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Determining offshore wind and deep geothermal technology deployment potentials in the Netherlands for the period 2010-2020.

Towards a comprehensive model of deployment potentials for renewable energy technologies

- Master Thesis -

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PREFACE

This analysis is carried out as part of the master thesis course of the Science and Innovation Management programme at Utrecht University. A number of people have contributed to this thesis, directly or indirectly. First, I would like to thank Robert, Thomas, and Simona for all their provided feedback. Second, I would like to thank all interviewees for providing the empirical content. And third, I would like to thank many colleagues at Ecofys for providing content and ideas for improvements. In addition, I would like to thank Ecofys for also providing the opportunity to experience moments of the daily practices of a consultant.

Stefan Mackaaij

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SUMMARY

1. Introduction

Understanding the emergence of renewable energy technologies is recently put central in research since the need to influence innovation towards more sustainable directions is high on political agendas. Where many studies focus principally on cost developments for deployment potentials of renewable energy technologies, this research focuses primarily on supply constraints of renewable energy technologies in order to determine their physical deployment over time. This supply-based perspective provides insight in the prominent factors of market upscale processes and thereby reveals prospected deployment bottlenecks over time.

Two promising renewable energy technologies are chosen as case studies for this research: deep geothermal and offshore wind. Both technologies have huge potentials to contribute significantly within the required transition towards a sustainable energy system in the Netherlands. Deep geothermal energy is nevertheless almost neglected within the current policy framework in the Netherlands and there is only a projection for deep geothermal by the Dutch Energy Research Center of 11PJ in 2020. Offshore wind has received more attention and there is an explicit target for offshore wind of 6000MW in 2020 within the 'Clean and Efficient' program. The chosen cases hence also provide insights for policy.

The following main research questions have been set up:

What is the deployment potential of deep geothermal- and offshore wind technology taking into account supply constraints in the Netherlands in the period from 2010 till 2020? What kind of insights will there be for policy? And what kind of insights will there be for innovation system theory development?

2. Theoretical Framework

There exist different strands of literature that address renewable energy technology deployment issues. First, potential studies describe that geographical, technical, economic, and implementation constraints determine the deployment potential. Second, diffusion studies show that the process of a technology to go through the learning curve also affect the deployment potential. And third, innovation system studies show that this process can be accelerated by creating the right boundary conditions in which a technology can flourish. However, no particular study has specifically investigated the maximum potential deployment of renewable energy technologies taking into account supply constraints, yet.

The deployment potential is the maximum amount of energy that can be produced from the maximum installed capacity over time and is characterized by the potential market uptake of renewable energy technologies under predefined framing conditions. A well-functioning technological innovation system is assumed as a framing condition in this report. This means that the Dutch government and business communities have ideal incentives to deploy the respective renewable energy technology. Economic hampering factors therefore receive less emphasis.

A new framework has been set up in this research that is based on a conceptual model to determine the deployment potential of renewable energy technologies. Two variables affect the deployment potential: supply constraints and key deployment factors. Supply constraints are direct hampering factors and are based on the supply chain and spatial limitations. Key deployment factors are hampering factors which are based on the boundary conditions that have to be shaped in order to create such an environment. This process takes time and is therefore a mediating factor. These aspects are often nation-specific except for the technological maturity status which depends on global developments.

3. Research Design

The specific focus on the Netherlands provides a deeper analysis to understand the influencing factors from a supply-based perspective. The total supply chain of deep geothermal and offshore wind will however cross borders. An exploratory approach has been chosen since there are no existing theories that provide a format to determine the deployment potentials. The most suitable design to execute this research is therefore a case-study approach. The data is collected through an extensive desktop study in which a wide array of documents is used. The gathered data is also validated through interviews with experts in the deep geothermal and offshore wind sector in the Netherlands.

4. Deep Geothermal Energy

The Netherlands has good subsurface conditions for the utilization of deep geothermal energy. The technology for the direct use of deep geothermal energy is matured and is therefore not considered as a possible constraint. Only two deep geothermal projects have been realized until 2010 and therefore the Dutch deep geothermal market is still in its infancy. This research shows that the most important supply constraints are the availability of sufficient drilling equipment, the availability of sufficient human capital and spatial limitations in the subsurface. Although there are sufficient projects in the pipeline at this moment, more successful deep geothermal projects must be realized in order to reduce obstacles related to geological uncertainties. Drilling method improvements will increasingly de-clutch the negative influence of low gas prices on deep geothermal energy deployment. Consistent and long-term supportive policies consequently form the basis for an optimal deployment of deep geothermal energy in the Netherlands.

The analysis shows - supposing that the Dutch government and the deep geothermal industry take all required precautionary measures in 2011 - that approximately 400 deep geothermal doublets may be realized in 2020.

5. Offshore Wind

The Netherlands has good average wind conditions on its continental shelf of the North Sea for the utilization of offshore wind energy. The technology for offshore wind energy has not fully matured yet and the Dutch offshore wind market is also still in its infancy since only two offshore wind farms have been realized until 2010. This research shows that the most important supply constraints are the availability of sufficient installation equipment for turbines, foundations, and electrical equipment, the availability of sufficient manufacturing capacity for offshore wind turbines, foundations, and electrical cables, the availability of sufficient human capital, the availability of sufficient ports, grid inlet limitations, and spatial limitations on the North Sea. There are sufficient projects in the pipeline. However without additional financial support they will probably not be realized. Experiences are insufficiently shared among organizations within the offshore industry which needs to improve in order to create an experienced pool of human capital and a cost-effective supply chain. The projected offshore wind projects in other countries are a subsequent bottleneck for offshore wind deployment in the Netherlands. Consistent and additional long-term supportive policies are therefore required in order to create a financial attractive climate in order to support the deployment of offshore wind in the Netherlands.

The analysis shows - supposing that the Dutch government and the offshore wind industry take all required precautionary measures in 2011 - that approximately 1700 offshore wind turbines may be realized in 2020.

6. Analyses

The cross-comparison shows that production facility and installation equipment-, human capital-, and spatial limitation issues are similar within both renewable energy technologies. The results of the deployment potentials show that the projection by the Dutch Energy Research Centre of 11PJ in 2020 is quasi-ambitious and that the target of the Dutch government of 6000MW in 2020 is very ambitious. It shows furthermore that the mandatory EU renewable energy target of 14% of the final energy use in the Netherlands in 2020 can be attained much earlier if the proposed actions in this report are undertaken by the Dutch government as well as the deep geothermal and offshore wind industry. It shows subsequently that the Dutch renewable energy target of 20% of the primary energy use in the Netherlands in 2020 can merely be attained if the proposed actions in this report are undertaken by the Dutch government as well as the deep geothermal and offshore wind industry.

Innovation system analyses provide insights about inducement and blocking mechanisms and provide detailed recommendations for policy. These outcomes are however often predominantly based on on qualitative assessments. Deployment potential assessments provide insights in possible upscale bottlenecks of the supply market and could therefore strengthen the qualitative outcomes of innovation system analyses with quantitative arguments in order to improve policy recommendations with explicit requirements bases on numbers and timeframes.

7. Conclusion and Discussion

The deployment potential for deep geothermal energy is a maximum of approximately 400 realized deep geothermal doublets in 2020 and the deployment potential for offshore wind energy is a maximum of approximately 1700 realized offshore wind turbines in 2020. Both renewable energy targets of the EU and NL may be attained when all proposed actions will be undertaken by the Dutch government, the deep geothermal industry, and the offshore wind industry in 2011. Deployment potential assessments provide insights in possible market upscale bottlenecks and may strengthen the policy recommendation outcomes of innovation system analyses with quantitative arguments. The findings of this research need additional and more extensive empirical research in order to test the further usefulness of the introduced deployment potential framework.

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1. INTRODUCTION

1.1 Background

1.1.1 Renewable Energy Deployment

Economies strongly depend on fossil fuels in order to meet societal needs for living standards and to sustain economic growth. But the use of fossil fuels - such as oil, natural gas, and coal - has several drawbacks among which energy security and environmental degradation issues. Renewable energy technologies can, for a large part, solve these issues and are therefore an important spearhead within energy policies. However, the actual diffusion of renewable energy technologies proceeds slowly (IEA 2009 p.74; Jacobsson & Johnson 2000 p.626). The main reason for this is that the current energy system is typically aligned for fossil fuels, as expressed by 'carbon lock-in' (Unruh 2000 p.817). To illustrate, the energy system have benefited from long periods of experience to set up optimal institutional arrangements and to lower the costs of fossil-based technologies. So the implementation process of renewable energy technologies in the current fossil-based energy system is tough, especially since these technologies often have lower technical performances in their early phases of development and are more expensive (Geels 2002 p.1261). Therefore, the diffusion of renewable energy technologies strongly depends on government policies, mainly because the external costs of environmental degradation are not taken into account, i.e. they cannot turn their environmental benefits into an economic advantage (Tsoutsos & Stamboulis 2005 p.755).

1.1.2 The Dutch Situation

The Dutch government is aware of the need to cease the dependence on fossil fuels and has set ambitious targets in the 'Clean and Efficient' program to speed-up the transformation towards a sustainable energy system (SP&E 2007 pp. 8-12). A sustainable energy system is specified as a stable and reliable system that only supplies energy from renewable energy technologies (Energy Transition Board 2008 pp.5-10). But there is still a long way to go before the Dutch energy system will be completely sustainable. The total share of renewable energy in the Netherlands was only 3.4% in 2008 due to a growth of a half percent in the former year, see figure 1 (CBS 2009 p.6). So the current way of acting needs to be overturned drastically in order to attain the target of 20% renewable energy in 2020, which is one of the main goals from the 'Clean and Efficient' program (SP&E 2007 p.8).

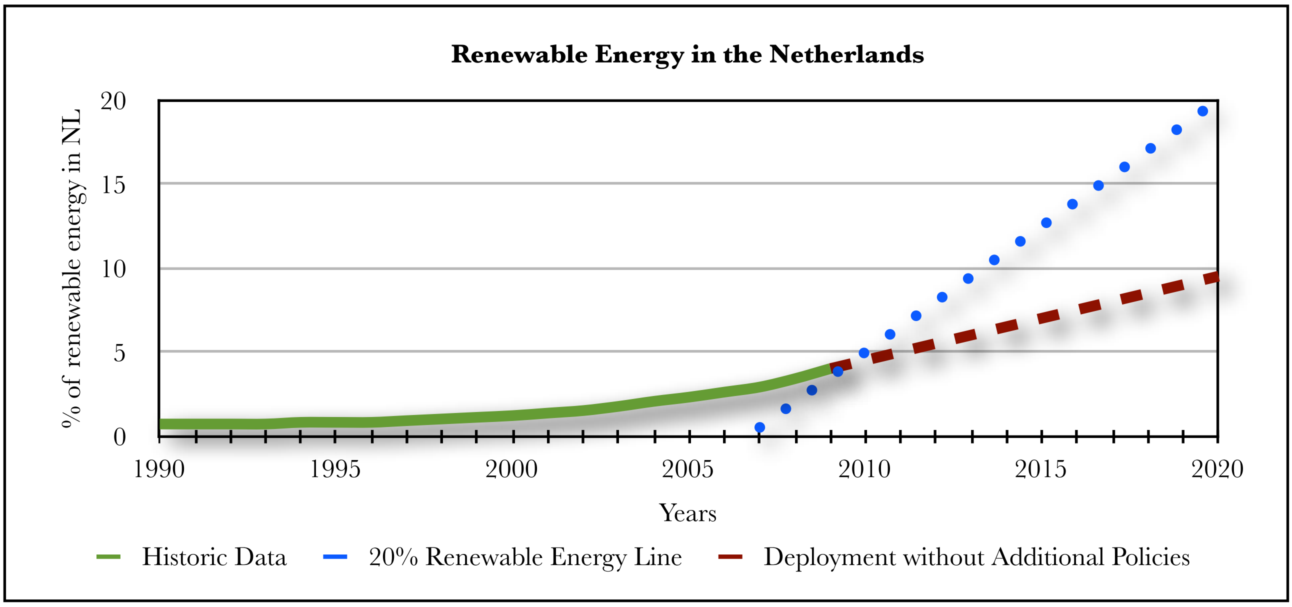

Figure 1: Percentage of Renewable Energy in the Netherlands based on CBS data.

1.2 Problem Description

1.2.1 Physical Deployment of Renewable Energy Technologies

Therefore, understanding the emergence of renewable energy technologies is recently put central in research since the need to influence innovation towards more sustainable directions is high on many political agendas (Hekkert & Negro 2009 p.584). However, less specific emphasis is put on how fast renewable energy technologies can be physically deployed. Where many studies often principally focus on cost developments for the potential deployment of renewable energy technologies over time (e.g. Hoogwijk *et al.* 2004 pp.905-909; de Vries *et al.* 2007 pp.2598-2606; van Vuren *et al.* 2009 pp.5134-5135), this research primarily focuses on supply constraints of renewable energy technologies in order to determine their physical deployment over time. This supply-based perspective provides insight in the prominent factors of market upscale processes and reveals the anticipated bottlenecks over time. Consequently, the outcomes can be used to remedy identified bottlenecks in advance.

Therefore, initial recognition of supply-based bottlenecks enhances the potential deployment of renewable energy technologies through the opportunity to establish effective policy measures in advance. Even more since technological change often elapses in a S-curve, which means that new technologies regularly nuisance delays in their early phases of implementation (Schilling & Esmundo 2009 p.1769). Time is therefore a basic dominant factor that influences the potential deployment of renewable energy technologies, because it takes time to enlarge the current supply market. Figure 2 clarifies this statement since in this simplified example almost half of the potential energy is lost due to a two-year delay. To illustrate, it takes time to build the industrial capacity, e.g. production facilities and installation equipment, or to create human capital, e.g. qualified personnel. In addition, permit application procedures are habitually also time-consuming, especially for large renewable energy technologies.

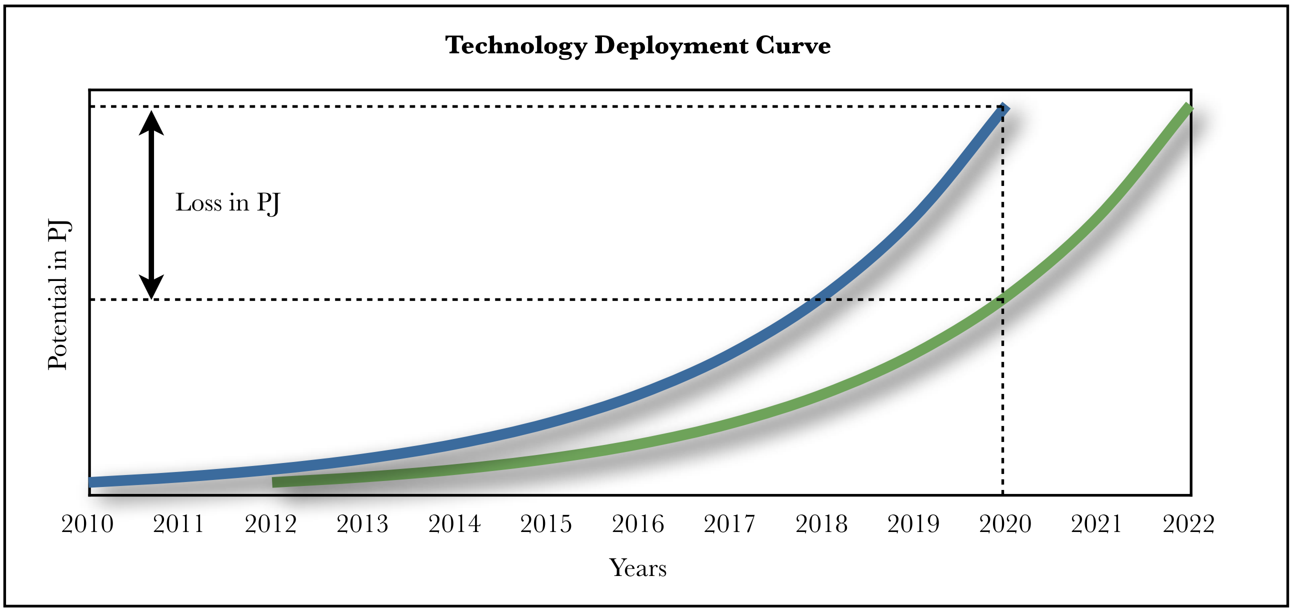

Figure 2: Identical Deployment Curves with Starting Points on 2010 and 2012.

The type of potential that fits best in this approach is the deployment potential since it describes the maximum upscale process of renewable energy technologies (Krewitt *et al.* 2008 p.3). In this report, the deployment potential is expressed as: the maximum amount of energy that can be produced from the maximum installed capacity, characterized by the potential market uptake of renewable energy technologies under pre-defined framing conditions, within a certain timeframe. Here, a well-functioning innovation system is assumed in which the respective technology supply market can flourish. Moreover, it puts lesser emphasis on economic hampering factors and is thus a 'pull out all the stops' approach, i.e. an approach where both the Dutch government and business communities have ideal incentives to deploy the respective renewable energy technology. In addition, a timeframe of one decade has been chosen, i.e. from 2010-2020, to link to the aim of the Dutch government to achieve a share of 20% of renewable energy in 2020 in its 'Clean and Efficient' program.

1.2.2 Case Selection

Two promising renewable energy technologies are chosen as case studies for this research: deep geothermal and offshore wind. Both technologies have huge potentials to contribute significantly within the required transition towards a sustainable energy system (Ajayi 2009 p.750; Balat 2006 p.55; Markard & Petersen 2009 p.3545; Tavner 2008 p.4399). However, deep geothermal energy is almost neglected within the 'Clean and Efficient' program in contrast with biomass, onshore-, and offshore wind, which are seen as major contributors in order to attain the 20% renewable energy target in the Netherlands (SP&E 2007 p.29). This is exposed in the fact that there is a target of 6000MW for offshore wind in 2020; where no explicit target has been set up for deep geothermal, primarily due to the excellent gas infrastructure and subsequent price advantages in the Netherlands. Hence, the chosen cases also provide insights for policy.

1.2.3 Research Questions

As based on the problem description, the main research questions are:

What is the deployment potential of deep geothermal- and offshore wind technology taking into account supply constraints in the Netherlands in the period from 2010 till 2020? What kind of insights will there be for policy? And what kind of insights will there be for innovation system theory development?

The outline of this research report is as follows. Section 2 provides an elaborated overview of current literature and introduces a framework to analyze deployment potentials. Section 3 explains the methodology for data gathering and analysis. Section 4 and 5 present the results for both renewable energy technologies. Section 6 presents the results of the cross-comparison of both cases and the insights for policy and innovation system theory development. And section 7 concludes this paper with answers to the research questions and recommendations for further research.

2. THEORETICAL FRAMEWORK

2.1 Theory

This section gives an overview of the scientific literature around renewable energy technology deployment. More specifically, first, it elaborates the scientific literature concerning renewable energy potentials. Second, it addresses the necessity for a renewable energy technology to go through the learning curve in order to realize the transition process towards a renewable energy system. Third, the innovation system approach is elaborated which, with the right boundary conditions, can accelerate the processes to go trough the learning curve.

2.1.1 Renewable Energy Potential Definitions

Assessments for renewable energy technology potentials have emerged because of the serious challenges the world is facing in the sphere of future energy production and consumption[1]. Renewable energy technology potential studies provide insights in the opportunities to realize the transition towards a sustainable energy system by providing answers on questions like: what is the potential contribution of solar boilers in 2020 or which role can electric vehicles play in reducing greenhouse gas emissions in 2030? Nevertheless, it is tough to give precise answers since they are often based on assumptions of average values and trends (de Vries *et al.* 2007 p.2591). Therefore, renewable energy potential studies habitually adopt a scenario approach to make the assumptions transparent (Hoogwijk *et al.* 2009 p.27). In the specific case of renewable energy technologies, the potential availability of wind, solar, or biomass can vary between locations and over time but has a theoretical infinite supply (de Vries 2007 p.2590). This means that the potential of renewable energy technologies hardly varies by the resource availability but rather by other constraints such as technological developments, land-use demands or labor costs variation (Hoogwijk 2004 p.16). As a result, different types of potential can be defined which, finally, determine the total potential of a renewable energy technology (Smeets *et al.* 2007 p.62).

An often-used method to determine the potential of renewable energy technologies is the approach developed at Utrecht University by van Wijk & Coelingh (1993), which is for instance applied by Hoogwijk *et al.* (2005 p.227), de Vries *et al.* (2007 p.2591), and Smeets *et al.* (2007 p.62). In box 1, the total potential of a renewable energy technology is categorized in 5 different types of potential (Hoogwijk 2004 pp.16-17).

Box 1: Different types of potential (Hoogwijk 2004 pp.16-17).

- The **theoretical** potential is the theoretical limit of the primary resource. For solar-driven sources this is the solar energy or solar energy converted to wind or biomass.
- The **geographical** potential is the theoretical potential reduced by the energy generated at areas that are considered available and suitable for this production
- The **technical** potential is the geographical potential reduced by the losses of the conversion of the primary energy to secondary energy sources.
- The **economic** potential is the total amount of the technical potential derived at cost levels that are competitive with alternative energy applications.
- The **implementation** potential is the total amount of the technical potential that is implemented in the energy system. Subsidies and other policy incentives can give an extra push to the implementation potential, but social barriers like noxious smell can reduce the implementation potential. The implementation potential can be both higher and lower then the economic potential, but can never exceed the technical potential.

[1] To illustrate, first, fossil fuels are a finite source and its conventional way of production will seize over time that, eventually, will raise energy prices and create international tensions (Bentley 2002 p.189). Second, the supply of energy from fossil fuels mainly depends on a small group of politically unstable countries, which is not desirable since import costs of energy are an important factor for the competitive position of national economies (Correljé & van der Linde 2006 p.532, 540). Third, the extensive use of fossil fuels contributes heavily to the degradation of the environment resulting in local air pollution and climate change (IPCC 2007 p.39). And fourth, the global demand for fossil fuels is even expected to grow due to emerging economies as India and China (IEA 2007 p.2).

Hence, the total potential of a renewable energy technology depends on geographical, technical, economic and implementation constraints. Regrettably, the exact definitions of potential types vary in literature, e.g. Strangeland (2007 p.2), Krewitt *et al.* (2008 pp.2-3), Hoogwijk & Graus (2008 pp.6-7), or Resch *et al.* (2008 pp.4049-4050). This makes it hard to define them unambiguously across different types of models and studies[2]. However, most approaches are often related and fit in one or more categorized potentials of the Utrecht University approach (Hoogwijk 2004 p.17).

However, this report will focus specifically on the potential deployment of renewable energy technologies. But before this potential can be determined, an important, but complex, aspect needs to be taken into account: the process of a renewable energy technology to go through the learning curve. This process is considered important since 'bad technology' diffusion can limit the potential deployment of renewable energy technologies on the long run[3] (Sagar & van der Zwaan 2006 p.2602).

2.1.2 Maturity of Technology

The maturity process of a technology is complicated and often characterized by various stages from invention to wide spread implementation (Grübler *et al.* 1999 p.249). Different learning mechanisms play a role in each stage of the technology life cycle (Junginger 2005 pp.14-15; Sagar & van der Zwaan 2006 p.2602). The learning, or experience curve, is often used to describe the maturity process of a renewable energy technology by showing how cost reductions depend on the diffusion and adoption of new technologies and vice versa (Neij 1997 pp.1099-1100). A very important aspect of technology development is that it is a collaborative process, for instance between universities, suppliers, and consumers (Carlsson *et al.* 2002 p.234). The development of a new technology can be seen as a process that consists out of an 'era of ferment' and an 'era of incremental change' (Anderson & Tushman 1990 p.606). An 'era of ferment' is a period in which a new technology induces turbulence and uncertainty because there is little agreement for technology standards since firms are still experimenting with different designs of the technology (Henderson & Clark 1990 p.9). But eventually, a dominant design will arise which signals the 'era of incremental change'. In this era, the focus of firm's lies on efficiency and market penetration by lowering production costs through design simplification or production process improvements (Anderson & Tushman 1990 pp 617-618). Technological change is, therefore, cyclical and elapses in a S-curve: "first there is an initial period of turbulence, followed by rapid improvement, then diminishing returns, and ultimately replacement by a new technology discontinuity" (Schilling & Esmundo 2009 p.1769). This technological cycle is depicted in the left image of figure 3.

Accordingly, the maturity process of renewable energy technologies does not only include technology developments but also requires changes in the society as a whole such as firms, institutions and consumers (Kemp *et al.* 2007 p.78). This is called a transition and can be described as "a process of the co-evolution of markets, networks, institutions, technologies, policies, individual behavior, and autonomous trends from one relatively stable system to another" (van der Brugge *et al.* 2005 p.136). The transition process will reinforce itself over time because of multiple causality and co-evolution of independent developments (Rotmans *et al.* 2001 p.16). This means that several developments first have to occur before other developments or innovations can emerge. An example is the all-steel body technology that first had to

[2] For example, the IPCC's Fourth Assessment Report (AR4) uses the term 'technical potential' to determine the total amount of avoided greenhouse gas emissions as a result of implementation of reduction measures. But the 'technical potential' is described differently in the Utrecht University approach where it is only limited by practical and physical limits (van Vuren *et al.* 2009 p.5126).

[3] To illustrate, it is possible to fully deploy a technology but if its current performance cannot yet meet market demand it will only lead to bad experiences by customers. These bad experiences can decrease the change for further technology deployment of later generations on the long-run, as was observed in the competition between the first- and second-generation of biofuels in the Netherlands (Suurs & Hekkert 2009 p.678). Another example was the stagnation of the wind turbine market in California due to the diffusion of an 'incompetent technology', which was based on a short term wind turbine deployment policy (Alkemade *et al.* 2007 p.164). And the decreasing biomass gasification industry in the Netherlands is a last example, whereby the high expectations about the technology could not be met with the actual performance of the deployed installations (Negro *et al.* 2008 p.74). Hence, a maximum technology deployment on the short-run does have effects on the long run, even if later generations are far more improved.

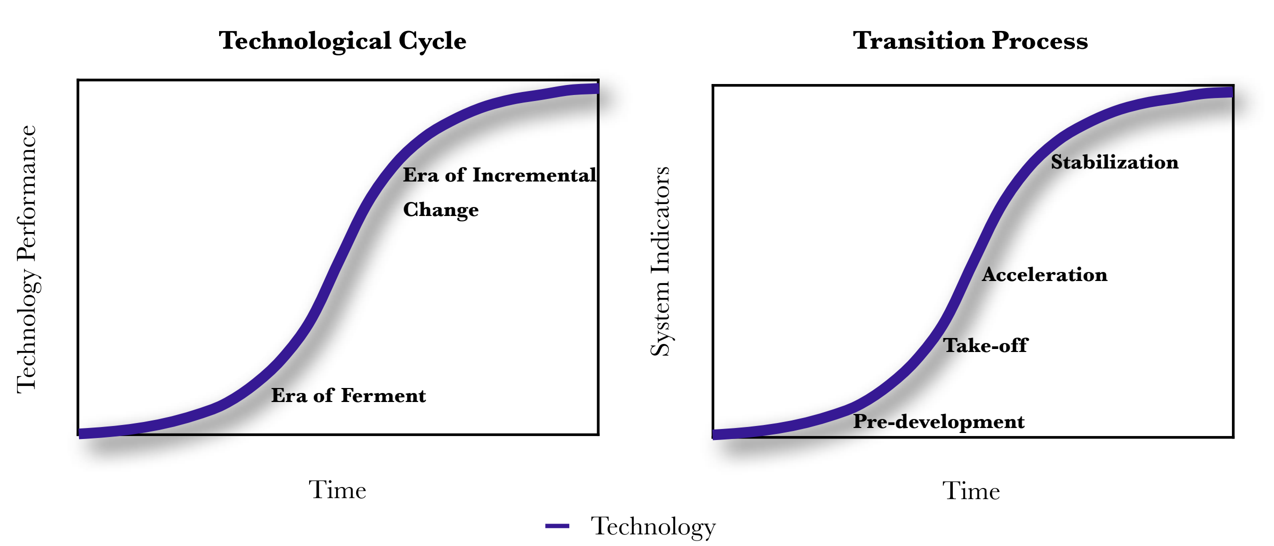

Figure 3: S-shaped Curves for Technology Cycles and Transition Processes

be invented besides the combustion engine and the moving assembly line before the revolution could prosecute to transform the car industry into a mass-production industry, i.e. to complete the transition process (Nieuwenhuis & Wells 2007 pp.207-208). Therefore, the transition process also elapses according a S-shaped curve (Rotmans *et al.* 2001 p.17), which is depicted in the right image of figure 3. Subsequently, four different transition phases can be distinguished within the entire transition process; these are summarized in box 2.

