project (upfront or along the way). Especially opportunities are a 'specialization' of the staff within PROM.

Resolving uncertainty

By adopting RO, often a different stance towards risk and rewards is taken by the project owner compared to a traditional approach. Over time, uncertainty is resolved: price developments will tend to favor or disfavor implementation of the RO, when based on market uncertainty. Technological developments result in new markets or applications. Thus, while a path is created, at t=1, the chances for the options in the project change, as will the 'distance' to its moment the option matures and exercise criteria. As the project progresses through time, these uncertainties will change, thus the value of the options is affected (shown in section 3.1).
Learning over time is important for RO adoption. Without monitoring, the implementation or abandonment of adopted RO is more likely to go wrong. An example of active learning is the application of learning options, such as the construction of a pilot plant.

It is possible that discontinuous events happen that were not foreseen. Traditional PM deals with the 'known knowns', and reduces other to manageable levels. RO tries to take along the ‘known unknowns’, which over time can be converted into known knowns. But there are also ‘unknown unknowns', which can seriously affect a project path and the value and exercise conditions of the options. These cannot be valued or adopted as RO within projects and involves a too 'fuzzy' project scope.

**Specialized resources**
Whenever specialized resources are required to exercise a real option, it is necessary to keep an eye on the equipment. It is considered irrelevant whether the required resources are available in-house or not. Specialized equipment or staff may need to be booked a certain time in advance. Acquiring resources on a short time notice can significantly increase the cost of obtaining these. Thus heightening the RO implementation cost and reducing the total payoff. Monitoring can help map the availability of these resources over time. It can adjust the RO implementation windows, depending on the cost of acquiring these resources versus loss of revenues if a later time slot is reserved.

**Reassessment of RO**
Deriving from the uncertainty evolvement over time, it is advocated that the adopted RO have to be reassessed over time. A reassessment revisits the RO design, criteria, valuation and assumptions to check the validity with the changing environment. As time passes, the situation can change. So can the environment deviate from the assumed range of developments incorporated in the RO analysis. In other words: reassessments check the validity of the real option with the initial design and the actual project at the moment. It reduces the chance that an option is exercised or abandoned in the wrong conditions. Thus, it presents a risk before the project owner and managers, as reassessments present expenses and efforts. This tradeoff can be compared with the scope, cost, time and quality tradeoff in traditional PM.

Important indicators for the intensity of reassessments is the relative impact of the real option on the total project value, the dimension of uncertainty and the required resources to implement the real option. A higher relative impact of the RO implementation on the total project makes a difference between a project being a bless or burden for a project owner. The dimension of uncertainty is represented in a volatility value of the underlying commodity developments. A higher volatility rate entails larger deviations. Thus a greater impact on the project.

**Change in legal requirements, such as regulations, EIA or permits**, can also initiate a reason for reassessment or the real option. It can alter the exercise cost, implementation time, thereby the option payoff. Or in the worst case, the existence of the adopted real option. A small example: the construction of a bridge, with an initial overcapacity to build on a second deck. A change in building requirements can demand additional strength of the bridge. Thus, the option to build a second deck is 'killed' (however, there is a cost saving that the bridge still meets the renewed requirements, thus saving retrofitting cost).
'Actor desk' 
Mentioned in section 5.3.1 under the RO management planning: though the relations with external actors need not be intensively managed when RO are active. Especially when a real option has a long time before maturing (e.g. multiple years), actors can lose interest. Actors can change throughout time. 'Keeping an eye open' on the background can be helpful to track opportunity windows for the adopted RO. Background activities as a PR-team or centre can support external actors when these request information regarding the project and adopted RO. The latter one is likely to draw their most attention, because it entitles changes to the project as known to the actors so far. Maintaining a balanced openness can reduce formation of an 'antitrust environment'.

Documentation
Discussed in 5.2, all assessed RO (including those which were not adopted) have to be documented. The results of the analysis, assumptions, decision rules and monitoring approach should be stored. Reassessment results and changes over time in the RO design, assumptions and conditions should be added. An adequate documentation system can provide a project owner a comprehensive view of the impact of the RO on the project performance, and the changes over time in the evolvement and resolving of uncertainty. RO can be abandoned, resulting from an analysis. This as well should be documented. It enables a build-up for experience towards project owner regarding the adoption and implementation of RO. It enables review whether the valuation assessment was valid, or that many (unexpected) changes over time had to be processed. Based on the documentation, reassessment and monitoring procedures can be optimized for the adopted RO.

5.3.3 Decision Rules
The purpose of the decision rules (or criteria) in the implementation part of RO in projects is clear: the criteria which have to be met for which the option can be exercised.

The RO management planning partly influences the decision rules. A company can implement preferences towards an option exercise moment (so maximizing the options payoffs) or a 'satisfying' payoff, where a certain minimal threshold is to be met. An example can be that the project owner considers the time-to-market\(^{11}\) for the assets more important than the highest possible payoff.

Typically, ROA assessments focus on the most optimal point of exercising, maximizing the (direct) payoffs. However, the standard practice fully ignores interaction with competitors, thus the element of acquiring a strategic advantage is not taken along (Brealey, Myers et al. 2006; Maritan and Alessandri 2007).

Monitoring & control also influences the decision rules through reassessments. A deviation from the assumed uncertainty evolvement path can require to set a new decision rule for a real option.

5.4 Cost of adopting Real Options in a project organization
This paragraph will extend on the opportunity efforts to adopt RO within a project organization. These expenses should not be ignored. Here, cumulative curves are developed for cost and effort to enable implementation of RO within a project organization.

Different ways exist to adopt RO within projects and its organization. This depends on the intensity of the analysis, monitoring and implementation of the assessed and adopted Real Options. To point out

\(^{11}\) A strategic advantage over its competitors
the difference, two extreme approaches are used in this section. These are loosely based on Coff & Laverty (2007) (see section 4.3.1). However, they do not address the cumulative effort towards monitoring. They do show the impact of upfront alignment or later alignment of the real option with the organization, however limited to a steady upfront value.

These two extremes are used to show the difference between the required opportunity expenses. The most effort for RO implementation in LEPs is the monitoring of the RO conditions during the phase that the adopted RO is active. Reassessments are required from as uncertainty evolves and learning takes place over time, which may deviate from the proposed and expected developments at the project start. This could have its impact in altered exercise conditions or change in monitoring program. Conditions can change significantly, both in favor and disfavor of the RO. It requires effort on a continuous basis over time until the real option matures. In both approaches of Coff & Laverty (2007), realignment of RO is required to place the RO within the project organizational routines. Where an integrated approach also focuses on keeping the option tight with the project and its organization, an isolated approach merely monitors and reassesses the exercise conditions just prior the exercise moment. Thus, the isolated approach would require less effort during the time the option is active.

However, they ignore all forms of expenses and effort required to enable the adoption of RO within a project organization. In their isolated approach, it is assumed that all expenses and effort are grouped at the exercise moment. This is an element the author disagrees upon. There are a number of expenses and effort that must be carried out upfront. It is impossible to carry out all activities just prior the exercise moment. The valuation assessments and (technical and implementation) design of the real option need to be known in advance in order to be able to determine an exercise moment.

Besides realignment of the RO with the project organization, another important element is the alignment of project members and external actors. This process requires time and needs dedication from the project organization in both approaches. Thus, resources (and thereby efforts) are to be allocated in order to align actors in the process. The effort to align actors can be carried out on a continuous basis, thus keeping all actors continuously aligned. As discussed in the previous paragraph, this is not effective nor efficient. By initiating actor commitment initiatives when an option nears its exercising criteria and the (expected) developments tend to favor meeting the set exercise conditions of the option, a more efficient way to deal with actors is proposed. Especially with long operational lifetimes in LEPs.

Whenever specialized resources are required to exercise the option, the payoff of the option could be lowered in the early phases after the decision moment (as specialized equipment is likely to be booked in advance). In the integrated approach, monitoring of the availability of the specialized resources is assumed. This way, by monitoring the availability, cost reductions can be obtained for exercising the option. Whereas an isolated approach would not reconsider the availability of the resources just prior to the exercise moment. Thus, the resources would be required on a short term, inducing higher cost to acquire the necessary specialized resources.

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12 Here, it is assumed that all actors are eventually aligned by adopting a process approach. This is an important assumption, which may not be realistic, as the result is often a result from negotiations and shows different characteristics compared to the start of the process. However, this is not the focus in this research.
Traditional PM practice takes all decisions concerning the PLC in the upfront phases. Though PM practice can be prepared for scope changes along the way (in terms of capital reserves), it is not accounted deliberately exploited. It remains in the assumption that there is one line of developments and one project end-state. The adoption of RO within a project organization brings along additional effort and expenses, in terms of (identification and valuation) assessments, monitoring and control. At the other hand, the adopted RO enhance the project returns when implement, as these generate revenues.

Regardless of the intensity of an implementation approach, the adopted RO pose opportunity expenses. Typical factors which present cost at the project start are:

- RO identification & valuation (both require skilled staff)
- ROA approval (management dedication)
- Optional (only for RO 'in' projects): Integration of RO with actual project design
- Development of RO management plan
- Development of initial implementation plans
- Review of the ROA with the proposed management plans, verify the set decision rules
- Setting up the monitoring & control department (PROM)

A monitoring & control element is assumed to be present in all approaches. If no dedicated monitoring of developments and evolvement of uncertainty would occur, the adopted real option would never be exercised.

Assigned option managers carry out tasks of setting up the monitoring department according to the RO management planning. The cost over active time of the real option consists mainly of monitoring and reassessments of the RO, next revisiting, revising and documenting implementation plans and conditions. For an intensive approach, these variable costs are higher (due to more intensive monitoring and more frequent reassessments) than an a lean approach.

Finally, indirect implementation costs can occur for the costs that have to be made to enable physical exercise of the option. This refers to indirect factors, such as additional costs to acquire (specialized) resources which have to be attained at (unexpected higher) expenses, obtaining permits and alignment of actors. For the proposed extreme intensive approach, these are already conducted upfront. These cost prior to exercising the real option is minimum, as all has already been accounted for. The lean approach requires effort, time and cost to carry out the assigned additional tasks. Thus leading to a longer implementation time and cost to enable implementation.

Both approaches are represented in figure 18. Here, a fictitious most likely option payoff is presented next to cumulative opportunity expenses. In chapter 6, this figure will be expanded. The intensive approach shows higher upfront and variable costs, but less cost to enable the actual exercise. The lean approach shows lower upfront costs, these expenses are postponed to the exercise moment. Less intensive monitoring allows lower cost. But, the cost to enable implementation is significantly higher than with the intensive approach. Which approach would be cheaper, depends on the adopted RO and the impact is can have on the total project performance.
Figure 18 - The cost of adopting RO can be assigned to upfront cost (at t=0), variable cost for monitoring & reassessments and indirect exercise costs.

Important to realize is that the most likely option payoff does not represent the actual option payoff. A better representation would be to use VARG (Value At Risk & Gain) curves, which will be further implemented in chapter 6. However, these cumulative expenses for adopting RO lowers the total NPV distribution of the project. Thus, figure 7 shown in chapter 3 proves inadequate to capture these costs. The overall value distribution is to be shifted to the left with the expected opportunity cost. Thus, it should lead to a revision of the figure into a new shape, compared to a traditional approach. See the figure 19 below for the renewed shape including monitoring cost for the real options taken along in the project.

Figure 19 - Cumulative expenses regarding the management of RO within the project organization will reduce the overall project returns

Adding up the cumulative expenses to enable RO adoption, a renewed decision rule whether RO should be implemented in a project can be proposed. Using the earlier rule presented in section 3.1.2, an adapted formula is presented here:

\[ NPV_{flex} = NPV_{passive} + c - m \]
Where $m$ represents the cumulative expenses concerning the adoption of RO within a project organization. It refers to all presented indirect factors to enable RO implementation discussed in this and the previous chapter.

The project owner and/or manager have a choice where they put effort and expenses to adopt RO within the organization. A part of the expenses is made in the upfront phases of the project. Identification, assessment and a first RO management plan have to be designed. This concludes with an upfront estimation of $m$.

Depending on the size of the options and the impact of the flexibility on the project performance, $m$ can range from marginal importance to a significant part of the project cost. Based upon this renewed decision formula, real option practitioners can gain a renewed insight that the value of flexibility $c$ is corrected for an expected cost $m$ in order to enable adoption. It is important to notify that $c$ represents the value of RO which may affect the project returns. The cumulative expenses to enable the adoption of RO, $m$, are real costs. Thus, a project owner can require that a certain option value $c$ must be obtained to justify the real expenses $m$ to be made.

$m$ is not a clear-cut value, but can be 'designed'. In this paragraph it is showed by adopting two general extremes. An intensive or lean approach show different effort and expenses to adopt and implement RO within a project and its organization. Chapter 6 will discuss different configurations for the implementation of RO within a project and its associated expenses and effort.
6. **Real Options implementation in projects**

Chapter 5 has discussed a conceptual design to adopt RO within a project organization. This chapter focuses on the implementation of RO in projects, and the interactions between the project owner and manager. Three implementation approaches are discussed in section 6.1. It also elaborates on the impact of opportunity expenses on the adopted RO characteristics. Section 6.2 elaborates on the necessity of adequate monitoring, by showing the cost of a wrong option exercise or abandonment. Section 6.3 dives into the evolvement of a real option value over a PLC and the interaction between an options owner, project manager and project owner.

**6.1 Three implementation approaches**

Two extreme forms of RO adoption in project organizations are presented in paragraph 5.4. These form the basis for proposing three different implementation approaches for RO within projects. The creation of an implementation tool for implementation of adopted RO within a project, is a result of monitoring & control, shaped by the decision rules and the RO management planning (see paragraph 5.3). In this section, focus is shifted to the required expenses and effort of enabling RO implementation.

Three classifications of expenses and efforts can be made: upfront (at the project start), variable (during the projected option lifetime) and indirect implementation (at the exercise moment of the RO) costs. Per RO, a different distribution of efforts and tasks can be set to these categories. They will be discussed in this paragraph.

An adopted portfolio of RO can show interactions and path dependency issues. It is important that the project owner and manager have a clear overview of these relations and effects of an exercise decision. The implementation of a RO is an irreversible event that can have impact on the RO portfolio configuration. Each portfolio of adopted RO will show unique characteristics. It is thinkable that merely one real option is adopted. The company profile sets the limit for the amount of RO and the impact of RO that is allowed on the project. A case sensitive optimal amount of RO can be searched by applying screening models and scans for flexibility in the design. The best basis for the identification of RO is to investigate the type and degree of uncertainties surrounding the project.

The choice for an implementation approach can be supported by a few indicators. First, there is the chance and the expected impact of exercising the real option in the project. It can be justified to allocate certain efforts upfront, leading to a reduced implementation time. This brings up a second indicator, which is the expected loss of revenues due to the implementation time. A third important indicator is the economies of scale that can be attained by expanding equipment. This can justify the alteration of certain capacities of the base equipment to facilitate RO implementation. However, this alters the type of real option into a real option 'in' a project. Benefiting from economies of scale can reduce the exercise cost, but if the option is abandoned or not exercised, the project owner sustained additional costs without generating revenues.

Determining the chance on the options exercise and the most likely impact of the adopted RO within a project, calls for a valuation and assessment method that provides more than a sole figure for the value of flexibility, c. An valuation analysis proposing a single value for the set of RO is not sufficient, thus numerical methods are disfavored. It is best to adopt valuation and analysis methods that can provide a graphical overview, range or distribution of the chance and value for a real option.
Different valuation iterations could be initiated to analyze the impact of economies of scale for real options versus a later adjustment of equipment. A (Monte Carlo) simulation approach presents the most promising way to conduct these assessments. Though its critique is the lack of structure (Amran and Kulatilaka 1999), it provides the most elaborate toolkit of including statistical results. Simulation allows to assess a portfolio of RO simultaneously with different project configurations with the same random seed. Thus, it provides the best comparison between different configurations and the impact of the different approach on the RO and total project value. A lattice approach can provide a more structured overview to the project owner, including different scenarios over time that can favor exercising or abandoning an adopted real option. However, a lattice approach can only cope with one real option. Literature proposes altered valuation methods to deal with portfolios of RO in lattices. Though, these quickly become a complex assessment, where the project owner and manager can lose track on the assessment method and value of adopting RO.

These indicators present the project owner and manager a guide to choose an implementation approach of RO in the project. The choice of a configuration is significant, as the allocation of resources for monitoring presents expenses to the project organization. An estimation of the required adoption and implementation expenses, \( m \) (see section 5.4), have to be included. The project owner would require to state its expectations towards the allowed expenses to justify the added potential value for adopting RO.

In the remainder of this paragraph, three different approaches are discussed. Each approach can be tailor made per real option, but some general elements are identified and assessed. First, an extreme is presented as committing as many elements upfront as possible, followed by its entire opposite. A third approach can be seen as a mix of both. All are discussed below, and special attention will go out to the associated cost of this per real option in general and some special characteristics that indirect burdens can pose.

6.1.1 An upfront approach
This approach would result in performing all analyses upfront concerning the options implementation. By placing these analyses in the early phases of the project, the present value of the cost will be higher, as a later assessment will result in lower cost, discounted towards \( t=0 \). Though, it can reduce the options implementation time. This would especially hold for permits, or the reservation of specialized resources for the implementation of the real option. It thus holds the base cost plus some additional cost for obtaining permits, or specialized resources.

After the project start, reassessments of the option will take place, where analyses will be executed to test the options validity with the context the project is operating in. So it would include additional cost concerning the monitoring and reassessments.

This can be represented in figure 20. A fictitious development path over time for a real option is given. It is assumed that the real option can be exercised at any moment within the given window, and matures at the moment that the revenues the option generates, no longer compensates for the direct exercise cost (thus: \( PV_{\text{option}} - E < 0 \), where \( E \) is the option exercise cost). The figure does not show the matching exercise criteria, when exactly to exercise the real option. See Copeland & Antikarov (2003) for a more elaborate explanation.
Figure 20 - Cumulative development over time of a real option and its cost to take the option along in the project, not discounted to present value and time is not to scale. Note: after the option expires, there is no need to continue monitoring.

The black lines represent the opportunity expenses, which accumulate over time. The cumulative value is the eventual value for $m$. The horizontal black line represents the upfront expenses that need be made to adopt and enable the real option. The red lines represent the 10 and 90 percent curves, or the VARG curves. At each point in on the horizontal line, there is a spread of the real option value. The option value decreases over time, considered the analysis which is carried out at point $t=0$. The option value decreases for multiple reasons: first, the uncertainty is resolved over time, resulting in a lower volatility of the asset (cash flows). Second, time passes by, the options exercise gets less time to generate revenues, assumed that the option assets will generate revenues until the end of the project lifetime.

Monitoring, reassessments and revising the implementation plans create expenses to keep the option 'alive'. Over time, the opportunity expenses intersect with the remainder potential value of the real option. That is, if the real option is not exercised yet at that particular point. Beyond this intersection point in time, the opportunity expenses become larger than the most likely options payoffs. Keeping the option alive after this point, results in ever increasing opportunity expenses, while the value of the real option keeps lowering. Thus, it is unwise to keep the option alive after this point. The cumulative opportunity expenses $m$ can revise the maturity date of the real option towards an earlier point in time. Compared to an assessment which does not consider $m$, the maturity date will be earlier in time. But this does not cover the 'full load'.

The opportunity expenses are real, in the sense that these are cost with which the investor is faced along the way for adopting the real option. The options value is a potential, not yet real revenue for the project owner. Therefore some sort of 'correction factor' can be required. This is represented by the red double arrow between the opportunity cost and the options value curves. So comparing $m$ versus $c$, an adopted (set of) RO must hold sufficient value to justify the opportunity expenses.
Consider another situation, where the maturity date for the real option is not limited to the average payoffs. A situation which can occur is that a real option has a time-bounded maturity date. A small example: a change in regulation can have a date which can enter into force in the (near) future. This can threaten the existence of a real option, thus setting the option maturity date at this level.

A situation like this is presented in figure 21. Here, the VARG curves are not shown. There is a considerable chance that the maturity date is before the opportunity expenses can intersect with the RO value development over time. Logically, after a real option matures, all implementation activities concerning this option can be ceased.

Figure 21 - The expected value of real option and an early maturity date

An upfront approach could best be applied when an adopted real option has a large chance of being implemented, while it has a relatively significant impact on the total project returns. In other words: proper implementation is of high priority for the project owner. This way, higher opportunity expenses can be justified.

Another motivation for adoption an upfront approach is the source and degree of uncertainty. More volatile and sudden developments require a more intensive approach. This way, a project owner has a better eye on the developments of the option value over time. Sudden unexpected developments can alter the option value path, thus whether it matches exercise or abandon criteria.

6.1.2 A lean approach

A lean approach focuses on minimization of opportunity expenses for the real option in the project. It makes a lean approach the extreme opposite of the upfront approach. The upfront effort and expenses to assess and adopt RO are required and fulfilled. But the variable monitoring and reassessments are reduced to a minimum level of effort. Therefore, the option is monitored whether it will reach its initial set decision rules, but not reassessed over time. A reassessment is conducted when the real option nears its initial set of exercise conditions.

A representation of this approach is provided in figure 22. The same value development path is adopted as in the figure in 21. This allows a better possibility to compare these approaches.
Figure 22 - Adoption of a lean approach, where reassessment is only carried out prior to exercising the option

The lean approach also faces an amount of upfront expenses. These are required to adopt and enable RO within the project. But after that, number of differences can be noticed compared with the upfront approach. First, the cumulative variable expenses for monitoring are lower over time. This results in a smaller shift in the maturity date. Less opportunity expenses results in a later intersection in time with the option value curve.

The effort to enable the implementation however is larger compared to the upfront approach. When the real option matches or nears its set exercise criteria, a reassessment is conducted. This allows revisiting the real options validity and assumptions. These are likely to have evolved over time. If the developments have turned out exactly as been assessed before, the reassessment would show that the conditions have not been altered. But if this is not the case, the option would have to be refitted prior to exercising. This introduces costs and effort, but revising the option can also entail that the decision rules which were set at the project start are no longer valid. Thus, it enhances the chance on wrong option implementation. The costs to revise and realign the real option with the project is shown as the blue line in the figure. These expenses can vary. Revising the real option costs time, thus the implementation time increases, lowering the option value. These interactions need to be considered. A project owner should be prepared in advance to be faced with such costs and effort.

Depending on the amount of uncertainty, a worst case scenario is that a reassessment shows that the real option is no longer viable and can best be abandoned. Proper implementation should have been carried out earlier. The next paragraph elaborates upon this element of ‘falling asleep’.

Figure 21 can also apply in the lean approach, if the real option matures before an intersection can occur. The real option maturity date need not be reset in that case.

This approach is likely more effective when there is a relatively small chance that the option would actually be implemented combined with a relatively small impact on the total project performance.
Few monitoring and reassessments efforts are considered required when mature technology and only consists of market uncertainty. However, monitoring remains important. When the market is ready, the option can be exercised. This has an increased chance of happening according to the original composed implementation plan, as the technology is not altered.

6.1.3 Mixed approach
There are numerous examples possible between the two opposite approaches presented in 6.1.1 and 6.1.2. A mix of tasks can be carried out upfront and prior to the actual exercise. The intensity of monitoring and reassessment tasks can be varied over time. A mixed approach aims to benefit from economies of scale where possible, with a tailor-made approach towards the monitoring and reassessments. This approach would be favored in cases where specialized resources are required, economies of scale apply and/or permits or assessments can be combined. Especially when the chance of exercising the options may be small, but the potential impact (relative to the project size) is large.

A requirement for taking this approach is that the degree of uncertainty (either market or technological of nature) is not too large. The expectations concerning the range of developments need to be trustworthy to carry out physical tasks upfront. Whether it is worth exploiting economies of scale, should be analyzed upfront at the valuation analysis where a benchmark (conventional) design is compared to a flexible design.

The impact of this approach on the maturity date of the real option will lie between the effects of the upfront approach and the lean approach. The main advantage of this approach over the lean approach is the reduced likelihood of wrong implementation of a real option, while expected to be cheaper than an upfront approach.

Choosing one approach, need not condemn the project owner and manager to stick to it. In paragraph 6.3, the dynamics of the option development over time are elaborated. From a lean approach, monitoring and reassessments can be intensified. Reassessments and implementation tasks can be shifted towards earlier points in time when a real option becomes more important for the project (example: a higher chance of implementation or increased impact on the total project performance). Figure 23 presents this principle. The other way around can be possible as well, from an upfront approach, monitoring & reassessment tasks can be loosened if a real option becomes less prominent in the project. In all cases, it is unwise to ‘throw away’ realized tasks and effort upfront to enable implementation. Therefore, going ‘back’ from a mixed approach to a lean approach should only be considered in extreme cases.

![Figure 23 - From a lean approach it is possible to move to more intensive approaches](image)

6.2 Costs of wrong implementation
This section aims to describe the importance of adequate monitoring and control for adopted RO. The cost of wrong exercise decisions are elaborated upon in this paragraph. By conducting a valuation analysis for a (portfolio of) real option(s), results in a set of decision rules. These are
determined by the analysis itself or the project owner when meeting satisfying exercise conditions. Thus, a decision rule can be a subjective element determined by the project owner. Depending on the chosen implementation approach and stance towards risk & uncertainty, a bias to exercise or to abandon the option are identified. Here, a simplified approach is used: an adequate decision rule is obtained from the analysis and no reassessments are necessary to enable a good implementation. In other words: the future does not entail changes unaccounted for in the analysis.

Concepts of wrong exercises of real options are elaborated with a simple binomial lattice structure. An abstract example for a growth option is used to enlighten this. It is assumed that the underlying commodity follows a GBM price process (see section 3.4 and Annex 4D). Figure 24 presents a fictitious project with a growth option to expand its project with new assets. The green boxes represent scenario's where exercising the real option is favorable for the project returns. The option expires after $t=6$. This example will be used to discuss the different types of bias and wrong RO exercise concepts. The numerical values do not pose any addition to the discussion of the principles, and are therefore left out.

Figure 24 - A project with a call option, initiated at $t=0$, green areas favor exercising the growth option
The bias towards abandoning or exercising an option can be substantial for the revenues of the option. These findings are based upon literature mainly assessed by Coff and Laverty (2007). Linked to these events, there can be the case of a 'itchy trigger finger' or 'falling asleep' (Copeland and Tufano 2004), thereby missing the optimal decision moment.

6.2.1 Bias to exercise option
A bias to exercise a real option can be created by a project manager making promises to its work force and by carrying out frequent realignments with the organization routines (Coff and Laverty 2007). Carrying out tasks upfront can increase or create such bias.

When such a bias exists, management can consider to exercise the option when the conditions are almost favorable, represented in the orange fields in figure 24. This can lead to two different paths within the proposed lattice. First, there is a chance that the conditions favor the exercise decision in the next time step and the option does become in-the-money. However, an early exercise dedicated resources to the implementation of the option too early. From a NPV-perspective, the exercise becomes sub-optimal, but still generates profit. The second possibility is that the price moves away from the 'exercise area' where the option becomes profitable. Exercising early can thus result in losses instead of enhancing the returns of a project.

6.2.2 Itchy trigger finger
Having an 'itchy trigger finger' is not the same as a bias to exercise an option. Exercising a real option prematurely will destroy some of the option value (Copeland and Tufano 2004). However, Copeland & Tufano (2004) assume a growth option as an American type of option paying 'no dividends'. This results that an early exercise would never be profitable. In engineering projects, this often not the case. When a growth option is exercised and implemented, it is likely to generate revenues for the project assuming that demand exists for the project deliverable(s). These revenues are same as stock dividend payments. In that case, an early exercise (before its maturity date) can be beneficial. The difference between the two concepts is that the itchy trigger finger will be used when an option is already in-the-money, while a bias to exercise can provoke exercising an option before the option is at- or in-the-money. Overall, both concepts will lead to reduced value extraction from the option.

6.2.3 Bias to abandon option
Fully isolating a real option can create this bias to abandon a real option. The longer a real option is not integrated within the actual main project assets, the larger the reassessment expenses become and required effort. This can create an incentive to abandon the real option.

The (indirect) exercise cost and effort increase, thus the overall profit of the option is lowered. With longer active lifetimes for a real option, it can enhance the possibility that the option is abandoned while it still holds value for the project. The yellow boxes in figure 24 represent valid scenarios where the option can be abandoned. In these states, favorable conditions for option exercise can no longer be reached: The option is and will remain out-of-the-money for the remainder of the project. In any other scenario, the option holds value for the project. Thus, it would be unwise to abandon it. On average, a bias to abandon leads to reduced project returns, in case the option still holds the promise to reach favorable exercise conditions.

---

13 The optimal allocation of money considering the NPV approach is to postpone cash outflows up to the latest moment possible, and cash inflows as early as possible.
6.2.4 Falling asleep

The 'cost of falling asleep' refers to the maximum value which can be extracted from the option (Copeland and Tufano 2004). This differs from the bias to abandon the option. Falling asleep refers in this context to inadequate monitoring of the real option. It will result in either a late awakening or no awakening at all. The falling asleep phenomenon especially matters in the green boxes of figure 24. In the case of late awakening, the option will be exercised at the point where one or more green boxes have already been 'passed' over time. Thus leading to suboptimal value extraction. An added perspective is when the real options operational lifetime (thus generating revenues) is further shortened.

When the real options operational lifetime is not affected by a late exercise, the revenues are generated in later project phases. Though it does not harm the absolute revenues, it is sub-optimal for the project financial performance from the NPV-perspective.

6.3 Option value over time

This paragraph discusses two important items concerning RO adoption and implementation in project. First, the dynamics of the presented graphs in paragraph 6.1 concerning the value developments of a real option over time. Second, the interception of a bias and wrong exercise discussed in paragraph 6.2. The interrelation is shown between these two concepts and what the role between the proposed option owner, project manager and owner.

6.3.1 Changes in value over time

The figures presented in 6.1 are analyses of a real option value stated at the project start: t=0. This paragraph elaborates upon interaction between the graphs and the advancement in time for the options valuation.

This is enlightened by adopting the same graph for the real option value development in paragraph 6.1 and the lattice developments from 6.2. A lattice approach allows a structured overview of assumed real option value developments. One real option is considered, so portfolio interaction effects are not discussed in this paragraph. For sake of simplicity, this is the same growth option as in paragraph 6.2. At t=0, the project is started (the FID is taken) and the real option is adopted. The real option is assumed to mature after t=6. This maturity date is set by management. The (most likely) real option value does not outweigh the required opportunity expenses at that point anymore. If the real option is not exercised before t=6, the project owner 'takes his loss' and is faced with a suboptimal cost for adopting the real option. Figure 25 shows the adopted binomial lattice and figure 26 shows the real option value development over time as expected at t=0.
Considering the figures, there is a substantial chance that the real option will result in a negative value (of a path into down-scenarios), or positive (when following upward scenarios). This has its
impact on the decision to exercise the option, as there is a substantial chance that exercising the real option turns into a negative value. It would be wise to await further developments over time towards real option developments and not exercise the option. The options manager, who has conducted the analysis, would give this advice to the decision maker.

At \( t=1 \), a certain time frame has passed. In figure 27, state \( u \) has been reached. Assumed that all equal conditions are still valid (so the external developments occur within the set boundaries of the analysis at \( t=0 \)), the bottom scenarios from \( d \), cannot be reached anymore. These are marked with a red cross in the figure.

![Figure 27](image)

**Figure 27 - From the situation \( u \) at \( t=1 \), the options value increases.**

This movement has an impact on the value development, in this case, in a positive way. There is an increased change that favorable scenarios for the real option exercise are reached. A number of lower placed scenarios fall off. Figure 28 represents the new value curve, assessed at \( t=1 \). Resulting from this graph and analysis, the advice from the option manager to the decision-maker is not altered. But the value of the option converges: the spread becomes smaller, compared with figure 26 with the assessment at \( t=0 \).

When a downside scenario, \( d \), is reached instead of \( u \), the opposite happens. Three out of six assumed favorable scenarios are stripped away. This lowers the likelihood of reaching favorable exercise conditions, thereby lowering the likely option value.
This 'exercise' can be repeated by the decision-maker and the options manager at each state. Thus, when reaching t=4, sufficient uncertainty is resolved to make drastic decisions. When all scenarios are towards the upside (the orange box at t=4), all possible option paths from that point result in a positive payoff. Thus, the advice would become to exercise the real option. At the extreme opposite, when the scenario develops downside (the yellow box at t=4), it becomes clear the growth option will merely result in additional losses. The advice would become to abandon the option.

At the orange scenarios, the options manager will know that the moment that the option becomes in-the-money is nearby. At this point in time, the price development for the next period can be determined with some degree of certainty\(^1\). He can change his advice to the management, in order to prepare them for the considerable chance that the option will become worth exercising. It allows the decision-maker to take additional preparations to prepare exercising and implementation, if they expect the scenario further to develop into favorable conditions.

It is assumed in this paragraph that no unexpected developments occur. The volatility of the uncertain asset is constant and does not change over time, as do all other conditions in the period t=0 to t=6. In the real world, there is a considerable chance in LEPs that uncertainty develops over time in an unanticipated way, meaning: developing differently than anticipated on at the start of the analysis. This can seriously alter the assumed price scenarios, option maturity time and design. This shows the importance of reassessments of the conditions over time. In a stable market, this is less important: the market moves slower, giving more time to anticipate on changes and these changes are smaller in their nature. In more dynamic markets, these developments will go faster and the

\(^1^4\) Right now, the prices of next month can be predicted with a higher degree of certainty than the prices of next year. The same applies here. At t=4, the price development for t=5 can be better estimated for the probability it reaches that point, than estimating the probability that the respective scenario is reached, estimating from t=0, so further back in time.
changes will be bigger. Reassessments can show an altered environment, possible affecting the RO lifetimes. This concurs with Yeo & Qui (2003), who mentioned that the maturity date of a RO can be difficult to set in advance and may be subjected to changes over time. To enable RO implementation with a degree of reassurance that an exercise decision will turn out for the best, reassessments and dedicated monitoring is important.

6.3.2 Minimizing bias in real options implementation

Upon the proposed design and reassessments, the minimization of a bias is important. Coff & Laverty (2007) elaborated upon the creation of a bias due a choice in the organizational approach concerning RO. They assumed a manager taking the exercise decision and management towards RO dedicated resources. A bias can be lowered by divorcing the management and ownership of a real option and the management taking the exercise decision. In the design proposed in this thesis, a slightly different allocation of roles is proposed.

In section 5.2 a PROM department is proposed, which shows a similar approach to PRM. A real option owner can be assigned per adopted option. This owner or manager is responsible for the implementation plans, design and monitoring of the real option. However, the real option owner or manager is not responsible for taking the exercise decision. Already mentioned in paragraph 6.3.1, the assigned real option manager advises the decision-taking management. This management is not or hardly connected to the dedicated resources which perform the monitoring and reassessment tasks. The real options manager has a budget per time unit to allocate upon monitoring and reassessment tasks, which is assigned by his higher management.

Monitoring of multiple RO at the same time is beneficial because interaction effects of portfolios can be quicker identified and reacted upon. Though the responsibilities for the RO must be clearly divided over the allocated resources and documented in the RO register.

The RO manager advises the decision-maker concerning the real options whether a real option should be exercised, abandoned or wait for further developments. This can happen on a periodical basis. All advises should be motivated, and can make use of the same type of value graphs as shown in 6.3.1. A RO manager who puts lots of effort in keeping 'his' option(s) valid, can create a bias to see his effort implemented. The opposite, an option which is disregarded can become detached from the project and a bias can be created to not implement such option. By a periodical report from a dedicated option manager, such an option is not disregarded from a project.

To reduce the impact from a biased RO manager to implement 'his' RO, the advice is checked by the decision-maker by testing the results versus the set decision-rules for the option exercise, and can be verified by another RO manager (not assigned with the option in consideration) who assesses the advice. An advice to exercise or abandon a RO needs more consideration than the advice to wait. This advice need not be considered as intensive as the advice to abandon or exercise the option. There is a certain time pressure involved in the decision to exercise a real option, as waiting can result in loss of revenues. So such an advice should be given a higher priority. The check reports on the validity of the advice. At that point, the decision-maker can take further action to deal with the considered option in the project: wait, exercise or abandon. This builds in a number of checks to minimize the likelihood that a real option is implemented at a point in time where it does not extract sufficient value from the options potential.
7. **Synthesis gas plant in the Port of Rotterdam area: A Case Study**

The second part of this thesis is dedicated to a case study. The purpose of this case study is to provide a fictitious example for a real options application to a LEP characterized with high uncertainty. However, the case study is developed in such extend that it could reflect a realistic setting. The data for the case study is extracted from literature and databanks which are publicly available.

In this chapter, a static and flexible plant are valued. Alongside, the RO implementation approaches discussed. Section 7.1 elaborates upon the plant design and adopted RO. Section 7.2 will dive into the valuation of the plant configurations and presents the analysis results. 7.3 will elaborate on the implications of the options implementation on the project. Section 7.4 presents a discussion on the results, and section 7.5 presents a number of conclusions of this case study.

Synthesis gas, or syngas, is a mixture of mainly carbon monoxide (CO) and hydrogen (H₂), and small fractions of carbon dioxide (CO₂) and methane (CH₄). There is a multitude of applications available for syngas, from heat, electricity production, to the production of transportation fuels or further processing into fine chemicals. It can be acquired through gasification of oil, coal, biomass or treatment for natural gas (Gasification Technologies Council 2008). Thus, it presents an alternative for natural gas and oil resources, which show volatile price developments over time (Eurostat 2009; CBS 2009a). Annex 5A elaborates further on syngas and its applications.

The port of Rotterdam (PoR) is one of the largest ports in the world, and contains over 5000ha of industrial sites (Port of Rotterdam 2009). There is also a (petro)chemical cluster present which heavily relies on oil, and an energy cluster which relies on gas and coal. A syngas production facility can be implemented to diversify the fuel portfolio. Coal can be used as an alternative for the production of the intermediate product syngas, which then can be sold to interested parties, to provide them an alternative for their dependency on oil and/or gas. The advantage is that coal price developments are less volatile over time, and pose enough reserves to accommodate the demand for the coming century (CBS 2009a; CBS 2009b; Shafiee and Topal 2010). Next to this, the PoR wishes to lower its emissions over time (Rotterdam Climate Initiative 2008). The inclusion of biomass gasification could allow to ‘green’ the need for fuels (Koppejan, Elbersen et al. 2009). Gasification also includes a possibility to capture the CO₂ in the process (Gasification Technologies Council 2009).

This chapter contains the made choices and assumptions in the valuation and creation of the model. More elaborate discussion of the assumptions and design of the plant can be found in annex 5. The main interest is the results of the value of the flexibility and the impact of the RO implementation in the project, and not so much the development of a syngas plant in the PoR.

7.1 **The plant & adopted real options**

Synthesis gas production facilities are capital intensive plants, and rely heavily on economies of scale in order to acquire acceptable production cost per unit of syngas (Rostrup-Nielsen 2002). Large installations are the consequence to allow a competitive position on the market. This is also the case for the PoR in search for alternatives to oil and gas. Small scale syngas production will not place an incentive for a cluster development, as is intended with this first facility. Direct demand for syngas is not yet present. A production facility could therefore convert the syngas into another product that can be sold to the market. Considering the port characteristics, the production of power (electricity) is taken as the favorable choice. Annex 5B shows an assessment concerning this part. In later phases,
demand for syngas can develop as new sites are developed or retrofitted. Here, the presence of a syngas production facility can play a crucial role by offering to produce syngas against a desired price.

Coal is the preferred first fuel, as it is relatively cheap and has a stable price compared to gas and oil. Current technology limit the availability of large scale biomass gasifiers (Sims 2002; Jin, Larson et al. 2009). Coal gasifiers are used instead. There is a degree of both market and technological uncertainty present here. It might very well be possible that during the lifetime, a viable large scale biomass gasifier is introduced. These expectations are not taken along in this analysis. The configuration of the plant is based on two literature sources (Jin, Larson et al. 2009; Martelli, Kreutz et al. 2009) for composing the benchmark plant.

A power plant based on gasification of either coal or biomass can be separated into four sections: the gasifier island, gas clean-up, oxygen supply and the power generation part. The gas clean-up and oxygen supply are closely related to the chosen gasifier type. In order to minimize initial capital cost, a tailor made approach is chosen: The gas clean-up is linked with the gasifier type when invested in. The oxygen supply section shows very large economies of scale. Thus, a base configuration can be formed, composed from Martelli et al:

A Shell coal gasifier with CO$_2$ venting is taken as a base configuration, with two coal gasifiers, gas clean-up and direct O$_2$ supply (as this is cheaper than direct air gasification (Jin, Larson et al. 2009)), with a power island put after it. The net power output is 789 MW$_e$, with a gross input of 1699 MJ$_{LHV}$ coal. Thus, the net efficiency is 46.44%. Martelli et al (2009) propose their detailed assumptions concerning efficiency losses and composition in their article.

An additional section is prepared in the flexible section, that 2 additional gasifiers can be added to the plant, for the purpose of syngas production for external customers. Thus, these need to be of another, more expensive configuration as CO$_2$ capture will be necessary. Otherwise, the syngas will contain CO$_2$, which is assumed to be an undesired product for the customer. There are two types of reference plants composed. A third configuration is flexible. These are listed below:

1. The 'base' plant
2. The 'lumpy investment' plant or full configuration
3. The flexible plant

The base plant is the C-IGCC according as described above: a power plant based on coal gasification with two gasifiers, with 789 MW$_e$ output, to be sold on the electricity market in the Netherlands. This plant does not have the possibility of selling syngas to the market, but merely produces it as an intermediate product for power generation.

The lumpy plant is the maximum configuration, invested upfront on immediate notice. At the project start, immediately four coal gasifiers are installed, and 'await' demand for syngas from the market. This configuration allows maximal profit from economies of scale, but 'lies dead' waiting for a rising demand in syngas. Thus, it is expected (prior to the analysis) that this investment will have a negative NPV.

The third configuration is the flexible plant. It originates from the base plant and can expand with two gasifiers. These produce syngas to be sold on the market. The required energy for the air separation unit and CO$_2$ capture are drawn from the power island of the base plant. As a consequence, there is less electricity that can be sold to the market. The options have been selected by conducting a literature analysis for syngas & gasification, together with a conceptual model for the
plant valuation, for more information, the reader is referred to annex 5C. As a consequence, the analysis of biomass gasifiers is excluded, as it is yet not economically viable to construct such gasifier (Jin, Larson et al. 2009). The coal gasifiers can be retrofitted to co-gasify biomass up to 25% of the LHV energy input. Thus, presenting this range of options:

1. A set of two sequential investment of two ‘smaller’ coal gasifiers.
2. An immediate investment in a large gasifier train (involving taking both free gasifier slots at once). 1 and 2 exclude each other.
3. A refit of the gasifier and feed preparation section to incorporate biomass co-gasification up to 25%.

An operational lifetime of the plant is considered to be 25 years (Jin, Larson et al. 2009), whereas the capital estimates and the construction period of 4 years are based on Martelli et al (2009). The project will be initiated in 2010, and thus be shut down at the end of 2038. This holds for all plant configurations. During the construction and operational phase of the plant, additional gasifiers can be placed to expand the flexible plant. The option would expire at the moment that the revenues are considered not to pay back the exercise cost: the construction cost of the gasifier. The different end-states of this project are shown in figure 29.

![Figure 29 - The different end-states which are considered in the syngas plant, the vertical line represents the maturity date.](image)

The option to retrofit the gasifiers & the feed preparation for biomass is considered to be an option ‘on’ a project, because the initial design is not prepared for the exercise of this option. The integration of the expanded ASU entails that the projects’ technical design is altered, thus the growth options are options ‘in’ the project.

The proposed C-IGCC is a large technical project, which is not 'standard' practice to build. Thus, it can be reasoned that the risk is fairly substantial. A 15% discount rate for such projects is not unusual, compared with a qualitative assessment based on the CAPM (Brealey, Myers et al. 2006) and a comparable thesis report assessing gasification (Spek 2009). For the options discount rate, alternative risks can be used, according to the ROA theory (see chapter 3). Because the payoff structure of the RO are not constant, hedging the payoffs would be very difficult. Besides, a risk-free discount rate would be difficult to explain to the project owner as unique project risks continue to exist on the RO. Different categories of risk exist (see annex 2 and the PMBoK, 2004 edition). Thus, it is reasonable to use a discount rate lower than the set 15%, but risk-free discounting would be unexplainable. The used discount rate for the options is set to 8%. 
Overall, 4% of Operation and Maintenance costs and a capital recovery factor of 15% are taken for the plant configurations, whereas the capacity factor of the plant is 85% (Jin, Larson et al. 2009; Martelli, Kreutz et al. 2009). The table below provides an overview for the capital cost estimates for the plant configurations and options exercise cost (Koppejan, Elbersen et al. 2009; Martelli, Kreutz et al. 2009).

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Capital cost, million Euro</th>
<th>Other necessities</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark plant</td>
<td>1362</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumpy plant</td>
<td>2251</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexible plant</td>
<td>1578</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Option, small gasifier</td>
<td>415</td>
<td>72.3 MW_e</td>
<td>Required electricity for CO_2</td>
</tr>
<tr>
<td>Option, large gasifier</td>
<td>761</td>
<td>144.6 MW_e</td>
<td>capture drawn from power plant</td>
</tr>
<tr>
<td>Retrofit to co-gasify biomass</td>
<td>79</td>
<td></td>
<td>Per set of 2 gasifiers</td>
</tr>
</tbody>
</table>

Table 4 - Overview of different cost for the plant configurations and real options

The options exercise can be modeled as follows. Hence, it is assumed that a small gasifier can be build when the syngas demand reaches 40% of the maximum expansion capacity. The second gasifier is constructed when 90% of the capacity is reached. It can be noted from the table that the large gasifier train profits from more economies of scale. Thus, the large gasifier can be exercised when a lower demand is requested. Hence, the large gasifier is assumed to be exercised when 70% of the demand is reached. The retrofit to co-gasify biomass is taken along that 15% of the nominal investment could be retained in the first year. Further, it is taken along that this retrofit will take two months to implement.

For the additional gasifiers, an implementation time of 2 years is taken for a lean approach or 6 months for an upfront approach. During the initial analysis, an implementation of 2 years is used. In section 7.3, an upfront approach is compared with this lean approach.

### 7.2 Valuation of the plant

This section will continue on the defined project configuration in the previous section. The inputs and outputs of the model are defined and modeled. Next, the model set-up is described. Finally, the analysis is conducted and the results are presented in paragraph 7.2.3.

The valuation method that will be used is Monte Carlo Simulation. Multiple sources of market uncertainty are considered, along with multiple RO. This excludes the possibility to adopt a binomial lattice. The value of flexibility is measured as the difference between the NPV_{flex} and NPV_{non-flex} of the configurations.

#### 7.2.1 Parameter estimations

The inputs and outputs are subjected to uncertainties. Literature suggests that mean reversion processes to model future price paths for oil, natural gas, coal (Laurikka 2006; Shafiee and Topal 2010) and electricity (Blanco and Soronow 2001b; Blanco and Soronow 2001c; Redl 2007; Wang, Wu et al. 2008) fits best. Annex 5C elaborates upon this use of GBM and MRP models in the case. Annex 5D contains an extended parameter analysis. For the extraction of values from historical data, the method proposed in Blanco et al (2001b) is used.

A partial problem arising for this analysis is the long term price forecasting. Prices can be modeled for a certain time period. Shafiee et al (2010) present a large review and present a model to predict price
developments up to 2018 for fossil fuels, using MRP trend price models. After such period, the prices are quite difficult to determine. It can go multiple ways. To correct this in the analysis, the volatility and MRR values found in the analysis will be subjected to a probability distribution based on the original derived values from the historical data. This is then combined with subjective estimates by the author and the expectations in literature, mainly based on Shafiee et al (2010), Wang et al (2008) and Redl (2007). Historical data is used to identify the model parameters. 30 years of forecasting shows limited applicability for using historical data as input. But it is the best there is possible. By subjecting the model parameters to distributions in later phases, this is assumed to present a more reliable price path prediction.

It is assumed that over a 30 year period, prices shift over time due to trends. Trends are identified in literature and taken along. Finally, the different uncertainties are stochastically correlated as it develops more reliable price paths. Based on literature, different correlations are set and used as constants throughout the analysis.

Below, the conclusions from the analysis and important assumptions made are presented and elaborated. Annex 5D contains a more extensive parameter analysis. First, the cost parameters are discussed: fuels and CO₂, followed by the plant outputs. Correlations and trends are assessed. All energy prices, except for power, have been converted to GJ, based on conversion ratios of Janssen et al (1991) and Silverman (2009).

**Plant input costs**

Historical price datasets have been used to assess the prices of oil (CBS 2009a), natural gas (Eurostat 2009; CBS 2009c) and coal (CBS 2009b). These are modeled as MRP models to create a random price path which it usable in the simulation model. The table below shows the extracted values, and the given probability distributions. In annex 5D these distributions are elaborated more extensively.

<table>
<thead>
<tr>
<th></th>
<th>2010 - 2020</th>
<th>2021 - 2030</th>
<th>2031 - 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Mean Reversion Rate</td>
<td>0.87</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>Volatility Min: 0.87 Max: 1.10</td>
<td>0.95</td>
<td>Min: 0.90 Max: 1.10</td>
<td>Most likely: 0.95</td>
</tr>
<tr>
<td>Coal Mean Reversion Rate</td>
<td>0.10</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>Volatility Min: 0.10 Max: 0.30</td>
<td>0.20</td>
<td>Min: 0.15 Max: 0.50</td>
<td>Most likely: 0.30</td>
</tr>
<tr>
<td>Natural Gas Mean Reversion Rate</td>
<td>0.03</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>Volatility Min: 0.03 Max: 0.40</td>
<td>0.20</td>
<td>Min: 0.20 Max: 0.80</td>
<td>Most likely: 0.50</td>
</tr>
</tbody>
</table>

Table 5 - The identified variables and given probability distributions for oil, gas and coal

---

15 Consider the natural gas price & oil price: when oil prices rise significantly, it is expected that the price of natural gas also grows. Thus, a correlation can be used to model this as well.
The price of biomass could not be extracted from a historical data set. An additional assumption is that biomass is considered carbon neutral, not needed to buy CO₂ emission rights. Based upon two reports from the ECN, an uniform price distribution is assumed between 6 and 10 Euros per GJ (Tilburg, Vries et al. 2005; Koppejan, Elbersen et al. 2009). It is expected that the availability of biomass will grow over time, this price will not be subjected to changes throughout the plants operational life time.

The pricing system for CO₂ is considered to be based on the proposed EU ETS system from 2012 onwards (EU 2008; Chappin, Dijkema et al. 2009; EU 2009). A few simplifications are applied. It is assumed that there is a cap model, where the emissions cap is lowered every year, thus resulting in an expected average price increase. It is assumed that no emission rights are grandfathered, but they all have to be bought on the market. A MRP model can be used to model the price developments for the CO₂ emission rights (Laurikka 2006), where it is assumed that the cap will be lowered each year. The volatility of the market its assumed to be high (Chappin, Dijkema et al. 2009), therefore a MRR rate of 0,8 and volatility of 35% are taken to model the price process.

**Plant Outputs**

A same approach is adopted for modeling the price of electricity. The price process is based on historical data (CBS 2009c). The prices of electricity can be modeled as a MRP process (Blanco and Soronow 2001b; Redl 2007). Though, the used data from CBS is concerning the base load price on the APX market. Redl (2007) shows that common for Europe, the prices on the spot market and futures converge to each other. Thus, the APX spot market is chosen to model the price process for electricity. Like the other parameters, over time the MRR and volatility are subjected to a probability distribution. Expectations are that the electricity price volatility will not grow excessively over time in the future (Wang, Wu et al. 2008), thus this is taken along in the estimates. See the table below.

<table>
<thead>
<tr>
<th>Electricity</th>
<th>2010 - 2020</th>
<th>2021 – 2030</th>
<th>2031 - 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Reversion Rate</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>Min: 0.25 Max: 0.45</td>
<td>Min: 0.35 Max: 0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most likely: 0.35</td>
<td>Most likely: 0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatility</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>Min: 15% Max: 40%</td>
<td>Min: 20% Max: 40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most likely: 30%</td>
<td>Most likely: 30%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 - MRR and volatility rates derived from historical data and subjected to uncertainty over time.

The syngas price is composed of two variables. First, the assumption is taken along that the project owner will not sell its syngas under its cost price. A capital recovery factor of 15% is used for retaining the capital investment cost of the syngas section, combined with the marginal cost for producing its syngas, thus cost of the coal fuel, electricity and CO₂ price. This is the minimal price. Next, an additional ’market’ component is used in a simplified way. The price of syngas also depends on the mean of the oil and gas price. Higher prices will lead to a higher syngas price, thus a higher ability to retain earnings for the project owner. A factor of 0,7 is assumed, setting the ’market price’ for syngas at 0,7*(0,5*(P_{oil} + P_{gas})) per GJ. Overall, the price is composed of the maximum of these prices.

The demand for syngas is to be modeled, as no demand in the PoR for syngas is present at the moment the plant is initiated. The demand for syngas is determined by its 'quality' and the CO:H₂ ratio. These are both important aspects, but a number of simplifications have been assumed at this part. The plant converts 99,98% of the carbon (into CO), but it would thus create a ratio that is
undesired for some applications. A 1:1 ratio is applicable for more customers (Apotheker, Elst et al. 2007). Thus, all syngas is transformed into this ratio by modifying it in the WGS-reactor of the plant. Concerning the quality of the syngas, it is assumed that the syngas is clean. All methane and CO₂ which are formed during the carbon conversion react to CO + H₂ or are captured. The demand is expected to rise when an incentive is created for customers to either retrofit their plant and use the syngas from this production facility, or new facilities which wish to set up a site in the PoR. Since a multitude of factors would determine the demand, ranging from cost price to location factors to the quality of the gas, a proxy is used for this. The incentive is modeled by solely a price difference between the mean of the oil and gas price per GJ, and the price of syngas. A larger price difference would entail a larger incentive to switch to the use of syngas of an external source. The advantage of the syngas plant would be the economies of scale and less worries or capital investment requirements of the external client. The larger the price difference is, the higher the chance a client will buy syngas. And so, two different categories are used: small users, requesting between 30-50% of the production capacity, and a smaller chance that a large consumer requests syngas, between 60-100% of the plant production capacity. The combination of these stochastic functions represent the uncertainty in the PoR area over time. This does not represent the reality, but for the purpose of this case sufficient. The probability distributions that a customer will appear is given in table 7. After the growth, the syngas delivery will continue to the end of the considered lifetime.

<table>
<thead>
<tr>
<th>Syngas demand</th>
<th>Price difference</th>
<th>Chance on small customer</th>
<th>Chance on large customer</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>x &lt; EUR 1 / GJ</td>
<td></td>
<td>0</td>
<td>0</td>
<td>Incentive considered too low</td>
</tr>
<tr>
<td>EUR 1/GJ &lt; x &lt; EUR 2/GJ</td>
<td>10% chance</td>
<td>1% chance</td>
<td>Discrete distribution</td>
<td></td>
</tr>
<tr>
<td>EUR 2/GJ &lt; x &lt; EUR 4/GJ</td>
<td>20% chance</td>
<td>2% chance</td>
<td>Discrete distribution</td>
<td></td>
</tr>
<tr>
<td>EUR 4/GJ &lt; x &lt; EUR 7/GJ</td>
<td>25% chance</td>
<td>3% chance</td>
<td>Discrete distribution</td>
<td></td>
</tr>
<tr>
<td>x &gt; EUR 7/GJ</td>
<td>30% chance</td>
<td>5% chance</td>
<td>Discrete distribution</td>
<td></td>
</tr>
</tbody>
</table>

Table 7 - Assumed distributions for syngas demand rise for the plant, x represents the price difference between syngas and the average price of (oil + gas)

**Trends**

Over time, prices shift. Virtually all (average) prices tend to move some direction over time. Based on literature, different trend have been identified and taken along in the analysis. Based on different literature, trends have been identified. These also have a 'limited applicability' over time. Beyond certain horizon, these identified trends on historical data lose their validity. This is 'solved' by subjecting the trend to a distribution resulting in growing ranges of growth over time. The trends for oil, gas and coal are based on Shafiee et al (2010). Based upon identified correlations, a trend for the electricity have been taken along. For CO₂, the trend is based on documents from the EU (2008;2009) and Chappin et al (2009) and are already corrected for inflation. Table 8 provides an overview.

The prices for oil, natural gas, coal and electricity are corrected for the inflation, as the identified trends are 'nominal' (Shafiee and Topal 2010). Thus, an annual increase of 3% for the inflation is

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16 This is a simplification, as carbon capture technologies cannot capture all CO₂ produced. This usually is around 80%. Hence, cost are compensated, as 100% capture is assumed, thereby higher cost for venting the CO₂ in the model.
taken along. For biomass, the expectations are that the availability can keep pace with the demand, a lower increase of 1% is taken along.