Box 2: The four phases during a transition process (van der Brugge *et al.* p.166).

- A **pre-development** phase of dynamic equilibrium where the status quo does not visibly change but changes take place under the surface.
- A **take-off** phase in which thresholds are reached and the state of the system begins to shift.
- An **acceleration** phase where visible structural changes take place rapidly through an accumulation of socio-cultural, economic, ecological, and institutional changes that reinforce each other.
- A **stabilization** phase where the speed of social change decreases and a new dynamic equilibrium is reached.

It is important for a renewable energy technology to go through the learning curve as fast as possible in order to speed-up the transition process[4]. Innovation plays a very important role in this process. During the last decade, innovation scholars have approached the analysis of (sustainable) transition processes from two different perspectives[5], which both

[4] The process that is of vital importance for the further development of renewable energy technologies after their implementation is labeled as 'learning by doing' (Suurs & Hekkert 2009 p.669). This phase arises from the moment a new technology is first practically used and lasts all through to until a technology matures. It involves many different mechanisms that all contribute to better performances and cost reductions of the technology (Sagar & van der Zwaan 2006 p.2602). Garud and Karnøe (2003 p.294-296) showed that 'learning by doing' was very important for the successful emergence of wind turbines in Denmark by taking small steps for a steady upscale of innovations, whereas the unsuccessful emergence of wind turbines in the United States could be explained by their short-term focus and linear innovation thinking. They use the notion of 'path creation', which describes innovation as a combination of strategies on the micro-level that mutual co-shapes the system context on the macro-level, i.e. actors shape technological paths (Garud & Karnøe 2003 pp.277-278). So as derived from the Danish wind turbine case, the best preferable strategy for maximum renewable energy technology deployment on the long run is to create a path in which knowledge must transfer between all actors involved accompanied by a slowly upscale of technology (Kamp *et al.* 2004 pp.1633-1635). Thus, learning by doing, for instance about technical specifications, user preferences or public policies, is very important for further development and technology upscale (Geels 2004 p.912).

[5] The first strand is the literature on Quasi-Evolutionary Theory (QET), which elaborated the concepts of landscape, socio-technical regimes, and niches that form the basis of a multi-level framework to analyze regime transformations (Geels 2002 pp.1253-1263; Geels 2004 pp.910-915; Kemp *et al.* 1998 pp.185-191; van der Brugge *et al.* 2005 pp.165-167). And the second strand is the literature on innovation systems, which is derived from the idea that a technological innovation lies at the core of a transition process to analyze a technological field by referring to systemic features (Carlsson *et al.* 2002 pp.233-235; Edquist 2005 pp.184-187; Jacobsson & Bergek 2004 p.817).

are based on concepts of the evolutionary economics (Markard & Truffer 2008 p.597). Both strands acknowledge that sustainable innovation needs to be understood as a build up process but the innovation systems approach involves a richer and more complete perspective on dynamics since the quasi-evolutionary theory approach misses insights into key processes that influence the successful breakthrough of a niche into the regime (Negro 2007 p.24; Suurs 2009 p.25). A well functioning innovation system can speed-up the process to go through the learning curve in order to realize the transition towards a sustainable energy system much faster; thus enhances the potential deployment of renewable energy technologies.

2.1.3 Innovation Systems

Background

One of the first developed models to understand science and technology and its relation with the economy is the linear model of innovation, which postulated that innovation starts with basic research, then adds applied research and development, and ends with production and diffusion (Godin 2006 p.639). However, this model has been obsolete because it lacks complicated feedback mechanisms and mutual interactions, involving science, technology, learning, production, policy, and demand (Edquist 1997 p.21; Lundvall *et al*. 2002 p.218). Therefore, the innovation system approach developed with its central idea that determinants of technological change are not only to be found in individual firms or research institutes, but also in a broader societal structure in which multiple components are embedded (Carlsson & Stankiewicz 1991 p.113; Jacobsson & Bergek 2004 p.817).

Since the 1980s, different subsystems developed where Freeman (1987) introduced the national innovation systems approach followed by Lundvall (1992) and Nelson (1993). Hereafter, the technological (Carlsson & Stankiewicz 1991; Carlsson 1997), regional (Cooke 1996), and sectoral (Breschi & Malerba 1997) innovation subsystems were introduced. The technological innovation system approach is the most suitable approach because it is created to discuss (trans-) national systems of organizations and institutions for one specific technology and provides a more in depth understanding of industrial areas than the other approaches (Carlsson *et al.* 2002 pp.242-243; Hekkert *et al.* 2007 pp. 415-416).

Technological Innovation System

A technological innovation system can be defined as "a set of organizations and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion, and utilization of varieties of a new technology or product" (Markard & Truffer 2008 p.600). Within a technological innovation system, distinction is made between so-called 'players' and 'rules of the game' (Edquist 2005 p.182). The players are the organizations (e.g. start-ups, large companies, universities, research institutes, government ministries etc.) that act and interact with each other. And the rules of the game are the institutions (e.g. laws, rules, standards, routines etc.) that shape the interactions between different organizations. All together, the technological innovation system forms a 'seamless web' (Callon 1987 p.84) but is divided in five system components for analytical purposes, in which different organizations and institutions are presented in every component (Suurs 2009 pp.48-49). As a result, the performance of a technological innovation system can than be determined by, first, the (sufficient) fulfillment of components and, second, the relations between components (Alkemade *et al.* 2007 p.140). A description of the five system components can be found in box 3, and the interactions are shown in figure 4.

But although structural technological innovation system analyses provide insights in systemic features, it also has two substantial shortcomings for an understanding of emerging innovations. First, the approach is quasi-static: it cannot explain the dynamics or emergence of innovation systems (Hekkert *et al.* 2007 p.414). And second, less emphasis is put

Box 3: Description of system components Suurs (2009 pp.48-49).

- The **supply** side covers all structures involved in the production and supply of technological artifacts and technological knowledge. This typically includes industries but also research institutes.
- The **demand** side relates to the use of technology. In terms of actors this includes end consumers but also firms and governments.
- The **supportive infrastructure** comprises all actors, institutions and technologies that support the other subsystems by generating, assessing, and transferring knowledge such as universities and other organizations within the educational system.
- The **government/governance domain** subsystem involves structural factors related to the policy domain. In terms of actors this involves ministries and other governmental organizations, but also provinces and municipalities.
- Finally, the **intermediary infrastructure** involves structural factors that support the relations and interactions between all subsystems. In terms of actors, an example would be a knowledge broker or a standardization institute.

on the entrepreneurial activities since the exploratory power lies mainly at part of the institutions, even though the rationale behind TIS are considered as both an individual and collective act (Bergek 2002 p.26). These shortcomings are addressed by focusing on key activities that take place within technological innovation systems in addition to the structural approach (Bergek *et al.* 2008 p.414).

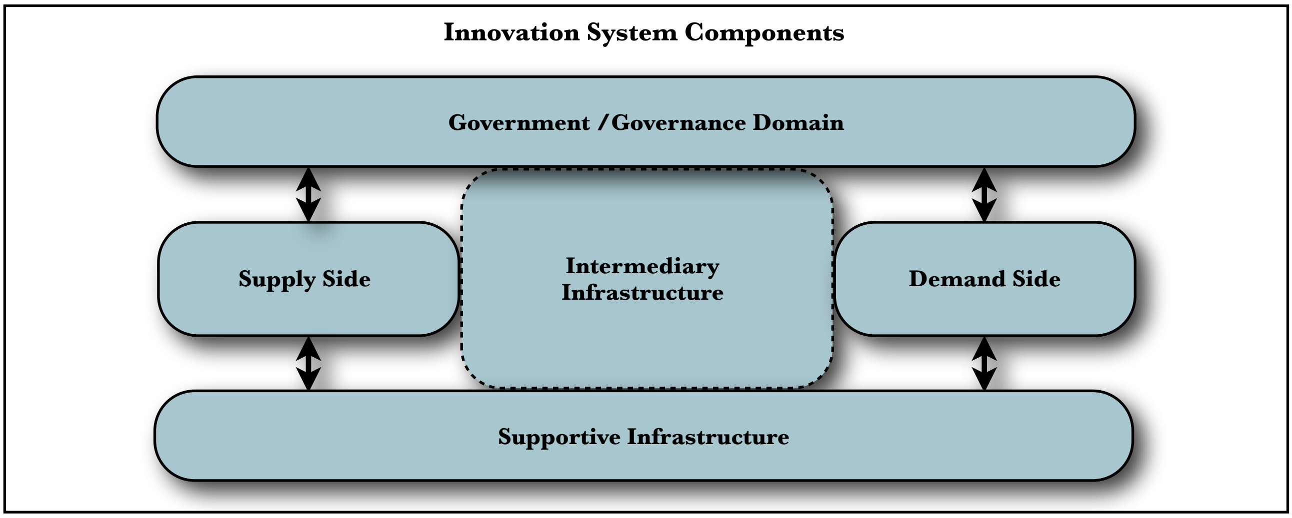

Figure 4: Five Components of an (Technological) Innovation System

Dynamics of Innovation Systems

The main function of a technological innovation system is to induce innovation processes and all activities that contribute to the main function are considered as system functions (Bergek 2002 p.28) or key activities (Edquist 2005 p. 190). Several lists of system functions or key activities exist in literature[6]. However, there is no consensus yet which specific list of system functions performs best in describing the dynamics of a technological innovation system (Suurs 2009 pp.51-53). This research continues with the work of Hekkert *et al.* (2007 pp.421-425) since this list of system functions has been empirically validated (Hekkert & Negro 2009 pp.592-593). An overview and brief description of these system functions can be found in box 4.

[6] See Bergek *et al.* (2008 pp.424-425) for an overview.

Moreover, these systemic functions are not independent processes but reinforce each other, and their interactions are important for the build-up process of technological innovation systems (Negro 2007 pp.33-35). The fulfillment of systemic functions could result in virtuous cycles constituted by positive feedback loops, such as a successful research project affecting other key activities, or in vicious cycles constituted by conflicting developments or a standstill, i.e. negative feedback loops (Jacobsson & Bergek 2004 p.823). An example of a virtuous cycle is a successful research project that contributes to [F2] knowledge development, which may result in high expectations among policy makers, which may contribute to [F4] guidance of the search that can trigger the start-up of a new subsidy program [F6] resources mobilization, which induces even more research activities [F2] knowledge development et cetera (Suurs 2009 p.58).

Box 4: Brief description of the seven system functions, derived from Hekkert *et al.* (2007 pp.421-425), Negro (2007; pp31-33), and Suurs (2009 pp.53-58).

[F1] Entrepreneurial activities.

Experiments of entrepreneurs are essential because their role is to turn the potential of new knowledge, networks, and markets into concrete actions, i.e. they generate, and take advantage of, new business opportunities (Carlsson & Stankiewicz 1991 pp.105-107).

[F2] Knowledge development.

This development of knowledge lies at the heart of every innovation process since the most fundamental resource is the modern economy is knowledge and the most important process is learning (Lundvall 1992 p.1).

[F3] Knowledge diffusion.

The diffusion of knowledge is essential in heterogeneous networks since the process of research and development meets government, competitors, and markets (Carlsson & Stankiewicz 1991 pp.110-111).

[F4] Guidance of the search.

Guidance in the search process shapes the needs, requirements, and expectations of actors with respect to the emerging technology that is often trapped in a technological paradigm (Dosi 1982 pp.147-148).

[F5] Market formation.

The formation of new markets through protection in niche markets is important since new technologies are often badly tuned to the current system, hereby a technology can go through the learning curve (Neij 2004 p.4).

[F6] Resources mobilization.

The mobilization of resources mobilization is necessary since they are the basic input to produce knowledge and prototypes (Jacobsson & Bergek 2004 p.820).

[F7] Advocacy coalitions support.

The support of advocacy coalitions is seen as a catalyst for a new technology to become part of the incumbent regime or even overthrow it by creating legitimacy for a new technological trajectory (Sabatier 1988 pp.157-159).

Motors of Change

Most recently, Suurs (2009) contributed to the different processes of cumulative causation by identifying four different motors of sustainable innovation based on case studies, namely, the science and technology push-, the entrepreneurial-, the system building-, and the market motor. These motors can be placed in sequence where the successful dynamics of one motor lead to the establishment of the next motor (Suurs 2009 p.230).

Box 5: Description of motors of sustainable innovation (Suurs 2009 pp.210-226).

In the beginning, a **science and technology push motor** appears where [F2-F4, F6] are the most important key activities. Especially positive expectations and research outcomes will lead to start-up of R&D projects and the allocation of financial resources, which result in knowledge creation and diffusion in conferences or workshops.

Consequently, an **entrepreneurial motor** appears where [F1-F4, F6, F7] are the most important key activities. Particularly, more organizations such as firms and local governments are entering the TIS, resulting in initial innovative projects that are used to lobby for resources such as subsidies. This motor is strengthened with the appearance of niche markets.

Next, a **system building motor** appears where [F4, F5, F7] are the most important key activities. In this stage the connections of organizations in networks are established. And they jointly lobby for policies to mobilize resources and regulations beneficial to the emerging technological field. The main aim of this lobby is to enforce the creation of a mass market.

Eventually a **market motor** appears where [F1-F6] are the most important key activities. In the last phase, all systemic functions are strongly fulfilled except for [F7], since it is no longer necessary to overthrow the current regime. Moreover, a new institutional structure is set up in this stage that directly facilitates the emerging technology by opening up possibilities for new entrants to adopt the technology and thereby develop market strategies that increase the demand even more until it is saturated.

The contribution of the work of Suurs (2009) is that each motor needs its own specific support with policies and strategies to overcome their barriers and stimulate its drivers; it is therefore important to recognize in which phase a respective emerging renewable technology stands.

2.2 Literature Gap

The theory section has shown that a lot of factors influence the deployment of renewable energy technologies. First, by describing that the total potential depends on geographic, technical, economic and implementation constraints. Second, by showing that a technology has to go through the learning curve to trigger processes of co-evolution, which form the basis of a transition process towards a sustainable energy system. And third, that the process to go through the learning curve can be accelerated by creating the right boundary conditions in which a technology can flourish. Renewable energy technology deployment is addressed in these strands of literature but no particular study has specifically investigated the maximum potential deployment of renewable energy technologies, mainly based on supply constraints, yet.

2.2.1 Literature Gap on Deployment Potentials

At present, different definitions of renewable energy potentials exist in literature, which are often not tuned to each other[7]. Subsequently, different types of potentials are used to determine final renewable energy potentials such as the realizable potential (Resch *et al.* 2008 pp.4049-4050; Strangeland 2007 p.2), market potential (Hoogwijk & Graus 2008 p.7), demand potential (Krewitt *et al.* 2008 pp.2-3), implementation potential (Hoogwijk 2004 p.17), or economic potential (Smeets *et al.* 2007 p.62). This demonstrates that the notion of renewable energy potentials is an unsettled concept. Moreover, the majority of these examples preferred reductive procedures, i.e. to go downward from the theoretical potential towards market or economic potentials of renewable energy technology supply, whereas the specific factors in order to move up from present levels are of equal importance.

The deployment potential however provides insight in the influential factors for market upscale processes from a supply-based perspective. The deployment potential is the maximum amount of energy that can be produced from the

[7] To illustrate, Strangeland (2007 p.2), Krewitt *et al.* (2008 pp.2-3), Hoogwijk & Graus (2008 pp.6-7), and Resch *et al.* (2008 pp.4049-4050) all determined the theoretical, and technical potential but used non-uniformed definitions.

maximum installed capacity, characterized by the potential market uptake of renewable energy technologies under predefined framing conditions, within a certain timeframe. In this report, a well-functioning technological innovation system is assumed in which the respective technology can flourish optimally. This means that the Dutch government and business communities have ideal incentives to deploy the respective renewable energy technology; economic hampering factors therefore receive less emphasis. Moreover, it presupposes that hampering policies are reversed in order to arrange an optimal institutional setting in which the respective technology supply market can flourish. The difference in approach is depicted in figure 5.

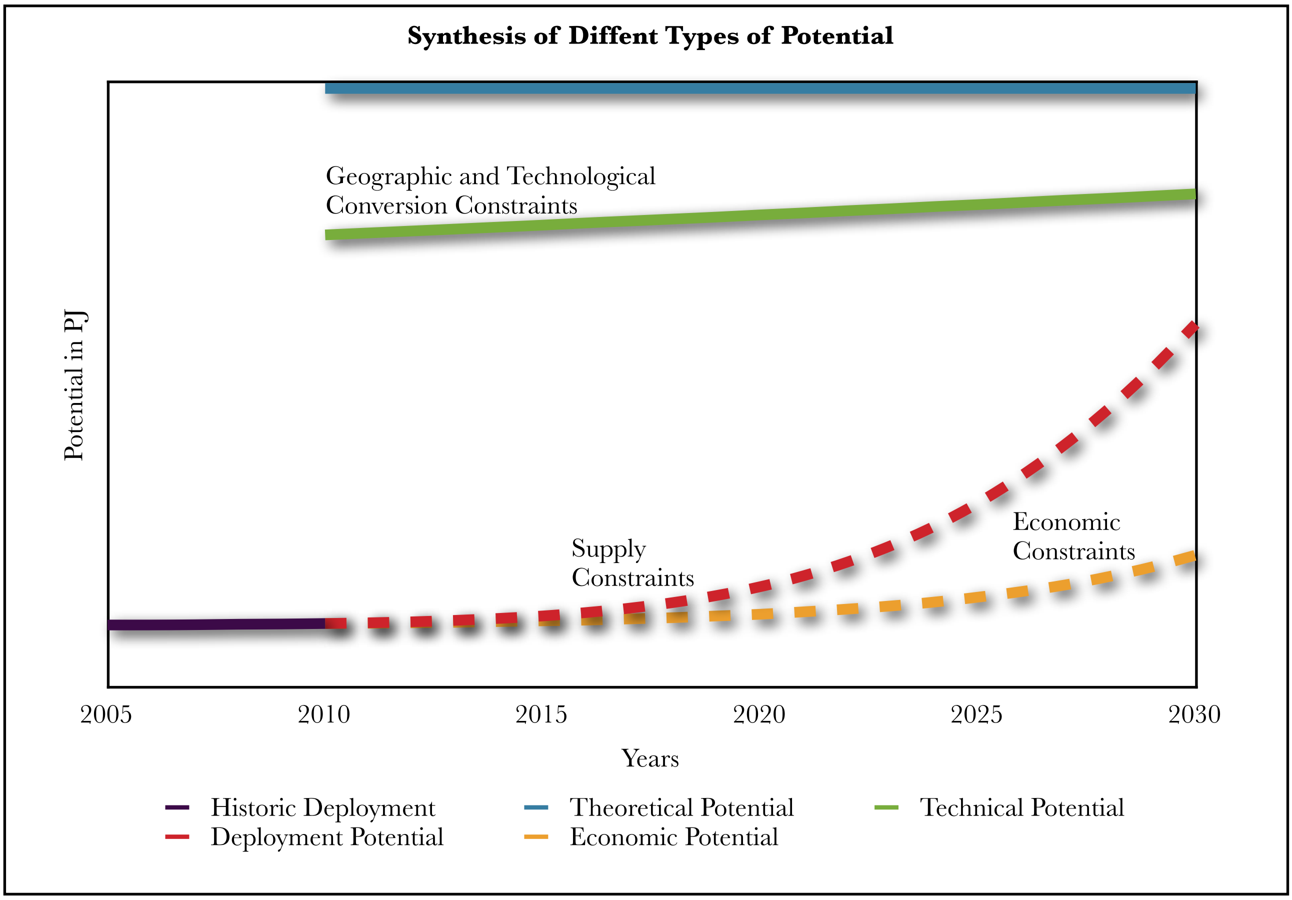

Figure 5: Synthesis of Different Types of Potentials

Figure 5 shows that there is a certain ceiling for renewable energy supply potentials, which is based on the physical limitations from a scientific point of view. This is the so-called theoretical potential. Below, the maximum potential is given that is based on geographical and technological conversion limitations. This is the so-called technical potential, which may increase over time due to technological advances[8]. Furthermore, it shows the historic deployment of the renewable energy technology, which is more or less only a starting point for further assessments. As described before, numerous types of potential definitions are used, however, this figure only depicts the deployment and economic potential in order to show the lucid variations in types of approach. The economic potential is derived from the deployment potential but includes economic hampering factors; therefore, its potential deployment is much lower.

2.2.2 Framework to Analyze Deployment Potentials

Bottlenecks regarding the supply of renewable energy technologies are the core features that determine the deployment potential. However, as described in the section 2.1, not only the technological and economic characteristics, but also the

[8] Note that the technical potential can exceed the total (national) demand for a renewable energy technology, as well as the deployment potential and the economic potential over time. These types of potentials are thus chiefly supply based. From a demand perspective, the technical potential can also decrease over time due to, for instance, better insulated dwellings.

quality of the surrounding technological innovation system determines the success of transition paths, i.e. to go successfully through the learning curve as fast as possible in order to speed-up the transition process. Therefore, the deployment potential of renewable energy technologies also depends on certain boundary conditions, which are expressed as key deployment factors in this report. These key deployment factors have to be shaped by all related actors[9]. So although a well-functioning innovation system approach is assumed, it takes time to create such an environment. Therefore, a conceptual model is framed which depicts the direct- and mediate consequences on the deployment potential of renewable energy technologies, see figure 6.

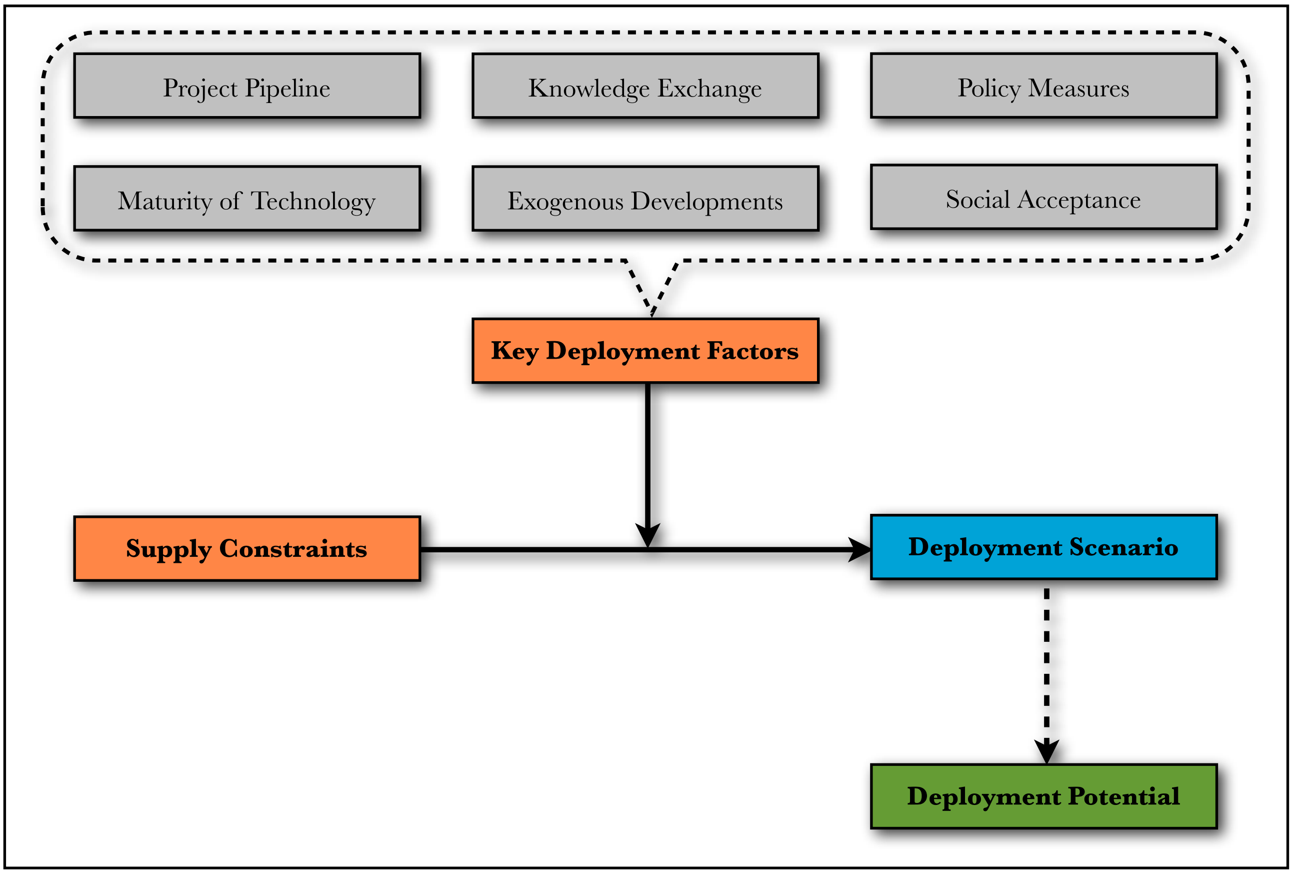

Figure 6: Framework to Analyze Deployment Potentials

Deployment Scenario & Potential

The dependent variable in the framed conceptual model is the deployment scenario, which is related to the deployment potential. The deployment scenario is the final outcome of the maximum number of renewable energy technology projects that can be realized under the pre-defined conditions within a certain timeframe, underpinned by a story line that weaves all influential factors and their associated assumptions into a chronological order. The deployment potential is the sequential step and is the final outcome in the maximum amount of energy that can be derived from the realized projects. This classification is introduced because the outcome of the deployment scenario, i.e. the number of projects that can be realized, is more accurate, thereby leaving the convergence on the exact amount of energy that can be derived more aside.

Supply Constraints

The independent variable in the framed conceptual model is based on supply constraints, which are hampering factors that affect renewable energy deployment. These constraints are based on supply chain and spatial limitation issues.

[9] To illustrate, the respective actors are generally the government, provinces, municipalities, universities, research institutes, business communities, and consumers in the Netherlands.