<table>
<thead>
<tr>
<th>Trend</th>
<th>2010 - 2020</th>
<th>2021 – 2030</th>
<th>2031 - 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
<td>0.132 [EUR/GJ*yr] TRIANGULAR Min: 0.10 Max: 0.25 Most likely: 0.15</td>
<td>TRIANGULAR Min: 0.10 Max: 0.35 Most likely: 0.20</td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.0757 [EUR/GJ*yr] TRIANGULAR Min: 0.05 Max: 0.15 Most likely: 0.08</td>
<td>TRIANGULAR Min: 0.08 Max: 0.25 Most likely: 0.12</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>0.0121 [EUR/GJ*yr] TRIANGULAR Min: 0.01 Max: 0.05 Most likely: 0.02</td>
<td>TRIANGULAR Min: 0.01 Max: 0.10 Most likely: 0.03</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1 [EUR/ton*yr] UNIFORM Min: 0.90, Max: 1.20</td>
<td>UNIFORM Min: 0.90, Max: 1.30</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>0.790 [EUR/MWh*yr] TRIANGULAR Min: 0.60 Max: 0.90 Most likely: 0.73</td>
<td>TRIANGULAR Min: 0.40 Max: 0.85 Most likely: 0.65</td>
<td></td>
</tr>
</tbody>
</table>

Table 8 - Trends per year adopted in the analysis

**Correlations**

The MRR, volatility rates and linear trends are assumed to deviate over time, and are therefore subjected to probability distributions. The distributions are correlated for the respective periods of 2021-2030 and 2031-2038 towards the end of the lifetime. A stochastic correlation of 0.7 is assumed, to allow shifts in correlations, but to prevent shifts in the variables which are not credible.

Finally, a number of correlations between different price developments have been assessed and implemented in the model. These are mainly based on literature sources. The correlations are implemented on the random shocks at each time step, whereas a Pearson correlations are used in the modeling software. The correlations are presented in the table below.

<table>
<thead>
<tr>
<th>Crude Oil</th>
<th>Natural Gas</th>
<th>Coal</th>
<th>Biomass</th>
<th>CO₂</th>
<th>Electricity</th>
<th>Syngas</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>0.86&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Ind.</td>
<td></td>
<td></td>
<td>See section of syngas price</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>-</td>
<td>-</td>
<td>0.43&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Ind.</td>
<td>0.89&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Ind.</td>
<td>0.56&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Ind.</td>
<td></td>
<td>Ind.</td>
</tr>
<tr>
<td>CO₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.70&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Ind.</td>
</tr>
<tr>
<td>Syngas</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 9 - Inconsistent correlations between the stochastic processes

These correlations are inconsistent with each other as these are based on different literature sources. Thus, these have been adjusted automatically by the software modeling package to create a consistent correlation matrix. Presenting the adjusted correlations below.
7.2.2 Model set-up

Three different plant configurations mentioned in 7.1 are considered in the analysis. The flexible plant is adopted with three RO: a large gasifier train expansion, two gasifiers independently and a possibility to retrofit the gasifiers for usage of biomass.

Because of the choice to subject the stochastic price models to a set of probability distributions, the number of runs for the simulation is increased. Thus, the maximum number of iterations for the software package (@Risk) is used: 10,000 iterations. This way, more different combinations can be analyzed, giving a wider range of results. When 500 iterations would be used, the model could only use less different pricing scenarios.

The discrete time steps are set to months. In total 300 time steps included in the model throughout its operational phase. It is assumed that the plants lifetime is not lengthened after 2038. Lengthening plant lifetimes often happens, but not considered in this analysis. However, even if it was taken along, the discounted value of any investment taking place 29 to 30 years from now is near zero. Thus, it would only marginally influence the plants performance.

The efficiency of the gasifier is often measured in 'cold gas efficiency', meaning the amount of energy remaining in the syngas, compared to the input energy from the fuel. For the Shell standard gasifier, which is used in the case, this efficiency lies at around 78-83%, with over 99% carbon conversion (Shell Global Solutions International BV 2006). In the model, the obtained gas conversion efficiency is 72%. There is a difference of 6% or higher. This can be explained by the assumed ratio conversion from the high content of CO towards H₂ at the WGS-reactor, where some energy is lost (Janssen and Warmoeskerken 1991). However, a difference of 6% can result in a lower production price for the syngas, but would compose a syngas composition that has a very high CO component in the syngas. This ratio is less interesting for many applications (Herder, Stikkelman et al. 2008).

7.2.3 Results & Discussion

This section will briefly review the direct value of flexibility. This is followed by a short discussion considering the sensitivity of the model.

Value of flexibility

The value of the options and the different configurations are presented in this section, resulting from the analysis conducted with the described assumptions and stochastic variables of the previous sections in this chapter.

The biomass co-gasification option, does not pose added value for the project value. The price difference between biomass and coal plus CO₂ is not sufficient for the savings that can be obtained by co-gasification. Co-gasification of biomass even shows a minor drop in the projects NPV. The
expected NPV for the base plant configuration is EUR -519 million. The expected NPV where the biomass co-gasification option is taken along, is EUR -520 million. This difference is small, stating that there is hardly any favor in taking biomass gasification along without any additional support policies from government, or more extreme price differences than assumed in this model. When the original formula for valuing flexibility is used:

$$NPV_{active} = NPV_{passive} + c \Rightarrow -520 = -519 + 1$$

The real option for biomass co-gasification should not be taken along, as the value is negative. The cumulative NPV distributions of the base plant without and with the co-gasification in the project are presented in figure 30.

![Figure 30 - Found cumulative NPV distributions for the base plant and the co-gasification option](image)

The real option does not improve the performance of the plant in hardly any scenario. A strong increase in CO₂ and/or coal prices enhances the options value, but results in a lower spread for the base plant. Thus it improves the value of the options, but it simultaneously lowers the plants competitiveness in the market, as it is faced with higher cost (assuming an equal correlation between the electricity, coal, oil and gas). In 25% of the iterations the real option is exercised. Altering heightening the threshold in the decision rule results less frequent real option exercise, and later on in the project. This results in less operational time which the real option can retain its investment. Another conclusion is that in over 90% of the simulation runs, the plant shows a negative value. Which is quite large, thus discouraging investment. This is also discussed in the next subparagraph.

Another alternative for the use of coal is natural gas. However, in hardly any scenario natural gas is beneficial for using rather than coal. Thus, in any normal situation, the usage of natural gas shows no value for the plant. This is applicable when the actual plant is reliable in its operation. If for any situation the plant is unreliable, this option would hold value. But this is not considered in this analysis.
The maximum configuration plant shows the lowest value for the expected NPV for all configurations. Since the co-gasification of biomass does not pose added value in this situation either, this option is not considered with the other plant configurations, both the maximum configuration and flexible configurations.

\[
\begin{align*}
ENPV_{\text{max config}} &= -1199 \text{ million EUR} \\
ENPV_{\text{flex,small gasifiers}} &= -467 \text{ million EUR} \\
ENPV_{\text{flex,large gasifier train}} &= -459 \text{ million EUR}
\end{align*}
\]

All configurations still have a negative value, regardless the adoption of RO. However, the flexible approach shows a considerable reduction in the expected losses. Thus, adopting a phased investment approach (which can be labeled for comparing the maximum configuration plant with the flexible approach) would be the best approach for this project. The large gasifier expansion performs slightly better over the 2 small gasifiers. This can be devoted by the economies of scale for the large gasifier option. The cumulative NPV distributions are presented in the figure below. Also, a few figures concerning the performance are presented in the table below.

<table>
<thead>
<tr>
<th>EUR in million</th>
<th>Minimum</th>
<th>10th percentile</th>
<th>50th percentile</th>
<th>90th percentile</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base plant</td>
<td>-1545</td>
<td>-889</td>
<td>-516</td>
<td>-109</td>
<td>1181</td>
</tr>
<tr>
<td>Maximum</td>
<td>-2327</td>
<td>-1660</td>
<td>-1192</td>
<td>-682</td>
<td>852</td>
</tr>
<tr>
<td>Configuration</td>
<td>With small gasifiers expansions</td>
<td>-1653</td>
<td>-1000</td>
<td>-472</td>
<td>138</td>
</tr>
<tr>
<td></td>
<td>With large gasifier expansion</td>
<td>-1667</td>
<td>-1015</td>
<td>-471</td>
<td>187</td>
</tr>
</tbody>
</table>

Table 11 - Performance figures for the different configurations

Figure 31 - Cumulative NPVs of the different configurations for the syngas plant
The maximum configuration shows the overall least value over the whole range of the analysis. Initially, the small gasifier expansions shows a slightly higher value, but is 'overtaken' at the 50th percentile. The upside potentials of these expansions are quite larger than the not flexible configurations. The base plant has its value in the lower percentiles because of the minimal initial investment costs.

Comparing the NPVs with each other shows that the maximum configuration is the least preferred approach. Considering the small difference between the two small and one large gasifier train expansions, it can be advocated that the large gasifier option would be preferred to follow. However, both options can be managed simultaneously.

The RO for the additional gasifiers are frequently exercised in the analysis. Both options have been assessed separately. For the small gasifier expansions, the first gasifier is placed in 92% of the simulation runs, and the second gasifier is placed in 77% of the iterations. The large gasifier option would be implemented in 87% of the situations. Though the maturity date is set in advance, there is a possibility that the option will not retain all earnings in the simulation run due to the assumed stochastic price developments. This is a risk presented before the project owner. In case the plant lifetime would be lengthened, the investment can still be earned back.

The value of flexibility for this approach differs per point of view. When the plant is considered as a growth series of growth options in the project compared to the base plant, the value of the flexibility is given in the table below.

<table>
<thead>
<tr>
<th>Value in million EUR</th>
<th>Value of flexibility, ( c )</th>
<th>( \text{ENPV}_{\text{flex}} )</th>
<th>( \text{ENPV}_{\text{base}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two small gasifier expansions</td>
<td>52</td>
<td>-467</td>
<td>-519</td>
</tr>
<tr>
<td>One large gasifier train expansion</td>
<td>60</td>
<td>-459</td>
<td>-519</td>
</tr>
</tbody>
</table>

Table 12 - The value of flexibility as growth options compared to the base plant

When the value of flexibility would be considered as a phased investment approach compared to the maximum configuration plant, the value becomes higher, see the table below.

<table>
<thead>
<tr>
<th>Value in million EUR</th>
<th>Value of flexibility, ( c )</th>
<th>( \text{ENPV}_{\text{flex}} )</th>
<th>( \text{ENPV}_{\text{max config}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two small gasifier expansions</td>
<td>732</td>
<td>-467</td>
<td>-1199</td>
</tr>
<tr>
<td>One large gasifier train expansion</td>
<td>740</td>
<td>-459</td>
<td>-1199</td>
</tr>
</tbody>
</table>

Table 13 - The value of flexibility as phased investment options compared to the maximum configuration plant

With the adoption of the lean approach, there is still considerable value for the flexibility. The NPV is enhanced with 11.5% when the options are considered as growth options. But when the option is considered as a phased investment portfolio, the improvement of the investment boosts the expected NPV with where the value of flexibility is 61.7% of the \( \text{ENPV}_{\text{max config}} \).

**Sensitivity analysis**

Despite ‘all efforts’, all configurations produce a negative NPV. A short sensitivity analysis has been conducted to investigate the causes for these results. A number of significant influencing factors are discussed here: the \( \text{CO}_2 \) policy, the effect of changing MRR, volatility rates and trend prices. This paragraph concludes with some notions concerning the discount rate. This analysis is conducted by shifting the values to extremes and compare the model behavior by rerunning the simulations.
The most noticeable impact is the CO₂ policy assumed during this research. The EU ETS layout is at the time of model construction not fully clear. The amount of emission rights that are 'grandfathered' (distributed for free amongst the emitters) is unclear, as well as the development throughout the projects lifetime for this. This is compensated by setting an upward yearly trend price. However, eliminating the CO₂ pricing policy seriously enhances the project performance. Especially in later project phases, the cost for CO₂ emissions become equal or in certain iterations double the fuel cost. Thus, the inclusion of CCS system with solid capture costs, would in the end reduce uncertainty, thus lowering the gasifier options value, but would increase the park spread of the plant. Thus, overall competitiveness of the plant would improve. However, with constant developments for the other price commodities, biomass will be fully erased as potential source for gasification purposes on economical considerations. Another gap can be identified on the longer term impact of CO₂ prices. Though Chappin et al (2009) mention the consequences that the CCS installations will become worth investing in, the effects on the electricity prices are difficult to determine.

The MRR and volatility rates and the trends have been assessed in new simulation iterations to review their impact on the project if the 'playing field' changes in the project. The results are briefly summed in table 14.

<table>
<thead>
<tr>
<th>Action</th>
<th>Results</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% lower MRR rates</td>
<td>ENPV flex drops ±25%</td>
<td>Lowering the MRR rate is similar to removing the 'memory effect' of MRP models: approaching a GBM model</td>
</tr>
<tr>
<td>50% higher MRR rates</td>
<td>ENPV flex increases ±20%</td>
<td>Exact opposite happens: prices become more deterministic and show more stable paths. Higher ENPVs are the result.</td>
</tr>
<tr>
<td>50% lower volatility</td>
<td>Same effect as higher MRR rate: Price shocks become less intensive</td>
<td></td>
</tr>
<tr>
<td>50% higher volatility</td>
<td>5-6% increase in RO value</td>
<td>Results in an increase in extremes, so that higher and more profitable end-states can be reached</td>
</tr>
<tr>
<td>Removing trends</td>
<td>Negative value for all flexible configurations</td>
<td>Option value for 2 small gasifiers and large gasifier become EUR -130 million. Overall decrease of NPV flex by ±18%</td>
</tr>
<tr>
<td>50% increased trends</td>
<td>NPV flex significantly increases in all scenarios</td>
<td>NPV flex as growth options shows increase of 100% of RO values. Phased investments options (compared with max config plant) a growth of 5% in RO values.</td>
</tr>
</tbody>
</table>

Table 14 - Actions and results for varying the MRR & volatility rates and trends

Considering the results, the options value can be seriously influenced. However, these changes are generally 'inelastic': the percentile change in external variables exceed the percentile change of the results.

No analysis has been conducted on the correlations. But removing or increasing these will result in much less predictable models with more often negative marginal values, which has been experienced during the model construction. No other analysis has been conducted on other assumptions as O&M cost and capital costs. The focus of this analysis is to investigate the behavior of the model and not to seek and justify better model performance.

The influence of the discount rate is analyzed by adopting a lower value. Copeland & Antikarov (2003) mention in their consolidated approach to discount the values at the rate of the Weighted Average Cost of Capital (WACC). This is considered as unappreciated in projects: the options lower the risk profile, but it does not eliminate all risks (De Reyck, Degraeve et al. 2008). Martelli et al (2009) assume of 17% of the capital costs for engineering problems and risks firing. It would be unrealistic to assume that all risks are compensated. The financial risk is compensated, but there are many more types of risks which are not covered by adopting RO in the project (Miller and Lessard
This depends on the taken private and debt equity ratio. For this project, it is assumed to be 7%. When all values in the simulation are discounted against these values, the value of the project significantly changes, in the favor of the project returns. All projects NPV values rise significantly, and all configurations return a positive ENPV value. But the extremes also become much bigger. The impact on the value of flexibility is clearly shown in figure 34. The growth options compared to the base plant have become negative: the best investment from this point of view is the base plant, and do not prepare for later expansions. From the maximum configuration view, the options remain valuable and continue to show a significant impact: over 60% of the simulations show a positive NPV with the options taken along, whereas the maximum not flexible configuration does not make it to 50%. Another notice is that the option to co-gasify biomass remains unattractive: the required investment can still not be retained.

The difference between the flexible configurations and the maximum configuration does become significantly smaller. The RO values drop significantly. More interesting: the base power plant becomes the best alternative to invest in.

7.3 Implementation policy
This section will elaborate on the indirect organizational cost of taking RO along in the project. In section 7.2 the value of flexibility is shown for a syngas production facility. But for taking RO along in the project, organizational efforts and cost are assumed. These are discussed in section 7.3.1, continued in 7.3.2, where the impact of these cost are represented on the option value. For sake of simplicity, the option of the large gasifier train expansion is taken along. The options value for 2 small gasifiers is almost the same, thus posing the same distribution. Co-gasification of biomass posed no additional value in the valuation analysis, so there is hardly any point in taking this option along unless all circumstances change significantly.
7.3.1 Monitoring & control system

As mentioned in section 7.1, a lean approach is used for the valuation of the plant. An options implementation time of 2 years is considered. After the option is exercised, it will start generating value 2 years after that point. This lean approach is considered to do as least as possible upfront, and all just prior to exercising the option. Thus, it lengthens the options implementation time, which will be first discussed. After that, the cost of waiting will be elaborated for its application in this case.

Concerning executing this project in the PoR, different permits and an EIA are required (Putten, Vaan et al. 2008). The permits are building permit, environmental permit and an emission permit. These will be briefly discussed in this order.

An EIA is required due to the size of the upfront plant, regardless its initial configuration. Thus, cost and effort are associated to carry out this assessment. The time required to undertake this EIA generally is 9 months or longer (van Breda and Dijkema 1998). Thus, when this is to be carried out again at the options exercise, essential cost is required. If not taken along upfront, the initial conditions for approval of the impact assessment alter, thus requiring to redo the analysis. So, performing the EIA ‘fully’ upfront would result in slightly higher cost, but time savings later on. Same holds for the required permits. In case of project execution in the Netherlands, the EIA procedure is integrated with the other permit procedures (InfoMil 2009). The environmental permit is required for construction of any unit capable of producing more than 20MWth capacity (Stigter 2007). A building permit and emission permit are also required for the base configuration. The expansion options allow doubling the production capacity, thus these will be necessary. It is presented to the project owner that these can be requested upfront or at the options exercise.

A number of assumptions have been generated concerning the options organizational cost and monitoring. These cost would apply for construction an options plan and setting up a project real options management section within the project organization. These assumptions are subjective, and based on the authors' previous experience with (student) projects and assessment of the main article where the plant configuration is based upon: Martelli et al (2009). The assumed figures are shown in the table below.

<table>
<thead>
<tr>
<th>Element</th>
<th>Assumed cost upfront [1000 EUR]</th>
<th>Assumed cost lean [1000 EUR]</th>
<th>Unit</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upfront valuation cost</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>Irrelevant of options implementation approach</td>
</tr>
<tr>
<td>Upfront organization cost</td>
<td>300</td>
<td>300</td>
<td>-</td>
<td>Cost to implement PROM in the project organization</td>
</tr>
<tr>
<td>EIA cost</td>
<td>200 [part for options]</td>
<td>Upfront 600 Option exercise: 500</td>
<td>-</td>
<td>Upfront all is cheaper than splitting</td>
</tr>
<tr>
<td>Permit costs</td>
<td>100 [part for options]</td>
<td>Upfront: 200 Option exercise: 200</td>
<td>-</td>
<td>Same as above</td>
</tr>
<tr>
<td>Monitoring cost</td>
<td>150</td>
<td>150</td>
<td>Per year</td>
<td>2 skilled FTE per option (including actor commitment management)</td>
</tr>
<tr>
<td>Reassessment cost</td>
<td>10</td>
<td>10</td>
<td>Per reassessment</td>
<td>Reassessment of the RO conditions</td>
</tr>
</tbody>
</table>

Table 15 - Assumed indirect costs for the syngas production facility project, in thousands EUR. ‘Part for options’ represents the cost dedicated for the real option in the project.
The additional cost for the upfront approach is assumed to be corrected that the options implementation time is reduced from 2 years to six months. It is considered as realistic that the negotiations and agreement for the syngas delivery, some time can be posed between them making the deal and the actual need for syngas. After six months, syngas delivery can take place. In addition to this perspective, speeding up the implementation process is considered possible against additional cost. This is difficult to quantify, but can be used to illustrate the principle of these implementation systems.

In the simulation of the options valuation, the 'cost of waiting' has been assessed. This is considered as the difference of one and a half years of which the option is still being implemented under the lean approach, while under the upfront approach revenues are generated. These payoffs have been discounted over time against the earlier defined 8%. Thus presenting a present value of the cost of waiting for 1.5 years. See the figure below for the results.

![Difference between waiting cost](image)

**Figure 33 - The difference between cost of waiting for 6 or 24 months**

This loss of revenues shows an average value of EUR 87 million, but can also be zero. This is the case when there is an average there is simply no demand yet, thus no costs to lose. If these additional cost can be obtained by speeding up the implementation process, the options operational lifetime is extended in this case.

Assuming that the lean approach does not take part in reassessments, the cost before the options exercise will be EUR 1.1 million, the maximal monitoring cost over the full lifetime of the project is nominal EUR 4.35 million. For the upfront approach, including an assumed 6 reassessments per year, would be EUR 6.6 million per year. However, if this could reduce the options implementation time by 1.5 years, there is over 95% chance that this will pay off in additional revenues, if there are no additional cost for lowering the options implementation time. A certain increase in the options exercise cost (when the implementation time is lowered) can be justified. In terms of a mixed approach: if placing the EIA and permits upfront can happen, thus lowering the options
implementation time by 6 months, this is very likely to pay off, as the discounted cost of waiting 6 months is EUR 30 million on average, which would also justify over 95% of the cost of waiting. Thus, this could seriously enhance project returns.

This element should initiate a feeling at the project manager how to organize the options implementation, by scanning for indirect factors that can either enhance or reduce options value. Especially in capital intensive projects, a quick implementation time can enhance project returns: revenues are created in lower time steps, which is extremely beneficial from the NPV theory perspective.

7.3.2 Impact on plant & real option value

Resulting from 7.3.1, the chosen type of approach can affect the options value and thereby the entire project performance. If a mixed approach could be used as proposed and assumed in 7.3.1, and assume an average, the present value of the project can be heightened with 30 million euro’s. During the standard analysis, this could enhance the options value by 5% in the perspective of the option as a phased investment in the project. When the option is considered over the entire project lifetime, the possible options development is different to the value given by c. For the large gasifier train option, its added value is presented in figure 36.

![Development of option value over time](image)

**Figure 34 - Real options' payoff over time in the project**

What can be noticed is that this figure is different to the figures presented in chapter 6. This is due to the demand driven part of this model: at the start of the project, it is assumed that no demand exists yet for an external syngas producer. This develops over time, depending on the oil and gas price developments. These are stochastically modeled. So the demand will differ per iteration of the simulation, which proposes a different price scenario. This explains the bows in the model. When the options value is beneath zero, it would not be exercised at that moment, given the scenario.

When the assumed organizational, monitoring & options permit cost are taken along, its impact would be minor. As the average options value is at its peak nears 200 million EUR, where a full upfront approach would result in a little less than 7 million EUR of dedicated monitoring. And this assumes that the option is not exercised over its lifetime. After all, as discussed in chapter 6, there is no need to continue monitoring when the option has been exercised. If additional construction cost are known, these can be added at the point of exercise, thus proposing a moment where an upfront approach would no longer be beneficial. To enlighten this, a theoretical increase of 10% of the exercise cost is considered, or a nominal 76 million EUR. This value is also discounted over time, as
later implementation would reduce the present value of the cost. This is again presented in a same figure, 37 below.

![Development of option value over time](image)

**Figure 35 - Including a 10% increase in exercise cost to speed up the implementation process**

The figure shows now that the maturity date is affected. The approach would be beneficial up to 2034 (assuming the average developments). Beyond this point, the effort required to speed up the implementation process is not worth the added revenues.

When this figure would be reassessed by the appointed options manager, he would notice that the curves converge over time. Thus, based on these developments, he can advise the management considering waiting, exercising the option or abandoning, when the developments are negative. And this could remain the case, as in a little over 10% of the iterations exercising the option will result in losses for the project. These figures can support designing and updating the implementation policy. If the developments are favorable, a company can decide to take an advance on obtaining permits or other tasks and prepare for speeding up the options implementation time. The opposite can also be possible, resulting into a lean approach, or ultimately abandonment of the option.

### 7.4 Discussion of model

The model presented in the options valuation and assessing the choice of monitoring, control and implementation perspectives for the owner are difficult to determine considering the theoretical character of the case. As mentioned in the introduction section of this chapter, a serious attempt is carried out to put the plant in a realistic perspective. However, the lack of experience of the author or empirical data concerning organizational issues for projects (such as the cost for a project risk management section) cause a limitation on showing the impact.

The excluded technological uncertainty in this model can pose an additional value of these can be estimated. For now, a constant exercise cost of the option has been assumed. But, as mentioned in chapter 3, these are subjected to market developments: new technology can propose a new value within the option if this is reassessed. These effects could not be taken along quantitatively, as with the strategic advantage of being able to deliver syngas to the market within 2 years, instead of an often assumed 4 year construction period.

Other than most ROA, it is considered that no market exists yet. In common analyses of real options valuation, the price of the underlying asset payoffs are considered uncertain, while the market is considered deterministic or at least stable in its existence. Thus, the illustrational case could be been
topic of better strategic selection. However, defending that ROA should be generally applicable and not only at specific cases. This is showed here, but entails some level of difficulty.

A mechanical flaw in any analysis regarding DCF tools is that long term investments are of marginal character. The impacts over long lead times pose only marginal influence on the project performance. So any real option to lengthen the plants lifetime at the end of the project, hardly poses any value at the project start.

In terms of model sensitivity, the model behaves robustly under extreme changes in variables. The historical data used in the model show however limited applicability for longer term future price predictions. Subjective probability distributions have been added to cope with this, but this limits the models validity. However, it is difficult to assess any future vision beyond 20 years. The concept of strategic advantage over competitors is not taken along in this analysis. But being present at the market, ready to deliver syngas in half the time of a total plant construction holds value.

7.5 Conclusions
Despite adopting a flexible approach, the expected NPV for flexible configurations remains negative. There is a difference in RO value considering the base investment. The value of RO as a growth option is significant lower than the value of phased investments. Table 16 shows an overview of these values. The real option to expand only once with a large gasifier train is more interesting due to the economies of scale (reduction of exercise costs) compared to two gasifiers. The biomass cogasification option worsens the project performance, showing a negative option value.

<table>
<thead>
<tr>
<th>Value of flexibility in million EUR</th>
<th>As growth option compared to base plant</th>
<th>As phased investment option compared with maximum config plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two small gasifier expansions</td>
<td>52</td>
<td>732</td>
</tr>
<tr>
<td>One large gasifier train expansion</td>
<td>60</td>
<td>740</td>
</tr>
</tbody>
</table>

Table 16 - Summarized value of flexibility for the syngas production facility project

There is a considerable cost of waiting in this case, which is considered significantly higher than the cost of monitoring options over the full project lifetime. 95% of the simulation iterations posed that the cost of waiting exceeds a present value of EUR 7.5 million. Thus, reducing the options implementation time of 2 years towards a lower time by earlier obtaining permits and conduction an EIA for the maximum configuration may increase the project returns. Increased exercise cost can be justified if the options implementation time is shortened. Shortening the implementation time results in an overall increase of 5% in the ENPVs.

The opportunity expenses in this project are marginal compared to the potential options value. In 87% of the simulation iterations, the large gasifier is exercised. By mapping the developments of the option value over time by reassessing the conditions, the options manager can advise the decision-maker to alter the monitoring strategy, depending on the price and demand developments. This can either be to intensify or loosen monitoring, preparing for exercising or abandoning the option. Reassessments help to keep track on the RO chance of exercising and impact on the project, which may deviate over time if the MRR, volatility rates or trends may change over time (as an example). As well as concerning the validity of options or availability of resources to implement the RO. It enables more effective RO implementation and thus improving the project returns.
8. Conclusions & discussion
In order to provide a structured answer to the proposed research questions, this section has been cut up in four different sections. First, the concept of real options in projects are discussed. Next, an organizational approach is proposed how real options can be implemented in a project organization. In section 8.3 the interaction between ongoing project management and RO are given. In section 8.4, the conclusions of the case are briefly presented. Finally, 8.5 reflects upon the conducted research.

8.1 Real options in engineering projects
Adopting RO in a project entails investment in flexibility in upfront project phases. This reduces the cost of altering the strategy along the way. A well-balanced portfolio of RO enhances the project performance by lowering the project downside risks and exploit the upside potentials. Adopting RO entails widening the project scope to enable the adopted options to be implemented without intermediate scope changes. Loosening a project scope is often a cause for project failures or schedule and budget overruns. Therefore, it is important that the RO are clearly defined and assessed at the project start in a structured manner.

An extensive literature review resulted in a list of factors which affect the adoption of RO within project organizations and implementation in projects. These factors are points of attention for the project owner to assess in order to determine whether RO are to be adopted in a project.

- Risks in RO
  The adoption of RO does not entail a risk-free project, nor risk-free RO. Unique project and option risks remain, resulting in unrealistic settings for risk-free discounting. This element is time-dependent.

- Experience with RO and portfolios of RO
  Managers seeing RO as a black-box need to be overcome, as they need to understand the impact of RO on their projects and how these have to be managed. Cumulative build-up and exchange of experience needs to take place. Most projects are eligible for portfolios of RO, careful balancing by adequate selection is required.

- Financial health
  Adopting RO places a financial burden on the project owner. Sufficient capital should be available to enable implementation of RO, but can be subjected to macro economical developments. This sets a limit to the impact of RO a project owner can bare in a project.

- Monitoring the RO
  RO need to be monitored and reassessed to determine whether they should be exercised. The approach within organizations may lead to a bias to exercise or abandon an option prematurely. Resources are required during the RO active lifetimes to keep the RO 'alive' and valid and determine the right time to exercise the option.

- Cost of waiting
  Implementing an option can take time before the acquired assets will generate revenues. There is a degree of choice between upfront implementation or at the moment of exercise. This results in a tradeoff between upfront effort versus exercise efforts, the required implementation time with loss of revenues for longer implementation times, and the flexibility for the options assets.

- Project contract changes
  The degree of uncertainty which is exploited by the RO, can initiate a rethinking the project contracts. When learning effects are to be maximized, flexible contracts may be preferred.
• Specialized resources
Specialized staff or equipment can be required for executing tasks involving the implementation of a real option. These may need to be booked some time in advance, or against substantial higher cost. Thus, it may lead to reduced flexibility in exercising the option.

• Permits, EIA and regulation
Depending on size and activities involved for the option, permits, EIA or regulation could apply. This needs to be known upfront, as permits could perhaps be combined, saving costs. Changes in these aspects can influence the option characteristics.

• Technological developments
New developments may alter the expected uncertainty evolvement. Thus changing the option characteristics. Technological developments anticipated upon must have some degree of reliability development path to be adopted.

• External actor alignment
RO with long lifetimes require another actor alignment at the time of option exercise. This will require additional efforts, resources and implementation time to align the actors compared to a traditional approach. PR-activities concerning the active RO in a project over time is required and multiple process approaches rather than one.

Overall, compared to a traditional approach, these points of attention entail additional effort to assess upfront and along the PLC to keep the options alive. An estimate of these costs should be made upfront by the project owner, rather than solely focusing on the potential added value for adopting RO. This leads to a revised formula:

\[ NPV_{flex} = NPV_{passive} + c - m \]

\( m \) represents the estimated costs for the opportunity expenses to enable RO adoption and implementation. By assessing the factors elaborated in this report, the project owner will have a better balanced decision moment whether to adopt RO or use a conventional project approach. These first assessments can also provide reasons to abandon real options in a project, as the burden would be too heavy on the project owners organization.

8.2 Adopting Real Options in projects and its organization
Real Options have to be identified and assessed in the upfront phases of a project. In the design phases, RO can be identified, valued and assessed on the required effort to adopt a RO approach in the organization and implement RO in the assigned project. Conventional PM uses project plans to support taking the Final Investment Decision. This project plan is commonly intended to be short and to the point elaborating on a project benefits and approach. This plan can be extended by including an Project Options Plan. This plan includes the first scan of the proposed RO portfolio, including value, interaction effects, design and a first implementation plan (assessing the discussed factors) including the required efforts next to the value of the RO.

Based upon the identified factors and required efforts, a conceptual design is proposed to adopt RO within a project organization. The approach to integrate RO in project organizations shows similarities with project risk management. A synthesis of required tasks is derived from the factors, and using PRM as a basis for these tasks.
At the initial upfront project phases, a qualitative and quantitative assessment of RO should show its potential value. A management planning approach can be created, how RO will be treated throughout the PLC. These are documented with all information regarding the RO, as technical design, value (and method of assessment), technical design and assumptions. Resulting from that analysis, a implementation plan for the RO is created. This includes the monitoring approach. Monitoring & control is implemented to enable optimal RO exercise and extraction of value. It also initiates reassessments on the RO conditions and validity. Unforeseen changes can enforce revisiting the options design and decision rules. These have to be tested with the project scope definition and be revalued. Resolving uncertainty over time by learning or price developments will cause the options value to change.

Combining RO adoption with PRM has a couple of advantages. First, a number of tasks is the same in nature, leading to synergies and reduced adoption cost. Second, opportunities identified along the way can easier be taken along as RO mainly focuses on opportunity exploiting. Third, it reduces a bias for keeping non-viable RO alive. Resources can more easily be reallocated in the combined department. By assigning option managers and risk managers to control each other work with consultations before exercising an option, a bias to exercise the option at the wrong moment (not meeting the exercise conditions) is also be lowered.

The options implementation plan is derived from $m$ and consists of three elements: RO management planning, monitoring & control and the decision rules. The company's financial health and stance towards risk 'shapes' the RO management planning. This determines the desired portfolio of RO which the company can bear in terms of resources and capital. It sets the project scope, the monitoring rules and decision rules. The decision rule can be obtained by the valuation analysis, or by a satisfying exercise rule by the project owner and/or users.

$m$ does not represent a solid value, it is subject of design. A tailor made implementation approach per option can be proposed. Three implementation approaches have been designed in this thesis:
• Upfront approach, where as many tasks and factors are executed upfront with intensive monitoring and control. Leading to quick implementation but against higher opportunity expenses.

• Lean approach, minimal effort is put upfront, but prior to the moment of exercise. Resulting in lower cost, but a large reassessment before implementing the option, resulting in a longer implementation time.

• Mixed approach, where maximal benefit is sought for exploiting economies of scale and an 'average' between the first two approaches.

At this point, the valuation method for RO can become helpful. Lattice and simulation valuation tools can show chances, distributions and side statistics concerning the RO. Thus, guiding a project owner and manager towards choosing an implementation approach to optimize value extraction from the adopted RO.

8.3 Real Options Methodology in projects: impact of uncertainty and dynamics

Reassessments are required to check the adopted RO on their validity. The documented items have to be checked with the renewed conditions over time. These may have developed differently than anticipated in earlier analyses. Uncertainty is resolved due to learning or new price developments. Thus, RO value change: the options spread is adjusted. Earlier unknown elements can turn into known elements which could not be assessed before. An updated design and set of decision rules can be documented in the database for the adopted RO. Reassessments lower wrong exercise decisions or abandonment of options. It does entail an increase in opportunity expenses.

The assigned option owner/manager advises the decision maker regarding option activities: wait, exercise or abandon. Reassessments show renewed values and expected developments over time which helps creating this advice.

The opportunity expenses can affect the RO value and maturity date. The shifts in value combined with opportunity expenses A new point can be enforced where can force a new point where the real options payoffs will no longer compensate for the opportunity expenses and exercise cost. This is represented in the figure below. At the 'new' red line, the expected value of the RO exercise will not be sufficient to compensate for the made opportunity expenses. Depending on the company's stance towards exploiting uncertainty, additional demands can exist for the justification of real opportunity expenses and potential option value.
8.4 Case value

A syngas production facility is used as a case study to show the potential of RO and identified factors to enable RO implementation. A simulation approach is used to value different configurations for a C-IGCC plant: a power plant, a large plant and smaller flexible plant. The first two are non-flexible, the flexible plant starts with the power plant and can expand with two additional gasifiers at once or per gasifier. Biomass co-gasification is also considered as a RO within this configuration.

Co-gasification of biomass is not valuable to adopt in the assumed price scenarios. The option for two small gasifiers is less preferred than one large set of gasifiers, which can profit more from economies of scale. In 87% of the simulation runs the large gasifier option is exercised. In general, the addition of two gasifiers under syngas conditions improve the returns of the project. However, the overall expected NPV remains negative: -459 million Euros. The non-flexible configurations perform worse: the power plant returns an expected NPV of -519 million Euros, the large plant -1199 million Euros.

There is a considerable cost of waiting involved for the option, which would favor obtaining the required permits upfront in order to reduce the options implementation time. By applying such a mixed implementation system, the option value can be enhanced by 5% from the view of the maximum configuration plant. The impact of options implementation time in this case would be an important element for the project owner to focus on in the options planning. Considering the option value, the variable cost for monitoring & control in this case is only marginal, thus showing minimal impact on the option characteristics.

8.5 Reflection & discussion

The performed research literature review combined with own input resulted from assessing a variety of literature in the fields of ROA, PM and literature assessing the integration of both fields. The result is a more comprehensive overview of factors which have not been addressed before. The factor \( m \) for all opportunity expenses is new and should result in a better balanced decision moment whether or not to adopt RO in a project and its organization.
The conducted research fails at the point of validation. The low adoption rate of RO in practice and difficulties encountered within the set project scope of identifying and discussing the factors, did not allow sufficient time within the project scope of this research to start up an expert validation. This is a shortcoming in both the literature review and proposed conceptual framework. This work can be enhanced by including such a validation assessment. The high and abstract level is expected to sometimes trouble the reader with visualizing the impact. Though it is tried to use pragmatic examples on occasions to enlighten the working principles, it can be hard to get a 'total' picture.

The proposed design does not elaborate on the value or necessity of strategic advantages when an competitive environment exists. This can affect the choices regarding RO exercise moments, but has been marginally point of attention in this research.

A qualitative view on RO has been provided, but it is suspected that the interaction effects within portfolios of RO on projects needs more attention. These interaction effects become increasingly important when the amount of adopted RO rises, and are expected project control tasks more difficult.

Because of the theoretical character of the investment, not all factors such as company profile and preferred RO management planning could be enlightened. The results still provided a negative investment result despite the effort of including flexibility in the approach. A real project could enhance the discussion and illustrate more principles of the proposed design.
Postlude

Arriving at this point in the thesis report, the first thing that comes to my mind is "What a ride!" My knowledge concerning the field or ROA was limited at the start of my graduation project, with some level of overconfidence regarding my contribution which I could deliver to in this field of research.

After my kick-off, much effort went into understanding and practicing ROA, combined my knowledge of (strategic) project management. This way, I came to some interesting points of view regarding the implementation of real options in actual projects. It took time however to develop an approach how RO could be adopted. I ended up in a field where limited knowledge is presumably present. This simultaneously posed an opportunity and a threat. The opportunity to contribute in RO literature by assessing the implementation issues of real options in a project organization throughout the PLC made me enthusiastic. But considering the theoretical character of this research, it also poses limited validation options, especially within the time scope of this project and general character of the research. Arriving at the end point, I think I can honestly say that at this report presents some contribution to this field of research.

I think that adopting a SEPAM point of view added value for my findings. By using my broad orientation on technological, economical and societal elements in my education, it brought some new perspectives within my research, helping in identification and discussion of factors.

Looking back at the project, I can say that it was a bumpy ride. I chose a discipline where I had limited knowledge upon. However, The original purpose of the research question has not changed. How to reach my endpoint however, did change. A serious assumption which posed difficulty for me to take along, was to look beyond the point of taking options along in the project, and then work backwards for the implementation in the project, using PM and RO literature. However, overall the literature review took fair more time than anticipated, along with setting up the case. This forced to reconsider my project planning a couple of times to cope with new things I learned on the way regarding my topic. This shows a weakness in my research, as validation of my findings have not been carried out. For some duration in the project, I could run towards a 'safe corner' called 'Microsoft Excel', reinforced with '@Risk'. Here I learned to assess RO and build my case. This hands-on approach resulted in an interactive process with my theoretical parts, where I could use my model as testing area, and how I could present my findings. However, it also showed that adopting RO in LEPs is a case sensitive item. This meant adopting a high abstract level to create a conceptual design how RO can be adopted.

Being less stubborn could have helped picking up more incentives given by my graduation advisors, trying to keep on track and focus on the project. However, the desire to a 'complete analysis' resulted in some deviations from this path. In the end, I think a well balanced report is presented, but shows opportunities to be improved. I would proudly call this a 'crown' on my education.

Anton Ammerlaan, March 2010
Literature


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Appendices
Annex 1 - Abbreviations used in thesis

The following abbreviations have been used throughout this report. Each abbreviation is explained when first mentioned, but are also listed in this section.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>DCF</td>
<td>Discounted Cash Flow</td>
</tr>
<tr>
<td>E</td>
<td>Exercise cost</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>FID</td>
<td>Final Investment Decision</td>
</tr>
<tr>
<td>GBM</td>
<td>Geometric Brownian Motion</td>
</tr>
<tr>
<td>HP</td>
<td>High-Pressure</td>
</tr>
<tr>
<td>IC</td>
<td>Internal Combustion</td>
</tr>
<tr>
<td>IGCC</td>
<td>Integrated Gasification Combined Cycle</td>
</tr>
<tr>
<td>LEP</td>
<td>Large Engineering Project</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>MRL</td>
<td>Mean Reversion Level (long term equilibrium price/trend)</td>
</tr>
<tr>
<td>MRP</td>
<td>Mean Reversion Process</td>
</tr>
<tr>
<td>MRR</td>
<td>Mean Reversion Rate (speed which price moves towards MRL)</td>
</tr>
<tr>
<td>PLC</td>
<td>Project Life Cycle</td>
</tr>
<tr>
<td>PM</td>
<td>Project Management</td>
</tr>
<tr>
<td>PRM</td>
<td>Project Risk Management</td>
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<tr>
<td>PSM</td>
<td>Project Scope Management</td>
</tr>
<tr>
<td>PoR</td>
<td>Port of Rotterdam</td>
</tr>
<tr>
<td>( PV_{option} )</td>
<td>Present Value of option</td>
</tr>
<tr>
<td>ROA</td>
<td>Real Options Analysis</td>
</tr>
<tr>
<td>Syngas</td>
<td>Synthesis gas</td>
</tr>
<tr>
<td>VARG</td>
<td>Value At Risk &amp; Gain (10th and 90th percentile curves)</td>
</tr>
<tr>
<td>WACC</td>
<td>Weighed average cost of capital</td>
</tr>
</tbody>
</table>
Annex 2 – Project management, an introduction

In order to provide a proper introduction on project management, a clear definition of a project is in order. The Project Management Institute defines a project as “A temporary endeavor undertaken to create a unique product or service”. Temporary is defined in such way that each project can be marked with a definite begin and a (pre-determined) end, when a project is completed (PMI 2000). This wide definition is used because projects happen all over the place. Where projects originate from, is open for discussion. Though, the Manhattan project during WWII seems to mark the beginning of the project management discipline (Meredith and Mantel 2006). Projects themselves seem to be quite long into existence, as building a pyramid can be labeled as a project, or even cavemen gathering ingredients and preparing mammoth stew. This last sentence also shows how diverse projects can be. These can take place in engineering disciplines, but as well in finance disciplines. In virtually any discipline, projects are initiated and carried out.

A clear definition of project management is also given by the PMI (2000), which is: “Project Management is the application of knowledge, skills, tools and techniques to project activities to meet project requirements”. Both definitions of a project and project management will be adopted in this thesis. Project management implies different management skills and area’s which are influenced and need to be combined in order to execute a project. These need to be combined in a well-balanced way to be able to execute a project successfully. Figure 36 shows the different fields of management where a project manager has to pay attention to.

The focus in this thesis will lie on strategic project management, especially for large engineering projects (LEPs). The strategic level is considered ‘the highest level’ in the management of a project (Turner 1993). Operational project management is organized as shaped by the strategic level of project management. In other words: the organization of the strategic PM level dictates the shape of the operational PM organization.

A number elements of the project management discipline will be introduced and briefly discussed in this section. First, the concept of the project life cycle is introduced. Next, the project scope management will be discussed. Followed by the importance of management of quality, time and cost. Risk management will be included as well. This section is concluded with a brief paragraph of different existing types of project outsourcing contracts.
Project Life Cycle

A project can be divided into a number of phases. Though each project is bound to be different in some way, some general phases in projects exist. The reason why projects are divided into phases is to gain control over the project in terms of manageability. All phases of a project together, is called the project life cycle, or PLC (PMI 2004).

Phases are generally organized as sequential events. Though it is possible that the next phase is initiated while one is still not finished. This would depend on the risks involved for starting the next phase earlier. Each phase commonly has some form of deliverable attached to it. This deliverable is reviewed and could be used as input in a next project phase.

A PLC generally defines:
- The (technical) work to carry out in each phase
- When and which deliverables are attached to each phase, including verification & validation
- Who is involved at each phase
- How the project and phases can be controlled and approved

Some characteristics in a PLC can be labeled as common. These are present in almost all projects. A PLC can be designed very differently per project. Organizations can even decide to aim for standardization of methods of designing PLCs. The advantage of such method is that a PLC can quickly be assessed at a project. Some general PLC characteristics are:

- Project phases usually sequential and can contain different number of (sub)phases, but generally hold phases labeled as initiation (start-up, design), intermediate phases as execution (construction) and operation. Final phases can be commissioning or shutdown/demolishing of the project assets.
- Associated cost and staff is likely to be lower in the initial phases, in the intermediate phases these rise as the project is being executed, and in the finalization phase(s) the cost and staff reduces again. This is also represented in the figure below.
- Uncertainty levels regarding achieving (or failure to meet) project goals are largest in the starting phases of the project. As the project progresses, the uncertainty regarding project completion decreases.
- The possible influence of project stakeholders decreases as the project progresses. The presumed cause for this is the costs to change in the project. These usually increases with the projects progress. In late phases a change in the projects design is much more costly as in the initiation phase(s), thus lowering the desires of stakeholders to ‘mess’ with the project in later stages.

Please refer to the Guide to Project Management Body of Knowledge (2004) for a more thorough elaboration and discussion on these topics.

**Project Scope Management**

A project scope is included in all projects. The scope identifies what the aim of the project is, and what is not. The scope of a project can be compared with a problem demarcation: what are the borders in which the project has to stay in. The project scope is referred as ‘The work that needs to be accomplished to deliver a product, service, or result with the specified features and functions’ (PMI 2004).
The project scope is an important basis for the project. This is also reflected in figure 38. The project organization and the scope together defines how quality, cost and time are linked to each other. The scope determines the priorities between these other important elements in project management (Turner 1993).

An ill-defined project scope is a frequent cause for budget and time overruns of a project. It is important for all involved stakeholders and workers in a project to have a clear defined scope. The defined scope of a project will act as a basis for decisions to be taken in the interest of the project completion within it set boundaries. However, this does not entail that the scope needs to remain unaltered throughout a project. A project's scope needs to be reassessed from time to time, or even on a continuous basis, if circumstances require so. As mentioned in chapters 1 and 2, everything around us is subject to continuous change. Depending on (both external and internal) developments, a previous adequate project scope may become ill-defined to operate within the new set of conditions. Project scope change is therefore an important issue, especially within projects which are undertaken in a dynamic environment. Defined activities need to be assessed whether these fall within the identified scope (under possibly changed conditions), and while they are executed remain within the project scope. A task could drift away from its original focus, which causes wrong interpretations and could threaten the project from being executed within its goals. Likewise, if drifts show a beneficial character for the project but is out of the defined scope, it could be worth re-examining the project scope to increase the project's results.

As can be derived from the text above, project scope management is widely present throughout all phases of a project and virtually in any task, a mind has to be kept on the project scope in order to fulfill the identified goals to the specific project. There are a lot of elements involved in project scope management. An overview is given in the figure below, a more elaborate overview is given in the Project Management Body of Knowledge (PMI 2004). Further in this section, a few key contributions of project scope management and scope definition are discussed.

The important project scope definition outputs are given below. These outputs shape the ‘design space’ which the involved project members have to execute the project:

1. Project scope statements. This involves a description the project deliverables and the required work in order to achieve these goals. These statements form the central aim for all
involved project members to aspire. Detailed planning is allowed by a proper statement description, by which the project execution is guided and evaluated. A higher level of detailed planning would allow a better overall control of the project scope. Such statements would generally include a layout or reference to the following elements:

- Project objectives
- Product scope description
- Project requirements
- Project boundaries
- Project deliverables
- Project configuration management requirements
2. Requested changes. Any request proposed to alter the project management plan or other elements needs to be reviewed and documented.

3. Project Scope Management Plan (updates). This involved possible updates to the project scope management, resulting from accepted change requests of point 2.

The work breakdown structure (WBS) is one important and integral output of a project scope. The WBS breaks up the entire project and divides this into numerous smaller tasks, which are more manageable. Especially in large projects, breaking down the tasks allows to better monitor the project's progress and whether the project stays within scope. The WBS is derived from the identified project scope, and may consist of different levels. Though each project is unique (see the introduction paragraph of this chapter), each WBS generally has the same structure. The lowest level of the WBS are labeled as work packages and can be actively managed. Also, the smaller packages allow easier and more reliable estimations of required time and cost to complete these packages. A generic outline of a WBS is given in the figure below (PMI 2004).
The figure shows that commonly the WBS is derived from project deliverables. Such approach usually gives suitable basis to split a large project into more manageable parts and eventually work packages. It should be noted that a careful balance is necessary how detailed a WBS should be. Work packages can be sized into too small sizes, resulting in higher efforts in attempt to manage the packages, as well as sub-optimal use of resources and synergies.

The output of a WBS will give a structural overview of required resources, cost estimations and schedule possibilities for the project execution (and organization).

**Project Quality, Cost & Time**

These three items, project Quality, Cost & Time are generally important constraints on a project. There is often a trade-off between these elements which have to be prioritized according to the set project scope (thereby including a projects requirements). Usually time is an important focus in projects, but time may not always be the main priority: it strongly depends on the type of project and its promises made to the stakeholders.

As shown in figures 38 and 39, these elements are shaped by the identified project scope and the organization structure of the project. Each element will be discussed briefly and their interactions. For a more extensive review on these elements, please refer to the PMBoK (PMI 2004).

*Project Time management* is associated with the scheduling of the activities or work packages resulting from the project scope. In other words: planning is the most important aspect in projects common time management perspectives. The following activities can be identified:

- Activity definition. From the project scope and the WBS, work packages can be transformed into schedule activities. Here, perspectives can be generated how to schedule, execute, monitor and control the activities.
- Activity sequencing. The requires identification of relationships between activities and lining these into an achievable project schedule. This includes whether activities can be carried out parallel, or other activities need to be finished first before the next can be initiated etc.
- Activity resource estimation. This element is closely related to the project cost estimations, as resources generally are responsible for a large part of project costs. Resources include people, equipment and material, in what quantity and how long these are used.
- Activity duration estimation. The duration of activities heavily depend on earlier identified activities, such as required resource types, quantity and time needed & availability. The duration estimation can be difficult and strongly depends on the type of activity. Usually, as time and activities progress, the duration estimations become more reliable and precise.
- Schedule development. As all other elements have been defined, the activities can be placed into a scheme of planned start and finish dates without conflicts between resources and applicability. This is most likely an iterative process, as estimations can change over time. The schedule will form the basis on which a project progress can be tracked. Project risks are likely to play a significant role in revising the schedule.
- Schedule control. After the schedule is implemented, monitoring is needed to check whether the project stays on track and if the schedule needs revising. This element implies managing factors which cause change, and implement changes when these occur or are redeemed necessary.
**Project Cost management** is closely related to resource estimations. People, equipment and materials are likely to be responsible for a large part of the budget. But this aspect is more than solely cost estimations. It is involved in planning, estimating, budgeting and controlling cost to every aspect of the project. This also holds for the project organizational cost, the influence of decisions made on the cost of (final) product use, maintenance and supporting the product, service or result of the project. This broader view is often mentioned as life cycle costing. However, here we limit to the direct associated project cost, but it is important to mind other implications of cost in further phases of the products life as well. Project costs play therefore a crucial role in an early project scope definition. Decisions on cost in the project phases can have significant influence on the product usage costs in the future.

A cost management plan is usually in order for larger projects. Such plan would include how to set the required precision levels to cost estimates (in different PLC phases), how reports are carried out to monitor and control the costs, the criteria to value work, thresholds for control (when to act).

The most important elements in project cost management are briefly elaborated below.

- **Cost estimating.** For each identified activity the costs are estimated, based upon the resources needed. Usually, a level of variation is included to account for uncertainty levels in the estimation and identified (project) risks. It also involves estimating what impact a change in expenditures will have on the rest of the project. An amount can be accounted for contingency planning to cope with risks which may fire, or inflation rates for projects with a long time-span. The accuracy of the actual cost for activities will change over time, as more information may become available.

- **Cost budgeting.** The estimations of the individual work packages or activities are aggregated towards a basis for measuring the projects performance related to the spent cost. The cost baseline is a time-phased budget outline for the project. Also, project funding requirements can be identified: when cash should be present to allow continuous progression of the project.

- **Cost control.** This area investigates the causes for cost variations. They review factors which influence cost variations, manage change if this occurs and guard cost performance of the project. Cost variations can be positive as negative, but important is that these are larger than anticipated or are of an unexpected nature. These could harm other project goals such as quality or schedule problems or influence risks in the project.

**Project Quality Management** includes all processes throughout the project phases and the organization. Quality is defined as “the degree to which a set of inherent characteristics fulfill requirements”. Important element is the requirements set for a project, what happens by performing a stakeholders analysis where all involved people state their demands and wishes to the specific project. Though, quality is not merely in the end-product of the project, but is reflected in all activities of the performing organization in executing the project: policy, planning, work procedures, quality assurance, quality control. Below, quality planning, assurance and control will be briefly elaborated. Important note is that cost of maintaining a certain set quality level may not necessarily be more expensive. Especially when viewed from a broader life-cycle costing perspective, a high quality may lead to lower product cost in the end. Prevention usually entails lower cost than cost to repair identified flaws in later project phases.
• Quality planning. This implies the identification which standards regarding quality are important, and how to assess the quality level. This process should be performed parallel to other planning processes, as these interact. Changes in project schedule may very well affect project or product quality in the end.
• Quality assurance. This department is entailed to check all activities and processes whether these meet the identified requirements and quality levels.
• Quality control. Performing control involves testing whether project results match the relevant quality standards. Next to this, causes for (unwanted) deviations in quality are tracked and eliminated. This is a continuous process which must be carried throughout the entire project. Lessons learned in the early phases could prevent iterations of the same mistake in later phases, thereby eventually reducing costs to fix the problem.

The elements quality, time and cost were briefly discussed and can be elaborated on further. But the stretch is to show the interactions of these elements with each other and how these relate to a project organization and a project scope definition. Fulfilling the requirements and achieving all project goals will likely be a distribution of effort over all elements. Priorities may be allocated differently in projects, but may also shift within a project over time. Acquiring a higher quality may cost more time and induce higher costs. Executing a project fast may reduce the ability to perform quality control and an adequate quality assurance department performing checks ‘en-route’.

Risk management

Risk management has been given increasing attention in the recent decades in project management. It has grown into a fully accepted and settled discipline within project management, but is still developing (Williams 1995). This is also important, as we live in a dynamic world, in which we continuously adapt ourselves to a changing environment (and change it ourselves again). The definition of risk has not uniformly agreed upon in the past, but the basic idea is the same. The definition used here is based on UK PRAM 2nd edition 2004 from (Verbraeck 2009): “A risk is an uncertain event or set of events which, should it occur, will have an effect on the achievement of objectives. Risk consists of a combination of the probability of occurrence of a perceived threat or opportunity, and the magnitude of its impact on objectives”. Many definitions define risk as likelihood of occurring multiplied by impact or effect. This may not hold true for all events, and the loss of human life is hard (if not impossible) to reflect in financial numbers. Therefore, a more careful approach towards a risk definition seems in place.

Identifying and managing risks play a crucial role in accepting and executing projects. In the project scope definition process, attention is already drawn to the identification of risks. Risk identification if placed rather early in the project life cycle. By doing so, a view can be generated of the project surroundings, and what risks are to be faced and dealt with. But risks are widely present in all area’s possible. An overview of different types of risks which can play roles in projects and some simple forms of examples (Verbraeck 2009):

- Inherited risks – from previous projects or company
- External risks – such as legislation, or economical developments
- Supply risks – availability of raw materials and resources
- Strategic risks – these are risks related to timing, product or service development
- Commercial risks – risks on contractual changes
- Financial risks – change in interest rates, credit or currencies
- Business risks – such as marketing, HR or HSE risks
- Communication risks – misunderstanding, crisis situations
- Project management risks – such as scheduling, resource availability
- Technology risks – new, undeveloped technology

A risk management approach in project management will contain the following aspects (PMI 2004):

- Risk management planning. The planning phase is first applied. A good approach in the first phases of the PLC will improve the other five tasks. The core task is to develop an approach to plan and execute risk management activities throughout the project. The context of the project and associated risks are established. Here, it should become clear what role the management of risk will play in the PLC.

- Risk Identification. Risks are listed and documented according to their expected priority. Important to note is that this needs to be an iterative process, as new risks may emerge during a projects progress. This section can closely be related to the qualitative and quantitative risk analysis, as well as the response.