Supply chain constraints affect the maximum expansion of the current supply chain, i.e. determine the maximum growth of the market. Examples of supply chain constraints are: scarcity of components, limited material, lack of skills, or installation capacity upgrading matters. Subsequently, spatial limitation constraints affect the maximum growth in certain regional locations and are therefore also important[10].

Key Deployment Factors

The mediating variable in the framed conceptual model is based on key deployment factors, which are the external deployment constraints that determine an ideal growth of the supply market by taking more aspects into account. For instance, it requires efforts, thus time, to create a well-functioning innovation system for optimal renewable energy technology deployment. Except for the technological maturity status, these aspects are often nation-specific as it takes into account the current project pipeline, degree at which knowledge is shared, exogenous developments, current policy measures, and societal acceptation issues. These deployment factors form the basis for a comprehensive story line for the deployment of renewable energy technologies in a nation.

Box 6: Description of key deployment factors:

The project pipeline is a starting point of research since it simply outlines the projects that are projected or being realized within the timeframe of research. Moreover, it takes time to realize renewable energy projects, i.e. to go from the actual start until the utilization of renewable energy technology projects. Therefore, it indicates to what extent the renewable energy technology motor is already cranked up and provides insights in the existing supply chain

The degree of technological maturity, i.e. the point of the renewable energy technology on the learning curve, determines to what extent it can be deployed since the diffusion of renewable energy technologies is not a linear process where "science finds, industry applies, and man conforms" holds (Smits & Kuhlmann 2004 p.6). It is a process of co-evolution, which means that not only the technology changes but also the whole society, for instance to adjust needs and user practices (Kemp *et al.* 2007 p.78).

Sharing knowledge, i.e. experiences due to 'learning by doing' processes, is a necessity for a smooth upscale of renewable energy technologies. Thus, learning by doing, for instance about technical specifications, user preferences or public policies, is very important for further development and technology upscale (Geels 2004 p.912). The best preferable strategy for maximum renewable energy deployment on the long run is to create a technological trajectory in which knowledge must transfer between all actors involved accompanied by a steady upscale of technology (Kamp *et al*. 2004 pp.1633-1635).

Exogenous developments are external processes that affect renewable energy deployment but are hard to influence and these changes often take place slowly (Geels 2002 p.1262), e.g. oil and gas price development dependence, economic growth prospects, or spatial arrangements of existing infrastructures (Bergek *et al.* 2008 p.421). These external processes are very important to map since they often influence the entire supply market of renewable energy technologies.

Current policies in place related to the respective renewable energy technology are important to map and to determine whether these policies are functioning sufficiently. If certain policies are not properly functioning than those need to be refined and re-implemented, which takes time. Hence, clear and consistent long-term signals (in terms of desired developments and intended support programs) are a necessity for renewable energy technology deployment (Foxon & Pearson 2008 p.159; Hillman *et al.* 2008 p.609; Negro *et al.* 2007 p.936; Negro *et al.* 2009 pp. 29-30).

The social acceptance of a new technology is a prerequisite for its introduction and adoption over time (Sauter & Watson 2007 p.2270). The 'Not-In-My-Back-Yard' (NIMBY) bias is an example that can hamper renewable technological deployment. The NIMBY opinion insinuates that positive attitudes, to for example renewable energy, are opposed when people actually are confronted with it (Wüstenhagen *et al.* 2007 p.2686). Consequently, social support for new policy measures creates legitimacy for a new technological trajectory (Sabatier 1988 pp.157-159).

[10] Note that spatial limitation issues are taken into account in the technical potential of renewable energy technologies. However, regional spatial limitation issues can already hamper renewable energy deployment. Therefore, a distinction is made in regional and national spatial limitations.

3. RESEARCH DESIGN

3.1 Methodology

This section gives an overview of the used research design of this report. More specifically, it explains how the empirical research was conducted. First, by defining the research method and the respective domain. Second, the methods for data gathering are explained. And third, a description is given for the analysis of the gathered data.

3.1.1 Research Method

This research solely focuses on the supply constraints and key deployment factors to determine deep geothermal and offshore wind technology deployment potentials in the Netherlands in the period from 2010 till 2020. The focus on the Netherlands will provide a deeper analysis to understand the influencing factors from a supply-based perspective, which hamper the maximum deployment of deep geothermal or offshore wind technology in a specific country. However, it should be noted that the total supply chain of geothermal heat and offshore wind technology exceeds the Dutch borders, so the specific focus on the Netherlands will, hence, also crosses its national borders.

An exploratory approach is chosen since there are no existing theories that provide a format to determine the deployment potentials, which are specifically based on supply constraints and key deployment factors for renewable energy technologies. The research population exists out of all actants, human or non-human[11], that affect or are involved in the supply constraints for deep geothermal and offshore wind technology in the Netherlands in the period from 2010 till 2020. Furthermore, the most suitable design to execute this research is a case-study approach since there is 'little control over events' and the focus is on 'a contemporary phenomenon in some real-life context' (Yin 2003 p.1). The cases have been chosen since both estimated technical potentials are very high but consequently, deep geothermal is almost neglected in the 'Clean and Efficient' program, where offshore wind has a specific target of 6000MW in 2020. Hence, these cases provide insights for policy.

The research is executed as follows. The two case studies are presented in individual chapters. Within these chapters, first, a general introduction, technology description, and maturity analysis is given of the respective technology. Hereafter, the research results are given. First, the Dutch project realization process is phased with their coupled determined average throughput times under ideal circumstances, i.e. without delays. Second, the identified supply constraints are presented within the selected phases and are eventually classified in order of importance over time. And third, the historical background and the key deployment factors are given that together with the identified supply constraints form the basis for the deployment scenario underpinned by a story line which waves all influential deployment factors and linked solutions into a chronological order.

Subsequently, the results of both cases are cross-compared in order to identify common barriers and main constraints. Next, the determined deployment scenarios of both technologies are compared with projections of the Dutch government and balanced against the mandatory 14% renewable energy target of the European Commission and the 20% renewable energy target of the 'Clean and Efficient' program in the Netherlands. And lastly, an analysis is conducted whether the outcomes of this report could contribute to innovation system theory development.

3.1.2 Data Collection

The data is gathered through an extensive desktop study in which a wide array of documents is used such as scientific articles, scientific books, national statistics, national policy documents, professional literature and other publications such

[11] An actant is a concept from the Actor Network Theory that is part of a network in which no difference is made between human or non-human actors such as people and technology (Callon 1986 p.206).

as newspapers and websites. Search engines such as Scopus, Omega, Google Scholar and LEXIS-NEXIS are used to gather the required quantitative and qualitative data. Subsequently, the gathered data is validated through interviews with experts in the deep geothermal and offshore wind industry in the Netherlands. The interviews were held in a semi-structured way, which means that questions were asked in a open way to allow interviewees to provide more information about the topic, e.g. to reveal the rationales behind observed events, and to avoid socially wishful answers.

3.1.3 Data Analysis

The gathered data has been used to determine the respective deployment potentials of deep geothermal and offshore wind technologies in the Netherlands for the period 2010 till 2020. More specifically, quantitative and qualitative assumptions of the identified supply constraints, the identified key deployment factors, and the remedying promises are made in order to determine the final deployment scenario until 2020 in absolute numbers of realized deep geothermal projects and realized offshore wind turbines. Subsequently, the outcomes are cross-compared in order to reveal commonalities and dissimilarities with an emphasis on supply constraints. Next, the outcomes are compared with the target for offshore wind and the projection of the Dutch Energy Research Center (ECN) for deep geothermal heat in 2020. Furthermore, the outcomes are evaluated against the mandatory EU renewables directive and the subsequent Dutch renewable energy target in 2020. Finally, the contribution in innovation system theory is determined by comparing the approach of this research to the innovation systems theory approach.

4. DEEP GEOTHERMAL ENERGY

4.1 INTRODUCTION

4.1.1 BACKGROUND

Deep geothermal energy is stored as heat in the earth's interior due to the physical processes occurring there (Barbier 2002 p.6). At present, only the outer part of the earth's crust can be exploited and utilized (EGEC 2009 pp.3-4). Deep geothermal energy originates from the primordial heat, which is the heat generated during the earth's formation, and the active decay of long-lived isotopes such as ^{40}K, ^{239}Th, ^{235}U, and ^{238}U (Barbier 1997 p.8). Deep geothermal reservoirs are often found at depths in the region of 2 to 4 kilometers and can be used for direct heating applications, for electricity generation, or both with a Combined Heat and Power (CHP) plant (Yari 2010 p.112). The focus of this thesis is on the direct application of deep geothermal energy since the Netherlands has a large low-heat demand, which can be satisfied directly with deep geothermal energy (Harmsen & Harmelink 2008 p.15).

Two factors determine the potential of geothermal heat[12], first, the heat that can be recovered and, second, the quality of the geothermal reservoir. The recoverable heat is different per location due to specific geological characteristics such as the presence of magmatic intrusion (Tselepidou & Katsifarakis 2010 p. 1409). Therefore, a distinction is made between high and low enthalpy areas, where the average geothermal gradient is (much) higher in high enthalpy areas (Dickson & Fanelli 2004 p.22). The quality of the geothermal reservoir depends on its transmissivity, which is the product of thickness and permeability of the aquifer[13], and should be sufficient in order to produce several thousand liters of hot fluids per day (Lokhorst & Wong 2007 p.342). This means that not every location is suitable for geothermal heat extraction; nevertheless, it is also possible to create geothermal reservoirs artificially (Gallup 2009 p.327), which is explained in the next paragraph.

The earth's temperature increases with depth, which is expressed as the geothermal gradient. The average geothermal gradient is approximately 25ºC per kilometer in low enthalpy areas (Hammons 2004 p.535). Accordingly, temperatures of 150ºC or more can even be reached in low enthalpy areas. This depends on the requisite depth and site-specific characteristics (Tselepidou & Katsifarakis 2010 p.1409). These temperatures can be used to generate electricity but also for direct purposes in the industrial sector, which predominantly necessitate high temperatures (Stephens & Jiusto 2010 p.2020). But the layers of the earth are more compressed at those depths, which means that the rocks are less permeable, i.e. fewer fluids flow through. So a geothermal reservoir has to be created. Hydraulic fluids are injected into the reservoir that fracture the existing cracks in order to enhance the porosity and permeability of those layers until the geothermal reservoir is satisfactory in order to put in practice (Zaigham & Nayyar 2010 p.1125). Consequently, cold water is injected, which heats up in order to create a geothermal reservoir wherefrom hot geothermal fluids can be extracted (Tran & Rahman 2007 p.77). This technology is called Engineered (or Enhanced) Geothermal Systems[14] (EGS).

4.1.2 TECHNOLOGY DESCRIPTION

The technology for direct use purposes is not that complicated and has been referred to as "the most versatile and oldest form of utilization of geothermal energy" (Dickson & Fanelli 2004 p.37). A deep geothermal system operates by means of a two-well system, which consists out of a production- and an injection-well and is called a doublet. The production

[12] See appendix B1 for more information about, first, the different geothermal technologies (shallow and deep), second, the geological background of the earth, and third, geothermal resources.

[13] The term aquifer means literally an underground layer of water-bearing rock.

[14] EGS is also expressed as Hot Dry Rock (e.g. Tran & Raman 2007 p.77; Zaigham & Nayyar 2010 p.1124). But there is a slight difference since Hot Dry Rock describes a technology that uses dry hot rocks, which is a new and innovative technology that is currently under development and not yet economically attractive (Duffield & Sass 2003 pp.23-24). But EGS also use hydrothermal systems - i.e. there flow some fluids in the geothermal reservoir - instead of only using hot dry rocks, another designation is Hot Wet Rocks (Barbier 2002 p.57).

well taps hot fluids from the subsurface where a heat exchanger extracts the heat and transfers it to a secondary fluid system (Kulcar *et al.* 2008 p.323). Geothermal fluids contain a variety of dissolved chemicals due to their elevated temperature and may therefore not be discharged on the surface (Barbier 2002 p.19; Rafferty & Culver 1998 p.261). Hence, the injection well pumps the cooled fluids back into the subsurface.

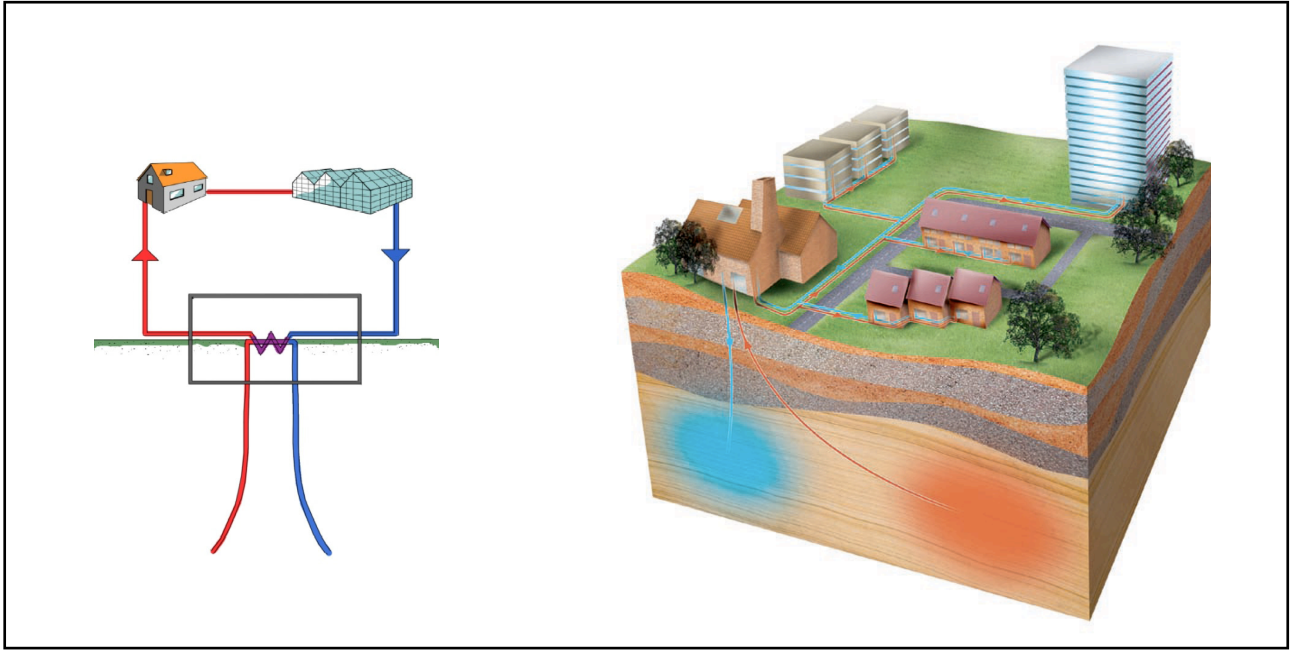

Figure 7: Direct Use of Deep Geothermal Technology and Cascaded Geothermal Systems

The operating procedure increases the production life of a geothermal doublet[15], since it sustains the pressure of the geothermal reservoir, and reduces the risks of subsidence (Fridleifsson 2001 p.306). The extracted heat can be used for the heating of residential areas, industrial estates and business parks. It can also be used in a cascaded manner, see figure 6, where the consumers are connected in series and every subsequent user utilizes the wastewater from the preceding user, thereby increasing the overall capacity of the geothermal doublet (Barbier 2002 pp.47-48).

4.1.3 Deep Geothermal Market in the Netherlands

Current Status

Deep geothermal energy projects for heating purposes are mainly suitable for district-, horticultural-, and industrial uses (Barbier 2002 p.3; Dickson & Fanelli 2004 p.37). Until 2010, three deep geothermal projects have been realized in the Netherlands. The first project extracts heat from water out the galleries and shafts of former coal mines[16] since 2008 (Lokhorst & Wong 2007 p.343). The horticulturist A+G van den Bosch initiated the two other deep geothermal energy projects, which are productive since 2007 and 2009 (SPG 2009 p.1).

Deep Geothermal Energy Potential in the Netherlands

According to Hagedoorn (2009 p.1), Lokhorst & Wong (2007 pp.343-344), and SPG (2004 p.3), the Netherlands has good subsurface conditions for the utilization of deep geothermal energy since it has a geothermal gradient of approximately 30ºC per kilometer (depth) and has sufficient geothermal reservoirs that are suitable for the extraction of deep geothermal energy. Especially the provinces Noord-Holland, Zuid-Holland, and Noord-Brabant, as well as the northern and eastern parts of the Netherlands have good geothermal reservoirs, see figure 8. However, this does not

[15] See appendix B1 for more information about the sustainability of geothermal reservoirs.

[16] Officially, this project belongs to the deep geothermal definition since there was drilled to depths of more than 500 meters.

imply that other locations are not suitable since large parts of the subsurface map are still uncertain for geothermal heat utilization in the Netherlands[17].

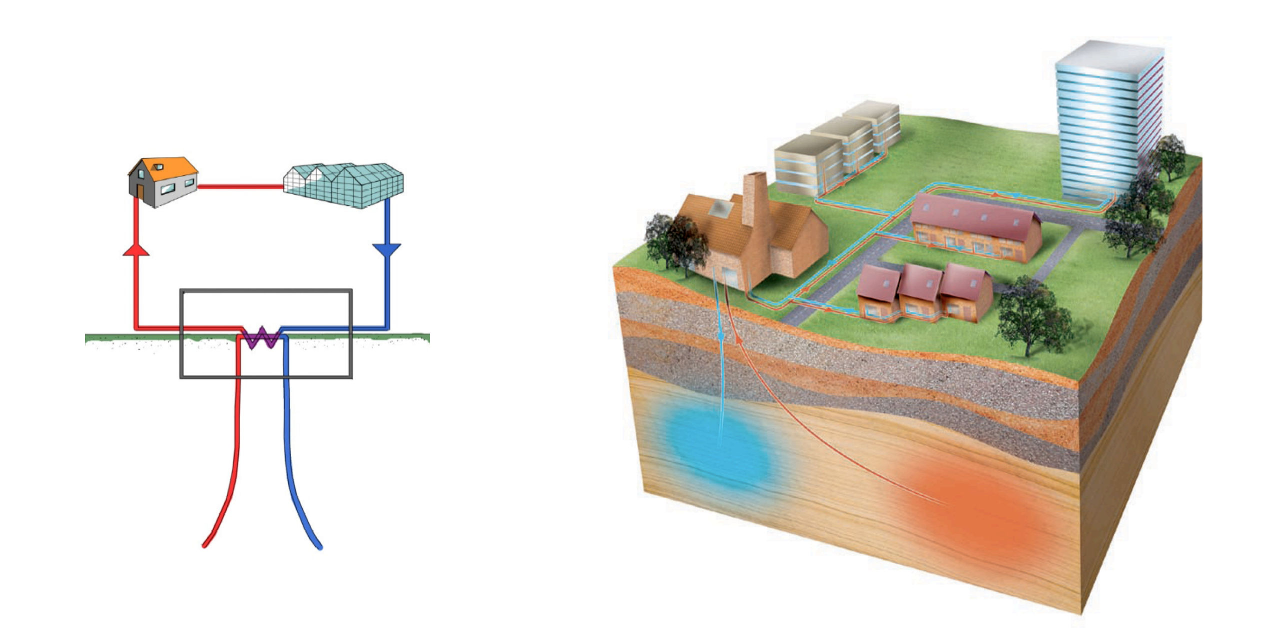

Figure 7: Direct Use of Deep Geothermal Technology and Cascaded Geothermal Systems

The geological potential of geothermal heat has been estimated according to the 'Heat in Place' (HIP) method and is approximately 90.000PJ in the Netherlands[18]. The final potential of deep geothermal heat in the Netherlands will be much lower, however, still high enough to be a major contributor in the Dutch renewable energy supply. According to Lokhorst & Wong (2007 p.344), only a minor part can be extracted techno-economically as location-specific reservoir properties play a determining role. Another subsequent constraining factor is the matching of the subsurface-related heat supply and the surface-related heat demand since the distance to transport heat determines to a large extent the economic potential of a project (Thorsteinsson & Tester 2010 p.805).

4.1.4 Maturity of Technology

The technology for direct use of geothermal heat can be considered as mature since it is applied for over more than 100 years without radical alterations (Barbier 2002 pp.61-62; Fridleifsson 1998 p.4; MIT 2006 p.9). However, there are some other developments that are important to mention, which are allocated to the use of the extracted heat, the geological knowledge and the drilling process.

Usage of Extracted Heat

The extracted heat via the geothermal doublet is the main product and must therefore be efficiently exploited. Two main characteristics determine this process: the heat exchanger and the distribution system. Heat exchangers exist in different forms, but so-called plate heat exchangers are applied in the majority of geothermal applications (Rafferty & Culver 1998 p.1). This type of heat exchanger uses multiple, thin, slightly separated metal plates to transfer heat

[17] The current geological knowledge comes mainly from oil and gas exploration data (Hagedoorn 2009 p.3; Lokhorst & Wong 2007 p.341). But a lot has still to be discovered in the subsurface and the potential of geothermal heat strongly depends on site-specific characteristics (TNO 2008 p.2). The depicted sandstones do all have the characteristics of a thickness of more than 50 meters and a flow rate - permeability - of more than 300 mD, and the geothermal gradient of the sandstones lies between 20-40ºC per kilometer (Lokhorst & Wong 2007 p.344).

[18] The HIP method takes into account "the average thickness of a sandstone layer, the average difference between aquifer temperature and surface temperature, and the lateral extent of the reservoir. Moreover it also involves the heat capacities of the rock matrix and the pore water, which are calculated separately on the basis of the average reservoir porosity" (Lokhorst & Wong 2007 p.344). So the actual HIP potential for the Netherlands would even increase if more aquifers were taken into account.

between two fluids. An important advantage of plate heat exchangers is that the fluids are exposed to a larger surface area, because the fluids are spread out over the plates, and can therefore be more effective[19] than other forms of heat exchangers (Rafferty & Culver 1998 p.1).

Another important aspect is the insulation of the distribution system since heat losses in the distribution system insinuate a decrease in temperature, especially for those at the end of the sequence. The technology for (geothermal) district heating systems is globally used. For instance, 90% of space heating demand in Iceland and about 100.000 residents in Paris are covered by geothermal district heating systems (Thorsteinsson & Tester 2010 p.804). However, further research on these topics can still improve its performance in order to optimally use and distribute the extracted heat (e.g. Kulcar *et al.* 2008 p.329).

Geological Knowledge

Geological knowledge development is important since it decreases the geological uncertainties that investors face in new geothermal projects (TNO 2008 p.1). Another important factor is to improve the geological knowledge about the interference between geothermal doublets and other subsurface utilizations such as carbon sequestration or gas storage (Mijnlieff & van Wees 2009 p.4). A last important topic is related to the geological knowledge about geological reservoir creation through hydraulic stimulation methods, e.g. the possibility to rouse earthquakes (Huang & Liu 2010 p.293).

Delft University currently investigates another geological development. They explore whether CO_2 combined with water can be re-injected in the geothermal reservoir since the dissolved CO_2 is heavier than the narrative water and will therefore not have a tendency to move upward (Wolf *et al.* 2008 pp.3-4). This option is additional but can prove to be an extra advantage due to its CO_2-emission reduction potential in the context of, for instance, the European Emissions Trading Scheme (ETS). Nonetheless, various geological questions still have to be addressed such as long-term effects of CO_2 on the seal and the favorable injection rate of CO_2 (Wolf *et al.* 2008 p.4).

Drilling Process

The current drilling process is a large debit of the total costs for the realization of geothermal doublets (EGEC 2009 p. 8; Teodoriu & Falcone 2009 p.245). The current drilling method stems from the oil and gas industry where drilling leads to quick returns on investment, due to the sale of oil and gas, though geothermal projects may only break-even years after the geothermal doublet have been completed (Teodoriu & Falcone 2009 p.238). It is therefore of utmost importance to further improve drilling methods[20] in order to reduce costs (Stephens & Jiusto 2010 p.2023).

Casing drilling is a new drilling method that allows for drilling and casing with the same tubular (MIT 2006 p.214). This will reduce overall costs because tripping costs are then minimized[21]. Delft University is currently investigating a promising innovative drilling method: composite drilling, which can reduce costs significantly. This light weighted drilling method exists of a composite casing that is drilled via the casing drilling process. The composite drilling method needs considerably less working space, has better isolation pipes, has an improved skin and better endurance for

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[19] The overall capacity can also be increased when the flow rate of the second distribution system is increased (where the best option is a plate heat exchanger due to its large surface area), but a higher base temperature is than required since the heat transfer will be less effective (see: de Swart 2007 p.5).

[20] A description of the most common drilling method for geothermal projects can be found in appendix B1.

[21] "The traditional process for the construction of a well first drills the hole section to depth followed by removal of the drill pipe, insertion of the casing and cementing of the casing in place. Time and costs associated with tripping to perform this operation can be substantial, especially for deeper wells" (Polsky *et al.* 2008 p.101). Other drilling developments that are based on casing drilling and some revolutionary drilling technologies are extensively described in the MIT (2006 pp.214-215) report.

corrosion, and can be operated by smaller drilling rigs (Wolf *et al.* 2008 p.3). However, this promising drilling technology has not been demonstrated yet.

4.1.5 Conclusion

Based on the current developments and on the conclusions of Barbier (2002 pp.61-62), Fridleifsson (1998 p.4), and MIT (2006 p.9), only minor advances are expected that will not substantially change the technology for the direct use of deep geothermal energy (the geothermal doublet and heat exchanger) in the coming years. Therefore, the direct use technology of deep geothermal energy is considered technologically mature, which means that developments are mostly focused on cost reductions and not on technology performance improvements. Thus, the technology itself is not considered as a possible constraint. Nevertheless, the deep geothermal market is still in its infancy in the Netherlands since there are only two real deep geothermal projects realized so far.

4.2 Results

This section presents, first, the results of the phasing analysis for the Dutch project realization process and its coupled average throughput times under ideal circumstances, i.e. without delays. Second, it presents the identified supply constraints within the selected phases, including a classification of the identified supply constraints in order of importance over time. Third, it presents the key deployment factors, which determine the ideal growth of the supply market. And fourth, it presents the qualitative and quantitative assumptions that form the basis for the deployment scenario.

4.2.1 Phasing of an Average Deep Geothermal Project in the Netherlands

The deep geothermal energy timeline is analytically divided into four phases that describe the process from the actual start until the utilization of a typical geothermal doublet in the Netherlands, see figure 9. It is based on the assumption that both the Dutch government and business communities have ideal incentives to deploy deep geothermal projects; therefore no major permit application procedure-, contracting-, or installation delays are taken into account. An extensive description of the four phases can be found in appendix C1.