- Qualitative risk analysis. The aim is to prioritize identified risks for further analysis, as it may become time-consuming and costly to assess all risks. This is usually carried out by assessing a combination of probability of occurring and its impact on the project. This is an iterative process, mainly aimed to get a quick indication of the possible impact of a risk on the project.

- Quantitative risk analysis. This involves a more thorough risk assessment, where risks are modeled for their possible impacts on the project, starting with the high prioritized risks. The aim of a quantitative risk analysis is to give more insight how the risk influences the total projects outcome, also to support making decisions in the presence of uncertainty.

- Risk response planning. The response planning is triggered after the risk analysis, and will involve the development how to deal with specific assessed risks. Risks are addressed according to their priority, and the response must be in accordance with the significance of the risk on the total project impact. This can be to enhance opportunities in a project, or to reduce threats. The identified approach in the risk management plan can be used as a base for creating response plans.

  - Risk monitoring and control. In the projects progress, new risks may arise and identified risks need to be monitored and acted upon. Risks may also change over time. Response plans need to be reviewed in the presence of changing risks. Trends need to be analyzed in order to identify new risks and monitor identified ones. When a certain risk fires, the earlier identified plans need to be activated. All actions need to be tracked, so that faults won’t be
made over and over again. Such examples are the base load for risk monitoring and control. This is an iterative process.

Risk management is tightly coupled to project cost, quality and time management. Creating contingency plans reduces cost variance but may require time to put into action before the risk is treated and back on ‘acceptable levels’. Treating risk by upfront research will increase cost. Taking a risk may result in undesirable deviation in meeting the requirements and goals of a project (loss of quality). Therefore, risk management, especially in complex projects, are not to be underestimated if one is to try to accomplish projects within the set requirements in terms of time, cost and quality.

Project Contracts

This section will merely concentrate itself to project contracts related to outsourcing of activities or an entire project to (sub)contractor(s). More aspects are involved in setting up contracts in project management. Frequently, project owners do not execute the project themselves. Specialized companies are capable of executing the project against predetermined arrangements. The reason for outsourcing projects is that these companies can have expertise and/or reputation regarding specific technologies. Specialized equipment required to execute the project may not be available otherwise. Or it may be a requirement to operate on certain locations ('local content' requirements). Contractors could also be willing to absorb certain risks in the project (transferring these from the project owner to the contractor). Many projects involve multiple contractors and subcontractors to be able to carry out all activities.

The choice for a certain type of contract is generally based on multiple elements. The projects constraints are an important input, and the complexity of the project. It thus holds a strong relation to possible risks in projects. A low-tech project which uses proven technology in familiar terrain is likely to face less challenges than bringing a new technology to the market.

A list of different possible outsourcing contract types which are common in Project management (PMI 2004):

- **Fixed-price or lump-sum contracts**
  Usually applied in low-tech projects where a well-defined product is delivered to the client. The simplest form is a purchase order with a fixed price. A lump-sum would include a ‘fine’ for the contractor to deliver the project too late or when it fails to meet set and agreed requirements. The relation between the client and contractor can be labeled as ‘strictly business-like’.

- **Cost-reimbursable contracts**
  This type of contracts becomes more attractive in larger, complex projects where risks start to take more significant positions in a project. The contract will involve payment for the actual cost plus a fee representing the ‘profit’ for the contractor. Different incentives can be included in contracts to push the contractor to work as efficient as possible. The relation between the client and the contractor becomes more trusted. More or less a sense of cooperation is achieved between these two stakeholders.
  Three basic types of this contract exist:
    - Cost + Fee or Cost + Percentage on Cost. The contractor claims its cost made and can either receive a fixed (agreed) fee or percentage over the cost.
- Cost + Fixed Fee. The contractor is allowed to reimburse the cost made and receives a fixed fee based upon the front-end estimated costs. The fee will not change along with the actual project cost, unless a scope change will occur.
- Cost + Incentive Fee. This contract includes an additional incentive for the contractor. The contractor reimburses costs and receives a pre-determined bonus if the project is delivered above the agreed minimum level (for example against lower than expected cost while maintaining quality and keeping the deadline).

- Time & Material contracts. T&M contracts form a kind of hybrid structure between the above two types of contracts. The contract value is not fully laid down at the time of awarding. Thus, the contract’s value can grow through time as it were a cost-reimbursable contract type. Though, is can also reflect fixed-price elements, when both parties agree on certain project elements.
Annex 3 - Project Plan

In Annex 2, a number of project management concepts have been briefly explained. This section will use a number of these concepts to discuss the importance of proper project management for decision makers prior to initiating an investment.

Prior to committing to an investment, a high degree of companies will evaluate the investment in a project. The point to invest in a project is called the FID: Final Investment Decision. Usually, a series of documents and/or analyses are required for the decision makers to allow a solid ground for evaluating the projects costs and benefits. These documents can be integrated to form a 'consistent and coherent' project plan, which is part of a projects integration management (PMI 2000). This section will briefly go into the contents of such a plan.

The purpose of developing and maintaining a project plan is to include the processes which are required to coordinate the various project elements in a coordinated way. If it's approved and after the FID, the project plan will function as a guideline for the project execution. Thus, the plan document contains many different elements, as project management has many disciplines to deal with. A number of 'common ingredients' are listed and discussed. It should be noted, due to the unique characteristics each project may possess, that each project plan may contain different (additional) elements or entails a different allocation of attention (PMI 2000).

- Project Charter
  Contains the background information for the project: the need for undertaking the project and a description of the intended project result.
- Project Management Approach (or Strategy)
  A (short) description how areas of non-critical nature in the project will be approached and dealt with.
- Scope statement
  Project objectives & deliverables are listed, including what will not be taken along
- Work Breakdown Structure
  An overview of identified project tasks as a breakdown structure, at the level control will be exercised
- Cost estimates, (scheduled) start & finish dates, responsibilities of the deliverables
  Within the WBS at the level control will be exercised
- Performance measurements
  For controlling & monitoring the technical scope, schedule and cost
- Milestone plan
  List of identified milestones and scheduled completion dates for each
- Resource plan
  Identification of resources, mainly staff, and the expected cost & effort
- Risk management plan
  First scan of risks involved with the plan, including: key risks, assumptions & constraints, planned responses and contingencies (where appropriate)
- Subsidiary management plans
  A diversity of plans to execute project control effectively, namely

17 These are not presented in order of importance.
- Scope management plan
- Schedule management plan
- Cost management plan
- Quality management plan
- Staffing management plan
- Communications management plan
- Risk response plan
- Procurement management plan

• Open issues
  All important notifications about the intended project which are uncertain or has not been decided upon.

A basic elaboration on multiple of above points can be found in the previous annex, and a more thorough elaboration on these topics can be found in the Project Management - Body of Knowledge editions (PMBoK). Extensive overviews of interactions of these plans and how these can contribute to creating an effective project guideline for execution (PMI 2000; PMI 2004).

Important to note is the Project Scope. The scope lists the project's objectives and deliverables, integrated in the project plan and pose a target to reach with and while executing the project. An ill-defined scope is quite often a cause for project failure, or overruns in budget and/or time. The scope need not be ill-defined from the project start onwards, as is discussed in the previous annex. Keeping track on the project scope during all project phases is important. Scope changes over time may be inevitable, and is even likely in large engineering projects with longer lead times or innovative techniques being applied or even developed. Project Scope Management and especially control are therefore elements not to be underestimated in any project phase. Project scope control

Scope change requests, on any basis, will need to be documented and processed. Corrective actions due to 'granted' changes need to be updated. Changes which are not granted should also be documented, as these may serve future change requests or become a 'learning moment' for any future projects, or to review later on. In other words: any outcome is important for the project execution and eventually, success.
Annex 4 - Real Options Analysis, some introduction concepts
This annex provides an additional explanation on different concepts which are linked with Real Option Analysis (ROA).

The contents of this annex are:
  4A. Financial stock option example
  4B. The value of flexibility, a simple example
  4C. The consolidated approach by Copeland & Antikarov
4A. Financial stock option example

In order to properly explain Real Options, the basics of the financial options theory will be shortly elaborated below. This is based on existent literature and a small, simple (and unrealistic) example. This section is merely used to provide a basic explanation of the financial option theory and to link this with the real options approach.

In the financial world, an options involves ‘the right, but not the obligation’ to obtain a stock against a predetermined price on the market, which can be exercised within a certain time frame (before the maturity date) (Luehrman 1998; Yeo and Qiu 2003; Copeland and Tufano 2004). The same principle holds for ‘real’ projects. A company can have an option to invest, which allows the right, but not the obligation, to invest in a project. By investing the company acquires an asset which will (commonly) generate value for the company.

This application on the financial market can be enlightened with a simple example with a call option. For the sake of simplicity any transaction cost is eliminated. This does not have any consequence for the working principles of the options theory.

Suppose a stock has a value of € 50 on September 1st, 2009. An investor is interested in purchasing the stock, because he/she expects the stock to rise significantly. Therefore the investor buys an option by paying the options premium (P) of € 1 with an exercise price of € 53 and maturity date of October 1st, 2009. Consider the chance that the stock will rise above € 54 (= stock price + option’s premium) is considered to be 70% (estimated by the investor). This situation is graphically presented in the figure below.

![Figure 41 - Schematic representation for the call option on a stock](image)

If $S$ rises above the € 54, the investor will exercise his option and make a profit using his obtained option. His profit can be calculated by $S-P$ in case he exercises the option. In case $S$ remains under € 54, the investor has no initiative of exercising the option, because the option is worthless. He would make additional loss by exercising his option to buy a stock for € 54 (as the option gives him the right to do so) instead of buying the stock on the market for less than € 54. The option’s pay-off structure can be graphically represented below. The profit (or loss) of the investor buying this option can be written as $\text{MAX} (-1, S-P)$. 

![Figure 41 - Schematic representation for the call option on a stock](image)
Leuhrmann (1998) compares the present value of the acquired asset with the stock price (S), while the investment necessary to acquire the asset is the option’s strike price (X). When the option is ‘in the money’, thereby indicating that S>X, a company would invest. The company would not invest, when the option is ‘out of the money’. Real Options Analysis allows to take these type of managerial decisions into account in evaluating projects whether to invest or not.

Flexibility to change course in a project has a certain value, because it has the possibility to limit the downside of the losses, while possible profits can be upgraded (Yeo and Qiu 2003). To place this line in context, another example can be used based upon a fictitious R&D project. See Annex 4B for the example.
4B. The value of flexibility, a simple example

To illustrate in what way managerial flexibility can enhance the project's value, a small example will be used to elaborate on this section. The example is based upon course notes from MIT courses on Real Options by Prof. R. de Neufville (2002) and involves an option to abandon a project (Neufville, Clark et al. 2002).

Consider a R&D project to develop a new type of technology. To initiate the project, $100 is required. Another $1100 dollar is required to finish the project and fully develop the technology. The (license for the) technology is to be sold to the highest bidder. This is a decision up to the management, and will have to be taken after one year. The possible revenues of this project are considered at the start to divert to either $100 or $2000 at the end of the projects’ life. The chances for a favorable and worse market are fifty-fifty. A discount rate of 10% is assumed. First, a NPV-approach will be applied to the case. After this a real options approach is applied in a simple way to show the difference towards the valuation of the same project.

The situation of the project is represented in the figure below.

![Schematic representation of R&D project using traditional NPV-approach](image)

The cash-flows and present value are given in the table below.

<table>
<thead>
<tr>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of cost</td>
<td>Initiation cost</td>
<td>Cost to continue</td>
<td>Sales revenues</td>
</tr>
<tr>
<td>Cash flow</td>
<td>-$100</td>
<td>-$1100</td>
<td>0,5 * $2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0,5 * $100</td>
</tr>
<tr>
<td>Present value</td>
<td>-$100</td>
<td>-$1000</td>
<td>+ $868</td>
</tr>
</tbody>
</table>

Table 17 - Cash flows of the R&D project using traditional NPV

The Net Present Value shows that the value of the project is negative, therefore the project should be rejected to invest in. What if an approach is adopted including flexibility, using the option to abandon the project is a worsening market is expected. In other words: the development of the R&D project is only continued if the market is expected to end in $ 2000 revenue for selling the technology. Again, the situation is represented in the figure below.

The project will be abandoned if the expected developments are downwards. The option to abandon is worth more than the option to continue in case of a bad market situation. The present value of continuing is - $1017, while the value of the option to abandon is - $100 (the initial start-up cost of
the project). The option with the highest value will be chosen and therefore the option to abandon will be exercised in the event of a worsening market. When the market is favorable, the option to abandon is worth less than the option to continue, and will therefore not be exercised. The cash flows of this approach are represented in table 18.

![Figure 44 - Schematic representation of the project including the option to abandon](image)

<table>
<thead>
<tr>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of cost</td>
<td>Initiation cost</td>
<td>Cost to continue</td>
<td>Sales revenues</td>
</tr>
<tr>
<td>Cash flow</td>
<td>- $ 100</td>
<td>0,5 * - $ 1100</td>
<td>0,5 * $ 2000</td>
</tr>
<tr>
<td></td>
<td>0,5 * $ 0</td>
<td>0,5 * $ 0</td>
<td></td>
</tr>
</tbody>
</table>

| Present value | - $ 100 | - $ 500 | + $ 826 | + $ 226 |

Table 18 – Cash flows of the R&D Project including the option to abandon

The NPV of the R&D project here shows a positive value of $ 226. Therefore, the project should be carried out in this approach.

This small example is able to show what impact managerial flexibility has on project values. Including managerial flexibility on a certain level can dramatically change the projects value perspectives and hence whether or not to invest in such a project. The traditional NPV analysis would have ignored this option completely and a manager would have refused the project based upon his findings.

A number of remarks have to be made to this small example. The assumed discount rate is chosen arbitrarily, and incorporating the option to abandon the project halfway influences the project riskiness. The used example can be explained as a Decision Tree Analysis approach (DTA). This method allows to capture flexibility, but uses one overall discount rate. This is inappropriate because each option involves a different level of risk. Thus, the discount rate should be varied per option to correctly correlate with the enclosed riskiness (Boute, Demeulemeester et al. 2004). The discount rate can be chosen using different methods, for example arbitrary or by using the Capital Asset Pricing Model (Brealey, Myers et al. 2006). This model uses a risk-free interest rate, including a risk-premium determined on the riskiness involved in the project, thereby determining a certain rate of return on the project. This rate of return can be used to calculate the net present value. By transforming the approach into a risk-neutral approach, where the investment is compared to a risk-free investment allowing the same payoffs, a risk-free rate can be used to determine the value of the option and the project.
The option of abandoning the project is neglected by the traditional NPV approach, leading to a lower, negative NPV. Managers can decide not to invest in such projects, while these may very well be profitable if managed correctly. By applying a real options approach more flexibility can be incorporated in the project valuation upfront, leading to a more trustworthy number whether or not to invest in a project.
4C. The consolidated approach by Copeland & Antikarov

Much of current publications in real options take one variable as uncertain for valuation of the project with or without options (REFS different publications). Other variables are kept constant or subjected to deterministic equations. Reality poses different challenges, thereby limiting the validity of these results. Quite often projects are exposed to multiple sources of uncertainty rather than one. Copeland & Antikarov (2003) developed an approach to deal with multiple uncertainties simultaneously.

The key difference is that not solely numerical methods are used to determine the value of the option and the project (with flexibility), but they use Monte Carlo simulation, combined with a lattice model. All identified uncertainties are translated into probability distributions and put into a NPV-model, which uses Monte Carlo simulations to construct a probability distribution for the present value of the project. The approach describes the use of WACC as discount rate. The output distribution provides statistical data such as the project volatility rate, which can be used to construct an event tree showing the present value derived from the simulation. The options can be built in the lattice and valued accordingly to determine the specific value of flexibility is that option is applied. So the latter part is equal to the construction of ‘simple’ option binomial lattices.

Two main inputs are considered in this consolidated approach: historical data and (subjective) estimates of management. Both elements are important. Historical data may provide a good (or the best) basis to estimate future developments. But this is subjected to the condition that the future can be based on historical developments. In other words: no significant changes in the market are expected for the projected time. Especially in niche markets or volatile commodities this is hard to establish. Subjective estimates of professionals or management can replace historical data to provide projections for possible price paths. Especially when significant changes are expected which are out of line with past developments, these subjective estimates may be a better alternative. A combination can also be used to predict possible future price paths for commodities. This depends on the lifetime of the project and availability of historical data. If the projected lifetime is relatively short (for example less than 10 years), historical data can provide a good basis, if no sudden changes are expected. If the time horizon extends over that period, covering long term predictions, historical data becomes less suited for the job. A simple illustration for this is the oil price. Historical data is likely to predict unreliable future price paths, considering the developments in the past 5 years for the price on the market.

Volatility continues to play an important role, as the previous determined volatilities (per uncertainty used) will contribute in the output distribution. Copeland & Antikarov (2003) anticipate on actively adapting the volatility rate over time. They propose to increase the volatility in time by multiplying this factor by the square root of time. However, especially over larger time periods the volatility can increase to unlikely high numbers. The concept intuitively makes sense: with higher volatility rates, the confidence bands widen. Thus resulting in a larger range where the distribution may result in. However, one applying this formula should revisit the data used and the projected number of time steps in the analysis.

The type of uncertainties to be used in the consolidated approach is ‘free of choice’, as any uncertainty model or distribution can be applied to generate the present value output variable. The most common model to represent an uncertain variable is the one of a Geometric Brownian Motion.
An expansion to the GBM model is a Mean Reversion Process (Sources). This can also be expanded with random price jumps (both upwards and downwards). These models pose the biggest share in modeling uncertainties. See annex 5 for more on these concepts.

There is a ‘failure’ in the consolidated model presented here above. Estimating, modeling and combining different uncertainties into a Monte Carlo simulation model is ‘doable’. But the model assumes a single output variable representing the present value of the project. The event tree which is derived from the simulation results is used to value the project and the options which can be set in the project. This may work well for simple options and compound options, if these are options ‘on’ a project. In the model it is assumed that all options can be exercised without any change necessary to the original composition of the project or assets. Real options ‘in’ a project change the technical design to cope with additional complexity (Wang and Neufville 2005). The payoff structure of such project (with or without flexibility) changes and cannot be compared as easily as with options ‘on’ a project. Because the technological design of a case where options ‘in’ a project differs from a similar project where no options have been built in.

The applicability of this model is therefore limited. Relating to the illustrational case in this report, the syngas production facility is subjected to multiple sources of uncertainty. These can be modeled accordingly and used to produce a NPV-distribution. However, there are differences within the technical design perspective for the benchmark electricity plant and the additional syngas production section. The NPV distributions will be different, because of different investment cost and payoffs.
4D. Drivers for Real Options

The valuation assessment of simple real options is based on two main assumptions: the absence of arbitrage and a random price development over time. Both concepts are discussed in this paragraph, to enlighten what assumptions lie beneath the field of ROA. This is used to assess the implications for implementing options later on.

No Arbitrage principle

An important implication for Real Options Analysis is that the no-arbitrage principle applies. The valuation of options is sometimes not a straightforward task. Especially simple real options, and also real options on projects, can be valued by creating a securities portfolio with the same pay-off value. One assumption made when valuing options this way, is that the no-arbitrage principle applies (Park and Herath 2000). Arbitrage is defined as “Purchase of one security and simultaneous sale of another to give a risk-free profit” (Brealey, Myers et al. 2006). A relatively simple example explains this concept:

A person can acquire Product A for € 250.- per piece in the Netherlands. The exchange rate for the euro to the US dollar is 1.40 (so € 1.- equals $ 1.40). The price of Product A in the US is $ 200. The person would then buy Product A in the Netherlands and sell this in the US, thereby acquiring a profit of $ 21.43 per product. Under these circumstances the person is not subjected to any risk, assuming a constant exchange rate between acquiring product A in euro’s and selling in dollars (hence the ‘simultaneous sale’). The person has earned a risk-free profit of $ 21.43 or € 15.31.

Such situation would not last for long, as many (rational) persons would start performing these actions to acquire risk-free profits. If the no-arbitrage principle applies, such actions as the above described example are not possible. Hence, the arbitrage principle states that no profit can be made without taking any form of risk. Park (2000) shows in the use of the binomial model for option valuation how the no-arbitrage principle must apply to value options. If arbitrage is possible, any profit-seeking party would exchange the option or securities portfolio for the specific item holding the maximum value. When no-arbitrage applies, the replicated portfolio equals the value of the option and no preference exists of choosing one investment over the other. This way, the value of the option can be linked to the value of the hedging portfolio.

Geometric Brownian Motions

Geometric Brownian Motions (GBM) can be used to model price developments on either historical data or (subjective) estimates by management. The assumption that a commodity price can be modeled by a GBM type of model is significant in order to be able to create some level of uncertainty in the respected commodity price process. This paragraph elaborates on the technique, as it is a very important pillar in RO valuation. The method is briefly explained, together with its drawbacks and extensions to this approach which are often used in literature.

18 This example does not reflect the reality, as different other institutional factors such as customs duties and taxes may apply before the product can be sold on the market, other factors as transport & storage cost will cause a difference in cost price of the commodity. It does demonstrate the principle how arbitrage can affect trade and valuation of commodities.
The motion was discovered in 1827 by a botanist called Robert Brown. This was based on the movement patterns that particles followed within water suspended pollen grains, resembling a zigzag path. Following on this discovery, Brownian motions became widely applied in multiple fields. Also in the finance theory: the Black-Scholes model is based on the GBM theory (Blanco, Choi et al. 2001a). This way it also came to use creating a stochastic price process.

An alternative name for GBM is ‘random walk’ (Guthrie 2009). The main principles for the model is that there is a non-random effect causing growth or decline, and a random movement taken from a distribution. The main input parameters are the volatility, expected variability and the asset price at t=0. The GBM implies a lognormal distribution for the prices of the asset, since the price changes are based on a logarithmic change. In such sense this is realistic, as prices cannot turn have negative values. Another implication is that the price changes are independent from each other (there is no memory effect), while the mean and volatility are constant.

The binomial lattice model for valuation of real options is an example of a structured layout of a development following a GBM, which weakly converges into a lognormal distribution, depending on the used parameters. Thus, options can be valued accordingly to express their value when a structured lattice is presented. By taking very small time steps in the lattice, the eventual terminal distribution will represent the same characteristics as with a GBM model (Amran and Kulatilaka 1999). The general representation of a GBM model is (Hahn and Dyer 2008):

\[
\frac{dS}{S} = \mu dt + \sigma dz
\]

The variables are explained below in table 2. Applying the foundation of Ito’s Lemma, an important contribution in stochastic calculus, it is possible to transform the stochastic process into a log asset price (Hahn and Dyer 2008):

\[
d \ln S = \left( \mu - \frac{\sigma^2}{2} \right) dt + \sigma dz
\]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>Commodity / asset price</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Growth rate (or drift)</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Standard deviation of returns (volatility)</td>
</tr>
<tr>
<td>$dz$</td>
<td>Wiener process (random 'shock' with mean zero and variance of $dt$)</td>
</tr>
</tbody>
</table>

Table 19- Variables used in a GBM model

Either a mean value can be used, or a certain drift rate, where the price can in- or decrease over time. The Wiener process provides a random shock at each modeled time step, with can be provided by a normal distribution with mean 0 and variance of 1, which is corrected for the time step. The time step is determined by the model, and should be in the same order of magnitude for the volatility of the commodity price. By taking multiple time steps, and multiple simulation runs, random paths can be generated for future price developments. Figure 10 below shows a number of sample paths for a GBM model.

The obvious reason to model prices by using a GBM approach is that there are many factors influencing the price of a commodity. In this event, it is assumed that price developments are
randomly situated. This is a limitation of the model, since it will be possible to predict price developments up to a (usually short or mid-term) horizon with a certain reliability. For long term this cannot be predicted, nor point estimates or even ranges. Historical data may often be unavailable or not usable for long term prediction of price developments (Neufville and Scholtes 2010).

Though random development is assumed, it is possible to correlate price developments with each other. This way, different price developments can be stochastically correlated with each other in order to form a more credible price development regarding each other (Kienzle and Andersson 2009).

There are some disadvantages related to the use of GBM models. The assumption that the price developments follows a lognormal distribution, does not hold for all types of commodities. Over time, volatility rates are not constant, which is assumed in the classic approach. Extreme volatility rates cannot be capture using this model, as the jumps will become too high to represent credible price behavior. This is the case even if a volatility rate can be determined, based on historical data (Blanco, Choi et al. 2001a). Though, the latter one can be solved by using (subjective) expert or management estimates (Amran and Kulatilaka 1999; Copeland and Antikarov 2003).

In extension of the GBM model, other stochastic price processes have been developed over time to create a more reliable and/or realistic future price path. These can compensate partly for the disadvantages mentioned above. The most common extensions are the Mean Reversion Processes (MRP) and MRP with a jump diffusion model. A MRP model uses the same base principles, but has a certain 'memory effect'. It uses a long term mean where the price aims to reverts back to, while random shocks (by applying a same Wiener process as in a 'basic' GBM) create a price path . The generic formula for this type of process is (Blanco and Soronow 2001b):

\[ S_{t+1} - S_t = \alpha(S^* - S_t) + \sigma \varepsilon_t \]

The meanings of the variables are given in the table below. A representation of a number of sample paths are given in figure 45 below. The 'Mean Reversion Rate' (MRR) determines how strong the price wishes to return to its long run equilibrium. The formula makes sense in that way that when the MRR is modeled as zero, a normal GBM model follows. The added value of a MRP model is that there is an inherent desire to revert back to a certain mean, resulting in a narrower terminal price distribution.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>Commodity / asset price at $t$, or at $t_{n+1}$</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Mean reversion rate</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Standard deviation of returns (volatility)</td>
</tr>
<tr>
<td>$S^*$</td>
<td>Mean reversion level or long run equilibrium price</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>Random shock to price between $t$ and $t+1$</td>
</tr>
</tbody>
</table>

Table 20 - Variables in a MRP model (Blanco and Soronow 2001b)
The long term equilibrium price can also be implemented using a trend price or growth rate, rather than a constant mean (Shafiee and Topal 2010). This approach reduces the likelihood that unrealistic price paths are generated. There is a higher level of difficulty obtaining the variables for developing a MRP model, however, the volatility rate can be determined more accurately. Another simplification is that the MRR can differ over time and may be subject to seasonal patterns (Blanco and Soronow 2001b).

Another addition can be made to include sudden jumps. For certain commodities, discontinuous events can cause a sudden price jump (both upwards or downwards) in its pricing developments. By including a jump diffusion element, the model can be extended from a MRP model to a jump diffusion model. Such jump would be represented by adding a Poisson distribution with a certain impact on the price (Blanco and Soronow 2001c; Shafiee and Topal 2010). Though, sudden price jumps can never be accurately modeled, but it can improve the reliability of the model, when sudden events can impact on price developments.

To sum up, GBM types of models, with the extensions of MRP and jump diffusion, can be very useful to model stochastic future price paths. The possibility to generate random walks based on variables which can either be abstracted from historical data (if available and useable for future situations) or generated by expert or management estimates. By applying large iterations to this process, using Monte Carlo simulation, numerous scenarios are randomly generated. Valuation techniques in ROA rely heavily on this approach, such as the binomial lattice. But there are limitations to the usability of a GBM approach. Though, with the appropriate knowledge of its limitations, analysis can adjust variables or describe its reliability limitations accurately.
Annex 5 - Case: Syngas production facility
This annex contains the partial analyses carried out for the composition of the illustrational case in this report.

Mentioned in the report, it will be a theoretical case. So far, there is no synthesis gas production facility in the Rotterdam port area. Though, in the future, a syngas cluster can be beneficial as an alternative for oil and natural gas, considering the uncertain future price developments. The case will be analyzed from an investors perspective.

This annex contains the following documents:
- 5A. Syngas & application in the Port of Rotterdam
- 5B. Plant design & real options of the project
- 5C. GBM & MRP in the case
- 5D. Parameter modeling
- 5E. Construction of the model & assumptions
- 5F. Analyses results & discussion
5A. Syngas & application in the Port of Rotterdam

The port of Rotterdam (PoR) is one of the largest in the world, handling nearly 35000 sea-vessels each year and has over 5000 ha of industrial sites (Port of Rotterdam 2009). The port of Rotterdam includes a range over activities, contributing to the competitiveness of the port in the region, of which a (petro)-chemical cluster and energy industry. The chemical cluster in Rotterdam includes oil-refining and production of oil-products and chemical products used for further processing in the Netherlands and other regions the port of Rotterdam serves. The chemical cluster in Rotterdam heavily depends on oil for its feedstock, since many chemicals are oil-refined products. The energy cluster however makes more use of natural gas and coal as feedstock to produce energy usable in the Rotterdam port area.