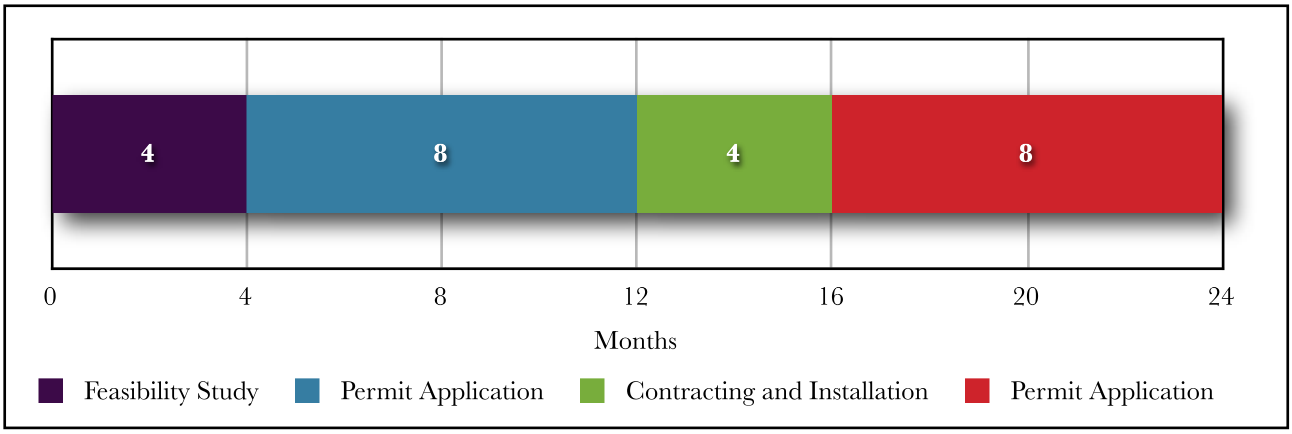

Figure 9: Average Deep Geothermal Project Realization Timeline in the Netherlands.

Average Timeline for Deep Geothermal Project Realization in the Netherlands

The first phase is the feasibility study phase, which is a preliminary research phase where geological and feasibility studies are carried out. The average time spent on this phase is set to 4 months in this analysis. The second phase is the first part of the permit application phase for the utilization of deep geothermal energy, which is the application process for an exploration license. An exploration license gives the right to explore for deep geothermal energy by one or more drillings in a specific area and a defined period, and is regulated under the Mining Act. The average time spent on this phase is set to 8 months in this analysis. The third phase is the contracting and installation phase, which mainly consist out of contracting, drilling, and installation processes. The average time spent on this phase is set to 4 months in this analysis. The fourth phase is the second part of the permit application process for the utilization of deep geothermal energy, which is the application process for an exploitation license. The average time spent on this phase is set to 8 months in this analysis. Subsequently, the last phase is the operation and maintenance phase, which covers all operational and maintenance activities undertaken once the deep geothermal doublet is operational.

4.2.2 Deep Geothermal Supply Constraints

This section describes the identified supply constraints per phase for the geothermal doublet realization process. The provided lists of suppliers are not intended to be exhaustive; given companies are mainly the leading active companies. It is recognized that for a study of this sort in a dynamic international sector, there may be omissions or incorrect designations of companies with significant capabilities.

Feasibility Study Phase

This phase is characterized by geological and feasibility studies, however, no serious supply constraints are identified that can hamper deep geothermal energy deployment. Large areas of the Dutch subsurface are already mapped due to many seismic measurements and drillings of the oil and gas sector. As stated in the Mining Act, all data of drillings and measurements belong to the public domain after 10 years. Most of the geological data is already public accessible due to the booming activities of the oil and gas sector in the Netherlands from the 1980s, e.g. over 5000 wells have been drilled and over 72.000 kilometers of seismic data has been collected for oil and gas exploration and production (van Wees & Kramers 2010 p.1). In addition, TNO Built Environment and Geosciences has recently introduced a public web-based 3D information system, called ThermoGIS. This program outlines the key geothermal reservoirs and allows assessing relevant parameters and underlying uncertainties therein (van Wees & Kramers 2010 p.2). However, it is still a challenge to translate this raw subsurface data for project usage, therefore, it is highly recommended to outsource these activities. In addition, most geological uncertainties will only reduce when more practical knowledge is gained in the Netherlands.

There are many geological consultancy- and engineering companies active in the Netherlands that can conduct the smaller geological quick scans as well as the larger required subsurface geological studies. Some large companies with geological expertise are IF Technology, Dick Swart Consultancy/PGMi, Well Engineering Partners, T&A Survey, Fugro ingenieursbureau, Geodelft/Deltares, Grontmij, and PanTerra Geoconsultants.

Concluding, at this moment there are sufficient geological consultancy- and engineering companies active in the Netherlands to conduct the necessary geological and feasibility studies for deep geothermal energy projects. Over time, these companies can enlarge their businesses in order to cope with future demand. Adding to, sufficient geological knowledge is currently available for the public, which will also increase over time.

Permit Application Phase - part I

This phase is characterized by the exploration license procedure. Until 2010, around 60 exploration license requests have been submitted to the Ministry of Economic Affairs and are processed in a very short time. It is, therefore, not expected that delays in the permit application phase will hamper the deployment of deep geothermal energy projects since this department can also be enlarged over time.

However, a first supply constraint has been identified with regard to the spatial planning of the subsurface. This is, to date, not a problem in the Netherlands as a whole, but in Zuid-Holland there already occur realistic scenes of overloading. This is because the largest part of the Dutch horticultural sector is also located in that area. The current environmental planning of geothermal doublets is arranged according to the France method[22] in order to prevent subsurface interference. In addition, the deployment of geothermal doublets can also interfere with other subsurface technologies such as CO_2-sequestration, gas storage, or heat- and cold storage. Therefore, it is of utmost importance to coordinate and direct the environmental subsurface planning beforehand in order to optimize the use of the stored subsurface energy, see figure 24 for an overview.

Concluding, even after a boom in exploration application requests, the Dutch Ministry of Economic Affairs processed all requests. And over time, the geological department can be enlarged with more human capacity. In order to optimally use the subsurface for renewable energy, it is important that the Dutch Government directs the spatial planning of the subsurface efficiently.

Contracting and Installation Phase

This phase is characterized by drilling and installation processes for geothermal doublets. The most important supply constraints are encountered in this phase. One supply constraint is the availability of dedicated deep geothermal energy drilling companies, since there is only one Dutch drilling company, NDDC[23], currently active in the deep geothermal energy sector in the Netherlands. The other drilling company that is active on the Dutch deep geothermal energy market has German roots, which is Daldrup & Söhne AG[24]. It is very common for drilling companies to operate in several countries; this means that the drilling industry is an international affair. Therefore, most drilling companies are active within a certain region, which is for the Netherlands mainly Northwestern Europe. Within Northwestern Europe, some large deep geothermal energy drilling companies are active, among which: KCA Deutag [DE], DrillTec [DE], Bauer Machinen GmbH [DE], ITAG [DE], Rotary Drilling Company [HU], and OGEC Cracow [PL]. In addition, there are also other Dutch drilling companies with lighter drilling equipment that could shift into deep geothermal energy projects over time[25], some examples are: Visser & Smit Hanab, de Ruiter Boringen en Bemalingen, Verhoeven Drunen, and Grondboorbedrijf Haitjema.

However, as mentioned before, the geothermal drilling process is almost the same as oil and gas drillings; only minor adjustments are needed (Augustine *et al.* 2006 p.3; MIT 2006 p.191). This means that much more drilling companies are available for deep geothermal energy projects. The main reason for drilling companies to ignore deep geothermal energy projects is that oil and gas drillings lead to faster cash return, due to the sale of oil and gas (Teodoriu & Falcone 2009 p.238). In practice, there is no boundary between deep geothermal or oil and gas drillings, since both drillings are aimed at comparable depths; it is more a financial issue because deep geothermal projects may only reach financial break-even years after the geothermal doublet have been completed (Stephens & Jiusto 2010 p.2023). Therefore, drilling companies have to bear more risks within these projects since there is less room for inaccuracy, unlike oil and gas

[22] This method uses an average lifetime of 30 years in order to determine the distance between the production- and injection well. Around these two circles, a rectangle is drawn with a little buffer zone. It is also called the cigar method. However, it is not certain to what extent this method is preferable since more practical experience is needed in order to confirm the France method (Kramers *et al.* 2009 p.22).

[23] The Northern Dutch Drilling Company is a subsidiary company of the Verkley Groep. Next to deep geothermal energy drillings the company operates also in oil, gas, and salt industries in Northwest Europe. This drilling company will execute the planned drillings in The Hague (Aardwarmte Den Haag project) and is also involved Delft Geothermal Project (DAP).

[24] The Daldrup & Söhne AG drilling company has executed the two deep geothermal energy projects for the horticulturist A+G van den Bosch. The company is currently drilling two geothermal wells for horticulturist Ammerlaan Grond- en Hydrocultuur.

[25] In practice, drilling companies with lighter drilling equipment are also used for deep geothermal energy projects. In The Hague, for instance, a lighter rig drills the first 250 meters because of mainly two reasons, first, to give special attention since the drilling will pass trough a groundwater reservoir, and second, the rental costs for a lighter rig are much lower

drillings where it is normal that only one out of three drillings is successful (SPG 2009 p.2; Teodoriu & Falcone 2009 p. 238). However, this issue will probably moderate when more successful deep geothermal energy projects are realized[26], e.g. due to risk and uncertainty reductions. Some large oil and gas drilling companies that are active in the Netherlands are: Northern Petroleum Netherland, Nederlandse Aardolie Maatschappij, Vermilion Oil & Gas Netherlands, and GDF SUEZ E&P Nederland etc.

The first supply constraint is, however, not the number of drilling companies but the availability of drilling equipment for deep geothermal energy projects, i.e. dedicated drilling rigs. Not every drilling company has multiple dedicated drilling rigs, which are required for deep geothermal energy projects. The availability of drilling rigs for deep geothermal energy projects is correlated with the oil and gas sector (Teodoriu & Falcone 2009 p.238), see figure 10. For instance, when oil prices are high this results in an increase of oil exploration and drilling activities. This however causes a decrease in drilling rig availability for deep geothermal energy projects (Augustine *et al.* 2006 p.5). On the other hand, when oil prices are low, this means that more drilling rigs are available. However, the competitive advantage of deep geothermal energy projects is the highest when oil prices are high and vice versa, due to the revenues of fossil energy savings (SPG 2009 p.3; Stephens & Jiusto 2010 p.2023).

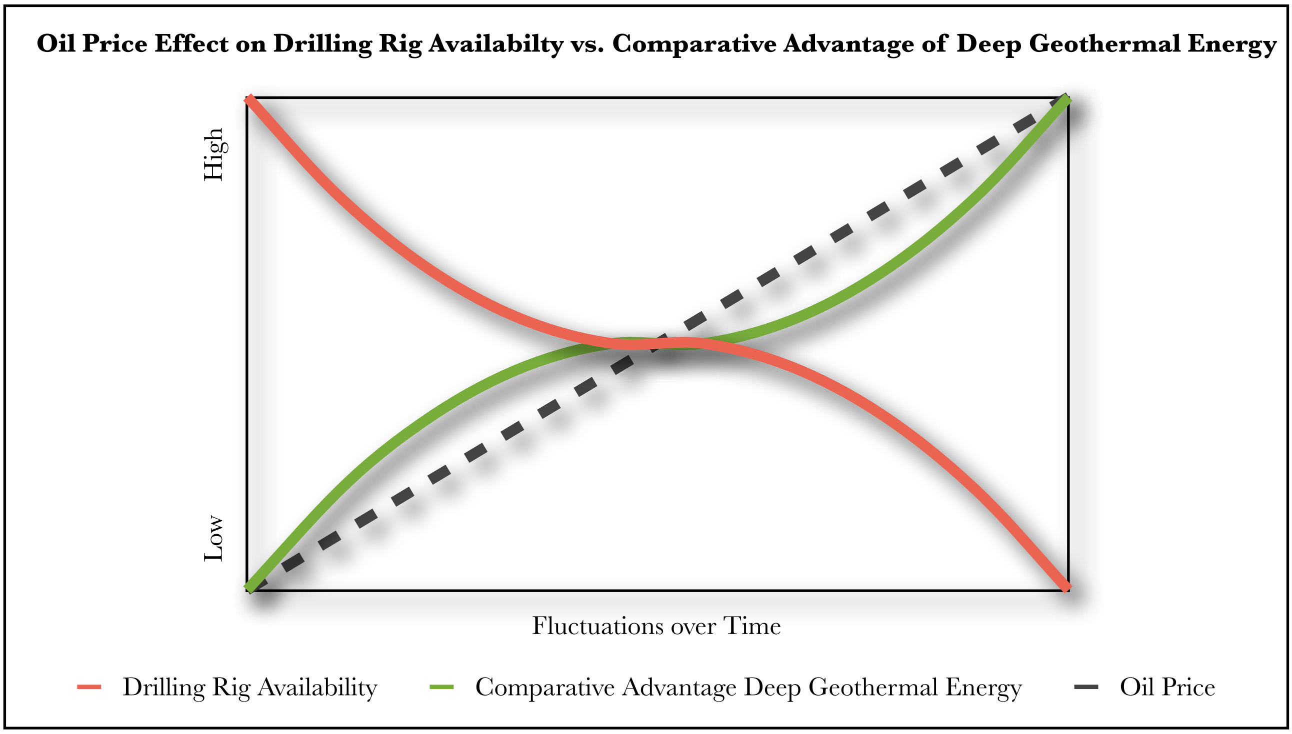

Figure 10: Oil Price Effect on Drilling Rig Availability vs. Comparative Advantage of Deep Geothermal Energy.

So there is a clear mismatch in drilling rig availability and competitive advantage for deep geothermal energy projects[27]. Though, the current economic recession has led to a (temporary) decrease in energy demand, which results in less oil and gas drilling activities, see figure 11. This means that a certain amount of drilling rigs is stacked, i.e. not operational, at this moment. Some of these stacked drilling rigs from the oil and gas sector may be hired for deep geothermal energy

[26] In the oil and gas sector, drillings on day-rate contracts are common but require a lot of knowledge off the drilling supervisor since he or she bears the entire responsibility. Oil and gas companies, frequently, have the knowledge in house to take the lead in the drilling process and thereby reduce costs. However, they are also able to meet setbacks in the drilling process, which is in almost every situation not the case for deep geothermal energy projects. Therefore, most deep geothermal contracts are lump sum based, which means that the total project costs will be higher compared to an ideal executed project on day-rate base, but any technical setbacks during the project are for the contractor. More successful deep geothermal energy projects can reduce geological uncertainties and thereby reduce costs.

[27] Nevertheless, anti cyclical investments are, probably, the most profitable options for deep geothermal energy projects, i.e. invest when the competitive advantage is at its lowest (SPG 2009 p.1).

projects in the meanwhile until the economy improves. However, this assumption has a very high uncertainty factor since it is not precisely known why these drilling rigs are stacked. Other reasons, such as maintenance, decommissioning, or transportation to other continents belong also to the possibilities besides the economic recession[28].

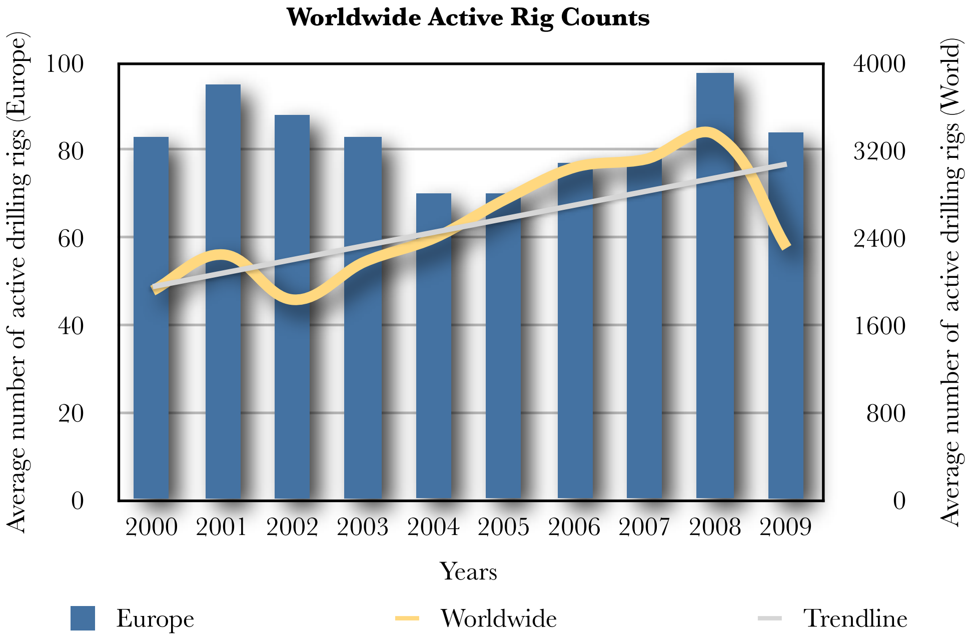

Figure 10: Worldwide Active Rig Counts, derived from Baker Hughes Data.

A more realistic option is to built new dedicated drilling rigs for deep geothermal energy projects since there are a lot of suppliers that offer this service in northwestern Europe, among which: Bentec [DE], Drillmec [IT], Huisman Equipment [NL], Herrenknecht [DE], Streicher [DE], and TTS Sense [NO] etc. Altogether, these manufacturers combined have sufficient capacity and they have a reasonable growth or redirection capability that could be brought in line on the short term. To illustrate, Huisman Equipment, as one of the smaller drilling rig manufacturers compared to the other examples, can already supply approximately 4 drilling rigs per year with their existing production line.

The second supply constraint is the availability of specialized personnel, which is also linked to the availability of drilling companies, because a specialized crew is required that can drill both wells for the geothermal doublet (SPG 2009 p.2). Personnel of all sort of educational levels are required, for instance geologists, drillers, assistant drillers, roughnecks, mud engineers, tool pushers, service engineers etc. Providing more specific geothermal education at under-graduate and graduate levels can straightforwardly enlarge this labor force over time. However, this is not the case for two very important functions, which are experienced drilling engineers who develop the well design, and experienced drilling manager who supervises the project. For both functions, on-field experience is required and can thus not easily be enlarged with training or educational programs. Nevertheless, a substantial part of these required personnel is, perceptibly, linked to the drilling rig availability of the oil and gas industry.

Concluding, the two identified supply constraints are both strongly linked to the drilling company availability. At present, few drilling companies, and thus drilling equipment and specialized crews, are active in the deep geothermal energy sector of the Netherlands. But this capacity can be increased through the enlargement of existing drilling

[28] Adding, the Baker Huge international rotor rig count is a monthly census of active drilling rigs exploring for or developing oil and gas. To be counted as active, an international rig must be drilling at least 15 days during the month. Rigs that are in transit from one location to another drilling less than 15 days are not included in the active rig count. However, the active rig counts do reflect, to a certain extent, the current energy demand since it is influenced by the price of oil (Baker Hughes 2010).

companies, involving new drilling companies, use foreign drilling companies, and involve oil and gas drilling companies; where the last two options also strongly depend on deep geothermal energy developments abroad.

Permit Application Phase - part II

This case is characterized by the exploitation license procedure. However, there is a strong tendency to replace the normal two-step process of for applications of geothermal heat since the second phase is coupled to a fairly prolonged period of non-activity of the geothermal doublet. This sequence is less logical for geothermal energy utilization than for other mining activities because it postpones the supply of renewable energy, and their economic savings, with almost one year. For oil and gas mining activities these losses in time are easily recouped by the financial rewards of later production. Therefore, a new proposal for a special geothermal permit procedure is currently developed, which will drastically reduce the throughput time of the total project realization process. The proposal combines the exploration and exploitation permit into one application. This means that approximately 8 months can be reduced in the throughput time when the new geothermal permit is granted. However, the procedures from the production permit application will not disappear, but will be altered. The procedures will be included in an extension application. So when the new geothermal permit is granted, it is possible to produce right away but an extension have to be applied for after 3 or 5 years[29].

Concluding, a new geothermal application procedure will improve the economic feasibility of deep geothermal energy projects, by reducing the payback time, and therefore can stimulate more horticulturists, municipalities, and industries to initiate deep geothermal energy projects.

Conclusion

At present, the most important identified supply constraint is the availability of sufficient drilling equipment. Over time, the availability of required human capital will become the most important supply constraint. And following, competition for the utilization of the subsurface will limit the maximum deployment of deep geothermal projects. Environmental planning of the subsurface is therefore very important since heat demand is mainly concentrated in similar areas.

4.2.3 Deep Geothermal Key Deployment Factors

This section describes the key deployment factors, which determine the ideal market uptake of deep geothermal energy projects. The following key factors are considered: the current project pipeline, maturity of technology, knowledge exchange, exogenous developments, policy measures, and social acceptance. After the introduction of these factors a conclusion is given for an optimal upscale scenario of deep geothermal energy projects.

Project Pipeline

Until 2010, approximately 60 exploration license applications have been applied for; where about 30 have been approved[30] (NL Olie- en Gasportaal 2010). This is a substantial improvement since there were only a few exploration license applications in 2007. The successful projects of A+G van den Bosch (in 2007 and 2009) have set the exploration license applications in motion, especially in the horticultural sector. The geothermal district heating system project in The Hague can cause similar events within municipalities and provinces, when executed successfully. At this moment, no serious actions are undertaken within the industrial sector with regard to deep geothermal energy projects. However, it is

[29] There are few conceivable reasons to refuse a production permit once the exploration activities have proved to be promising. This procedure can encourage investors and does not really require major changes in the Mining Law.

[30] See appendix A1 for an overview.

expected that the industrial sector will be initiated when higher temperatures are reached cost-effectively due to technological advances in drilling methods.

Maturity of Technology

As described before, only minor technological advances are expected that will not change the technology for direct use of deep geothermal energy substantially in the coming years. However, with regard to new drilling methods, it is announced that a first composite casing will be executed at the Delft University at the end of 2010 (NDDC 2010). This innovative drilling method will play a considerable role on the medium run. Composite drilling can lead to an enormous decrease in drilling expenses. Coupled with this development, the potential of deep geothermal energy projects will increase due to improved business cases for deep geothermal energy in existing district heating systems[31].

Knowledge Exchange

Many articles have also pointed out that deep geothermal energy, even in the Netherlands, offers a clean and viable source of energy with practically no CO_2-emissions (e.g. Hagedoorn 2009 p.1; Lokhorst & Wong 2007 pp.343-344; SPG 2004 p.3). However, more geological knowledge is required in order to reduce deep geothermal project uncertainties and subsurface interference possibilities with other technologies (Mijnlieff & van Wees 2009 p.4). In addition, more knowledge about hydraulic stimulation methods for geothermal reservoir creation is required (Huang & Liu 2010 p. 293). Therefore, two learning processes are considerably important at this moment, which are 'learning by searching' and 'learning by doing'. Recently, TNO has launched a web-based program called ThermoGIS, which is publicly accessible and comprises all available geological data in the Netherlands (ThermoGIS 2010). Consequently, a research program for ultra deep geothermal energy in the Netherlands is launched that will investigate geological issues regarding EGS utilization[32] (Energiek2020 2010).

Exogenous Developments

The fall of the Dutch cabinet has consequences for the deployment of deep geothermal energy projects since it takes time to come up with a new coalition agreement, which can also include possible changes in climate policy. At this moment, there is no subsidiary instrument for the use of deep geothermal energy, i.e. there is no level-playing field compared with fossil energy technologies. In other countries, such as Germany and France, the realization of deep geothermal energy project has boomed[33] during the past years (Auer 2010 pp.9-10). One main reason why the Netherlands has lacked to cope with these activities is the good Dutch gas infrastructure and their wealth of gas resources (SPG 2008 p.2). The gas prices are therefore lower in the Netherlands than in other surrounding countries (Eradus 2005 pp.1-2). This means that geothermal energy in the Netherlands has a much more difficult competitive advantage than in other countries. In addition, the tariff structure imposed on gas for agricultural applications also hampers deep geothermal energy deployment since the gas used, as co-firing fuel, in winter is much more expensive because it lacks the advances of the special horticultural large-use discount (SPG 2009 p.2).

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[31] Existing district heating systems require higher inlet temperatures, which means that deeper drillings are required in order to fulfill heat demand. The inlet temperatures can be reduced with natural gas co-firing, additional heat pumps, and insulation improvements of existing houses. Nevertheless, cost reductions in the drilling procedure, due to composite casing drilling, can further improve the business case of those projects.

[32] The research program is a cooperation of Grontmij, IF WEP, and Bright Capital, where Grontmij addresses the design and supply issues of a geothermal electricity plant, IF Technology and Well Engineering Partners address the geological and drilling issues, whereas Bright Capital addresses the financial issues of such a project (Technisch Weekblad 2010).

[33] To illustrate, in 2008: 167 deep geothermal projects provide building complexes and thermal baths with heat, thirteen deep geothermal generating plants feed heat into district heating networks, and much more are on the drawing board in Germany (Auer 2010 p.11).

Policy Measures

As reflected in many studies, clear and consistent long-term policy is a necessity for renewable energy technology deployment (Foxon & Pearson 2008 p.159; Negro *et al.* 2009 pp.29-30). It is therefore very important to further streamline the regulatory framework; a good example is the new geothermal permit procedure act that is currently in the making (Platform Geothermie 2010). Again, a stable and dedicated renewable energy focus is important for policy as possible planned gas or coal power plant also affect deep geothermal energy deployment since deep geothermal projects are in competition with residential heat. Nevertheless, this issue will not seriously affect deep geothermal energy deployment in this research due to the assumption that the Dutch government and business communities have ideal incentives in order to deploy deep geothermal energy in the Netherlands.

Social Acceptance

It is not expected that society will play a crucial role in deep geothermal energy deployment in the Netherlands since installation procedures are only temporary and spatial use, after the installation, is negligible. This takes the visual impact on the environment to a minimum, and therefore no NIMBY effects are expected. However, geothermal reservoir stimulation methods, as a result of deeper drillings, can cause for more social opposition. An example is the EGS project in Basel that caused vibrations that were noticeable on the surface and led to a (temporary) stop of the project. However, Switzerland it is more vulnerable for earthquakes than the Netherlands, due to their geographical situation. In addition, the oil and gas industry often uses reservoir stimulation methods, similar to EGS reservoir stimulations methods (Enermax 2010). Therefore, no social rejection for deep geothermal projects is expected on the short and long run in the Netherlands.

Conclusion

There are sufficient possible projects in the current project pipeline, however more successful projects have to be realized in order to trigger more initiatives for - and realizations of - deep geothermal projects. Nevertheless, it is difficult to influence and direct exogenous developments. Drilling method improvements, which lead to cost reductions, will increasingly de-clutch the negative influence of low gas prices on deep geothermal energy deployment over time. Consequently, consistent and long-term supportive policies form the basis for an optimal deployment of deep geothermal energy. A steady upscale of deep geothermal projects is therefore of utmost importance, which will be characterized by three main upscale periods: first, a so-called pioneering era (2010-2013) in which more successful deep geothermal energy projects have to be realized, second a so-called take-off era (2014-2018) in which the number of deep geothermal energy projects have to accelerate every year, and third, a so-called stabilization era (2018-2020) in which the market penetrates a desired project deployment level per year.

4.2.4 Deep Geothermal Deployment Scenario

This section describes a scenario in which deep geothermal energy doublets could optimally be deployed through an up scaling process until 2020, and gives an outlook to 2030. It presents the assumptions made for the deployment scenario, and presents the final outcome of the deployment scenario. The historic deployment of deep geothermal energy in the Netherlands can be found in appendix D1.

Synthesis of Gathered Data

The optimal deployment scenario, presented in this research, will not occur straightforwardly. This means that radical efforts are required from the Dutch government and the deep geothermal industry in order to realize the depicted deployment scenario.