This makes the port heavily dependent on oil for its chemical cluster and for coal and natural gas in its energy cluster. This creates a disadvantage for two reasons. The port of Rotterdam is sensitive for developments on the global energy market. The availability of fossil fuels in the coming decades is uncertain, as well as price fluctuations of energy sources. Second, a paradigm change has occurred in the past decades, leading to the negative image of fossil fuels. The impact of large-scale usage of fossil fuels show negative effects on the environment, while locally the concentration of emissions of exhaust gases put the Rotterdam area along the highest in Europe. More sustainable development is wished from the public and has become a desire of the port itself as well (Rotterdam Climate Initiative 2008).

A synthesis gas plant may provide a partial solution to the posed disadvantages. Synthesis gas, or syngas, can be used to diversify the fuel mix in the chemical cluster and energy industry. First, the concept of syngas will be introduced and explained. This is followed by a more elaborate description of the situation in Rotterdam and the possibilities for a syngas plant in that area.

Synthesis Gas

Though the technology itself will not be the main focus in the thesis research, a good introduction in the technology is considered desirable. This allows a more comprehensive understanding how the system works and how different investment options can possibly affect as well as the performance of the construction and operational phase of a syngas plant.

Synthesis gas, or syngas, is a combination of two gases: carbon monoxide (CO) and hydrogen gas (H₂). The process to put syngas to use was developed in the early 20th century by German scientists Franz Fischer and Hans Tropsch (Stranges 2003). This was in order to secure Germans need for transportation fuels, as it was short of oil supply lines. But the Fischer-Tropsch process was long indicated as ‘not viable’ to compete with oil, as the price of crude oil didn’t justify. However, this vision turned in the last few decades. New light ‘shines’ on syngas, as the reaction sequence allows several advantages over

![Figure 46 - Possibilities for using syngas are plentiful](Gasification Technologies Council 2008)
conventional technologies. New catalysts were developed which enhance the yield of the process. With the uncertain market characteristics of crude oil, syngas is becoming a more interesting fuel to use.

Synthesis gas is an intermediate step between the original energy source and its final product. Multiple fuel types to be used for syngas production, such as biomass, coal or natural gas. At the same time an extensive range of products exist which can use syngas in its production processes. This combination of gases allows a wide variety of possible uses for products, ranging from power generation to the production of transportation fuels. For an overview of products, see figure 46.

Syngas can generally be created in two different ways. Both are listed below and the general reaction formula’s are given (Rostrup-Nielsen 2002):

1. Partial oxidation of hydrocarbons
   \[ C_nH_{2n+2} + \frac{1}{2}n \text{O}_2 \rightarrow (n+1)\text{H}_2 + n\text{CO} \]

2. Gasification of coal, natural gas and/or biomass
   \[ \text{CH}_n + \text{H}_2\text{O} \rightarrow (1+0,5n)\text{H}_2 + \text{CO} \]

Especially the gasification of coal, natural gas and biomass has the interest of several parties. The demand for oil has resulted in large deviations in the price of crude oil. Syngas can be used to create (partly) the same end-products, while the price of coal for example shows much more stability. A schematic representation of a gasifier syngas plant is given in figures 47 and 48.
A syngas plant in the port area

The possibilities for using syngas are mentioned in the previous paragraph. For the Rotterdam port area, synthesis gas could well be used as an alternative for oil-based chemicals or be used in energy production in terms of electricity and heat.

To strengthen the position of the energy and chemical industry in the port, building a syngas plant in the Rotterdam port area can be a solution for this. This strategy would prepare the industries for uncertain times in the future (Herder, Stikkelman et al. 2008). The concept for a synthesis gas cluster, to prepare for uncertain times in the future, is a ‘cherished’ idea of some professionals and companies active in the energy & chemical cluster located at the port of Rotterdam. Thus, the idea is not new which is presented here. Different student and graduation projects have been devoted to the development and possibilities for such a cluster. Though, the concept of a flexible plant has not been tested yet in terms of valuation and implementation. This opportunity is used for applying a real options analysis for this plant. The remainder of this paragraph is devoted to give a charter for the initiation of such project.

Uncertain times in the future are a fairly vague term to use. A better clarification can be given by elaborating a bit deeper on the Rotterdam situation. The current situation, as described in the introduction paragraph in this section, holds until economic growth will put the price of crude oil under pressure. The consequence is tension on the market in which the commodity price is likely to show large jumps, resulting in new peak prices. Such developments, higher market prices, will create incentives to develop new oil fields or exploit current oil fields faster. But such developments happen with time delays investments have to be made and building of (upstream and downstream) facilities. These time delays can be up to several years. In the event that demand continues to increase, the price per barrel of oil can become ‘sky-high’. The same may hold for natural gas. This ‘cleaner’ fossil fuel is receiving increasing popularity for use, which may result in same developments.

A synthesis gas plant can be designed on a multi-fuel basis. Such design would be capable of using natural gas, coal, biomass or even oil as a feedstock. Though, it should be noted that oil is unlikely to be a commercially attractive alternative use in gasifiers. The product, a combination of CO and H₂ gases, remains unaltered. However, this may be subject to the required quality of the gas. If the price of a feedstock rises (for example oil), the plant has the possibility to switch to another feedstock (for example coal or biomass). This would create a more stable price of the syngas and for the other industries using the syngas as an alternative for oil.

However, there are a number of complications that prevent an instant successful implementation of synthesis gas plant in the port area. The current energy industry and chemical cluster in the port of Rotterdam is functioning, therefore it is unlikely that these companies wish to increase their dependency by relying on one large synthesis gas plant and modify their installations for the use of synthesis gas (for as far as modifications are necessary).

Syngas production facilities are characterized by high capital costs, so economies of scale play a significant role (Rostrup-Nielsen 2000). However, it can be assumed that it is unlikely that all capacity of a sufficiently sized plant, which profit from economies of scale, can sell all its produced syngas on the market. In other words: it is uncertain how a syngas plant deploys itself in the port area. On the other side, the potential payoffs for such investment can be significant if the demand for syngas will
rise in the future, as new facilities will connect to the syngas facility. An entire new infrastructure could emerge from the startup of such a plant.

It is thus an uncertain environment, subjected to energy demand developments on both a local and worldwide scale. If worldwide prices for oil and gas rise, the syngas alternative becomes more profitable for the chemical cluster and energy industry. Locally, the demand may also rise, if new facilities are designed or retrofits are planned. These are opportunities which can enable profitable implementation of syngas in the port of Rotterdam.

Static & flexible plant design
As mentioned in the previous paragraph, a syngas plant is subject to high capital costs. The best way to reduce the price of the product is by introducing economies of scale. Thus, building a large capacity syngas plant. However, due to the uncertain environment for the market for syngas in the Rotterdam port area, stepwise introduction of syngas can be a better way of creating a market and improving the chance of survival for this initiative. But that may result in possible loss of economies of scale for the production costs of syngas. This may lead to higher prices per unit of syngas, which may temper the implementation again.

The viability of syngas is likely to be correlated with the developments on the oil market. If the price per barrel of oil increases, the switch to use of syngas as feedstock in the industry becomes more attractive. When oil prices drop, oil may become a more attractive feedstock. Though, switching costs may hamper the change (Kulatilaka 1993). A company needs to have a certain degree of certainty not to waste additional investments or costs made to switch from input. A prospect of feedstock price developments and demand for the companies selling product(s) including its volatilities on the market are important indicators. A simple (non-realistic) example: It’s not worth the investment of say 2 million euro’s (direct investment costs) to spend, shutting down the plant (with indirect cost of lost sales) for implementing the switch and start the plant up again, while the price of oil in the mean time has dropped again, making oil the ‘cheaper’ fuel again.

In search for an alternative for oil or natural gas, coal and biomass can be considered as alternatives for the production of syngas, which can be processed to a final product. Thus, coal and biomass can compete with oil and gas. This becomes especially interesting when the price difference between oil and coal is significant.

Elaborated above, given the uncertainty and yet current absence of demand will discourage the deployment of a syngas production facility. Thus, an alternative approach is sought, incorporating flexibility. Thus, the case is considered within two configurations: a classic and flexible plant.

The ‘classic’ plant considers the investment in a single capacity plant, where no flexibility in the design in taken along. This entails that all piping and plant sections are designed for one capacity. The plant can be considered as a ‘lumpy’ investment, but does hold the possibility for implementing economies of scale, which would result in lower production cost per unit (usually nm³) of syngas.

The flexible plant is similar in technical design. However, the design is altered. The overall capacity is set to a higher level, but certain capital expensive sections, such as the gasifier, are reduced in size, but prepared for parallel set of gasifiers to expand in the future. This way the plant can be expanded against less cost than a conventional expansion in both direct and indirect costs. Direct costs in the
sense that less equipment has to be replaced, and indirect cost in terms of reduced downtime (therefore a reduction in lost sales). An additional benefit is that one can profit from technological progress made in the mean time, possibly leading to increased performance and/or reduced costs. With the initial investment, the plant is fully operational after realization, but with a significant lower capacity than the benchmark plant. Thus leading to smaller return cash flows. But the flexibility is expected to hold certain value. If the expansion options are exercised (subject to the feedstock and demand developments) additional profits may flow in. If the market developments turn out negatively, the losses are limited compared to the benchmark plant design.
5B. Plant design & real options of the project

This annex section considers a more elaborate view which RO can be taken along in the syngas project, and composes the design of the plant. Thus, it starts where annex 5A stopped. Here, a plant design of a synthesis gas production facility is analyzed, leading to the identification of real options for this project. These options are then qualitatively assessed and decided which options to take along.

Considerations for introducing a flexible plant design

Mentioned earlier in annex 5A, there is a wide variety of applications where syngas could be used as a feedstock for further conversion into products for the market. The currently present chemical cluster in the PoR represents a number of industrial sites where syngas could be used as a feedstock for the industrial processes. However, since there is no syngas cluster currently present, each active company has invested in its own feedstock. There is no incentive to shut this down for a switch towards syngas when this is not economically attractive (due to switch costs and required transport infrastructure through the PoR).

These may be temporal limitations however. When a company performs a retrofit or is in need to replace its feedstock preparation section, syngas facilities could become attractive. Investing in an own syngas production facility can quickly prove itself to be too expensive because of the high associated capital costs (Rostrup-Nielsen 2002). Downscaling the facility would likely result in higher costs per unit energy, thereby more quickly favoring the traditional feedstock fuels.

In order to facilitate the start up of a syngas cluster in the PoR, the syngas could be used for immediate further processing for an own, new product. This could facilitate an earlier start-up of the (flexible) plant, thereby generating cash inflows. Throughout the operational phases of the syngas plant, options to expand the plant can be exercised when demand for syngas rises in the area. Though the applications for syngas are quite wide (such as specialty chemicals), it should be noted that there should be demand and the location of the demand for the final selling product (if not syngas and heat). Another important factor is the infrastructure facilities present in the nearby area.

Electricity versus F-T fuels

Considering the infrastructure already located at the port, two interesting alternatives can present their selves other than the production of heat: the production of transportation fuels and electricity. The first would be processing the syngas by applying the Fischer-Tropsch process. The latter would be the use of an IC (internal combustion) or IGCC (Integrated Gasification Combined Cycle). Specialty chemicals would not justify the construction of a large scale synthesis gas production facility. Thus, it couldn't settle itself as a competitive alternative in the PoR market as economies of scale do not apply, resulting in a cost disadvantage for the current market settings. Whenever a small user of syngas would like to ‘tap’ in to the plants’ production facility, it can be assessed by both parties. By doing so, a syngas cluster can be initiated.

Fischer-Tropsch transportation fuels can be an awarding industry. Strongly related to the price developments of crude oil, which forms the main feedstock for transportation fuels. However, the

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19 The market setting is subject to uncertainties regarding price developments. If a chemical production facility uses an oil-based feedstock while it could use syngas, the viability of using syngas depends on the (both short and long term) developments of the oil-price.
The Fischer-Tropsch process is subject to extremely high capital costs, thereby providing the need for a large plant in order to be able to operate on competing price levels for the current, refinery industry. A common production capacity would lie near 60000 barrels of F-T fuels per day. The amount of syngas required to satisfy such plant throughput would be in the order of 35000 tons of coal per day (using 30% conversion shell technology). F-T fuels allow various ways to transport its final product, such as pipelines or shipping. Usage of trucks would seem cost-ineffective considering the daily throughput. Another thought to consider is the required storage of (intermediate and final) products (Apotheker, Elst et al. 2007; Putten, Vaan et al. 2008).

The other possibility is to include a IGCC facility to produce electricity. The advantage of using electricity is the (expected) rise in demand for energy and the presence of large energy users in the nearby area. This also favors the infrastructure, which is present nearby to transport the generated electricity towards the customers. There are significant economies of scale present for the size of the gas turbine. The range is about $800/kW_e$ for a 250KW_e size turbine, going downwards to $200/KW_e$ when the gas turbine has a capacity of 250 MW_e (excluding installation & gasifier costs) (Sims 2002). Larger units of gas turbine’s continue to $56/kW_e$ for 2003 dollar level (Jin, Larson et al. 2009). However, the latter does not include the HRSG & heat exchangers and the steam turbine. Thus, the total cost per MW_e output would more than doubled. A commonly used gasifier size would result in a net output of 400-500 MW_e (Jin, Larson et al. 2009; Martelli, Kreutz et al. 2009). The size of the gas turbine with such output is large enough to benefit some from economies of scale. The typical throughput for coal would be around 5700 tons coal per day, or a little less than 66 kg/sec.

Considering the general applicability for power and the presence of transportation infrastructure and demand in the nearby area, the base construction of the syngas production facility is an IGCC coal power plant. Coal is gasified, converted into syngas and used to produce electricity.

### Syngas plant sections

Deriving from different literature sources (Sims 2002; Baratieri, Baggio et al. 2009; Gasification Technologies Council 2009; Jin, Larson et al. 2009; Mondol, McIlveen-Wright et al. 2009), a syngas production facility can be divided in different sections. These are also indicated by the dotted boxes on figure 49. However, it should be noted that the design below is based on a biomass based feedstock, this design focuses on using coal as primary feedstock. The layout for the process however changes minimally. The identified sections are:

- Gasifier ‘Island’
- Gas clean-up
- Air Separation Unit
- Power ‘Island’

Based upon scalability of these different sections and the capital cost share in the total plant costs, it is possible to determine where flexibility can be best implemented. The mentioned sections will be briefly elaborated below, except for the Power Island. Concerning the power element this has been addressed in the previous paragraph of this section.
Types of gasifiers

Different types of gasification technologies exist. The choice between the most appropriate use of technology depends on the desired quantity or output. The figure below shows a brief overview of different technologies.

Considering the desired power output considered in the design, a Circulating Fluidized Bed (CFB) or Pressurized Fluidized Bed (PFB) are the only examples worthwhile considering. The assumed power output for the power plant using the IGCC is 500MWₑ. Therefore PFB type of gasifier would be the first choice considering the desired power output for the benchmark design. In the flexible design the
plant can be expanded by placing additional gasifiers on the location. These gasifiers may differ in size and technology, but the output (syngas) will be usable in the next sections.

The figure shows the types of gasifiers used for biomass. The primary fuel stock will be coal in the benchmark design and the first gasifier of the flexible design. Coal is the ‘first choice’ fuel type, as it is available on a large scale in the PoR area and shows a stable price development, especially compared to natural gas and oil (CBS 2009a; CBS 2009b).

In the flexible plant design there is a possibility to include two other gasifiers. The piping and site will allow two gasifiers to be fitted in parallel next to the initial places gasifiers. Two different sizes will be considered: one gasifier, expanding the capacity of the plant with 50%, or a set of two gasifiers (referred to as a ‘large gasifier train’) which have equal dimensions in terms of capacity. Thus doubling the plants syngas production capacity. However, gasification technologies are currently receiving increased attention in research & development. This may lead to improved gasifier designs: larger variability in feedstock constraints, increased efficiencies or lower capital costs. A larger variability in feedstock constraints are for example the exchangeability to fully operate on biomass, or the combination of biomass and coal (or co-firing). Here, these are labeled as single fuel or multi-fuel gasifiers. The total capacity of the plant will remain limited by the physical limitations at the piping sections.

There are four gasifier ‘slots’ in the flexible design. Two slots are already used in the reference plant lay-out. Hence, the options for the gasifier island in the flexible plant are two additional gasifiers from this ‘range of options’:

- Small gasifier, coal. After this they may be replaced by another gasifier, but against higher cost. Less capital cost involved than the large gasifier, however, cost per m³ of syngas will be higher due to lost economies of scale.
- Small gasifier, biomass. Same as the one above, but against different investment cost, such gasifier will be able to fully operate on biomass.
- Large gasifier train, coal. Equal in capacity compared to the original gasifier. Higher capital cost but more profits from economies of scale.
- Large gasifier train, biomass. Equal as the coal fuel, but able to fully operate on biomass.
- Refit the trains to co-fire biomass with the coal up to a maximum ratio of 25%. The percentage co-firing can be varied accordingly. However, when the price of biomass drops below the price of coal (combined with CO₂), the full capacity would be used.

Gas clean-up
The used fuel strongly determines the types of gases which will leave the gasifier. The used gasifier technology determines the set-up of this section as well. A clear example is provided by Jin et al (2009), where it is shown that the gas cleanup section for biomass content related gas clean up contains different process equipment. Biomass in general contains less sulphur which has to be filtered out, thereby saving on the capital cost for the equipment required.

It could be possible to design a large clean-up section for a variety of sources and gasification techniques for the flexible plant. But that would result in significant higher capital cost and most likely higher operational cost because more process steps are involved. A ‘tailor made’ clean-up section per gasifier would seem more efficient. The constraints on the feedstock are known, as well as the gasses leaving the gasifier which have to be filtered.
The choice of gas cleaning process equipment depends on gasification technology development. The composition of gases leaving the gasifier will determine the design of the gas clean-up section. This includes the risk that adding a second (and/or third) gasifier that is identical in set-up and fuel as the first gasifier, that a second gas clean-up section is needed. In that case, constructing a larger gas clean-up section at t=0 would likely been more cost-efficient (due to economies of scale). This does increase capital expenses when the capacity is not used.

Overall, a ‘tailor made’ approach will better fit in the technological design of a flexible plant lay-out in order to minimize capital costs related to the fuel price uncertainties. Therefore, it is assumed that each gasifier will implement its own gas-cleaning section. Thus, it will not be integrated in the initial basis design of the plant.

**Air Separation Unit**

Gasification processes can be carried out with direct oxygen or using air. The use of an Air Separation Unit (ASU) can provide oxygen for the gasifier. Nitrogen is largely filtered out, reducing the formation of NO\(_x\) in the gasifier. However, there are significant capital cost associated with the integration of an ASU in the plant.

An alternative is to create a process without an ASU, using air instead of oxygen. This would save on the capital cost for the ASU, but requires a plant lay-out change, see figure 50. An indirectly heated gasifier is required, including a separate combustor. The gas clean-up section is also expanded. Thus reducing the profitability of this plant lay-out. Next to this, the efficiency level drops. So at sufficient scale for syngas production, the integration of an ASU expects to be profitable. Jin et al (2009) uses a power output of 442MW\(_e\) in which it is found more cost-effective to integrate an ASU in the design. Next to this, the scaling exponent is estimated at 0.5, showing large economies of scale for expansion. Considering that the proposed reference plant layout entails an initial power output of 789MW\(_e\), an ASU will be integrated both the benchmark en flexible design.

For the flexible plant design, a choice remains in the dimensionality of the ASU. The ASU can be prepared for the full plant capacity, taking profit from larger economies of scale (at full operation) but higher initial capital cost, or matched at the initial operating capacity (with the power plant ‘behind’ the gasifier), allowing parallel construction of ASU’s as gasifiers are constructed. This leaves the opportunity open to include indirectly heated gasifiers operating on ambient pressure level. A ‘hybrid’ version is also possible, where 2/3 of the maximum capacity is provided by the integrated ASU. A second unit can be placed (with half the capacity of the first ASU, thereby leveling on the total capacity of the flexible plant). However, the scaling exponent of 0.5 shows that the additional investment becomes available at ‘marginal cost’. Though it should be acknowledged that the capital costs rise. However, the inclusion of an ASU has implications for the gas cleaning process. Oxygen-blown gasifiers operating at higher ambiances produces less tars and impurities (such as NO\(_x\)). This results in higher efforts required to clean the syngas: more process steps, equipment and costs. Figure 51 shows the indicative results for a biomass based gasification power plant. These results can be seen as comparable for coal gasification plants. Higher investment costs for indirect gasification, while the net efficiency shows little differences (Mondol, McIlveen-Wright et al. 2009).
The flexible plant will include an ASU which is based on the full potential capacity of the plant, which would be 200% of the flexible plant. The increased capital cost will quickly be compensated for the reduced cost in gas clean-up and placing new adjusted ASU’s.

**The projects Real Options**

The base scenario is an IGCC power plant using coal as a primary fuel. The flexible plant is proposed in the PoR to create a base station for the start-up of a ‘syngas cluster’. This cluster is supposed to develop such that other companies active in the PoR area which could use syngas, might ‘tap into’ the plant. These form the basis for (quickly) prepared expansions, in terms of placing an additional gasifiers + clean-up sections if needed.

It is theoretically possible to place additional gas and steam turbines parallel to the first one and hence use all syngas to produce electricity. It would thus mean that all produced syngas is used ‘internally’ for electricity production. No other users would be allowed to tap into the syngas production facility. This however would contradict with the initial mission of the syngas plant, which was to initiate the set-up of a cluster with one or multiple large syngas producers and multiple users of syngas to convert these further into a variety of final products otherwise produced with oil or natural gas.

When an option is exercised, to place another gasifier, not only syngas is produced, but heat as well. The heat, present as (high pressure) steam, can be used in various ways, also by other companies as well. Theoretically it is possible to divert the HP-steam towards steam turbines for additional electricity generation. The HP steam can be a valuable by-product, generating additional cash inflows for the syngas plant facility. The main product however remains syngas, and that product stream is considered to be the product sold. However, fact remains that HP-steam can deliver value. Though it can retain value, it is not taken along in this analysis.

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20 Most likely it is possible to tap into such production facility anyway, but at a very high price for the syngas. The producer of syngas is only willing to sell the gas when the buyer pays more than the production cost + profit from the electricity sales. This makes it economically unattractive for any commercial company to buy syngas as the gap between the ‘conventional fuel’ the buyer was using before and ‘syngas’ is too expensive and too unsure.
The benchmark plant
The reference or benchmark plant will be, as mentioned earlier, a coal Integrated Gasification Combined Cycle. The plant is based on a shell gasifier, where CO₂ is vented into the atmosphere (no capture and storage). The reference plant has a net electrical efficiency of 46.44%, producing a net power output of 789.0 MWₑ. This plant is based upon the SV configuration modeled in (Martelli, Kreutz et al. 2009). The size of the power plant is sufficient to benefit from economies of scale, so that costs per installed MWₑ remains acceptable. The specific plant elements and their respected costs are given in Table 21 below. More detailed capital costs and reference sizes can be found in Martelli et al (2009). Table 22 explains the variables and relationships.

<table>
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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal &amp; Sorbent handling</td>
<td>Coal, tonne/day</td>
<td>5447</td>
<td>1</td>
<td>0.67</td>
<td>40.4</td>
<td>5674</td>
<td>41.52</td>
<td>36,70515</td>
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<td>Coal preparation &amp; feeding</td>
<td>Coal, tonne/day</td>
<td>2464</td>
<td>2</td>
<td>0.67</td>
<td>101.6</td>
<td>5674</td>
<td>208.37</td>
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<td>Ash handling</td>
<td>Coal ash, tonne/day</td>
<td>477.8</td>
<td>1</td>
<td>0.67</td>
<td>38.1</td>
<td>692</td>
<td>48.83</td>
<td>43,171222</td>
</tr>
<tr>
<td>Stand-alone ASU, O₂ compressor</td>
<td>Pure O₂, tonne/day</td>
<td>2035</td>
<td>2</td>
<td>0.50</td>
<td>106.7</td>
<td>3942</td>
<td>195.95</td>
<td>173,23902</td>
</tr>
<tr>
<td>Standard gasifier, SG collers</td>
<td>Coal, MW LHV</td>
<td>737.4</td>
<td>2</td>
<td>0.67</td>
<td>178.1</td>
<td>1699</td>
<td>365.40</td>
<td>323,0446</td>
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<tr>
<td>LT heat recovery, FG saturation</td>
<td>Coal, MW LHV</td>
<td>737.4</td>
<td>2</td>
<td>0.67</td>
<td>17.3</td>
<td>1699</td>
<td>35.49</td>
<td>31,379403</td>
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<tr>
<td>COS hydrolysis</td>
<td>Coal, MW LHV</td>
<td>797.2</td>
<td>2</td>
<td>0.67</td>
<td>4.7</td>
<td>1699</td>
<td>9.15</td>
<td>8,0876993</td>
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<td>Gas cleanup balance of plant</td>
<td>Coal, MW LHV</td>
<td>815.2</td>
<td>2</td>
<td>0.67</td>
<td>6.1</td>
<td>1699</td>
<td>11.70</td>
<td>10,345286</td>
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<tr>
<td>MDEA AGR (H₂S capture)</td>
<td>S input, tonne/day</td>
<td>23.7</td>
<td>2</td>
<td>0.67</td>
<td>15.9</td>
<td>49</td>
<td>30.34</td>
<td>26,821138</td>
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<tr>
<td>Claus plant</td>
<td>S input, tonne/day</td>
<td>136.5</td>
<td>1</td>
<td>0.67</td>
<td>37.6</td>
<td>49</td>
<td>18.93</td>
<td>16,73299</td>
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<td>Siemens 9.4.3A gas turbine (GT)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>295.9</td>
<td>92.8</td>
<td>173,17</td>
<td>153,09753</td>
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<td>HRSG, ductwork &amp; stack</td>
<td>GT net power, MWₑ</td>
<td>232</td>
<td>2</td>
<td>0.67</td>
<td>33.8</td>
<td>587</td>
<td>73.84</td>
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<td>Steam turbine, condenser, aux.</td>
<td>ST gross power, Mₑ</td>
<td>274.7</td>
<td>1</td>
<td>0.67</td>
<td>74.0</td>
<td>360</td>
<td>88.70</td>
<td>78,417374</td>
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<td>Balance of plant</td>
<td>15.5% of plant cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>238,72</td>
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Table 21 - Capital Costs for major plant components (Martelli, Kreutz et al. 2009)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value / Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S₀$</td>
<td>Reference component size</td>
</tr>
<tr>
<td>$n$</td>
<td>Number of equally sized equipment trains</td>
</tr>
<tr>
<td>$f$</td>
<td>Cost scaling factor</td>
</tr>
<tr>
<td>$C₀$ (M$)$</td>
<td>Cost of reference component, in million USD (2008 level)</td>
</tr>
<tr>
<td>$S$</td>
<td>Required capacity</td>
</tr>
<tr>
<td>$C$ (M$)$</td>
<td>Overnight cost of component, in million USD (2008 level)</td>
</tr>
<tr>
<td>$C$ (M€)</td>
<td>Overnight cost of component, in million EUR (2010 level)</td>
</tr>
<tr>
<td>$e$</td>
<td>0.9 ; Cost scaling factor, Constant</td>
</tr>
</tbody>
</table>

Table 22 - Explanation of the variables and calculations in table 1

The costs provided in table 1 include engineering & overhead, general facilities, process (3.2%) and project contingencies (17% of the bare erected cost). A cost advantage is assumed to arise when multiple trains of equipment are bought. In table 20, $e$ is mentioned as the cost scaling factor. The price ($C$) for equipment is calculated according to the following formula (Martelli, Kreutz et al. 2009):

$$C = n^e \cdot C₀[S/(nS₀)]^f$$

When multiple trains of equipment are bought, it is assumed with this formula that the price is lowered, as savings occur at production and construction level. The gasifier is a standard Shell gasifier, with a Siemens 94.3A gas turbine. All major components (except the balance of plant) are
subjected to this cost formula. The total (overnight) capital costs are 1.36 billion euro’s, which is fairly high. The capital cost per kWh is around 1726 euro’s.

The cash outflows are represented by the costs for buying fuel (coal), and CO₂ emission allowances on the ETS market. Some important assumptions for the benchmark model are listed below:

- The ETS system (ending in 2012) is lengthened as intended by the EU commission (EU 2009). However, it is assumed that all CO₂ emission allowances have to be bought by auction. The emissions cap is lowered annually in a linear way, leading to new trend price. For more information concerning the price per ton CO₂, consult annex 5D.
- No CO₂ capture installation is included. All CO₂ is vented into the atmosphere. The choice is to acquire emission allowances on the ETS market.²¹
- Coal is imported in the PoR area, and will be the primary fuel. The proposed reference plant layout is based on Australian bituminous coal composition. The power input is measured in gigajoules lower heating value. From this point, using historical data (CBS 2009b), the throughput of coal is calculated. More about the modeling the coal price is provided in annex 5D.
- The construction period for the plant is assumed at 4 years, involving equal payments per period before the plant comes into production (Martelli, Kreutz et al. 2009).
- The operational lifetime of the C-IGCC plant is assumed at 25 years, according to the application of biomass based IGCC (B-IBCC) of Jin, Larson et al (2009), Martelli et al (2009) do not include an operational lifetime for their gasifier.

Another important topic is the used discount rate for the NPV calculations. A risk-adjusted rate is required to compensate all risks associated with the investments. Considering that large scale gasification is hardly common practice at the moment, the discount rate will be fairly high, given a qualitative assessment of the CAPM (Brealey, Myers et al. 2006). A rate of 15% is not uncommon in these technical projects, and seems appropriate to use to discount these events.

The flexible plant
The flexible plant is identical to the benchmark plant in the beginning, except that all preparations have been taken to double the capacity for production of syngas. This syngas will not be used to generate electricity, but is rather sold to external clients in the PoR. Below a number of conclusions for the flexible plant are mentioned (derived from the sections above):

- The Air Separation Unit is implemented for the full potential capacity (around 200% of the benchmark plant), due to the high economies of scale applicable for the ASU. This has implications for the required gas clean-up facilities as less extensive equipment is necessary, thereby quickly retaining the added initial capital cost.
- The required equipment for the gas clean-up section strongly depends on the type of fuel used. Therefore the required equipment are linked with the gasifier and chosen fuel type for the expansions. This saves on initial investment cost. It bears the risk that in the event of all expansions use coal as fuel, higher nominal capital costs are required than building a single

²¹ Including Carbon Capture and Storage (CCS) provides an additional dimension of large uncertainty and required infrastructure for further processing and sequestration of the CO₂, therefore not considered in this work.
large clean-up section (for one type of fuel such as coal). A ‘tailor-made’ approach is considered more appropriate.

- The gasifier island includes the feed preparation section.

The benchmark plant has two coal gasifiers. The flexible plant design has four slots, from which two remain available. The remaining two slots can be used to increase the capacity. Different options have been derived, able for implementation in the flexible plant design. They are briefly listed below:

- 1 coal gasifier, equaling 50% increase in syngas production capacity
- 1 biomass gasifier, equaling 50% increase in syngas production capacity

These two can be added in different combinations, i.e. 1 coal and 1 biomass, or 2 coal, or 2 biomass gasifiers. There are two slots available, hence, the maximum availability is clear.

- 2 coal gasifiers, 100% increase in syngas production capacity
- 2 biomass gasifiers, equaling 100% increase in syngas production capacity

Besides these options, there is an additional possibility for the coal gasifiers:

- The coal gasifiers can be modified by making an additional investment, such that biomass can be co-gasified up to 25% input (based on LHV)

However, a slightly different configuration is required for the syngas conditioning before this can be sold to the market. During the gasification process, CO₂ is formed. After this, additional CO₂ can be formed by adjustments in the Water Gas Shift reaction. Adding steam to the CO pushes the balance of the reaction towards formation of more H₂ and CO₂. CO₂ is partly also already present in the raw syngas stream leaving the gasifier. The CO₂ has to be captured from the syngas stream before the syngas can be sold to the customer.

Quite importantly, current practice is that there is no such large biomass gasifier yet capable of producing a net output 400 MWₑ solely based on biomass (Jin, Larson et al. 2009). So, the biomass gasifiers are not taken along in this options assessment. Mapping this technological uncertainty requires too much effort for this research. Though, the additional biomass gasification investment is taken along. So there will be three options paths:

4. A set of two sequential investment of two ‘smaller’ coal gasifiers.
5. An immediate investment in a large gasifier train (involving taking both free gasifier slots at once). 1 and 2 exclude each other!
6. A refit of the gasifier and feed preparation section to incorporate biomass co-gasification up to 25%.

The flexible plant section therefore requires an additional capture section for the CO₂. The benchmark plant (also the basis of the flexible plant) uses an MDEA (methyl diethanolamine) AGR for the capture of H₂S, based on the Standard Shell gasifier with Venting of the CO₂, hence the SV case. The same process principle can be extended to capture CO₂ from the raw syngas production. Martelli et al (2009) defined next to the SV also a SC case, with the same configuration, however extended with a CO₂ capture facility to remove CO₂ from the syngas. Such capture facility is depends of the fuel used, as coal generally holds more carbon than biomass (Prins, Ptasinski et al. 2007). The CO₂ is vented after removal from the syngas. As mentioned earlier in this paragraph, CCS is excluded from the case analysis, as it would require yet an additional separate infrastructure, which is not the focus for this research. Though, it should be stated that since the CO₂ has to be removed from the syngas,
a significant part for the CO₂ capture cost has already incurred. After this stage, emission allowances have to be bought for venting the CO₂ in the atmosphere. Further processing for underground storage could become economically viable more quickly. By venting, the drying & compression steps for CO₂ are not necessary. This saves on the capital cost, but enforces purchase of emission allowances, thus increasing variable cost. This is partly compensated by the reduced amount of energy required, since no compression has to be done with the gas. The amount of electricity that is required is to facilitate the syngas production & cleaning steps is provided by the power plant from the initial build section.

The 'lumpy' plant
Considering that there is no market yet for syngas, another alternative is taken along: a lumpy plant is considered as well. This considers the full, maximum configuration of the plant. All gasifier slots are used with coal gasifiers upfront. This presents the alternative profiting the most from economies of scale, but suffers from the burden that there is too low demand for the syngas, thus, the investor could not retain his earnings.

Other players in the market are not likely to abandon their own equipment, or retrofitting their plants to switch to syngas, without a proper cost incentive. There is also a lock-in for the current investments that already have been made in the chemical cluster. Equipment which has not been debited yet, would not be easily reconsidered by other plant owners to abandon their sunk assets and revert to syngas. Thus, that is the risk of this alternative.
5C. Use of GBM & MRP in the case

The purpose of this annex is two-fold. First, a general description for the Geometric Brownian Motions and Mean Reversion Processes are discussed. This is followed by applying these theories to the syngas case presented in the thesis report.

Earlier research indicates that energy prices, both electricity as most fuel prices like coal, natural gas and oil, can be modeled as Mean Reversion Processes (Blanco and Soronow 2001b; Wang, Wu et al. 2008; Shafiee and Topal 2010). The idea behind Mean Reversion Processes is prices show a ‘random walk’ with a (limited) memory effect of its last changes, and converge on the long term towards a trend or equilibrium. MRP is based on an extension of the Geometric Brownian Motion (GBM), which is based on the same principle, but simpler: GBM excludes the converging element and the ‘memory effects’ of the random walk. Both techniques are briefly elaborated in this section, where the formula’s are shown which are used in the analysis phase of the syngas plant configuration to model both inputs and outputs.

Because both plant configurations operate in the same market conditions, the designs can be assessed using the same inputs and output models. Different uncertainties influence the (financial) performance of the plant. These uncertainties are primarily guided by price deviations for both the feedstock and final product prices. The price for syngas and electricity as selling products, while the prices of coal, biomass and natural gas also show frequent price shifts on the market.

The valuation of the plant designs (both the benchmark and the flexible design) can be done based on average or expected values for the different fuels and selling products. However, this does not reflect the reality of the uncertain and dynamic world the case has to be placed in. Based on historical data of prices, averages or trends could be analyzed, resulting in expected values for commodities to calculate with. However, this provides a static picture with point estimates for the expected (financial) performance of the design. This likely results in false performance figures, because the ‘presumed’ states for the plant show low probabilities to actually end up in.

A more realistic approach would be to model the price variations using available historic data. Based upon this data, a simulation based model can be build to calculate different price paths. By sampling these distributions many times it is possible to develop a range of results for the price developments and thereby also the performance of the plant design. The identified options for the flexible plant design can also be valued under these uncertainty conditions.

**Geometric Brownian Motion**

The most common application in ROA which uses a GBM approach is the binomial lattice model. This model weakly converges towards a lognormal distribution, depending on the used parameters (Hahn and Dyer 2008). Its general form is presented as follows:

$$\frac{ds}{s} = \mu dt + \sigma dz$$

The variables are explained in the table below:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td>Commodity / asset price</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Growth rate (or drift)</td>
</tr>
</tbody>
</table>
An alternative name for GBM is ‘random walk’ (Guthrie 2009). The main principles for the model is that there is a non-random effect causing growth or decline, and a random movement taken from a distribution. The main input parameters are the volatility, expected variability and the asset price at t=0. The GBM implies a lognormal distribution for the prices of the asset, since the price changes are based on a logarithmic change. Another implication is that the price changes are independent from each other (no memory effect) and the mean and volatility are constant. Rewriting the formula into a recursive, time discrete formula gives (Blanco, Choi et al. 2001a):

\[ S(t_{i+1}) = S(t_i) \times e^{(r-q-\frac{1}{2}\sigma^2)}(t_{i+1} - t_i) + \sigma \varepsilon_{i+1} S \varepsilon \sqrt{(t_{i+1} - t_i)} \]

Again, the variables used are explained in the table below.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S )</td>
<td>Commodity / asset price at t_i or at t_{i+1}</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Standard deviation of returns (volatility)</td>
</tr>
<tr>
<td>( r )</td>
<td>Risk free rate of return</td>
</tr>
<tr>
<td>( q )</td>
<td>Asset or commodity yield</td>
</tr>
<tr>
<td>( \varepsilon )</td>
<td>Random shock to price between t and t+1</td>
</tr>
</tbody>
</table>

This method is the easiest and most implemented type of model to map financial assets with its uncertainty. As said earlier, the binomial lattice model is a simplified version applying this principle with one up and one down value per time unit specified. The size of the up- and down steps is determined by the volatility rate: If an asset is subjected to a large uncertainty, the volatility is larger. This leads to higher possible moves upwards and downwards (Copeland and Antikarov 2003).

There are several pitfalls related to the use of GBM models, which are mentioned below (Blanco, Choi et al. 2001a):

1. Not all asset price developments follow a lognormal distribution.
2. Extreme price changes cannot be modeled using GBM.
3. Estimating the volatility of the underlying commodity remains challenging. Current volatility (based on historical data) may not necessarily be the same as future volatility rates.
4. Volatility rates change over time. For short term price modeling, volatility rates based on historical data may fulfill its purpose. Using constant volatility rates over longer term price modeling may not represent realistic price developments.
5. Very high volatility rates may falsify model behavior. The drift rate will dominate the models price evolution.

Mean Reversion processes

As an expansion to the GBM model, commodity pricing can also be applied using mean reversion processes. The MRP assumes that the commodity price will converge towards a long term average. GBM does not account for prior changes in the price (no memory effect), while MRP does take this into account. "Mean Reversion can be thought of as a modification of the random walk, where price
changes are not completely independent of one another but rather are related” (Blanco and Soronow 2001b). Thus resulting in more realistic price movements.

The MRP model can be represented using the following equation (Blanco and Soronow 2001b):

\[ S_{t+1} - S_t = \alpha (S^* - S_t) + \sigma \epsilon_t \]

The variables are explained in the table below.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S )</td>
<td>Commodity / asset price at ( t ) or at ( t_{i+1} )</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>Mean reversion rate</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Standard deviation of returns (volatility)</td>
</tr>
<tr>
<td>( S^* )</td>
<td>Mean reversion level or long run equilibrium price</td>
</tr>
<tr>
<td>( \epsilon )</td>
<td>Random shock to price between ( t ) and ( t+1 )</td>
</tr>
</tbody>
</table>

Table 25 - Explanation of variables of a MRP model

Where GBM has a relatively easy way of determining the input parameters, based on historical data. The volatility is the hardest input parameter to estimate. Using Mean Reversion Processes to model future price developments shifts the difficulties to estimate the parameters towards a higher level. The Mean Reversion Level (MRL, or the long term equilibrium price or trend) and the Mean Reversion Rate (the speed of the price converging to the long term equilibrium price) have to be determined, next to the volatility of the commodity. However, this is also possible using historical price data. The important assumption is that historical price data can provide a basis towards future estimates (Blanco and Soronow 2001b).

For the implementation of ‘time shocks’, a Normal distribution can be used. These are then converted into ‘appropriate’ shocks using the input Mean Reversion Rate and the Mean Reversion Level. In order to use mean reversion for simulation purposes, the formula needs to be rewritten into a discrete time equation, the following set of formula’s arise (Dixit and Pindyck 1994; Dias 2004):

\[ x(t) = x_{t-1} e^{-\eta \Delta t} + \ln(P_{eq}) * (1 - e^{-\eta \Delta t}) + \sigma \sqrt{\frac{1 - e^{-2\eta \Delta t}}{2\eta}} * N(0,1) \]

\[ P(t) = e^{x(t) - \text{Var}[x(t)]} \]

\[ \text{Var}[x(t)] = (1 - e^{-2\eta \tau}) * \frac{\sigma^2}{2\eta} \]

The definitions of the variables are given in the table below.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta )</td>
<td>Calculated Mean Reversion Rate (corresponds to ( \alpha ))</td>
</tr>
<tr>
<td>( P_{eq} )</td>
<td>Long term equilibrium price (MRL) (corresponds to ( S^* ))</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Standard deviation of returns (volatility)</td>
</tr>
<tr>
<td>( N(0,1) )</td>
<td>Random sample from Normal distribution with mean 0 and variance 1</td>
</tr>
<tr>
<td>( P(t) )</td>
<td>Price of asset at time ( t )</td>
</tr>
</tbody>
</table>

Table 26 - Explanation of variables
MRP does not fully capture all characteristics in its modeling. First, in the analysis of historical data for an asset, price jumps can be identified which cannot be explained by the random walks, not with or without the ‘memory effect’. These price jumps are consequences of discontinuous events on the global or local market, influencing the supply and demand of assets and thereby the market price. Including a Poisson distribution could imply the modeling of unexpected price jumps, which after that lead to a recovery towards the identified MRL. However, when the time steps are larger (for example years), the impact of these sudden price jumps is limited. The price of the asset is likely to have converged to the MRL, depending on the half-life variable. Often, insufficient data prevents a proper modeling perspective for integrating price jumps, and these jumps interfere with the deterministic expectations for the price developments. See Shafiee & Topal (p 994, 2010) for a more elaborate discussion on these difficulties. Second, Mean Reversion Rates are quite often not constant, these may vary over time. MRR depend on several factors, like the nature, magnitude and direction of the price shock. Thus the MRR cannot be reliably determined over very long periods, as these are likely to change over times. Next to this, a trade-off is implied to continuously use different mean reversion rates over short periods (based on historical data) or to extract a longer term average value (Blanco and Soronow 2001b).

**Use of MRP in the case**

For modeling the performance of both the benchmark plant and the flexible plant, different uncertain variables have to be modeled. As mentioned earlier in the introduction, a wide range of literature (especially Shafiee & Topal (2010) includes a literature list of conducted research) suggest that applying MRP allows a relatively good fit for price modeling for coal, oil and natural gas. Blanco et al (2001a & 2001b) imply that energy prices over both short term and longer term can be adequately modeled using MRP. But the strong premise is that historical data provides a basis for future price modeling. This is a point of discussion, since the price developments of especially energy sources and carriers is uncertain. Future energy demand is expected to rise exponentially and considered as one of the most important problems our civilization is facing. The finite of oil is ‘in sight’, and the tight market of the pas years create a nervous environment for oil trading. This affects the volatility of oil, but also for other fuel resources, which may be alternatives for oil. However, the price developments on the market for oil and other fuel resources provide an uncertain investment climate.

In the absence of full knowledge about the market, historical price data is the best estimate at hand to model future price developments. From literature (Shafiee and Topal 2010) certain longer period trends can be identified and integrated in the model. Though, it should be noted that any trend has certain inherited variance. If one is to model price developments over de coming 30 years, the use of a trend remains tricky (Neufville and Scholtes 2010). Compare the situation with some 30 years ago and try to predict the developments for commodity prices. With the gift of hindsight, we can express this quite well, but not all developments can be predicted over longer periods of time. The use of a trend and data based on historical developments form the best approach. Implying the knowledge of these remaining limitations to the use of trend and data for long-term forecasting, should place the use of these modeling techniques in perspective. A pragmatic example to the syngas plant might be the attitude towards the use of fossil fuels and its impact of this attitude towards future market prices. People have just ‘recently’ become more aware of the problems of fossil fuels producing
greenhouse gases. It would be very hard, if not impossible, to predict how this attitude will develop itself in the coming decades, especially since this has merely just evolved.

The following uncertain variables will be assessed based on historical data and literature:

- Oil
- Coal
- Natural Gas
- Biomass
- CO$_2$

And the following ‘output’ factors:

- Electricity
- Syngas

These variables can be correlated with each other. Based on literature, earlier defined correlations will be used to correlate the ‘random walks’ with each other. This will increase the validity of the model, as it is more likely that the prices interact with each other. Example: a higher gas price and/or coal price will have its effect on the price of electricity. The price of oil will influence the demand (and thereby the price) of syngas.

With the available statistical data and literature sources, variables will be computed for the modeling of the prices in the nearby future. However, as mentioned earlier, price forecasting cannot be done accurately over longer term periods. In order to take this into account in the model valuation of the syngas plant, the uncertainties in the variables grow in steps over the time:

It is assumed that, based on the historical data and literature, the future price can be modeled accurately for the first ten years. The model assumes T=0 in 2010 (start of plant construction), after 2020 these variables become more volatile and receive a more variable MRR. The earlier trend remains in position, but with the stochastic approach for volatility and MRR, there can become a larger spread. This is an attempt to account for higher unpredictability for long(er)-term forecasting of pricing. In annex 5D these steps are explicitly presented what period will use which variables and corresponding distribution.

This approach has the advantage the use of a trend combined with a growth in the level of uncertainty over the longer period that it better reflects a range of possible futures. A large disadvantage is the required computational power, as more simulation runs are required to acquire a spread of the output variable(s), as the NPV.
5D. Parameter estimations

In this annex section, data is collected from historical sources where possible. These data are used to set-up a MRP-model to predict future prices with its inherent uncertainties. Running a Monte Carlo simulation with these models will result in an overview of possible future paths for the plant to be in, enabling to reflect on the performance of the plant design. All data analyses are carried out in a spreadsheet program. In this particular case Microsoft Excel is used, with @Risk as added tool for execution the Monte Carlo Simulation.

First, the input data are assessed. These are oil, coal, natural gas and biomass. Oil is not a primary feedstock, but can be considered as a ‘main indicator’ for energy sources on the global market. Oil is correlated with other types of energy source prices, as will be discussed later in the paragraph correlations. Next, the output data are assembled: electricity and syngas (HP steam is excluded from the analysis). This is followed by identifying correlations between the different inputs and outputs, based on literature. Finally, trends are discussed which are both based on the historical data and literature. Based upon these data, the model is put together in order to value the plant designs.

Input data

This paragraph will discuss oil, coal, natural gas and biomass in this order. Finally, CO₂ pricing is assessed.

Oil

CBS (2009a) provides an overview of daily crude oil prices for the market, from January 2006 until end of October 2009. Figure 52 below shows a graphical lay-out of these prices. Prices based on dollars per barrel have been recalculated towards euro’s with the exchange rate of that particular day. Next, the price has been converted from euro’s per barrel towards euro per gigajoule energy. The assumed energy amount in a barrel of oil is 5,736 GJ and considered to be constant over time (page 9)(Tilburg, Vries et al. 2005).

The data is based on 1000 price samples on a daily basis. This will not hold as a ‘secure’ base for future price estimations, especially for long-term horizons. However, the oil market shows very volatile movements and has changed dramatically in the past ten years. The expectations would be that crude oil will remain volatile as the market will remain ‘tight’: the end of the availability of oil seems in sight, while the demand for oil is stable or rising. Though new oil fields will be developed, the expected continuing growth in demand will cause the supply to ‘lag behind’. Developing a new oil field takes a period before oil can be brought towards the market.

It is expected that these recent figures combined with a trend (see the paragraph trends) will provide a good idea of the possible price path developments for the oil price, based on a MRP modeling process. This does hold for the ‘short’ term, but for the longer term volatility, the MRR and the trend are not so sure. Therefore, these will be subjected to a higher level of uncertainty as time progresses.

The calculated variables for the MRP model are based on (Blanco and Soronow 2001b), and give an annualized volatility rate of 30%, a mean reversion rate of 0,87 and a long term mean of 9,50 EUR/GJ (excluding the trend). One possible price path using this data is given in figure 53. In the table below the values are given for the MRR and volatility during the analyses over the longer periods. The MRL or equilibrium price will be subjected to a linear trend, defined in the paragraph trends in this annex.
Figure 52 - Daily oil prices in EUR/GJ (CBS 2009a)

Figure 53 - A possible price path for Oil, based on historical data, excluding trend

Table 27 - MRR and volatility values for oil prices during the analysis

<table>
<thead>
<tr>
<th>Oil</th>
<th>2010 - 2020</th>
<th>2021 – 2030</th>
<th>2031 - 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Reversion Rate</strong></td>
<td>0.87</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td></td>
<td>Min: 0.87 Max: 1.10</td>
<td>Most likely: 0.95</td>
<td>Min: 0.90 Max: 1.10</td>
</tr>
<tr>
<td><strong>Volatility</strong></td>
<td>30%</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td></td>
<td>Min: 25% Max: 45%</td>
<td>Most likely: 35%</td>
<td>Min: 30% Max: 50%</td>
</tr>
</tbody>
</table>

The volatility is not expected to decrease, as tension on the oil market is not expected to decline significantly over time. It would be more likely that the volatility increases over time, as the price will
quickly response to any rumor or development in the market. Oil is less easily brought to the market and against higher cost. The supply will remain delayed upon the demand. The MRR is likely to grow, as jumps become bigger due to the tension, the market will provide a more quickly reversion to the equilibrium (MRL) or trend. The MRR rate is considered minimum, the spread may grow over time, as uncertainty regarding price developments increase.

Coal

CBS (2009b) contains a historical dataset for coal prices in EUR/GJ dating from 1981 until second quarter of 2009. These data show a more stable (less volatile) price development than oil, which is in line with the general expectations. The availability of coal in the future is more secure than the availability of oil. Figure 54 provides a graphical overview of the used historical data to calculate the variable used for price developments.

The market for coal shows some volatile developments in the late period, but in general coal is considered to be a stable, cheaper energy source than oil. The data is used for calculating the variables for the MRP pricing model, based on the method presented by Blanco et al (2001b). The identified volatility is 21%, with a MRR of 0.10 (which is fairly low). This indicates that the price is less volatile than the price of oil and more slowly reverts to each long term equilibrium. This MRL is identified as 2.10 EUR/GJ. This is excluding the trend. This data enables computing random price paths, which one is given below in figure 55.

The same conditions do apply for coal as for oil: long term developments may divert from historical data extrapolations. Therefore, a trend is used based on historical data, and the volatility and MRR variables computed will be used for shorter term estimation, and will be ‘loosened’ in later time periods. The table below shows the values used for the MRR and volatility as time progresses.
Figure 55 - One possible MRP price development path, based on historical data

Mean Reversion Rate

<table>
<thead>
<tr>
<th></th>
<th>2010 - 2020</th>
<th>2021 – 2030</th>
<th>2031 - 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td></td>
<td>Min: 0.10 Max: 0.30</td>
<td>Min: 0.15 Max: 0.50</td>
<td>Most likely: 0.30</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Most likely: 0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatility</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td></td>
<td>Min: 20% Max: 35%</td>
<td>Min: 20% Max: 35%</td>
<td>Most likely: 25%</td>
</tr>
<tr>
<td></td>
<td>21%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Most likely: 25%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 28 - MRR and volatility values for coal prices during the analysis

The MRR was found to be quite low during the analysis of the historical data available. Figure 56 shows that the price of coal does not revert quickly back to the defined equilibrium price. In the future, coal will remain important on the market as an energy source. The MRR is assumed to increase over time, as prices (in a stable supply situation) may not have to fluctuate that much. The volatility is expected to remain either the same or to grow a little. Coal demand is expected to rise in the future, especially when gasifiers become more commercially attractive due to innovations & reduced costs. The spread for the volatility is expected to remain the same over the entire length as the market is assumed not to become unstable during the outlook period until 2040.

Natural Gas

The available data for natural gas strongly differs per source. CBS (2009c) and Eurostat (2009) counteract on each other for their represented gas prices per GJ. Both datasets are given below. The time interval for the available data differs, but one can quickly observe that the prices significantly differ. Eurostat (2009) data is based on industrial consumers in the Netherlands, buying gas through contracted amounts. These numbers account for the Netherlands. CBS (2009c) data is based on the recently introduced spot market TTF (Title Transfer Facility). This market serves as a virtual trading place for gas in the network, intended to promote trading in gas and liquidity of the gas market (Gas Transport Services 2009). However, CBS does not have statistical data available regarding more steady market developments. These are provided by its European colleague Eurostat. Both developments are shown in figure 56. The data provided by Eurostat (2009) however, do not entirely show the development one is expected, as gas prices do not lower during the final year 2009, while those of oil and coal do. The TTF curve shows rather very low prices per GJ for the use of gas, and
considering the spot market is not the best indicator for predicting longer term price developments, it is decided to use the Eurostat (2009) data provided.

The data from Eurostat shows a continuous growth trend. The calculated volatility is 19%, while the MRR is unexpectedly low: 0.03. The long term equilibrium price excluding trend is 11.01 euro/GJ. The extreme low value for the mean reversion rate combined with a volatility rate of 19% is that the prices may fluctuate significantly, but very weakly converge to the equilibrium. However, as mentioned earlier, the MRR rate is subjected to higher uncertainty levels as time progresses in the model, thereby compensating for this flaw. A possible price path is given below in figure 57.
The table below presents the values for the MRR and the volatility over the outlook period.

<table>
<thead>
<tr>
<th>Natural Gas</th>
<th>2010 - 2020</th>
<th>2021 – 2030</th>
<th>2031 - 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Reversion Rate</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>Min: 0.03 Max: 0.40</td>
<td>Min: 0.20 Max: 0.80</td>
<td>Min: 0.20 Max: 0.50</td>
<td></td>
</tr>
<tr>
<td>Most likely: 0.20</td>
<td>Most likely: 0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatility</td>
<td>19%</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>Min: 15% Max: 30%</td>
<td>Min: 20% Max: 30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most likely: 20%</td>
<td>Most likely: 25%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 29 - MRR and volatility values for natural gas prices during the analysis

The MRR rate is expected to grow significantly. As can be seen in figure 58, it nearly takes a decade for the price to revert to its equilibrium price, while the volatility of the price is significant with 19%. Yearly averages are significant, a significant growth of the MRR towards values of 0.20 and 0.50 remain smaller than those identified for oil (0.87). Therefore these rates do not seem inappropriate. The price will more quickly ‘turn towards’ its long term (trend)price, while volatility is maintained. The availability of gas over the long term is not as certain as for coal. The market is expected to tighten over the time, as gas is a relatively easy alternative to oil. The maximum volatility rate assumes a growth, but the most likely volatility is assumed to grow marginally.

**Biomass**

Biomass can also be used as an input for gasification to produce syngas (for further conversion into electricity or) to be sold to the present (nearby) market. Biomass is considered to be a CO₂-neutral input fuel, because it consumes CO₂ in the production phases. Though this ratio is unlikely to be 1:1, because CO₂ is emitted while the biomass is processed and transported. However, in this thesis biomass is considered to be a sustainable resource.

The amount and price of biomass is related to the land availability for production of biomass, and the progressing research & development to convert ‘waste streams’, such as agricultural wastes, into valuable biomass streams for use in gasifiers. But other factors play a role as well: the demand for biomass nationwide and national policy for support of using biomass over fossil fuels. Also, it is fairly reasonable to assume that if biomass becomes cheaper than fossil fuels (coal or oil) for certain applications, the demand will rise. Availability of biomass is not that flexible (due to agricultural performance, weather conditions and land availability), resulting in an increase in price.

There is little literature available containing a historical overview for biomass pricing data, let alone to predict the developments of the new and emerging market. The factors described above provide a difficult task to predict biomass prices in the coming decades. Currently, most biomass originates from wooden pellets coming from Canada, Russia, Scandinavia and the Baltic States, and is delivered against a price of 120 – 140 euro’s / ton, or equivalent to the price of coal plus 2,5-3,5 euroct/kWhₑ (Koppejan, Elbersen et al. 2009). This equals an added 7 euro per GJ energy above the price of coal. Due to the high uncertainty level for all developments together, the price of biomass is considered to follow an uncorrelated uniform distribution. The price is expected to lie between 6 to 10 euro’s per GJ energy. The uniform distribution is used to ‘exploit’ the maximum level of uncertainty for the possible biomass developments.