Box 7: Potential Demand for Deep Geothermal Projects in the Netherlands

The Dutch horticultural sector exists out of companies with open field- and greenhouse production facilities (Manrad & Gabriel 2009 p.490). The greenhouse production of vegetables and flowers has a cultivated area of approximately 10.274 hectares (Productschap Tuinbouw 2010). One deep geothermal doublet can provide enough heat for approximately 7 hectares of greenhouses, which depends on the specific characteristics of the cultivated vegetables and flowers (Harmsen & Winkel 2010 p.20). Most greenhouses are clustered in the Netherlands (Menrad & Gabriel 2009 p.496), this is an advantage in order to provide for CO_2-distribution pipelines such as the OCAP-pipeline in Zuid-Holland. However, a disadvantage of the clustered horticultural sector is that regional spatial limitations appear due to subsurface interference issues. This issue can also be overcome by installing entire district heating-networks for the horticultural sector (Schepers & Valkengoed 2009 p.69), however this increases the total costs for deep geothermal projects (Thorsteinsson & Tester 2010 p.805). Therefore, it is assumed that 55% of the existing greenhouses can be provided with deep geothermal energy until 2030. This means that approximately 700 deep geothermal projects can be realized within the horticultural sector.

The Dutch utilities sector exists out of dwellings and commercial buildings which either supply heat individually, via for instance a high-efficiency boiler, or collectively via a district heating system (Guerra Santin *et al.* 2009 p.1224). There are approximately 40 existing district-heating systems in the Netherlands (Entrop & Brouwers 2007 p.1). However, according to Schepers & Valkengoed (2009 p.20), only 13 large-scale district-heating systems exist, which means that 5000 or more dwellings are connected. A total of approximately 222.000 dwellings are connected to these district-heating systems, which are largely fed with gas as primary energy source (Schepers & Valkengoed 2009 p.30). There are currently 7 million dwellings in the Netherlands and approximately 60.000 dwellings are newly built each year (Daniëls *et al.* 2010 p.42). One deep geothermal doublet can provide enough heat for approximately 7000 dwellings, which depends strongly on whether it are existing or new dwellings due to insulation characteristics (Harmsen & Winkel 2010 p.20). Subsequently, existing district-heating systems require higher inlet temperatures compared to newly built district-heating systems which are habitually connected on new dwellings with low-temperature heating and better insulation (EGEC 2009 p.2; Hagedoorn 2009 p.3). This would thus require deeper drillings (for higher temperatures). However, deep geothermal energy can still provide heat, which than has to be stoked up to the required inlet temperature with gas, thereby acting as a transition solution until existing dwellings are better insulated. Therefore, it is assumed that 65% of the existing district-heating systems (due to the supply of residential heat) and 40% of the newly built dwellings (due to the fact that it is less efficient to match heat demand and supply within sparsely populated areas) can be provided with deep geothermal energy until 2030. This means that approximately 90 deep geothermal projects can be realized within the utilities sector.

The Dutch industrial sector exists out of different sub-sectors, e.g. iron and steel-, ethylene-, pulp and paper industry etc. (Phylipsen *et al.* 2002 pp.666-667). These sectors have different temperature requirements which is roughly divided in heat demand higher than 500ºC, between 100-500ºC, and below 100ºC. According to Harmsen & Hamelink (2008 p.69), the heat demand in the industrial sector below 100ºC is approximately 70PJ and for heat demand between 100-500ºC approximately 330PJ. One deep geothermal doublet can provide for temperatures of approximately 70-90ºC at depths of 2-3 kilometer, which equivalent to approximately 0,1PJ independently of the temperature (EGEC 2009 pp.3-4; Harmsen & Winkel 2010 p.20). However, just as the horticultural sector, the lion's share of the industrial sector is clustered in the Netherlands (Phylipsen *et al.* 2002 p.670). Therefore, it is assumed that 20% of the industrial sector with heat demand below 100ºC and 2% of the industrial sector with heat demand between 100-500ºC (due to EGS developments) can be provided with deep geothermal energy until 2030. This means that approximately 200 deep geothermal projects can be realized within the industrial sector.

Pioneering Era (2010-2013)

Within this era it is of utmost importance to create the necessary boundary conditions for an optimal deployment scenario in the Netherlands in which the supply market can flourish. This means that precautionary actions have to be taken in order to remedy supply constraints in advance. Subsequently, it is of utmost importance to realize deep geothermal projects successfully for a steady upscale of deep geothermal projects in the Netherlands. It is hence recommended to involve experienced drilling engineers and project managers in early phases of projects. In addition, more research must be executed about subsurface interference issues between deep geothermal wells and other subsurface technologies such as carbon capture and storage- or shale gas technologies. Another important research topic is related to the geological knowledge about geological reservoir creation through hydraulic stimulation methods. Therefore, the following assumptions are made:

Four projected deep geothermal energy projects will be realized in 2010[34]. As from 2011[35], the Dutch government and the Dutch deep geothermal energy supply market will undertake the described actions in box 8. Until 2014, only two extra drilling rigs and coupled specialized crews are needed, which will be filled in by the current drilling companies that are active on the Dutch deep geothermal market, i.e. NDDC and Daldrup & Söhne AG.

Box 8: Required Actions to be undertaken by the Dutch government and the deep geothermal supply market.

- First, the Dutch government gives clear signals in their coalition agreement that they want to stimulate deep geothermal energy in the Netherlands with consistent long-term policies. This includes a roadmap for the Dutch deep geothermal energy supply market in which a specific target for heating purposes is outlined of approximately 80PJ in 2030, including the outline of an optimal market upscale scenario.
- Second, the Dutch government implements the new deep geothermal application procedure, which will be further streamlined in order to proceed smoothly. This reduces the total average timeframe in which a deep geothermal doublet can be utilized and thus increases the feasibility of these projects due to reduced payback times.
- Third, the Dutch government refines the existing deep geothermal guarantee scheme in order to cover a larger share of the financial burden due to drilling errors. Consequently, the governmental funds for this guarantee scheme is expanded in order to reduce the large uncertainties which are present during the investment phases of deep geothermal energy projects.
- Fourth, the Dutch government provides for deep geothermal energy programs for under-graduate and graduate levels and mandates geological as well as science and technology studies to focus more thoroughly on deep geothermal energy matters in order to gradually enhance the supply of human capital over time.
- Fifth, the Dutch government provides for more acquaintance about deep geothermal energy possibilities within the industrial sector, the utilities sector, and horticultural sector. Subsequently, the Dutch government provides for more acquaintance about deep geothermal energy in provinces and municipalities.
- Sixth, the Dutch deep geothermal supply market develops specialized training programs, which are related to deep geothermal project realization processes, in order to retrain and educate personnel, for instance graduates or personnel from other professions, for all kinds of activities.
- Seventh, the Dutch deep geothermal supply market provides for the initiative for research programs, which are related to subsurface interference issues and geological reservoir stimulation methods, which are funded both by the public and private sector. These results will, first, tackle and settle the discussion of the environmental planning of different subsurface technologies, and second, reduce geological uncertainties which are a large burden for deep geothermal energy projects.
- Eighth, the Dutch deep geothermal supply market shares the attained experience, for instance via scientific as well as other publications, via meetings of the Platform Geothermie, and at conferences such as the annual geothermie update in the Netherlands of T&A Survey or at foreign conferences of the International Geothermal Association (IGA) and European Geothermal Energy Council (EGEC), since this is a necessity in this early phase of deep geothermal energy deployment in the Netherlands.
- Ninth, the Dutch deep geothermal supply market takes precautionary measures in order to solve the scarce availability of drilling equipment for deep geothermal energy projects at this moment. This means that sufficient drilling equipment must be tendered for in advance and that collaboration options with the oil and gas industry must be explored, e.g. drilling rig and human capital rental possibilities.

Take-Off Era (2014-2018)

Within this period a serious boom may be realized for deep geothermal energy projects, due to the approximately 25 successfully executed projects within the pioneering era. From this moment on, more companies enter the Dutch deep geothermal market each year. In addition, incumbent firms will enlarge since they already gained practical experience

[34] The first project will be executed in Pijnacker for Ammerlaan Grond en Hydrocultuur (New Energy 2010), the second project will be executed in Den Haag for Aardwarmte Den Haag (Aardwarmte Den Haag 2010), the third project will be executed again in Pijnacker for Gevr. Duijvestijn (Gebroeder Duijvestijn 2010), and the fourth project will be executed in Delft for the TU Delft (NDDC 2010).

[35] Due to the fall of the cabinet in 2010 and the required time to come up with a new coalition agreement

with former deep geothermal projects. Furthermore, the gained practical knowledge combined with research results and technological advances will increase competition between drilling companies and thus further reduce the total costs associated with deep geothermal energy projects. Therefore, the following assumptions are made:

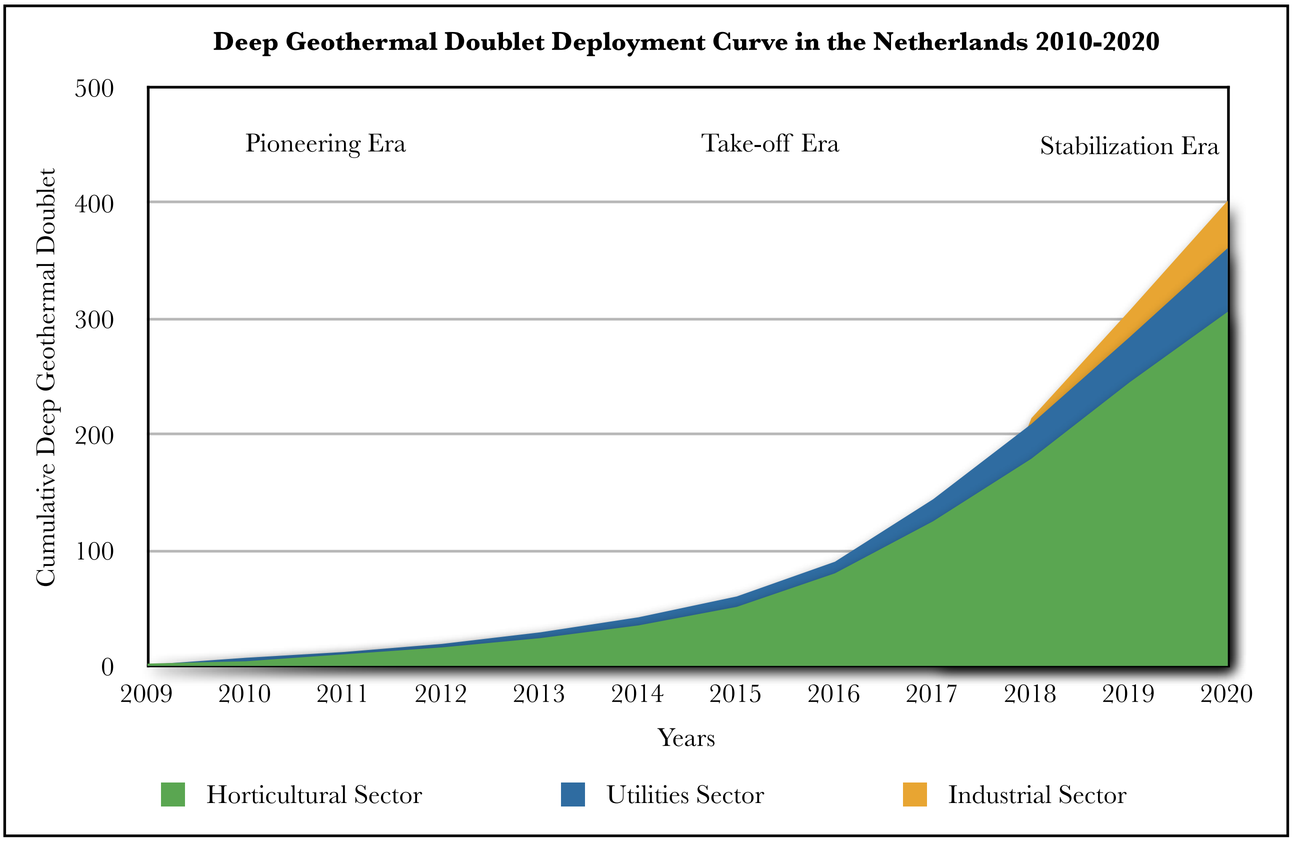

Figure 11: Deep Geothermal Doublet Deployment Curve in the Netherlands (2010-2020).

Up to 2014, approximately 30 deep geothermal doublets are realized, mainly in the horticultural sector. The implemented actions of the Dutch government and the deep geothermal supply market have increased deep geothermal project incentives within the horticultural sector due to improved business cases. Subsequently, more deep geothermal projects will be realized within the utilities sector. Figure 11 and 12 depict the deep geothermal market upscale process; the specific requirements for drilling rigs and specialized crews can be found in box 9.

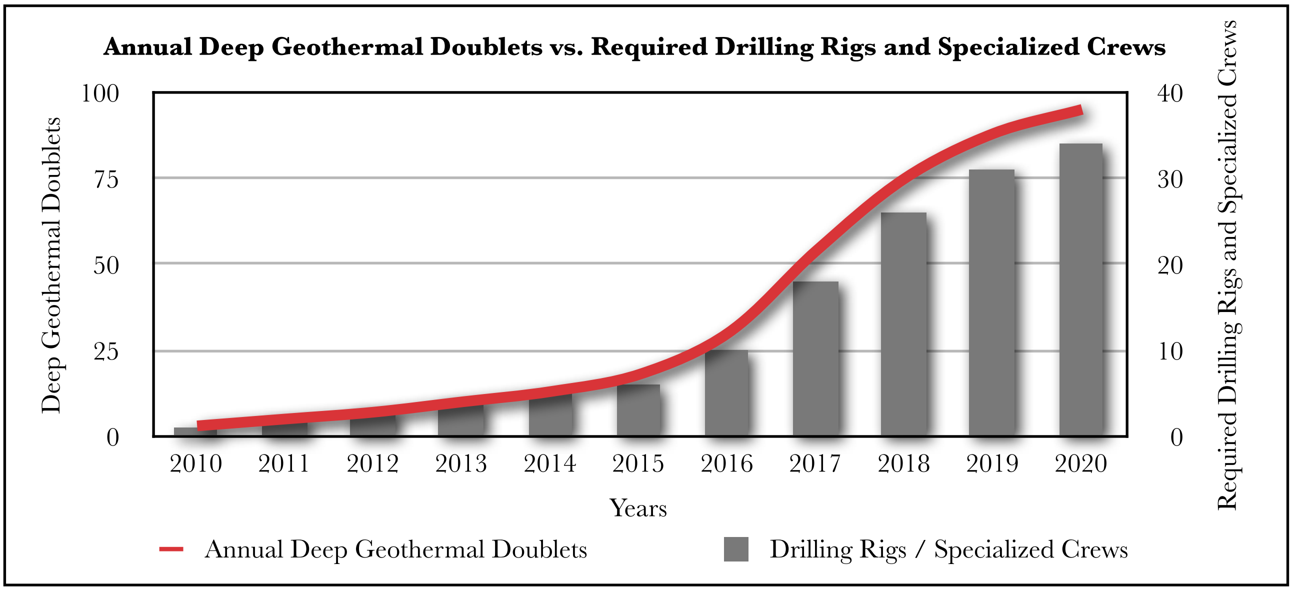

Figure 12: Annual Required Drilling Rigs and Specialized Crews in the Netherlands (2010-2020).

Furthermore, it is assumed that the composite casing drilling method of Delft University - firstly introduced in 2010 - can be commercially utilized in 2015. This will reduce drilling costs and therefore trigger more deep geothermal energy projects. Moreover, a first EGS pilot project is expected in 2016-2017, due to the Dutch research program - founded in 2010 - for ultra deep geothermal issues. At the end of the take-off era, some first signs of regional spatial limitation issues will show up in Zuid-Holland since the lion's share of deep geothermal energy doublets is realized in the (clustered) horticultural sector.

Box 9: Providing Sufficient Drilling Rigs and Human Capital

There are enough drilling rig suppliers active on the international deep geothermal market that have reasonable growth or redirection capability that could be brought in line on the short term. Nevertheless, the Dutch company Huisman Equipment BV alone can already provide for sufficient drilling rigs, since they can supply approximately four drilling rigs per year with current production facility capacity. But if necessary, other drilling rig supplier can be used as back up. Another option is to borrow drilling rigs from the oil and gas sector. The term borrowed is used because no drastic shift is expected from the oil and gas sector to the deep geothermal market until 2030, due to the fact that there will be a constant demand for oil and gas. The demand for oil is not affected by deep geothermal projects and although deep geothermal projects replace gas demand, gas will still be preferred above coal power plants in terms of CO_2-emission characteristics. However, since oil and gas demand fluctuates, drilling equipment (and human capital) may be temporarily used within the deep geothermal sector. One drilling rig can realize approximately three deep geothermal projects per year. In sum, the lack of sufficient drilling rigs can be remedied when planned well in advance.

The implemented educational and training programs by the Dutch government and the deep geothermal supply market - in 2011 - have taken care of the first human capital enlargement in 2013. This has to do with the fact that these educational programs are part of an existing education, therefore a range of two years is assumed for this first wave. Subsequently, personnel from other professions are trained and re-educated for the deep geothermal energy market in the Netherlands. Moreover, foreign personnel can be attracted in order to enhance the pool of human capital for deep geothermal energy projects. However, due to the booming deep geothermal markets in their own countries, this share will be negligible. Per drilling rig approximately 15 units of personnel are required for the drilling process itself, including one experienced drilling manager. This is based on the fact that approximately 4 employees are required in order to operate the drilling rig, and consequently, three shifts are required in order to drill 24 hours a day and 7 days a week.

According to the CBS (2010 pp.7, 218, 234) approximately 85.000 students graduate each year, among which approximately 11.000 in sciences, mathematics, informatics, technique, industry, and architecture as main educations in the Netherlands for both higher vocational education (HBO) and higher education (WO). Subsequently, Eurostat (2009 p.255) projected that approximately 8500 students graduate in science and technology studies in the Netherlands each year. It is assumed that approximately 0,5% of these graduates can be used for the deep geothermal market in the Netherlands. Moreover, this share will slightly increase over time, due to the introduced educational programs. Consequently, it is assumed that a similar amount of personnel can be attained through inter-profession mobility each year. This means that sufficient new human capital can be attained for the depicted deployment scenario in figure 11. Note that a large share of the required human capital also comes from intermediate vocational education (MBO), e.g. driller, assistant driller or roughneck. However, with respect to the experienced drilling engineers and experienced drilling supervisors, this is more difficult to realize. Therefore, apprentice programs should be implemented in 2011, allowing multiple prospective drilling engineers and drilling managers to gain experience so that they can realize projects after 4 or 5 years of practice. Furthermore, it is assumed that a small share - circa 5 - experienced drilling managers and experienced drilling engineers may be transferred from the oil and gas sector as from 2014. In sum, the lack of human capital can be remedied but must be planned well in advance.

Stabilization Era (2018-2020)

Within this period, the annual growth of deep geothermal doublets stabilizes to approximately 90 deep geothermal doublets a year. However, the deep geothermal market maintains to enlarge simultaneously due to the fact that more EGS projects will gradually be executed over time. These projects require deeper depths and therefore longer drilling periods. Therefore, the market more dedicated EGS drilling equipment and human capital is continuously required on the long run. Therefore, the following assumptions are made:

The horticultural sector continues to grow, however this also requires more CO_2-distribution pipelines and, due to the fact of spatial limitation issues in the subsurface, more district-heating systems in the horticultural sector. The utilities sector also continues to grow: more deep geothermal doublets are connected to district heating systems and newly built dwellings are provided with new district-heating systems connected to deep geothermal energy. In addition, more experience, i.e. knowledge, is gained with EGS projects in the Netherlands, which triggers the industrial sector into the Dutch deep geothermal market. Especially, since higher temperatures can be reached more effectively, which increases the potential demand for deep geothermal energy in the Netherlands. Ultimately, see table 2 for a quantitative overview of the made assumptions from 2010-2020[36].

Supply Constraints vs. Solutions	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Deep Geothermal Doublets (cumulative)	7	12	19	29	42	60	90	144	214	307	402
Deep Geothermal Doublets (annual)	4	5	7	10	13	18	30	54	70	93	95
Drilling Rigs (annual)	1,3	1,7	2,3	3,3	4,3	6,0	10,0	18,0	23,3	31,0	31,7
Production Capacity			4	8	12	16	20	24	28	32	36
Human Capital (cumulative)	20,0	25,0	35,0	50	65	90	150	270	350	465	475
Total Capacity (cumulative)				90	184	286	297	517	648	790	943
Education of Students (cumulative)				60	123	192	168	352	444	546	657
Inter-Profession Mobility (cumulative)				30	61	94	129	165	204	244	286
Experienced Human Capital (cumulative)				3,3	4,3	6,0	10,0	18,0	23,3	31,0	31,7
Total Capacity (cumulative)				10	10	10	15	19	26	38	45
Already Present (cumulative)				10	10	10	10	10	10	10	10
Share of Oil & Gas							5	5	5	5	5
Educated Personnel with Experience (cumulative)								4	11	23	30

Table 2: Quantitative Overview of Deep Geothermal Deployment Assumptions (2010-2020).

EGS Era (2020-2030)

Within this period, the transition process from deep geothermal towards EGS projects is put into practice resulting in a stabilization of annual doublet realizations. However, the annual growth of deep geothermal energy projects will slightly decrease over time, which is the outcome of the transition towards more EGS project, see figure 13. Towards 2030, the horticultural-, utilities-, and industrial- sector already show saturation effects. Ultimately, approximately 1000 deep geothermal/EGS doublets can be realized as a result of the implemented (major) efforts - started in 2011 - of the Dutch government and the deep geothermal supply market.

4.4 Conclusion

According to Hagedoorn (2009 p.1), Lokhorst & Wong (2007 pp.343-344), and SPG (2004 p.3), the Netherlands has good subsurface conditions for the utilization of deep geothermal energy since it has a geothermal gradient of approximately 30ºC per kilometer (depth) and has sufficient geothermal reservoirs that are suitable for the extraction of deep geothermal energy. Subsequently, based on the current developments and on the conclusions of Barbier (2002 pp. 61-62), Fridleifsson (1998 p.4), and MIT (2006 p.9), only minor advances are expected that will not substantially change the technology for the direct use of deep geothermal energy (the geothermal doublet and heat exchanger) in the coming years. Therefore, the direct use technology of deep geothermal energy is not considered as a possible constraint. Nevertheless, the deep geothermal market is still in its infancy in the Netherlands since there are only two real deep geothermal projects realized so far.

[36] The production capacity of Huisman, which is a Dutch drilling supplier, is approximately four drilling rigs per year. This individual production facility is already sufficient to supply the required drilling rigs. Subsequently, other drilling rig suppliers can also be used in order to enhance the drilling rig fleet. Moreover, drillings rigs may also be borrowed from the oil and gas sector. Furthermore, approximately 15 units of personnel are required per drilling rig. It is assumed that approximately 0,5% of the 8500 science and technology graduates and completed with approximately 20 graduates from intermediate vocational eduction can be supplied for deep geothermal energy projects. It is assumed that this will grow with 10% each year. Moreover, it is assumed that approximately 30 units of personnel from inter-profession mobility can be attainted, which will grow with 5% annually. Next, it is assumed that approximately 1 experienced supervisor per deep geothermal project is required. At this moment, it is assumed that approximately 10 experienced drilling managers are available for deep geothermal projects in the Netherlands. Subsequently, it is assumed that 5 more experienced drilling managers from the oil and gas sector will enter the deep geothermal market. Consequently, the supply of experienced drilling managers will be enlarged in 2017 due to the introduced apprentice programs of the Dutch deep geothermal market.

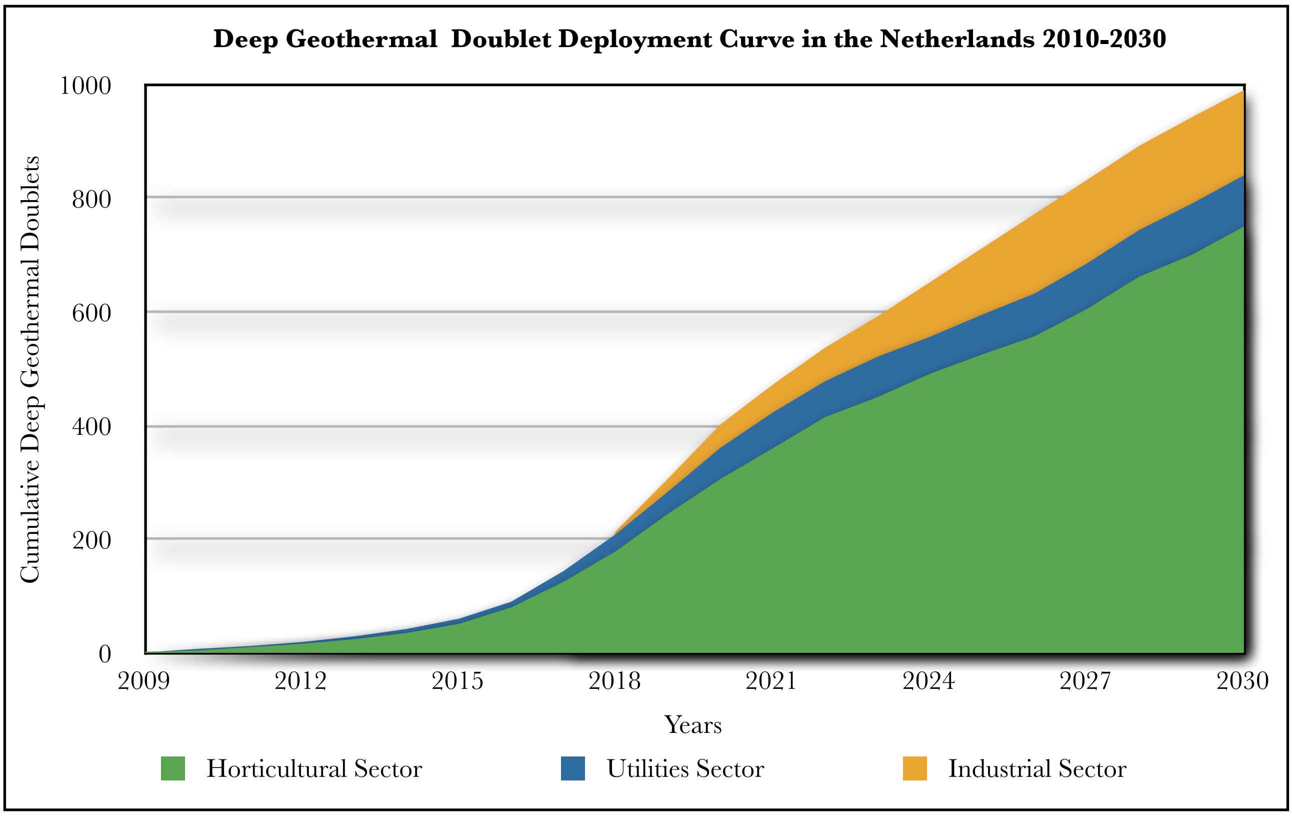

Figure 13: Deep Geothermal Doublet Deployment Curve in the Netherlands (2010-2030).

At present, the most important identified supply constraint is the availability of sufficient drilling equipment. Over time, the availability of required human capital will become the most important supply constraint. And following, competition for the utilization of the subsurface will limit the maximum deployment of deep geothermal projects. Environmental planning of the subsurface is therefore very important since heat demand is mainly concentrated in similar areas. Subsequently, there are sufficient possible projects in the current project pipeline, however more successful projects have to be realized in order to trigger more initiatives for - and realizations of - deep geothermal projects. Drilling method improvements, which lead to cost reductions, will increasingly de-clutch the negative influence of low gas prices on deep geothermal energy deployment over time. Consequently, consistent and long-term supportive policies form the basis for an optimal deployment of deep geothermal energy.

Furthermore, this research showed - supposing that the Dutch government, first, provides for long-term policies in their coalition agreement with a specific target for deep geothermal energy, second, implements the new deep geothermal application procedure, third, refines the existing deep geothermal guarantee scheme, fourth, provides for deep geothermal energy educational programs, and fifth, provides for more acquaintance about deep geothermal possibilities in different sectors; the deep geothermal supply market reacts by first, developing specialized training programs, second, providing initiatives for deep geothermal research programs, third, exchanging attained experiences, and fourth takes precautionary measures in order to solve anticipated supply constraints in advance - that approximately 400 deep geothermal doublets may be realized in 2020.

5. OFFSHORE WIND ENERGY

5.1 Introduction

5.1.1 Background

Wind is caused by the movement of air masses, due to different thermal conditions of these masses, and originates from the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and the rotation of the earth[37] (Ackermann & Söder 2002 p.83). Wind turbines convert this kinetic energy of the wind into mechanical power, where after a generator converts it into electricity (Ackermann & Söder 2000 p.330; Garud & Karnøe 2003 p.282).

The power of the wind has been utilized for at least 3000 years, for instance to navigate boats, to grind grain or to pump water (Sahin 2004 pp.503-504). Over the last decade, the amount of onshore wind turbines has grown rapidly; however, this expansion did not occur without problems (EWEA 2009 p.41). The development of onshore wind has in some cases been marked by social controversy[38], where visual impacts and noise were reported as main problems of onshore wind turbines (Devine-Wright 2004 p.127). In general, geographical potentials of onshore wind energy are still huge, nevertheless, some European countries already face saturation effects since suitable and financially viable onshore locations are becoming increasingly scarce (Markard & Petersen 2009 p.3545). For these reasons, and the current development in technology (with pre-series of 5MW turbines and beyond), offshore wind energy is becoming more feasible (Breton & Moe 2009 p.646; Larsen 2010 pp.25-26).

Offshore wind has certain advantages over onshore wind energy. Firstly, larger uninterrupted areas, which are suitable for major projects, are available at sea (Henderson 2003 p.35). Secondly, the average wind speed values are higher on sea than on land, approximately 30-50% (although it is site specific), and generally increase with distance from the shore[39] (Sahin 2004 p.530). Thirdly, less air turbulence occurs, which allow the turbines to harvest more effectively the available wind energy, and reduces the heavy loads on the turbine (Markard & Petersen 2009 p.3547). And fourthly, lower wind shear take place, which is the difference in wind speed and direction over a relatively short distance, allowing for the use of shorter towers (Henderson 2003 p.35). Altogether, offshore wind turbines can thus generate more electricity per installed capacity than onshore (Markard & Petersen 2009 p.3547).

Against these advantages, some drawbacks need to be mentioned. Firstly, the offshore environment is much more harmful due to higher wind speeds, waves, and salty conditions (Smit *et al.* 2007 p.6432). This requires specific technological solutions, such as the development and modeling of new materials required to withstand the offshore environment (Tavner 2008 p.4398). Secondly, the accessibility of the offshore wind turbine locations is far more difficult and depends on weather windows, which makes operating and maintenance, installation, and grid integration processes more expensive (Greenblatt *et al.* 2007 p.1475; Henderson 2003 p.36; Smit *et al.* 2007 p.6432).

5.1.2 Technology Description

Offshore wind technology is referred to as "one of the most advanced technologies in the field of new renewable energy sources" (Markard & Petersen 2009 p.3546). Currently, three-bladed turbines with horizontal axis, which are entirely based on onshore turbine designs, dominate the offshore wind market (Larsen 2010 p.25). A typical offshore turbine exists out the following main components: a foundation, a tower, a nacelle structure, a rotor hub with rotor blades, a power train, and a control and safety system (Bansal *et al.* 2002 p.2184), see figure 7.

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[37] See appendix B2 for more information about the physics of wind.

[38] The NIMBY (not in my backyard) issue mostly clarifies the resistance towards onshore wind turbine locations (Agterbosch *et al.* 2004 p.2049).

[39] An exception is, for instance, the United Kingdom where the speed-up factor over the hills means that the best wind resources are still close to shore (Henderson 2003 p.35).

Wind turbines require a stable foundation to keep the turbine upright under the most extreme conditions (Manwell *et al.* 2009 p.306). At present, different substructure designs exist but most used foundations are based on monopile technology and gravity-based structures (EWEA 2009a p.51). A transition piece connects the foundation and the tower, which together form the main frame of the wind turbine (Manwell *et al.* 2009 p.302). A nacelle, which contains the generator, gearbox, and the rotor hub, is mounted on top of the main frame (Ackermann & Söder 2000 p.332). The nacelle can be pointed towards the wind direction in case of strong winds, or moved out of the wind direction in case of too strong wind speeds, by means of different mechanical devices (Sahin 2004 p.518). The kinetic energy of the wind is captured by the aerodynamically shaped blades, which make them rotate around a horizontal hub that is connected to a shaft inside the nacelle (Breton & Moe 2009 p.650). This shaft powers a generator that converts the mechanical energy, which is increased via a gearbox[40], into electricity (Tavner 2008 p.4399). This is called the power train. The acquired power is then taken to an offshore node, which contains conversion equipment[41], by sub sea cables (EWEA 2009a p.29). The offshore node is connected to an onshore substation that imports the renewable energy into the onshore grid. However coastal regions are often less interconnected and can thus require an expansion of the grid in order to distribute the provided capacity (Markard & Petersen 2009 p.3547).

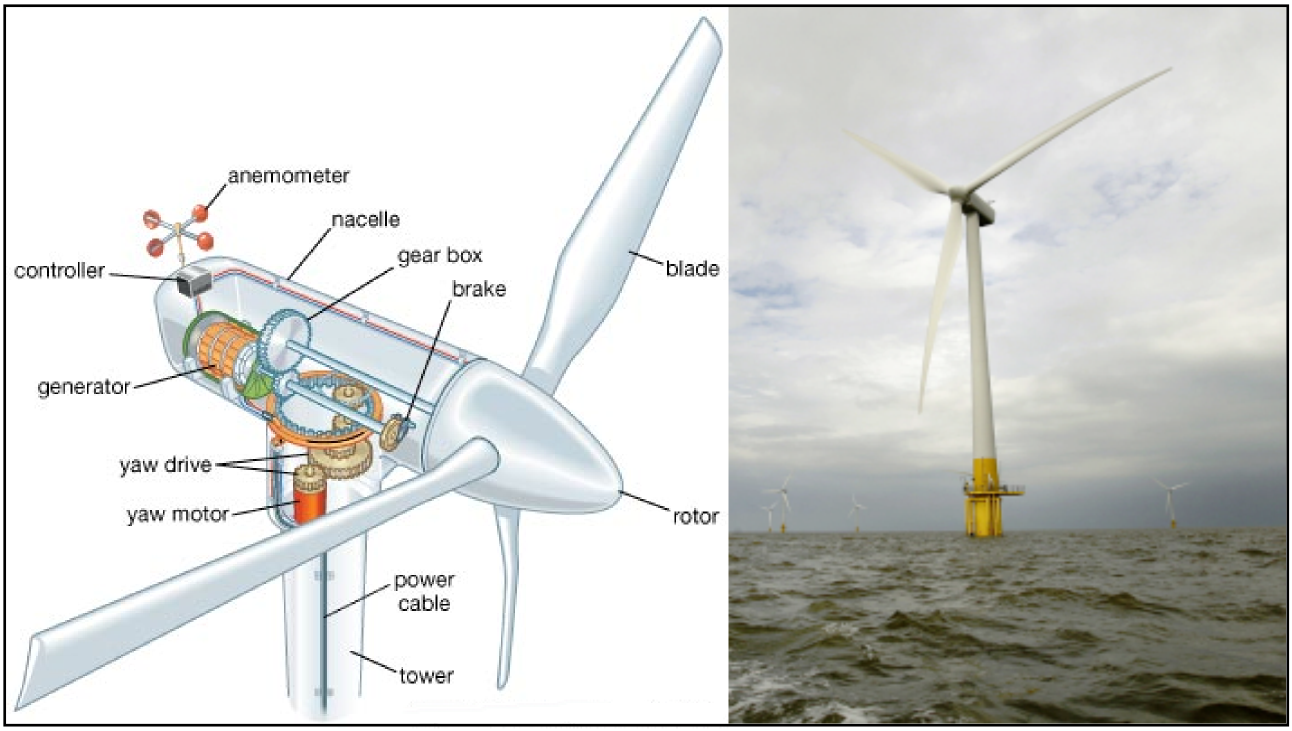

Figure 14: Main Components of an Offshore Wind Turbine

The highest efficiencies can be reached when the wind turbines use the wind speed for which the turbines are designed, which is usually between 12-20 m/s (Ackermann & Söder 2000 p.335; BWEA 2005 p.3). At these wind speeds, the full capacity is reached by the power output. Above the optimal wind speed, the power output must be limited in order to keep the power output close to the rated capacity and, thereby, reducing the total load on the rotor hub and the whole wind turbine structure (Sahin 2004 p.521). Hence, the control and safety system of a wind turbine can adjust the angles

[40] Within the current offshore wind turbine development pace, it is not clear whether the current gearbox concept (three-stage units) will be applicable for larger offshore turbines, since those will require an extra gearbox stage, which makes it more complex with higher failure probabilities (Henderson 2003 p.39). Therefore, direct drive systems are currently developed for new offshore wind turbine designs (Larsen 2010 p.25).

[41] Two high voltage-converting methods exist: alternating current (AC) and direct current (DC). The capital costs and electricity losses are higher for HVDC converter stations; while the costs of cables and losses per km is lower than corresponding HVAC converter stations (EWEA 2009a p.29). Therefore, a trade-off exists in the use of DC vs. AC, where AC lines are more preferable to connect wind clusters that are not far from the coast and vice versa (Weight *et al.* 2010 p.3170).

of the blades, also known as pitch control, or even stall the wind turbine when a certain high wind speed is reached, for instance in a storm (Ackermann & Söder 2000 p.336).

5.1.3 Offshore Wind Market in the Netherlands

Current Status

Large companies, many of which are from the electricity sector, mainly dominate the current offshore wind energy market since it is a capital intensive and risky business that requires particular financial and organizational resources (Markard & Petersen 2009 p.3535). Until 2010, two offshore wind farms are constructed and operational in the Netherlands: the Egmond aan Zee wind farm in Egmond aan Zee and the Prinses Amalia wind farm in IJmuiden. The Egmond aan Zee wind farm is located between 10 and 18 kilometers from shore, and is the first offshore wind farm which was built off the Dutch coast. This farm is fully operational since 2007. The Prinses Amalia offshore wind farm is located 23 kilometers from shore, and is therefore the first offshore wind farm that was constructed beyond the 12-mile limit. This farm is fully operational since 2008.

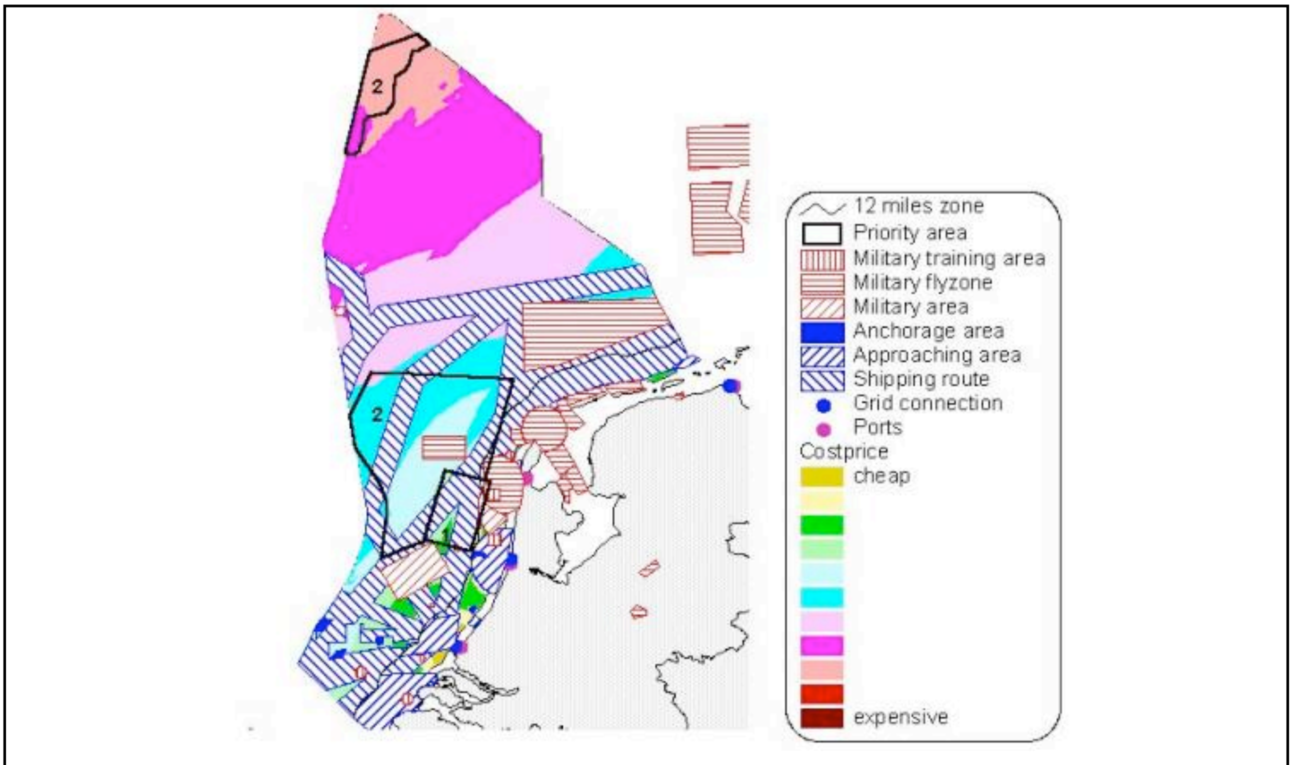

Figure 15: Dutch Offshore Wind Potential and Costs of Sites (Kooijman *et al.* 2003 p.3).

Offshore Wind Energy Potential in the Netherlands

According to Breton & Moe (2009 p.648) and Tambke *et al.* (2005 p.15), the average offshore wind speeds are very good at the North Sea, which increases with the height of the hub. The total surface area of the Dutch part of the North Sea is approximately 57.000 km^2 (Kooijman *et al.* 2003 p.3). However, limitations due to shipping lanes, oil and gas platforms, visual impacts (12 miles from coast zone), military practice areas, and nature preservation areas have to be taken into account and reduce the available space significantly (Markard & Petersen 2009 p.3547). Nevertheless, according to Kooijman *et al.* (2003 p.3) still more than 30.000 km^2 of the Dutch part of the North Sea is potentially available for offshore wind farms, see figure 9, however installation costs increases further offshore. Contrarily, the Dutch government has estimated that only 10.000 km^2 on the North Sea is potentially available for offshore wind (Creative

Energie 2007 p.8). In addition, FLOW[42] (2009 p.4), estimated that only about 3000 MW could be installed in near-shore areas[43], which means that the remaining capacity must be installed further offshore in typical water depths of more than 30 meters. The total costs associated with wind farms in far-shore regions are much higher than near-shore regions since a lot of research still has to be executed in order to drive the total costs down, including costs for installation-, grid connection-, and operation and maintenance processes (Larsen 2010 p.24).

5.1.4 Maturity of Technology

The technology for offshore wind is referred to as "partly immature" since it is mostly applied at near-shore areas for over slightly less than a decade (Breton & Moe 2009 p.649; Larsen 2010 p.24; Markard & Petersen 2009 p.3546). However, the offshore wind sector is an "emerging industrial giant", and it is expected to follow the same path as onshore energy in the past due to dramatically increased RD&D efforts and economies of scale (EWEA 2009a p.9). The main technological developments are attributed to the following subjects: offshore wind turbines, foundations, grid connection, installation, and operation and maintenance.

Offshore Wind Turbines

The design of wind turbines is constantly evolving, mostly due to cost reduction goals (Bansal *et al.* 2002 p.2184). To date, offshore wind turbines are still adjusted versions of the largest onshore wind designs, designed to withstand high capacity factors (Larsen 2010 p.25). But the current trend is to develop larger dedicated offshore wind turbines of 7 MW and beyond (Markard & Petersen 2009 p.3548). The main driver for this trend is to offer economies of scale since manufacturing, installation, and maintenance costs are mostly driven by the number of turbines instead of the turbine size (Carbon Trust 2008 p.42). The scale-effects of large offshore wind farms, therefore, seem to justify the extra costs for construction, grid connection, and maintenance (Markard & Petersen 2009 p.3546). Another important development is the current trend of turbine manufacturers to move to 'direct drive permanent magnet generators' in order to improve reliability[44] by avoiding gearboxes. Gearboxes are responsible for the greatest percentage of outage time (Ribrant & Bertling 2007 p.167; Li & Chen 2009 p.1175). The permanent magnet generator is a multi-pole and low speed generator, which is directly driven by the wind turbine (Wu *et al.* 2009 p.1661). Different types of direct-drive permanent magnet generators have been developed but the weight of such generators is a significant issue, requiring further design improvements (Fernandez *et al.* 2010 p. 1309; Mueller & McDonald 2009 p.768). In sum, increasing power output per square kilometer and improving the offshore wind turbine reliability is vital to the success of the offshore wind sector in the future, especially since larger machinery and increasing distances from coast can enhance the economic losses for non-operation and associated maintenance (EWEA 2009a p.48).

Offshore Wind Foundations

There are many different types of substructures, which all have their pros and cons. At present, there is no standard offshore substructure design, most used foundations are based on monopile technology and gravity-based structures (EWEA 2009a p.51). But with the prospects of offshore wind farms to go 'far-offshore' in the near future, other substructure types will become more cost-efficient, see table 1 for an overview.

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[42] A consortium of RWE, Eneco, TenneT, Ballast Nedam, Van Oord, IHC Merwede, 2-B Energy, XEMC Darwind, ECN, and TU Delft developed the Far and Large Offshore Wind (FLOW) program. It has two main objectives, first, to speed up the deployment of offshore wind by building a first 'far-offshore' demonstration wind farm, and second, to reduce the costs associated with offshore wind energy (FLOW 2009 p.8).

[43] A distinction is made between 'near-shore' and 'far-shore' areas. Typically, areas with distances below approximately 50 kilometers and water depths below approximately 30 meters are considered as near-shore. All other available areas for offshore wind are considered far-shore.

[44] The absence of a gearbox reduces the number of rotating parts and thus maintenance, which is an important item in the total costs in offshore wind energy production.

Type of structure	Brief physical description	Suitable water depths	Pros	Cons
Monopile steel	One supporting pillar	10-30m	Easy to manufacture, experience gained on previous projects	Piling noise, and competitiveness depending on seabed conditions and turbine weight
Monopile concrete (installed by drilling)	One supporting pillar	10-40m	Combination of proven methods. Cost effective, less environmental (noise) impact. Industrialization possible.	Heavy to transport
Gravity based	Concrete structure, used at Thornton bank	>40m	No pilling noise, inexpensive	Transportation can be problematic for heavy turbines. It requires a preparation of the seabed. Need heavy equipment to remove it.
Suction bucket	Steel cylinder with sealed top pressed into the ocean floor	n.a.	No pilling, relatively easy to install, easy to remove	Very sensitive to seabed conditions
Tripod / quadropod	3/4 legged structure	>40m	Less noise. Adequate for heavy large-scale turbines	Complex to manufacture, heavy to transport
Jacket	Lattice structure	>40m	Less noise. Adequate for heavy large-scale turbines	Expensive so far. Subject to wave loading and fatigue failure. Large offshore installation period (first piles, later on placing of structure and grouting) therefore sensitive for weather impact
Floating	Not in contact with seabed	>50m	Suitable for deep waters, allowing large energy potentials to be harnessed	Weight and cost stability, low track record for offshore wind
Semi submersible	Floating steel cylinder attached to seabed	120-700m	Very deep water, less steel	Expensive at this stage

Table 1: Overview of the Different Types of Substructures (EWEA 2009 p.50).

Offshore Grid Connection

Large-scale integration of wind power into the electrical energy system requires interaction with the rest of the production units in the system to make it possible for the system to secure a balance between supply and demand (Lund 2005 pp.2402-2412). This means that when wind power output falls, grid operators must be able to provide sufficient power from other production units to satisfy demand (Greenblatt *et al.* 2007 p.1475). In Germany, for example, the discrepancy between the power generated by the wind turbines on the North Sea and load concentrated in industrialized regions hundreds of kilometers away is particularly salient (Weight *et al.* 2009 p.3164). Another challenge is when offshore wind farm installments are too large, or the grid has a too small capacity, the total wind power output can exceed the total demand, whereby the excess wind power has an economic value of zero without storage[45] (Kennedy 2005 pp.1661-1662).

Furthermore, it is challenging to connect the offshore wind farms to the onshore grid since long distances have to be bridged, which also require special licensing procedures for underwater cables. In some cases the onshore grid tends to be less interconnected in coastal regions and therefore has to be expanded (Markard & Petersen 2009 p.3547). It is of utmost importance to plan this well in advance of the project in order to avoid delays and revenue losses (Gibson & Howsam 2010 p.4699). The EWEA, accordingly, launched its 20-year plan for an offshore energy grid in the North and Baltic Seas. They state that the entire European electricity grid needs to be "massively upgraded", underlining that a truly European grid, which harnesses renewable energies and improves security of supply, is "essential for a single European energy market" (Offshore Wind 2010a pp.48-49), see figure 16. Interconnection capacity minimizes load problems and reduces the loss of excess wind power, therefore flexible international exchange and markets may largely diminish the need for other integration solution for wind power in the Netherlands (Ummels 2009 p.140).

At present, high voltage alternating current (HVAC) cables and connections are regularly utilized for offshore wind farms but high voltage direct current (HVDC) cables and connections will be required for projects further offshore due to the fact that the losses per kilometer are lower (Carbon Trust 2008 p.37; EWEA 2009 p.29; Weight *et al.* 2010 p.

[45] For a brief overview of different energy storage possibilities, e.g. hydroelectricity or compressed-air storage, see Lindley (2010 pp.18-20).

3170). In sum, the integration of offshore wind power is challenging, and therefore requires new planning and operation processes, and planned grid expansion well in advance.

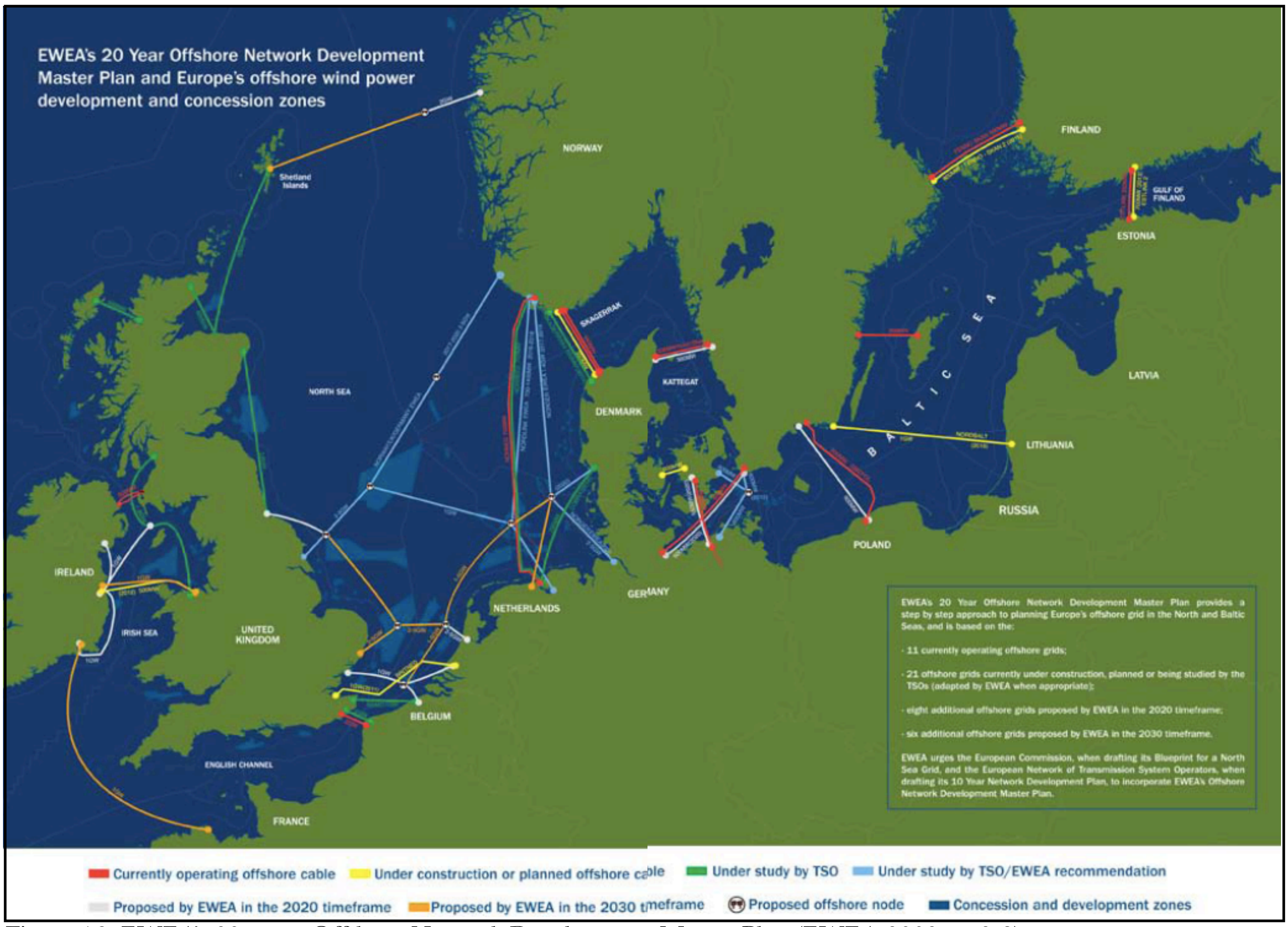

Figure 16: EWEA's 20-years Offshore Network Development Master Plan (EWEA 2009 pp.2-3).

Offshore Installation

At present, standard jack-up barges and some custom built-vessels are used for the installation of foundations and turbines (EWEA 2009 p.53). Jack-up barges are platforms, or even ships (jack-up vessels), with 4 of more legs that extend into the seabed and lift the vessel completely out of the water in order to install foundations and turbines more stably. But jack-up barges have some drawbacks. The lowering, raising, and repositioning of the legs takes a considerable amount of time and the water depth in which they can operate has to be less than 30 or 40 meters (Offshore Wind 2010b p.43). Furthermore, many of the installation vessels that are currently being used in the offshore wind sector are actually either too small, barely have enough lifting power, or are not as stable as they have to be (Offshore Wind 2010a p.15). More up-to-date installation vessels are often already booked in advance by the oil and gas industry (EWEA 2009 p.53). This means that contractors, regularly, can only choose between too large and unnecessarily multifunctional vessels, resulting in excessive day rates, or use smaller non-dedicated installation vessels, thereby taking more risks (Offshore Wind 2010a p.15).