Chappin et al (2009) do assume in their model that the price of biomass will not throughout time, but the availability will keep pace with the demand. In the model, a low increase is taken along of 1%,
thus allowing a net cost decrease over time, as the increase is lower than the inflation rate, which is assumed to be 3%.

CO\textsubscript{2}

The influence resulting from CO\textsubscript{2} pricing strategies may affect the choice for the investments to make in the future, and show significant addition of uncertainties for the choice of investments to make.

The EU ETS (Emissions Trading System) for CO\textsubscript{2} operates from 2005 onwards. This system will be used until 2012, but has ‘missed its principal target’. The price remained too low for creating sufficient impact on the market to change the market settings and shift towards other energy sources. The follow-up system, expected to be implemented from 2013 onwards, is most likely to show different characteristics. Instead of (largely) grand-fathering of emission allowances these will be auctioned, while the total amount of allowances is lowered throughout time.

The advantage of an ETS above ‘simple’ CO\textsubscript{2} taxation is that a cap can be introduced, where the total emissions can be controlled, while taxation cannot put a maximum level to the CO\textsubscript{2} emissions allowed. An ETS set-up has the disadvantage that the price fluctuates and therefore shows higher levels of uncertainty. An increased amount of uncertainty may hold emitting parties from investing in techniques to lower or avoid CO\textsubscript{2} emissions. A ‘simple’ carbon tax system is found to be more effective in lowering CO\textsubscript{2} emissions (Chappin, Dijkema et al. 2009).

The CO\textsubscript{2} pricing system is a policy instrument, which can be altered in any way possible. The usage of historical data for pricing of CO\textsubscript{2} is not possible, since the current ETS in use will be altered per 2012. If the current proposed system is to be implemented, it will remain remains a cap & trade system as it used to be, though the cap will be lowered stepwise, and these steps will be far more drastic than the period until 2012.

The model for the CO\textsubscript{2} price will be based on the simulation results based on Chappin, Dijkema et al (2009), which shows a fluctuating CO\textsubscript{2} price for an ETS scenario. The observations made from their analysis, done by creating an agent based model, are taken along in the price model for CO\textsubscript{2} in this analysis:

- The volatility for emission rights remains high for the coming decades
- The CO\textsubscript{2} price is strongly correlated with the price for electricity

The following assumptions apply to the model:

- Allowances will always be available on the market
- All emission rights are auctioned and have to be bought on the market\textsuperscript{22}
- Biomass is considered to be carbon neutral, thereby not requiring emission allowances
- Every time the cap is lowered, the long term equilibrium price for CO\textsubscript{2} rises\textsuperscript{23}

Since the ETS is a ‘market’, there will be demand & (constrained) supply of emission allowances. The price therefore can fluctuate. It is assumed that there is a degree of randomness in the development

\textsuperscript{22} Most likely, in 2013 half the allowances are still freely allocated, but this will be lowered throughout time (EU, 2008). For sake of simplicity, this rule is assumed to create a more transparent model.

\textsuperscript{23} Not het entire market is modeled, but it is assumed that by lowering the cap in steps, scarcity of CERs increases, forcing a new equilibrium price to be formed. Since supply is lowered, the price is assumed to rise.
of the price for CO$_2$. This is realistic, since different developments might influence the price of CO$_2$, the price development is not certain. A MRP model is used to model the price developments, alongside of other fuels used. The starting price for a CO$_2$ allowance is assumed to be 20 euro’s per ton, as this approaches the current price for CO$_2$, in this scenario it would equal the first ‘step’ in the carbon tax scenario of Chappin, Dijkema et al (2009). The EU intents to lower its cap annually, in a linear setting (EU 2008). The long term equilibrium price is therefore set to rise annually with €1 per ton CO$_2$, in that setting it would the price would start in 2010 with €20 per ton and rise up to €50 per ton in 2040. The annual increase is an assumption, based on the linear decrease of the emissions cap defined by the EU. Exact figures were not available in the assessed literature. The presented figures are expected to show some approximations of possible developments. The volatility of emission allowances is assumed to be high (Chappin, Dijkema et al. 2009), therefore taken along with a volatility rate of 35%, and a MRR rate of 0.8. These figures are the same for oil, which price is also considered volatile on the market. These figures do not change over time over time. It is unlikely that the volatility rate would not change over time, especially as more data becomes available as the new ETS is implemented. But currently no data is yet available and therefore this is used. The trend price is also assumed to apply throughout the plants lifetime.

As with other price forecasts over longer terms, trends are highly uncertain. As this is a policy instrument, there are a lot of variables which can easily be adjusted over time as discontinuous events develop. A stable lay-out for the ETS from 2013 onwards is assumed in which minimal changes are made. Assuming that changes are made, it can be expected that the emission allowances will not become cheaper over time. An annually increasing trend price (in any sort of increase) approximates this assumption.

A simulated price path for CO$_2$ is given in the figure below.

![Figure 58 - A simulated price path for CO$_2$ emission allowances](image)

**Output data**

This section will shortly discuss the parameter estimations for price modeling of electricity on the Dutch market, and for synthesis gas.

**Electricity**

Long term energy price statistics are difficult to acquire, especially since the Dutch electricity market has been liberalized since 1998. CBS (2009c) provides an overview for APX (Dutch electricity spot
market) from 2006 onwards. These prices are based on base load prices per day, which may not provide an accurate picture of longer term electricity market developments for longer term price contracts. The electricity is likely to be sold towards large consumers in the PoR area, and not fully be traded on the electricity spot market. Though this may result in ‘nice opportunities’ in cases where demand for power is high, and prices go up, but this is not the method to value the performance of the syngas plant. However, recent research showed that correlations exist between yearly averaged spot market prices and electricity future contracts (Redl 2007). These future contracts predetermine the amount of electricity to be delivered to the client at a pre-specified price. Prices per unit electricity (MWh) are commonly a small factor higher than the average spot prices, compensating for ‘bearing the risk of spot prices’ for the customer. These compensate for the hourly up- and down-movements. In the final year of the analysis (end of 2006, start of 2007), the future prices converge towards the average spot prices (see figure 59). Though it should be noted that Redl used CCGT-plants (using gas as primary feedstock) as main inputs for his analysis. He argues that there is no correlation between cost of generation using ‘hard coal plants’ and electricity prices, while there is a high degree of correlation between using CCGT on gas and electricity prices. In his analysis, the APX was taken along.

For the sake of simplicity in this thesis we therefore take yearly averaged spot prices to be equal to future prices. As these prices converge to each other over the time of the analysis (Redl 2007). CBS (2009c) provides an overview of historical daily prices, given in figure 60 below.
From this point a MRP model is created for the prediction of electricity prices in the future. The volatility is found to be 30%, with a long term equilibrium price around 56.3 euro/MWh. The MRR is found as 0.29. This is excluding any trend in price developments. Again, a possible price path modeled provided in figure 61.

![Simulated price for electricity [APX] based on historical data](image)

**Figure 61 - A random price path using historical APX price data**

The data computed will be subjected to a higher level of uncertainty as time progresses. The dataset starts from 2006 until October 2009, so usable for shorter term predictions, but using these data for longer term predictions or simulations is likely to give unreliable results. As with the other parameters, this is prevented by enlarging these factors with uncertainty distributions. These are represented in the table below.

<table>
<thead>
<tr>
<th>Electricity</th>
<th>2010 - 2020</th>
<th>2021 – 2030</th>
<th>2031 - 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Reversion Rate</td>
<td>0.29</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td></td>
<td>Min: 0.25 Max: 0.45</td>
<td>Min: 0.35 Max: 0.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Most likely: 0.35</td>
<td>Most likely: 0.40</td>
<td></td>
</tr>
<tr>
<td>Volatility</td>
<td>30%</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td></td>
<td>Min: 15% Max: 40%</td>
<td>Min: 20% Max: 40%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Most likely: 30%</td>
<td>Most likely: 30%</td>
<td></td>
</tr>
</tbody>
</table>

**Table 30 - MRR and volatility values for electricity prices during the analysis**

The MRR was found to be relatively low. Due to the nature of the APX market, 12 month spot averages, shouldn’t be too far away from each other. Therefore, the volatility of the is assumed to remain constant, while the MRR grows, so that the price path will converge to its identified long term (trend)price. Due to the uncertainty, the distribution assumes a larger spread for the volatility.

**Syngas Price**

The price of syngas is quite hard to determine, since there is no trading platform established for in the Netherlands. The price for which syngas can be sold to the market is therefore hard to come by.

Multiple factors determine the value for the syngas which is to be sold on the market. These are the energy value, H₂-CO ratio & purity. The energy content would be the most important indicator for the price of syngas. This is influenced by the H₂:CO ratio. The type of energy carrier may be determent per process: fine chemicals require a more specific ratio than heat generation (two randomly picked examples). Pure H₂ is likely the most valuable stream in the syngas, but transport
and the market are very small. A more robust ratio (less $H_2$ and more $CO$) shows a larger market potential as a higher demand is expected. The amount of $H_2$ can be varied by adding more water to the Water-Gas-Shift (WGS) reactor. However, the maximum amount of $CO_2$ possible is also dependent on the type of fuel used. Biomass for example allows more $H_2$ production per unit input than coal. The purity grade is also important, whether further clean-up after sales is important for the client. This would incur additional cost and thus loss of value for the syngas to be sold.

In the benchmark and flexible plant (see annex 5A & 5B) a clean-up section for the raw syngas is placed behind the gasifier. Therefore, it is assumed that pure syngas is sold to the market. The $H_2$-$CO$ ratio is assumed as a constant and set to 0.85. The price for syngas is related to the input cost of the fuel used. Generally, the cheapest fuel is coal, and therefore used as the base price for the syngas.

A relevant point is that syngas can serve as an alternative to oil for production of fine chemicals or transportation fuels (see chapter annex 5A). Therefore, the price of oil can be seen as an indicator for the market value (and potential) of syngas, though this only might be partly the case. If the oil price rises, market players become (more) interested in alternatives which have become (relatively) cheaper and show less volatile prices. As syngas can be produced from a variety of sources, the cost of production can be seen as less volatile, as the cheapest source can be chosen to produce the syngas.

The price of syngas is therefore considered to consists of two parts: the cost of producing syngas multiplied by a profit percentage, and the market value for syngas as it can compete with other feedstock, such as oil, for further processing. As it is an uncertain market, profit margins are higher in the early phases. If the price difference between oil and syngas become ‘too large’, other companies will take the initiative to produce syngas. Competition will force prices to go down towards marginal levels.

The price of syngas is calculated according to the principle that the customer does not pay more than necessary for the alternative. The ‘base’ syngas cost is the variable cost (fuel), plus plant O&M cost and CRF-related cost. CRF stands for Capital cost Recovery Factor, and assumes the level of the capital cost that has to be retained on a yearly basis for maintaining the syngas plant operational at profitable level. During the first period, where syngas shows more volatile market characteristics (as it is operational in the first steps of implementation) the profit levels will be higher due to the risen demand for syngas, while there is no large scale supply. After a few years, a new market will be emerged, originating from this profit perspective, driving the market value of syngas back to marginal levels and will be more weakly correlated to the price of oil. So the baseline price for syngas is linked to the price of coal, added with a correlated distribution for the additional market value based on the price of oil. A proxy is used for this for in the model, taking a factor of 0.7 times the average price of the oil and gas. Thus, taking the maximum price as selling price for the project owner.

**Syngas demand**

The demand for synthesis gas in the PoR area depends on the price of competing fuels for the final products, such as natural gas and oil. The higher the price becomes for these fuels, the more interesting the use of synthesis gas becomes for the industry. However, invested capital in feed preparation and switching costs prevent instant switching between different fuels as these may show price fluctuations. A few assumptions are used to allow implementation in the model of the syngas plant. First, it is assumed that a higher price for oil and/or gas increases the chance that a buyer
appears, which is interested in buying syngas from the plant. In the model it is assumed that the syngas is sold ‘to the market’, regardless of the final use. The buyer(s) of the syngas will use the gas for their own purposes.

There is another possibility that users will hook on the syngas supply, which would be a retrofit of a facility or construction of a new facility, where the owner wishes to use syngas from this plant rather than using another feedstock or uses capital cost advantages by buying its syngas. However, this chance is considered very small, as any player would assess the cost of the (preferred) feedstock and most likely base its assumption on the expected price developments in the future and make the most cost efficient decision.

There has to be a certain gap between the syngas price and the price of ‘conventional’ fuels to create an incentive to switch for using syngas. The larger the price gap, the larger the incentive to use syngas over natural gas, oil or any other fuel previously used for the potential syngas buyer. The price gap needs to justify the incurred switching costs, allowing to earn back these investments. The expected price developments (both for syngas as the competing fuels) need to be taken into account.

Because of incurred switching costs (for the buyer, therefore not directly taken along in this analysis), it is assumed syngas demand will not fluctuate from day to day basis. Customers will receive a continuous supply of synthesis gas. The price of syngas is based upon a combination of capital & O&M costs, plus the variable cost of the fuel (price of coal + CO₂ price).

Thus, if the price difference per GJ syngas differs from the price for the use of oil or natural gas, it is assumed in the model that an incentive is placed to hook on the syngas supply possibility. The larger the difference between price, the higher the incentive considered. This does not reflect a realistic position of the actors in the PoR, as not only a price incentive is enough. But for sake of simplicity, this proxy is used. The larger a price difference, the higher the chance that demand increases as a probability distribution. Thus, with a larger incentive it is not certain that syngas demand will rise.

When demand for syngas rises, it is assumed that the consumer for syngas will remain ‘connected’ for the entire modeled life time of the plant (operational lifetime is set to 25 years). The rise in demand is modeled as a discrete event, uncorrelated to earlier events. If a buyer for syngas arises, it is assumed that this buyer is interested in UNIFORM(30%, 50%) of the production capacity. There is a smaller chance of a large customer requesting syngas. The rise in demand is then modeled as UNIFORM(60%,100%) of the production capacity. See the table below for an overview, where x represents the price difference.

<table>
<thead>
<tr>
<th>Syngas demand Price difference</th>
<th>Chance on small customer</th>
<th>Chance customer on large</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>x &lt; EUR 1 / GJ</td>
<td>0</td>
<td>0</td>
<td>Incentive considered too low</td>
</tr>
<tr>
<td>EUR 1/GJ &lt; x &lt; EUR 2/GJ</td>
<td>10% chance</td>
<td>1% chance</td>
<td>Discrete distribution</td>
</tr>
<tr>
<td>EUR 2/GJ &lt; x &lt; EUR 4/GJ</td>
<td>20% chance</td>
<td>2% chance</td>
<td>Discrete distribution</td>
</tr>
<tr>
<td>EUR 4/GJ &lt; x &lt; EUR 7/GJ</td>
<td>25% chance</td>
<td>3% chance</td>
<td>Discrete distribution</td>
</tr>
<tr>
<td>X &gt; EUR 7/GJ</td>
<td>30% chance</td>
<td>5% chance</td>
<td>Discrete distribution</td>
</tr>
</tbody>
</table>

Table 31 - Chances whether syngas demand will rise with different price categories
The demand is limited in the model that it will not exceed the 100% capacity. Going over the 100% will create the incentive for another syngas production facility or retrofit of the current plant, which are not taken along in this analysis.

**Correlations**

Energy sources are likely to be correlated with each other. Based on different literature sources, correlations between the different parameters are used. These correlations can be applicable to fuels and products of the syngas plant. The correlations used are given in the table below. Where possible, real correlations are used, which have been corrected for inflation related issues in the used historical datasets.

<table>
<thead>
<tr>
<th></th>
<th>Crude Oil</th>
<th>Natural Gas</th>
<th>Coal</th>
<th>Biomass</th>
<th>CO₂</th>
<th>Electricity</th>
<th>Syngas</th>
<th>See section of syngas price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
<td>-</td>
<td>0.86&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Ind.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>-</td>
<td>-</td>
<td>0.43&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Ind.</td>
<td></td>
<td>0.89&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Ind.</td>
<td>0.56&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>Ind.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.70&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Ind.</td>
<td></td>
</tr>
<tr>
<td>Syngas</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 32 - Identified correlations used in model estimations

Due to the limited availability of data regarding correlations, some correlations have been estimated. This mainly accounts for syngas. Other correlations have been based on literature (Roques, Newbery et al. 2008; Shafiee and Topal 2010). Shafiee & Topal base their expectations on world prices, while Roques, Newbery et al use the UK as a base for estimating correlations between different parameters. The fuel mix for generating electricity in the Netherlands is mainly composed from coal and natural gas. From that perspective the data applicable in the UK can assumed to be useable for the Netherlands. According to Eurostat (2009b), the prices per unit electricity does not differ too much. Therefore, it is assumed that these figures are usable.

It should be noted that, most likely, there is a ‘driving force’ behind all these correlations, presumably worldwide development of the economy. A growth in prosperity is often correlated with an increase in demand for energy. Though, in this analysis the price of crude oil is used as main indicator and the development of the worldwide economy is left out of scope.

The price and availability of biomass is uncertain and may vary over the years, as discussed earlier. The availability of biomass is unlikely to be correlated with other energy fuel sources. However, the demand for biomass is: biomass will be more attractive to use as feedstock when prices of other energy sources are higher than of biomass. Or when CO₂ policies imply that the market position of biomass is favored above fossil fuels. However, since this remains significantly unclear and subject to public policy, the relation is taken along in the analysis as uncorrelated.
CO₂ is highly correlated with the electricity prices, as found in Chappin, Dijkema et al (2009). However, no quantitative figure is given for this correlation. Assuming that the correlation is high, the value of 0.70 is assumed to be a reasonable value.

Some correlations are left blank, with the notification that there is no direct correlation assumed. For example the correlation between electricity and crude oil. A correlation does exist however, but more indirectly through natural gas. Price development of crude oil is highly correlated with the price development of natural gas, and the gas price development is highly correlated with price of electricity. In that sense, the developments are correlated.

The expected price development for syngas has partly been discussed in paragraph inputs in this annex. The profit range for syngas is in the early phases rather high, partly correlating with oil as syngas can become a valuable alternative. The lower price level is the cost of production using the cheapest source for the time being: coal. In later phases, it is expected that competition will rise as more incentives are generated that syngas is a profitable market, thereby declining to marginal profits, based on the cheapest fuel available, assumed to remain coal over the years. The initial correlation with coal is therefore assumed to be high.

As time passes, the validity of the used correlations diminishes. Correlations may change over time, due to external developments, such as demand development, technological improvements, availability of new fuels and so on. The correlations are based on historical data, and hold limited applicability for longer term predictions of possible price paths. To cope with this element, the correlations could be subjected to a distribution in a range rather than a specific correlation. However, a probability distribution for a correlation between probability distributions will not have such realistic effects. The correlations will not abruptly change, but can slowly change over time. For the proposed lifetime of the plant, the correlations are assumed to remain the same. The identified trends are better input for deviations over time.

The software package, @Risk, transformed the identified correlations into a consistent correlation matrix. As the correlations were depicted from different literature sources, however all with Pearson correlations, @Risk has been allowed to convert the correlations, presenting a renewed correlation matrix below.

<table>
<thead>
<tr>
<th></th>
<th>Crude Oil</th>
<th>Natural Gas</th>
<th>Coal</th>
<th>Biomass</th>
<th>CO₂</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
<td>0.62</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>-</td>
<td>0.31</td>
<td>0.64</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.40</td>
</tr>
<tr>
<td>Biomass</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Ind.</td>
</tr>
<tr>
<td>CO₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Table 33 - Renewed correlation matrix with consistent correlations

Trends
The ‘traditional’ MRP model assumes a long term equilibrium constant price. However, the development of energy prices do not converge to a constant price over time, but rather show a growing trend. Especially over a longer period of time for forecasting price developments, it is important to take along trends. Trends may change significantly over times, as changes in technology, policy and innovations are developed and implemented. But historical data provide the
best input for analysis. A trend would be the best way, combining with the MRP model to simulate price paths. A number of trends have been found in the literature, especially by Shafiee and Topal (2010), which also use MRP to model the price developments. These trends are taken along in their analyses as linear trends on the world energy market. These trends are recalculated from energy units given into gigajoules for use in the model.

The trends are given in the table below:

<table>
<thead>
<tr>
<th></th>
<th>Trend [yr⁻¹]</th>
<th>Trend [EUR/(GJ*yr)]</th>
<th>Assumptions made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
<td>1.06 USD/barrel</td>
<td>0.132</td>
<td>1 USD = 1/1.4 EUR; 1 barrel = 5,736 GJ (Tilburg, Vries et al. 2005)</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.11 USD/10³ft³</td>
<td>0.0757</td>
<td>1 USD = 1/1.4 EUR; 1000ft³ = 28,32 m³ or 1.083 GJ (Silverman 2009) 0.035179 GJ/m³ (Janssen and Warmoeskerken 1991), averaged</td>
</tr>
<tr>
<td>Coal</td>
<td>0.4 USD/short ton</td>
<td>0.0121</td>
<td>1 USD = 1/1.4 EUR; 1 short ton = 907.2 kg; 25,97 GJ /t coal (CBS 2009b), assumed same coal energy content in Europe as in US</td>
</tr>
</tbody>
</table>

Table 34 - Linear trend in prices for fuel feedstock, derived from (Shafiee and Topal 2010)

As can be seen, the price of coal marginally increases compared to oil and natural gas. This confirms the general expectation that coal will remain the cheapest fuel in the near future.

No similar trend has been found for electricity & syngas prices. Though it should be noted that electricity prices fluctuate throughout the years, and show an overall growing trend (see figures 60 and 61). Since a direct trend is missing, it is possible to use the correlation coefficients to determine some sort of linear trend for electricity, as it mostly depends on the development of gas and coal prices. Chappin, Dijkema et al (2009) showed that there is a correlation between the CO₂ and electricity prices. The trends are assessed on the average price used in the historical data, from there the percentage is calculated for the annual increase. These trends are therefore taken along to identify a trend in electricity. This is converted back to the increase in the identified long term equilibrium price for electricity, and calculate the trend. This growth rate (in EUR/(MWh*yr)) will be assumed as linear. The table below shows the used data for calculating the trend.

<table>
<thead>
<tr>
<th></th>
<th>Correlation</th>
<th>% change in 2010-2011 for fuel/commodity type</th>
<th>Weighted % change for electricity</th>
<th>Absolute trend for electricity [EUR/MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas &amp; Electricity</td>
<td>0.89</td>
<td>0.75%</td>
<td>0.41</td>
<td>0.17</td>
</tr>
<tr>
<td>Coal &amp; Electricity</td>
<td>0.56</td>
<td>0.63%</td>
<td>0.26</td>
<td>0.09</td>
</tr>
<tr>
<td>CO₂ &amp; Electricity</td>
<td>0.70</td>
<td>2.80% [expected averaged growth]</td>
<td>0.32</td>
<td>0.52</td>
</tr>
<tr>
<td>Total: 2.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity long run mean: 56.27 EUR/MWh</td>
<td></td>
<td></td>
<td></td>
<td>OR 0.790</td>
</tr>
</tbody>
</table>

Table 35 - Changes over average nominal historical prices
For the Electricity a price increase of 0.790 EUR/MWh on a yearly basis is assumed. This seems reasonable, as it is less than 2% annual increase, and is in line with the other price increases for coal, gas, oil and CO₂.

Correlations and trends merely hold for a certain time period. Over longer periods, trends are very hard to predict due to external developments. However, it remains the ‘best guess’ there is to predict future outcomes in reasonable scenario’s. The correlations & trends identified in this section are estimated to hold validity upon 2018 (Shafiee and Topal 2010). Changes in the market for worldwide fuel, CO₂ and Electricity prices are hard to identify and process in a model. Higher uncertainty bands over the trend developments are therefore the best approximation to work with. Each identified trend is assessed below, and fitted with an uncertainty distribution for future price developments.

The price of syngas is assumed to follow the cost of coal, as the cost are expected to develop on a marginal level on the long run.

The identified linear trends are expected to hold until 2020. The remaining 20 years are split up in two different periods in which the linear trend can change. Probability distributions are used to build in more uncertainty in trend developments. The growth trend could be modeled per year, but since MRP models are used, the prices divert from the equilibrium price, performing random walks. Therefore, the chosen periods with 2 distributions are assumed to sufficiently enhance the analysis.24

The table below provides an overview for the trends and distributions to model these. Each trend is discussed in more detail below.

<table>
<thead>
<tr>
<th>Trend</th>
<th>2010 - 2020</th>
<th>2021 – 2030</th>
<th>2031 - 2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
<td>0.132</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>[EUR/GJ]</td>
<td>Min: 0.10 Max: 0.25 Most likely: 0.15</td>
<td>Min: 0.10 Max: 0.35 Most likely: 0.20</td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.0757</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>[EUR/GJ]</td>
<td>Min: 0.05 Max: 0.15 Most likely: 0.08</td>
<td>Min: 0.08 Max: 0.25 Most likely: 0.12</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>0.0121</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>[EUR/GJ]</td>
<td>Min: 0.01 Max: 0.05 Most likely: 0.02</td>
<td>Min: 0.01 Max: 0.10 Most likely: 0.03</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1</td>
<td>UNIFORM</td>
<td>UNIFORM</td>
</tr>
<tr>
<td>[EUR/ton]</td>
<td>Min: 0.90, Max: 1.20</td>
<td>Min: 0.90, Max: 1.30</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>0.790</td>
<td>TRIANGULAR</td>
<td>TRIANGULAR</td>
</tr>
<tr>
<td>[EUR/MWh]</td>
<td>Min: 0.60 Max: 0.90 Most likely: 0.73</td>
<td>Min: 0.40 Max: 0.85 Most likely: 0.65</td>
<td></td>
</tr>
</tbody>
</table>

Table 36 - Assumed trend development distributions for the longer term price developments

Important to notice is that the trends identified, and which are also used in this case, are 'real' trends, as they are corrected for inflation (Shafiee and Topal 2010). So, for the trends of the oil, gas, coal and electricity, a correction of an annual 3% price increase due to inflation is applied. CO₂ is here not taken along, as it is assumed that the correction for inflation is already in the trend.

24 These ‘future’ trends are assumed and based upon the initial identified trends, subjected to a higher level of uncertainty. The sample for the period 2021-2030 is chosen randomly, but the 2031-2040 is correlated, to prevent extreme jumps in the trend values.
Crude oil
Considering the past developments over a longer period, it can be expected that tightness on the oil market will remain existent. The finite reserves and the continuous growing demand reflect the expectation that the annual trend will increase. However, when alternative technologies are developed, the trend may be very low, up to higher variables. The most likely value for the trend price is increasing over time, while the spread grows.

Natural gas
As natural gas is a relative clean fuel, the demand for this fuel is assumed to be a bit the same for oil. Though the demand may not be as high as for oil, it is the first ‘substitute’ for oil as a transportation fuel in order to lower emissions. The finity of gas reserves is roughly the same as for oil. Therefore, the trend price is assumed to increase over time. Lower gas prices are unlikely, but a low band has been adopted to account for developments into that area.

Coal
The demand for coal is expected to increase in the future, but the present know coal reserves are sufficient for multiple centuries of secure supply. The price development is therefore considered more stable. The relative stable price is assumed to hold. Though there will be a small increase in trend price, but only marginal. This is related to the growing demand for coal in the western world for providing sufficient electrical energy, while this type of fuel becomes and remains cheaper than natural gas.

CO₂
The proposed EU ETS from 2013 onwards will show different characteristics. One assumption that can be made reliably is that emitting CO₂ to the environment will not become cheaper. The cap will be lowered on an annual basis. With a lowering of the cap, it is assumed that the trend price increase is EUR 1 per ton per year. In case of success, the cost for emitting CO₂ to the environment will grow slower (as more allowances remain on the market), in case of scarcity for CO₂ emission allowances, the price is expected to increase more quickly. These effects are also partly corrected by lowering the cap on a yearly basis. It is assumed that such carbon policy is created and sustained in a political stable environment and sustained at least until the end of the lifetime of the plant. Lowest growth rate is lower than the first 1 euro per ton, there is a possibility that the annual price increase becomes 20% higher. An uniform distribution is assumed, because there is very much uncertainty around this topic. An uniform distribution would fit best in such situation.

Electricity
The expectations for electricity is that fuel diversification will disrupt its correlation and trend price increase based on CO₂, coal and gas. The annual price increase in electricity therefore declines. If other (renewable) sources or carbon capture & storage (CCS) are used, the price for electricity becomes less sensitive to these changes (Chappin, Dijkema et al. 2009). These are reflected in a slowly stabilizing price. There remains a possible scenario that the influence of CO₂ pricing does not reflect in a slight growth in the annual increase.