There are three factors driving the current development of turbine installation vessels: first, the wind turbine size since larger turbines imply larger vessels, second, the water depth because when the water depth increases larger and more expensive vessels are required, and third, the distance from shore since this influences the transport costs (EWEA 2009 p.53). Many experts share the vision that self-elevating dedicated offshore wind vessels are best suited for operating in deeper waters, offering a large and stable platform for foundation and turbine installation (Offshore Wind 2010a p.17).

However, other concepts are also emerging such as the Dutch 'harbor at sea' concept, which can again reduce the demand for new self-elevating dedicated vessels for offshore wind purposes[46].

The installation of power cables is done by specialized vessels, which use a cable plough that digs a shallow trench in the seabed and buries the cable (Carbon Trust 2008 p.46). The installation of cables is not without risks; it is a difficult process to execute and there is a lot of opportunity to be "more efficient and to deliver more reliable installation equipment" (Larsen 2010 p.28). Both types of installation vessels, for foundations and turbines, and cables, depend heavily on weather conditions; new developments have to increase the weather window in which these vessels can operate (EWEA 2009a p.53).

In sum, offshore wind installation methods have not yet been optimized for large numbers of wind turbines. And according to the reflected trends, suitable installation capacity of turbines, foundations, and cables as well as suitable ports, storage and assembling facilities will be needed in the near future.

Offshore Operation and Maintenance

The main priority, in the context of operation and maintenance processes, is to increase the reliability of wind turbines and thereby minimize the unscheduled repairs (Carbon Trust 2008 p.47). Transfers to and from turbines can only occur with a significant wave height of 1.5m or less, using current transfer methods, and engineers may, therefore, only access the turbines from mid-April until the end of September (Offshore Wind 2010a p.21). But most damage occurs, naturally, in very windy conditions during other periods of the year. Therefore, the overall productivity output of an offshore wind farm would drastically improve if repairs and maintenance could be executed for a greater part of the year.

At present, most operation and maintenance access occurs via small crew transfer vessels (EWEA 2009 p.57). But future operation and maintenance activities can be conducted from offshore accommodation facilities, such as the 'harbor at sea' concept or floating jack-up hotel vessels, in a similar way that already occurs in the offshore oil and gas sector (Larsen 2010 p.29; Offshore Wind 2010a p.21). Improving operation and maintenance accessibility would drastically reduce travel times, especially for far-offshore wind farms. This can than reduce wind turbine downtime and thus the costs.

5.1.5 Conclusion

Based on the current developments and the conclusions of Breton & Moe (2009 p.649), Larsen (2010 p.24), and Markard & Petersen (2009 p.3546), major advances are expected to change the offshore wind turbine technology in order to push the capacity far beyond the current 5 MW capacity-level in the future. Besides the projected technological change, further developments are expected in the installation, operation, and maintenance procedures, especially when offshore wind farms will be developed far offshore. Therefore, offshore wind energy technology is considered as partly immature, which means that it is still at the beginning of the learning curve, especially for far offshore wind farms[47]. Therefore, developments are still focused on both learning processes, i.e. 'learning by searching' and 'learning by doing' (Suurs & Hekkert 2009 p.669), in terms of technology development and on improving installation and

[46] The harbor at sea design is an artificial island in the shape of a circle with a diameter of a kilometer, protected by a dike (Offshore Wind 2010a p. 37). The island itself is designed as a station for transporting, assembling, and maintaining offshore wind turbines and, therefore, can reduce the demand for new self-elevating dedicated vessels (EWEA 2009 p.61). Such an island reduces transportation time, increases harbor and storage capacity, and can also serve other functions such as recreation or lifeboat services (Offshore Wind 2010a p.37).

[47] In terms of near shore wind farms, the industry is at a demonstration phase and soon will enter a period of industrialization, which focuses on cost reductions by serial manufacturing and installation of wind turbines (Offshore Wind 2010 p.16).

maintenance processes. In addition, only two offshore wind parks are realized in the Netherlands so the Dutch offshore wind market is also still in its infancy.

5.2 Results

This section presents, first, the results of the phasing analysis for the Dutch project realization process and its coupled average throughput times under ideal circumstances, i.e. without delays. Second, it presents the identified supply constraints within the selected phases, including a classification of the identified supply constraints in order of importance over time. Third, it presents the key deployment factors, which determine the ideal growth of the supply market. And fourth, it presents the qualitative and quantitative assumptions that form the basis for the deployment scenario.

5.2.1 Phasing of an Average Offshore Wind Project in the Netherlands

The offshore wind energy timeline is analytically divided into four phases that describe the process from the actual start until the utilization of a typical offshore wind farm in the Netherlands, see figure 17. It is based on the assumption that both the Dutch government and business communities have ideal incentives to deploy offshore wind projects; therefore no major permit application procedure-, contracting-, or installation delays are taken into account. An extensive description of the four phases can be found in appendix C2.

Average Timeline for Offshore Wind Project Realization in the Netherlands

The first phase is the permit application phase for the utilization of offshore wind energy, which is the application process for a construction license. Basically, this license determines the terrain and period in which construction and producing activities for offshore wind energy are allowed. This procedure is applied under the Public Works and Water Management Act (WBr) and requires a mandatory Environmental Impact Assessment (MER). The average time spent on this phase is set to 18 months in this analysis. The second phase is the habitually complex front-end development and contracting phase which mainly consists out of development and contracting processes. The average time spent on this phase is set to 12 months in this analysis. The third phase is the manufacturing and installation phase in which the entire offshore wind farm has to be manufactured and installed. This includes the manufacturing of foundations, turbines, electrical equipment, and subsequently the installation of these components offshore. The average time spent on this phase is set to 48 months in this analysis. The last phase is the operation and maintenance phase, which covers all operation and maintenance activities undertaken once the wind farm is operational.

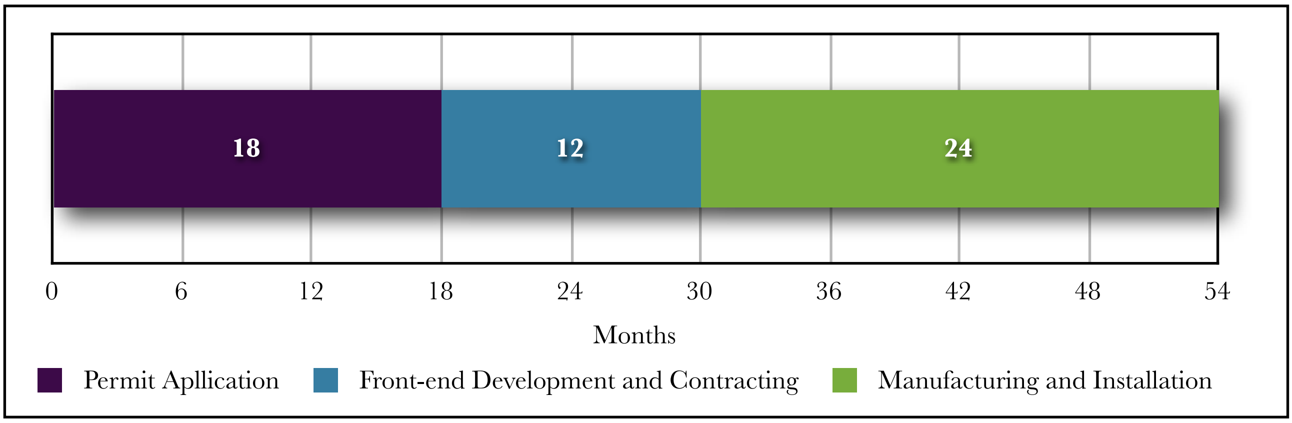

Figure 17: Average Offshore Wind Farm Realization Timeline in the Netherlands.

5.2.2 Offshore Wind Supply Constraints

This section describes the identified constraints per phase for the offshore wind realization process. The provided lists of suppliers are not intended to be exhaustive; given companies are mainly the leading active companies. It is recognized that for a study of this sort in a dynamic international sector, there may be omissions or incorrect designations of companies with significant capabilities.

Permit Application Phase

This phase is characterized by the permit procedure for a construction license and subsequently by the tender procedure for subsidies. As of 2010, around 20 wind farms are projected, where approximately 10 haven't applied for a construction license yet (Agentschap NL 2010). When the permit procedure carries on without delay, it is not expected that this phase will hamper the deployment of offshore wind energy projects since the responsible departments can be enlarged over time.

However, the current open license procedure has, in practice, several drawbacks. First, it is time consuming to find a suitable location and to obtain the required permits (NWEA 2010). Second, it is an inefficient procedure because many, often similar, environmental studies have to be conducted (Creatieve Energie 2007 p.10). And third, it imposes high financial risks to wind farm developers since construction- and subsidy concessions are not coupled in the Netherlands (Taskforce Windenergie op Zee 2010 p.4). As a solution to these drawbacks, the Dutch government has commenced three main proceedings. First, it has carried out an exploration of an optimal permit granting system by an interdepartmental offshore wind working-group (Anonymous 2010 pp.47-48). Second, it has set up a National Waterplan, which already designated two definitive and two possible offshore wind park areas in the North Sea[48] (National Waterplan 2010 p.5). And third, it has established a task force that examines how public-private partnerships could optimize permit-granting policy for offshore wind energy projects (Taskforce Windenergie op Zee p.5).

The designation of offshore wind energy project areas already accelerated current permit application procedures, and will increase even more if the Dutch government will provide the basic data, like soil- wave- and ecologic data, for these areas (Taskforce Windenergie op Zee 2010 p.16). This process can proceed even faster by integrating a department exceeding approach, where a central committee is responsible for all verification and authorization, in order to realize an effective and rapid deployment of offshore wind energy projects[49]. Finally, standardized approaches can accelerate the throughput time for offshore wind projects (Mast *et al.* 2007 p.1). In the United Kingdom for instance, complex procedures belong to the past[50].

Concluding, the current permit procedure reveals no hard constraints that can't be overcome due to the fact that the respective authorities are still streamlining the procedures since it is a new industry. When all proposals carry on through the permitting procedure without delay, this will not hamper the deployment of offshore wind energy projects. However, it is very important to address the above-mentioned issues in order to create sound boundary conditions in the

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[48] The first location is designated off the coast of Borselle ("Borselle") and the second is designated far off the coast of IJmuiden ("IJmuiden"). The other two possible areas are at north of the Wadden ("Wadden") and in front of the Dutch coast ("Hollandse Kust") (Taskforce Winenergie op Zee 2010 p.15).

[49] Such an approach forces an association, which represents all interests, where the government speaks with one voice, e.g. the Ministry of Economic Affairs, the Ministry of Housing, Spatial Planning and the Environment, the Ministry of Defense, the Ministry of Transport, Public Works and Water Management, and the Ministry of Agriculture, Nature and Food quality are all involved in the permit application process with their own interests. A developer can then present its plans to the steering committee and link up directly with government representatives.

[50] The Infrastructure Planning Commission (IPC) is an independent official body in the UK that acts in large-scale projects, among which onshore- and offshore wind projects, with the goal to use standardized procedures in order to come to less complicated and faster decision making. The IPC, as an independent body, is mandated to balance between national and regional interests, which radically speed up permitting processes.

Netherlands in order to attract investors and project developers, and thereby a significant part of the international supply chain, i.e. installation equipment and human capital.

Front-end Development and Contracting

This phase is characterized by development and contracting procedures, which are often complex and require qualified personnel who can execute these procedures successfully. Qualified personnel is currently available with knowledge about offshore construction and multi-contract handling. However, there are very few experienced players in the offshore wind field (Offshore Wind 2010a pp.10-11). Therefore, the first identified supply constraint is human capital, i.e. the lack of experienced contractors and offshore wind farm developers.

A second identified supply constraint is the planning of the grid connection in order to supply to the onshore grid. TenneT[51] estimated that approximately 4000 MW could be integrated in the existing grid without major adjustments to the network or balancing capacity[52] (TenneT 2005 p.2). But major adjustments are required when more offshore wind projects are realized, which have to be planned well in advance. A solution, besides the building of more natural gas fueled back-up power plants, is to create a pan-European electricity super highway, which will harness renewable energy technologies, including offshore wind, and improves security of supply (Offshore Wind 2010a p.49). But before such a network can be realized, the European Wind Energy Association (EWEA) stresses that the grid connection codes need to be harmonized in order to avoid unclear connection procedures and to optimize the operation of the entire power system (EWEA 2009 p.2). As a last, a smart energy network could harness offshore wind energy even more, due to the fact that excessive wind energy can be stored in electrical vehicles at night for back-up in the morning and evening when electricity demand is at its peak; however this requires a total shift in the current energy system which is not expected on the short run (Lindley 2010 p.20).

The last identified supply constraint is the spatial availability at the Dutch part of the North Sea. There is a certain zone in which different wind farms can interfere, which is called the wake-effect (Christiansen & Hasager 2005 pp.251, 253-255), but since there is a large spatial area available at the North Sea, this is not seen as a serious bottleneck on the mid-term run. However, this entails that the 'low hanging fruit', i.e. the near-shore sites, will be picked first since sites further off the coast require other, and more expensive, foundations and installation equipment due to deeper water depths.

Concluding, the availability of human capital, e.g. project developers, project managers, or contractors, is considered a supply constraint. This can be overcome to provide for educational intern programs, for instance for apprentices, in order to gain experience due to involvement in offshore wind energy projects. Another option is to use a part of the required human capital from the oil and gas industry[53]. So this supply constraint can be overcome, nevertheless, at this moment external communication, and thereby sharing of experience, is unsatisfactory due to the heavy competition between firms that do not want to share their obtained experience (Offshore Wind 2010a pp.32-35; Offshore Wind 2010b p.31). So this has to change in order to create more experienced human capital in the coming years. Grid

[51] TenneT is the Dutch Transmission System Operator (TSO), which carries out statutory tasks related to managing the Dutch transmission grid and maintaining the balance between supply and demand in the electricity grid.

[52] This is a penetration of approximately 10-15% of the gross electricity generation in the Netherlands. And since the Netherlands has a very large stock of natural gas fueled plants, which are very compatible with offshore wind energy due to adjustments within one hour; this would not require major adjustments (TenneT 2005 p.2). However, planned coal fired power plants form a serious tread to this, e.g. see Rooijers *et al.* (2009 pp.24-31) for an overview of current and planned electricity capacity enlargements.

[53] A total shift of human capital is not expected from the oil and gas sector is not expected on the short run. The demand for oil is not affected by offshore wind energy projects and the same holds for the demand for gas. Although offshore wind energy partially replaces electricity generated from fossil fuels, gas will still be preferred above coal power plants, due to their flexible characteristics as back-up capacity. So the demand, and employment, for oil and gas will stay at a similar level in the years to come.

connection does not have to be a serious bottleneck when planned well in advance, also internationally in order to sustain the balance between supply and demand of electricity and to avoid connection delays. Spatial issues will only arise on the long term, although resistance within certain near-shore areas from other interest groups is already rather strong.

Manufacturing and Installation Phase

This phase is characterized by manufacturing and installation procedures of offshore wind energy projects. The first identified supply constraint is the availability of offshore wind turbines. Traditionally, the availability of offshore wind turbines depended mainly on the growth of the onshore wind energy market since most offshore wind turbines are adaptations of onshore designs[54] (EWEA 2009a p.41). However, the current offshore market is becoming more relaxed since more wind turbine manufacturers have entered the offshore market resulting in increased competition and turbine availability[55], which will drive the costs down in the medium term. Nevertheless, wind turbine supply remains a critical constraint since no single Dutch turbine manufacturer is active in the offshore wind energy industry[56]. However, the offshore wind industry is an international affair, where Vestas and Siemens have the highest market shares in Europe. Other, at this moment smaller, offshore wind turbine manufacturers are REpower, BARD, Multibrid, and Nordex. In addition, other European companies are also striving to enter in the offshore wind turbine market on the short run, among which: XEMC/Darwind, Deawoo/DeWind, Clipper, GE/Scanwind, Gamesa, Enercon, Acciona, Mitsubishi, and Samsung[57].

The second identified supply constraint is the availability of substructures, i.e. the foundations of offshore wind turbines. This is a relatively small niche for large cap companies or is carried out by small manufacturers (BVG 2009 p.31). Conversely, foundations require the greatest increase in new factory capacity, new technologies to support larger turbines in mid-depth and deep water, and new higher volume manufacturing techniques to deliver economies of scale (Carbon Trust 2008 p.65). At present, there are multiple Dutch foundation manufacturers active in the offshore wind energy field, which are Sif/Smulders Groep, Ballast Nedam, and van Oord. Consequently, other foreign companies are also active such as Corus, MT Højgaard, Aarsleff, Bilfinger and Berger, Hochtief, Züblin, BiFab, NCC Construction, Blaft, and Dredging International. Altogether, these manufacturers combined have sufficient capacity and they have a reasonable growth or redirection capability that could be brought in line in less than a year (BWEA 2007 p.17). New entrants are also establishing, for instance EEW, and other potential entrants exist if the market requires extra capacity, e.g. companies within the oil and gas industry. However, due to quality and certification issues, currently, only a handful of European steel suppliers are used; therefore the likely limit to production is the availability of sufficient quality steel plates instead of foundation manufacturing companies (BWEA 2007 p.17). Consequently, most foundations, which are mainly made of steel, are affected by the global steel prices that make the choice of optimum foundation a function of volatile commodity markets[58]. In time, also qualitative steel suppliers from China will probably enter the European market (BWEA 2007 p.18).

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[54] The onshore wind turbine is less risky than the offshore turbine market, which causes bottlenecks in periods with high onshore demand. On the short term, this means that the offshore wind sector will be squeezed by global onshore market successes (Carbon Trust 2008 p.61).

[55] The availability of component supply is also very important since components, for instance gearboxes (including large bearings and steel), generators, large castings, and forgings, are crucial in order to assemble and to supply complete offshore wind turbines to the market.

[56] The only Dutch offshore turbine manufacturer was DarwinD, however, this company is taken over by the Chinese company XEMC due to the collapse of Econcern.

[57] Chinese manufacturers are also entering the offshore market such as Windtec and Sinovel, which will probably also compete in the European market, despite their transportation disadvantages, in the future (Carbon Trust 2008 p.64).

[58] A solution is the use of recycled steel from ships and oil and gas facilities (BVG 2009 p.31).

The third identified supply constraint is the availability of high voltage subsea cables, which are a necessity in order to transfer electricity from the offshore wind park locations to the onshore grid. More specifically, these are the inter-array (in-field), export (out-field), and also onshore grid expansion cables, where the main bottleneck is the export cable. At this moment, only three established players are active within the offshore market that offer export cables: Nexans, Prysmian, and ABB. Until now, offshore wind farm deployment has mainly be delayed by consenting or economic problems, but there is a consensus that if all projected wind farms are going to be realized a significant shortage of high voltage cables occurs unless further investments are taken in advance. Recently, NKT has entered this market and Draka, General Cable/NSW, JDR, and Parker Scanrope will likely enter the market in near future. Nevertheless, based on the current capacity and enlargement possibilities the supply of the export cables can be scaled up within a few years[59] (BVG 2009 p.28). Inter-array cable manufacturing is not considered as a bottleneck since the new entrants barriers are much lower and the establishment of new production lines is easier to realize. In addition, the supply of offshore substation transformers is tight, but it is not expected that this will be a bottleneck since the there is only a small fraction of global demand for transformers of this size, and therefore, sufficient supply will be available (BVG 2009 p. 32). Current offshore electrics suppliers are ArevaT&D, EDF, Siemens T&D, and Tiron, where Pauwels will soon enter this market. Nevertheless, production enlargement is still necessary since lead times for substation transformers can last up until 2 years.

The fourth identified supply constraint is the availability of installation vessels that have to install the foundations and turbine components in the offshore environment. There is a range of installation vessels operative at this moment, each with their own characteristics and specialism. For the installation of turbines jack-up barges and self propelled vessels are used, among which JB-109, SEA Worker, MPI Resolution, LISA, JB-114, JB-115, BARD Wind Lift I, SeaJacks Leviathan, and SeaJacks Kraken. Other vessels are also used to install turbines such as Eide, Rambiz, and Svanen. At this moment there is a lack of sufficient installation vessels, even more since it is an international affair. Currently, new installation vessels are being built such as the MPI Adventure, MPI Discovery, Shamal, Scirocco, Wind Carrier no.1, Wind Carrier no.2, Hull L209 DDW, Inwind, Gaoh, and Blue Ocean, but more are needed. A new trend is that turbine manufacturers are building own installation vessels in order to offer integrated services. An example is BARD, which hereby reduces the dependency on external installation vessels for their tripod foundation and 5MW turbine installation procedures. In addition, new turbine and foundations designs can be optimized to minimize installation time and the need for specialized transportation equipment. The usage of installation vessels that cannot meet demand completely is strongly discouraged[60]. Another possibility is to rent dedicated vessels from the oil and gas sector, such as the CW Heavy lift, for the installation of foundations and turbines. But these vessels are often too large and unnecessarily functional for the offshore wind business due to larger crane lifting capacity than necessary; resulting in disproportionate day rates for offshore wind projects (EWEA 2009 p.53; Offshore Wind 2010a p.15). Another bottleneck is the piling season restriction, which means that within this period no foundations can be installed[61].

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[59] A single extrusion line can produce around 200 km of core per year, bringing a completely new line on stream can take up to four years since it takes 2 years to test and certificate new cables. However, existing suppliers asserted that it is possible to expand production within 12-18 months (BVG 2009 p.28).

[60] For instance, E.ON had to lease the Resolution, which is fully dedicated installation vessel for the offshore wind business, from Certica when the Sea Jack collapsed and a leg of the LISA A sank into the seabed, which as a result increased the total project costs (Carbon Trust 2008 p.69).

[61] Most types of foundations require piling procedures, which is restricted in the Netherlands from 1 January until 1 July. However, there are other methods to install foundations, for instance drilling methods, but it is preferable to change the current seasonal restriction into a maximal noise level for piling procedures throughout the whole year, as is already implemented in, for example, Germany (Taskforce Windenergie 2010 p.41).

The fifth identified supply constraint is the availability of dedicated cable laying installation vessels for 'outfield' electricity cables[62], which are the export cables from the offshore wind park to the connection point of the onshore grid, i.e. an onshore substation (Offshore Wind 2010b p.41). There are sufficient installation vessels that can, theoretically, install electricity cables. However, the installation of outfield electricity cables often require specialized tools, depending on the subsoil conditions, since cable faults due to poor installation have been a source of disturbance of operating wind farms[63] (BVG 2009 p.36). Hence, the use of experienced cable laying contractors, with their special dedicated cable plough and remote operated underwater vehicle equipment, offers significant advantages (BWEA 2007 p.16). At this moment, only two dedicated cable installation vessels are active within the offshore wind market, which are the Skagerrak and Team Oman, and are owned by the cable manufacturers such as Nexans[64]. Though, a pool of other vessels can also be used to install electrical cables, among which the Coastal Spider, the ATM Explorer, Cable Innovator, Stemit Spirit, Ocean Intervention I, Ocean Intervention II, and the Giulio Verne. Nevertheless, the current trend is that more experienced players are priced out of the market, with the result that cable installation procedures are executed by less experienced players that can cause more insufficient qualities (BVG 2009 p.36). There is also no consensus on the best cable installation method, deep burial versus shallow burial. At this moment, shallow burial coupled with routine checks is seen as the best preferable option since it is a less complex process. The offshore wind energy industry can benefit from lessons learned in the offshore oil and gas industry where they have created standards under the Umbilical Manufacturers' Federation group, which meets to review standards and best practice for umbilical cable installation processes (BVG 2009 p.36).

The sixth identified supply constraint is the availability of ports, which are a necessity to service offshore installation work. The Netherlands has a number of ports from where it is possible to operate, where Rotterdam is the largest well-developed port with good connected infrastructure. However, other ports can also be used in the Netherlands such as IJmuiden, which gained experience with the installation of the existing offshore wind parks: the Prinses Amalia and Egmond aan Zee. In addition, the port of Den Helder can also be used as it has gained experience in servicing and offering maintenance and operation activities in the oil and gas sector, which can be translated to the offshore wind sector (Offshore Wind 2010b p.37). In the northern parts of the Netherlands, Eemshaven can play a role in wind farm installation processes, as well as the port of Vlissingen in the southern parts of the Netherlands. However, it is important to have sufficient quay surface available for (pre)assemble processes of the different components and to offer a good logistic connection for the supply of the different components and the installation of these components offshore[65]. When necessary, German ports such as Bremerhaven, Hamburg, Wilhelmshaven, and Cuxhaven, or British ports such as Aberdeen, Edinburgh, and Newcastle, offer additional capacity possibilities. The availability of ports will however not be a great supply constraint. Nevertheless, it can slightly hamper offshore wind deployment in the Netherlands when the international industry booms simultaneously, since port enlargements require huge efforts and time; assuming that Dutch offshore wind projects are given preferential treatment within Dutch ports.

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[62] Contrarily, infield electricity cables, i.e. inter-array cables, are the cables that connect the individual offshore wind turbines to an offshore electrical transformation substation.

[63] An example is the installation of the export cable in the Thornton Bank wind farm; the cable needed to be cut off when ploughshares that lay the cable trench in the seabed got stuck in an unknown obstacle, even after a thoroughly investigation of the route in advance and removal of several objects including a car wreck and a Second World War bomb (Offshore 2010a p.34).

[64] Nexans is a worldwide leader in the cable industry and offers different cables and cabling systems. Nexans has an own cable installation vessel, which is the fist purposely built vessel for the transport and installation of high-voltage power cables and umbilical's, named the Skagerrak. This vessel has also installed the NorNed cable(s) between Kvinesdal (Norway) and Eemshaven (the Netherlands), which is laid at depths of up to 410 meter and is 156 kilometers long. In addition, the Team Oman has installed the BritNed cable between the Isle of Grain on the River Medway in the UK and the Maasvlakte near Rotterdam, with a distance of 260 km.

[65] Besides geological considerations, i.e. as close as possible to the offshore wind park site, also draught, quay, open access, and ground condition characteristics can determine the best available port for a offshore wind park project.

The last identified supply constraint in this phase is the shortage of human capital, i.e. experienced personnel with the essential skills, that can operate installation equipment or supervise offshore wind installation projects. Therefore, investments are needed in training and skill development in order to create a skilled workforce, which is capable to operate the equipment needed in the upscale process of the supply chain. Subsequently, it is much harsher to create experienced human capital, which have to supervise projects, particularly given the long lead times associated with education and gaining experience. However, experienced offshore human capital can, to a certain extent, be borrowed from the oil and gas sector offshore. But it is very important to invest in educational and training programs to create this pool of project managers, for instance to involve apprentices in offshore projects in order to gain experience, and to share more knowledge between companies in order to learn from each other (Offshore Wind 2010a p.33). In addition, this issue concerns the entire offshore wind sector because when random projects fail this would have significant impacts on the image of the entire industry, which is not desirable.

Concluding, many supply constraints are identified in this phase. First, the manufacturing of turbines, foundations, and electrical equipment needs to be up scaled, second, the required installation equipment needs to be enlarged, third logistic facilities must be prepared, and fourth, sufficient human capital needs to be created in order to meet demand over time. Consequently, future development of offshore installation equipment depends largely on offshore wind farm requirements since these differ between far and near-shore wind parks. Adding to, insufficiently shared information between companies operating in the upper end of the supply chain forms a bottleneck for manufacturing firms the bottom of the supply chain in order to adapt and optimize their products and thereby reducing the large investment risks involved with offshore wind projects. Therefore, these uncertainties have to be remedied because these affect the respective technological market in order to form a cost-effective supply chain, which stimulate offshore wind energy deployment.

Maintenance and Operation Phase

This phase covers all operation and maintenance activities undertaken once the offshore wind park is operational. The first identified supply constraint is the availability of human capital, i.e. skilled personnel that can execute maintenance and operational activities offshore. This kind of personnel will require a technical background but can, unlike project managers, (re)educated on a relatively short time scale or even be borrowed from the oil and gas sector. Survey vessels are not considered as a possible bottleneck since there exist many variants and this fleet can also be enlarged within a relatively short time scale. Adding to, when wind farms will be located far offshore than survey vessels would not be the best option since transportations will take more time and therefore increase costs. Other options are survey helicopters, but these are more expensive, floating hotel vessels and artificial islands where repair crews can stay during maintenance and operational activities, thereby reducing transportation costs.

Concluding, when offshore wind energy projects increase in large numbers then specialized maintenance and operational personnel may become a serious bottleneck since energy, and revenue, is lost when a wind turbine is not operative due to technical issues. Adding to, the accessibility issues of far offshore wind parks will require new solutions for maintenance and operational activities.

Conclusion

At present, the most important identified supply constraints are the availability of sufficient installation equipment for turbines, foundations and electrical equipment as well as sufficient manufacturing capacity for offshore wind turbines (especially large turbines), and electrical cables. Subsequently, human capital - particularly for installation processes but also for operation and maintenance and contracting procedures - will be a serious bottleneck. Next, the supply of of foundations, the availability of sufficient ports, and connection to the grid will be important supply constraints. Furthermore, spatial issues will hamper the maximum deployment potential of offshore wind energy projects.

5.2.3 Offshore Wind Key Deployment Factors

This section describes the key deployment factors, which determine the ideal market uptake of offshore wind energy projects. The following key factors are considered: the current project pipeline, maturity of technology, knowledge exchange, exogenous developments, policy measures, and social acceptance. After the introduction of these factors a conclusion is given for an optimal upscale scenario of offshore wind energy projects.

Project Pipeline

Up to 2010, the Dutch State Secretary of the Ministry of Transport, Public works and Water Management has approved 12 construction license applications, which in total consists out of approximately 800 wind turbines that have an expected production capacity of 3,2GW (Offshore Wind 2010a p.43). However, approximately 70 permit application request were submitted to the Dutch licensing authority and some new projects are already projected or under planning, which means that more construction licenses will be approved over time (Agentschap NL 2010).

Maturity of Technology

Offshore wind technology is considered as partly immature, which means that the technology is commercialized for near-shore locations but is still at the beginning of the learning curve for locations far offshore (Breton & Moe 2009 p. 649; Larsen 2010 p.24). Major advances are expected with regard to technological change, e.g. larger dedicated offshore wind turbines of 7 MW and beyond, direct drive permanent magnet generators, new and improved substructure designs[66], and technological advances related to installation methods and operative and maintenance processes[67] for locations further off coast.

Knowledge Exchange

Practical knowledge is insufficiently shared between organizations in the offshore wind supply chain, although this is very important in this stage of development (Offshore Wind 2010a p.32). Currently, the heavy competition causes firms to keep their experiences internally, which has to change in order to form an experienced pool of human capital and a cost-effective supply chain that both stimulate offshore wind energy deployment. Consequently, the far and large offshore wind research program has been introduced, which consists of an ambitious R&D plan and a demonstration wind farm 75 km off the Dutch coast in 35 meters water depths (FLOW 2010 p.3). This program is introduced after the formerly closed public research program We@Sea and will provide more practical knowledge about offshore wind farm issues further offshore in the Netherlands. Subsequently, it aims to enable Dutch companies to claim a leading position on the international market for offshore wind energy (FLOW 2010 p.3).

Exogenous Developments

The fall of the Dutch cabinet in 2010 has consequences for the deployment of offshore wind energy projects since it takes time to come up with a new coalition agreement. In addition, the current SDE subsidiary instrument for electricity generation from renewable energy sources, including offshore wind, is under dispute since the decommissioned minister

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[66] For example, the Egmond aan Zee wind farm had experienced grouting settlement issues, which causes the transition pieces to sink several centimeters into the monopile foundations beyond the levels of design. In three of the 36 turbines, the bottom half of the monopile were to be filled with concrete to create a solid basis to prevent further slippage (Offshore Wind 2010a p.41). This caused that Det Norske Veritas (DNV), as the certification authority for these offshore wind turbine structures, has therefore temporarily withdrawn its certification standards for grouted connections.

[67] An innovative example is the Ampelmann access system, which makes it possible to access turbines in rough weather on heavy seas, thereby expanding the time frame in which it is possible to service offshore wind parks (Offshore 2010a p.24).

of Economic Affairs already proposed to abolish the current SDE subsidiary instrument. Other external developments that affect offshore wind deployment in the Netherlands are the projections of other countries, such as the United Kingdom, Denmark, and Germany, which also devoted offshore wind as a major contributor for their renewable energy targets. The EWEA translated these projections into a European vision of 40GW of installed capacity in 2020 and 150GW in 2030 (Offshore Wind 2010b p.30). In other words, an explosion of developments and deployment in the offshore wind energy market is expected in Europe.

Policy Measures

As reflected in many studies, clear and consistent long-term policy is a necessity for renewable energy technology deployment (Foxon & Pearson 2008 p.159; Negro et al. 2009 pp.29-30). By sending clear positive signals to the industry, e.g. by attracting a financial climate and appointing dedicated areas for offshore wind developments and electricity interconnectors, organizations within the supply chain can seek investment in key elements of the supply chain, e.g. turbine components, cables, vessels, human capital, while potentially lowering the risks and capital costs. Therefore, further streamlining the regulatory framework is a necessity for the deployment of offshore wind projects. A good example is the introduction of the National Waterplan in 2011, which outlines the long-term usage of the North Sea including new sections suitable for offshore wind farm development (Offshore Wind 2010a p.43). However, other issues regarding permit application procedures must be remedied, such as the multiple ministries that are involved within this process, the often-overlapping EIS studies that need to be executed, and the coupling of subsidiary measures to permit application procedures, in order to create standardized approaches that accelerate the total throughput time of offshore wind projects.

Social Acceptance

It is not expected that society will play a crucial hampering role in offshore wind deployment in the Netherlands since the NIMBY issues, e.g. visual or noise pollution, play no role offshore. Nevertheless, it must be mentioned that resistance from interest groups is rather strong with regard to locations near-shore that cross shipping lanes or military practice zones. However, this is not considered very important because sufficient other areas are available for offshore wind parks. A last social opposite issue can be the large subsidies that are required for offshore wind projects, especially on the short run. Nevertheless, wind energy will provide greater price certainty than gas in the future and can act as a hedge against potential future fuel price rises[68].

Conclusion

There are sufficient possible projects in the current project pipeline, however it is important to realize these projects successfully in order to trigger more initiatives and larger offshore wind farm designs. At this moment, practical knowledge is insufficiently exchanged among organizations within the offshore wind supply chain and needs to be improved in order to create an experienced pool of human capital and cost-effective supply chain. The governmental election process and the projected boom in the European offshore wind industry are exogenous development that are hard to direct or influence. Nevertheless, by refining and streamlining the current policy measures and thereby attracting a financial climate, organizations within the supply chain can seek investment in key elements resulting in lower risks and capital costs. Therefore, consistent and long-term supportive policies form the basis for an optimal deployment of offshore wind energy. A steady upscale of offshore wind projects is of utmost importance, which will be characterized by three main upscale periods: first a grounding area (2010-2014) in which more successful offshore wind projects have to be realized, second, a take-off era (2015-2018), and third, a shifting era (2018-2020).

[68] In addition, wind power may also lead to result in lower average annual prices paid by consumers for gas heating. The load factor of wind peaks in the winter months when gas demand for both heating and electricity is at its peak. Wind, by reducing overall demand for gas at that time of the year when it is most expensive, may lower the price of gas for home heating.

5.2.4 Offshore Wind Deployment Scenario

This section describes a scenario in which offshore wind energy projects could optimally be deployed through an up scaling process until 2020, and gives an outlook to 2030. It presents the assumptions made for the deployment scenario, and presents the final outcome of the deployment scenario. The historic deployment of offshore wind energy in the Netherlands can be found in appendix D2.

Synthesis of Data

The optimal deployment scenario, presented in this research, will not occur straightforwardly. This means that radical efforts are required from the Dutch government and the offshore wind industry in order to realize the depicted deployment scenario.

Box 10: Potential Demand for Offshore Wind Projects in the Netherlands

The potential demand for offshore wind is, hypothetically, equal to the total electricity demand in the Netherlands, which is approximately 430PJ (see box 14), since consumers mainly ask for energy and not for specific renewable energy technologies (Jacobsson & Johnson 2000 p.631). However, the supply of wind fluctuates and offshore wind technology can therefore not be used as base-load supply of electricity without back-up capacity (Tambke *et al.* 2005 p.3). A solution, besides the building of more natural gas fueled back-up power plants, is to create a pan-European electricity grid because flexible international change may largely diminish the need for other integration solutions for wind power (Ummels 2009 p.140).

At this moment, electricity that is generated with renewable energy sources is given priority in the merit order as stated in the 'Priority for Sustainable' regulation of the Dutch government (Rooijers *et al.* 2009 pp.17-18). Nevertheless, it is not expected that the entire base-load capacity will be replaced on the short run since new fossil power plants are scheduled in the coming decade and, from an economic point of view, many existing power plants are not entirely written-off. For more information see Rooijers *et al.* (2009 pp.25-29) for an extensive overview of existing and planned power plants in the Netherlands.

Nevertheless, it is assumed that the potential demand even exceeds the total electricity demand in the Netherlands. This is based on two arguments. First, a shift towards electrical vehicles in the Dutch transport sector is expected over time (Daniëls *et al.* 2010 p.193). Therefore, it is expected that the total electricity demand in the Netherlands will increase over time. Second, the costs of energy are an important factor in the rate of inflation and in the international competitive position of a nation (Correljé & van der Linde 2006 p.532). Therefore, it is assumed in this analysis that the Netherlands will export potential excessive electricity, thereby creating a competitive advantage.

In addition, a distinction is made between near-shore and far-shore areas on the Dutch part of the North-Sea. Near shore areas are within distances of 50 kilometers off the coast and water depths below 30 meters; the remaining area is labelled as far-shore. According to a report of FLOW (2010 p.4), only 3000MW can be installed in near-shore areas when special areas, oil and gas platforms, shipping routes, and depths below 30 meters are taken into account. This means that approximately 800 turbines can be installed, based on average wind turbines of 4MW. However, in this analysis it is assumed that approximately 1200 turbines can be installed in near-shore areas due to the fact that the Dutch government and business communities have ideal incentives to deploy offshore wind energy. The potential area for far-shore areas in enormous but require different foundation designs and installation methods etc.

Grounding Era (2010-2014)

Within this era it is of utmost importance to create the necessary boundary conditions for an optimal deployment scenario in the Netherlands in which the supply market can flourish. This means that precautionary measures have to be taken in order to remedy supply constraints in advance, which is extremely important in the current offshore wind industry in the Netherlands. Subsequently, it is of utmost importance to realize offshore wind projects successfully for a steady upscale of offshore wind projects in the Netherlands. In addition, more research must be executed within an international context about the following topics: new offshore turbine designs, grid connection issues, new installation processes, new foundation technologies for deeper water depths, and operation and maintenance technologies. Therefore, the following assumptions are made:

Box 11: Required Actions to be undertaken by the Dutch government.

- First, the Dutch government gives clear signals in their coalition agreement that offshore wind energy in the Netherlands will be stimulated with consistent long-term policies. This includes a roadmap for the Dutch offshore wind energy supply market in which an scenario is outlined for an optimal upscale of the market, including a focus on near-shore and far-shore areas.

- Second, the Dutch government designates more dedicated offshore wind areas and provides required basic data, like soil-, wave-, and ecological data, for these areas. This accelerates the throughput time of the permit application phase and slightly reduces the total costs of offshore wind projects since, firstly, less (overlapping) environmental studies have to be conducted, and secondly, less appealing procedures, commissioned by other interest groups, will occur. Subsequently, the Dutch government abridges the current pilling season, and replaces the respective condensed months with a noise level limit. This increases the time-window in which substructures, in particular monopiles, can be installed.

- Third, the Dutch government couples the subsidy tender to the construction permit procedure, i.e. introduces an offshore wind concession procedure, which includes spatial- and financial reservation simultaneously. This makes the reserved budget transparent and thereby avoids 'race-to-the-bottom' processes, which means that wining parties eventually cannot realize offshore wind parks due to insufficiently estimated subsidy needs.

- Fourth, the Dutch government participates in public-private partnerships, which will further reduce financial uncertainties through accommodating loans or act as a guarantor for loans of project developers. These measures reduce the total costs of attracting debt capital, which is especially important in the current economic recession.

- Fifth, the Dutch government establishes a central committee, which is responsible for all verification and authorization of offshore wind deployment procedures. This departmental exceeding approach, i.e. the one-stop shop principle, is a necessity to standardize permit application procedures.

- Sixth, the Dutch government approves TenneT with the rights to be the offshore grid operator in order to provide for the required sockets offshore. TenneT is considered as the best candidate due to consistency advantages with the onshore situation whereby it can offer scale- and coordination advantages such as the bundling of cables for dune crossing.

- Seventh, the Dutch government provides for the grid connection of offshore wind farms since the designation of suitable areas has a cluster effect on projects which makes a shared power grid the most efficient way of transport. Therefore, the fact that several offshore wind farms will share transmission makes it imperative that the Dutch government provides this facility, which subsequently provides for additional incentives for offshore wind developers to realize projects in the Netherlands.

- Eighth, the Dutch government invests in public RD&D funding in order to catalyze private RD&D investments and to maximum technology development in a small number of regional offshore wind clusters. The collaboration with the offshore market is very important to harmonize the specific RD&D focus, for instance early stage R&D, demonstration activities, and deployment processes.

- Ninth, the Dutch government acquaints that the new concession round for offshore wind farms will be introduced at 1 January 2014. This gives project developers sufficient time in order to design (new) wind farms. And in 2014, the first effects of the implemented policy measures should take shape in the (Dutch) offshore wind supply chain.

- Tenth, the Dutch government introduces dedicated offshore wind educational programs for under-graduate and grate levels and mandates maritime and science and technology studies to focus more thoroughly on offshore wind engineering and installation matters in order to gradually enhance the supply of human capital for offshore wind on over time.

- Eleventh, the Dutch government provides for extra harbor capacity and provides an island at sea from which far-shore wind projects can be realized more easily, due to accommodation and assembling possibilities.

- Twelfth, the Dutch government takes precautionary measures related to interconnection issues. This contains that more HVDC cables have to be laid between neighboring countries and the Netherlands due to the fact that such an European electricity grid will harness renewable energies and improves security of supply.

As from 2011[69], the Dutch government will undertake the described actions in box 11. Therefore, this era is characterized by a slow upscale process, see figure 18. Furthermore, four offshore wind farms will be constructed within this era; where three wind farms will be located in far-shore areas and one probably near-shore[70]. Moreover, it is not assumed that more construction processes will be executed until 2014. In addition, it is assumed that sufficient manufacturing and installation equipment is available to execute these projects since BARD disposes an own supply chain, e.g. its own manufacturing capacity, installation equipment and human capital[71], and the other two projected wind farms are relatively small.

Furthermore, it is assumed that the implemented long-term and consistent regulation and legislation will assist the development of offshore wind by forming a transparent market with clear procedures and financial arrangements since this creates an impetus for offshore wind park developers and the offshore wind supply market to enlarge their equipment and human capital. The offshore supply market will therefore invest in the necessary components due to the fact that it gained greater market certainties and returns. Moreover, it is assumed that the supply market will undertake the described action in box 12.

Box 12: Required Actions to be undertaken by the offshore wind supply market.

- First, the offshore wind supply market provides for the initiative for research programs. These results will tackle and settle the discussion for ,first, a dominant design for offshore wind turbines, and second, consistent installation methods. Furthermore, standardized products and processes make it more easy for the suppliers in the lower levels of the supply chain to adapt and optimize their products.
- Second, the offshore wind supply market shares the attained experience, for instance via scientific as well as other publications, via organized meetings, or at conferences such as the seminar organized by Navingo or at foreign conferences of the European Wind Energy Association (EWEA) and Global Wind Energy Council (GWEC). This is a necessity in the early phase of offshore wind deployment in the Netherlands.
- Third, the offshore wind supply market develops consortia, for instance with project developers, turbine manufacturers and banks. This will reduce uncertainties between organizations because of the shared commitment for offshore wind projects.
- Fourth, the offshore wind supply market takes precautionary measures in order to solve the scarce availability of installation equipment and production facilities. This means that sufficient installation vessels must be tendered for in advance, sufficient offshore wind turbine facilities need to be realized, and electrical cable production facilities need to be enlarged.
- Fifth, the offshore wind supply market organizes a meeting whereby other related sectors such as the oil and gas-, the shipbuilding-, and the steel sector also are involved in order to optimally deploy offshore wind energy in the Netherlands since it requires horizontal as well as vertical integration processes.

Take-Off Era (2015-2018)

Within this period, a serious boom is expected in offshore wind initiatives coupled with technological advances related to installation methods and equipment. New and larger offshore wind turbine designs (>5MW) with direct drive permanent generators will enter the market. This will reduce the related operation and maintenance activities since these turbines improve reliability. Subsequently, no single dominant design will show up for substructures since near-shore and far-shore areas have different site specific characteristics. Next, better installation methods will emerge due to

[69] Due to the fall of the cabinet in 2010 and the required time to come up with a new coalition agreement

[70] Two wind farms are appointed to BARD, which has to begin with construction in 2013. This is also the expected date since BARD is working on the German BARD Offshore 1 wind farm until early 2013 (Offshore Wind 2010c p.10). The other wind farm is not appointed yet, but is expected to locate in a near-shore location. In addition, according to the projection of FLOW (2010 p.4), construction processes for the first far-shore wind farm will start in 2012-2013. Therefore, it is assumed that the first offshore wind farm will be for realized by the FLOW consortium in the Netherlands in 2014.

[71] However, this is ambiguous since on the one hand it spares equipment and human capital for other offshore wind projects but on the other hand does not provide employment and experience for Dutch human capital because they are not involved in these processes.

improved dynamic positioning systems and installation equipment. The outcomes of earlier introduced research programs have contributed to these developments. Furthermore, the Dutch government has to lay more HVDC cables[72] between neighboring countries, which minimizes load problems and reduces the loss of wind power. In time, improved wind speed forecasts will further eliminate the discrepancy between wind supply and electricity demand.

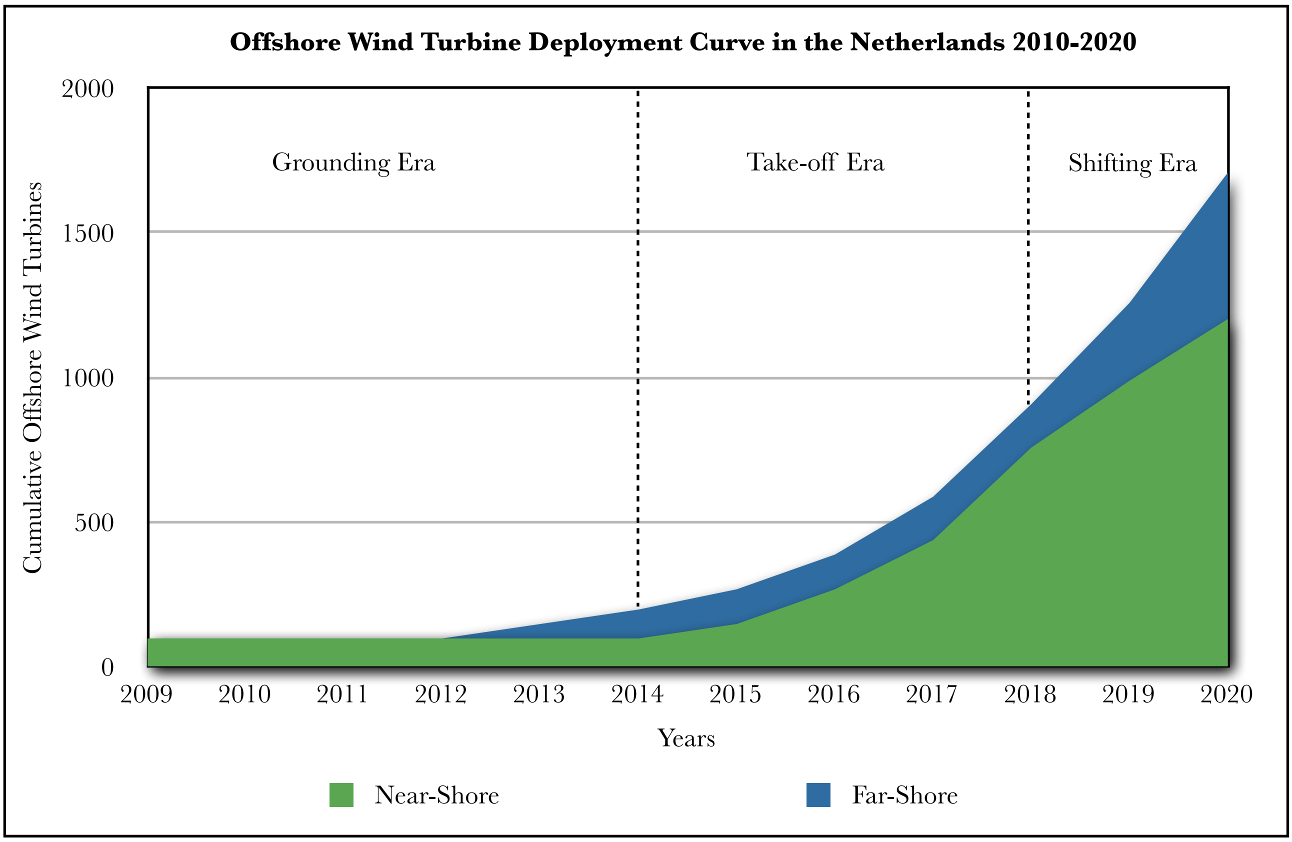


Figure 18: Offshore Wind Turbine Deployment Curve in the Netherlands (2010-2020).

Furthermore, it is of utmost importance to remedy the supply constraints in advance in order to enlarge the offshore wind supply market. Figure 18 and 19 depict offshore wind market upscale process; the specific requirements for the spread of vessels, offshore wind turbine production facilities and specialized can be found in box 13 and 14.

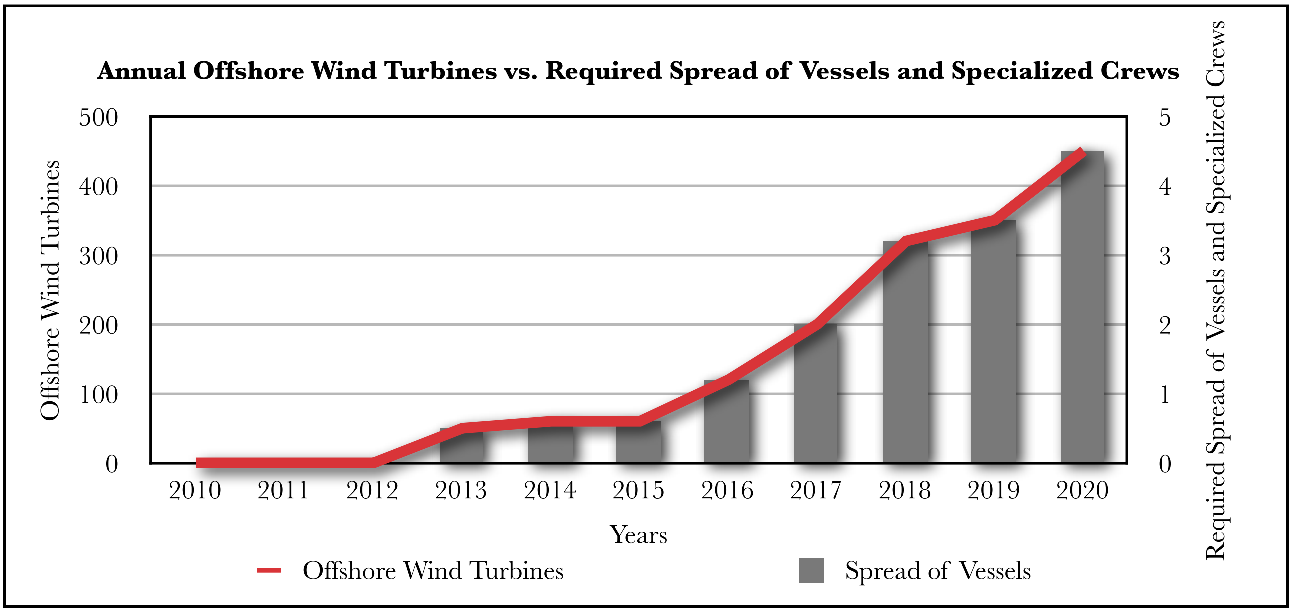


Figure 19: Annual Required Spread of Vessels and Specialized Crews in the Netherlands (2010-2020).

[72] Such as the NorNed, BritNed, and COBRA.

Box 13: Providing Sufficient Spread of Vessels, Offshore Wind Turbine Production Facilities, Electric Cable facilities.

There are insufficient installation vessels on the European market to install the projected projects until 2020. Approximately 15 installation vessels are currently used to install foundations and turbine components, and approximately 10 are being built. It is assumed that four existing installation vessels can be used of this fleet for Dutch offshore wind projects due to the fact that other countries also devoted offshore wind as a major contributor for their renewable energy targets. Therefore, new installation vessels must be tendered for in advance in order to be active on time. On average, it takes two years to tender and build a dedicated installation vessel for the offshore wind sector. Subsequently, the payback time for an installation vessel is approximately 8-10 years. Therefore long and clearly defined offshore wind targets are of utmost importance since these dedicated vessels can habitually not used within other offshore sectors. In addition, it is assumed that project developers and turbine manufacturers develop consortia, which accelerates purchase orders. Consequently, long-term contracts reduces uncertainties, which constrain new vessel orders. A division is made between installation vessels for foundations and the remaining components of the wind turbine, e.g. the transition piece, tower, and nacelle with blades. One dedicated vessel can install approximately 100 foundations or turbines per year, based on an average weather window from April to October. However, this average will increase over time due to technological advances in installation methods, which are coupled with weather window enlargements. In sum, the supply constraint for installation vessels can be overcome since it is mainly a financial issue, which requires long-term certainty. Moreover, one 'spread of vessels' is needed in order to install 100 turbines per year, which include one installation vessel for foundations, one installation vessel for turbines, and a small pool of service vessels.

The number of active offshore wind turbine manufacturers is increasing. From an economic perspective, it is more profitable to have the offshore production line located on site, which is currently not the case in the Netherlands. However, the defined offshore wind target in the UK has attracted offshore wind turbine suppliers to settle there. Therefore, it is assumed that the Dutch government should favor certain regions in order to create offshore wind clusters, preferably around ports. Two clusters could be located around the ports of IJmuiden and Borselle due to the designated offshore wind areas: "IJmuiden" and "Borselle". It is assumed that these sites attract offshore wind turbine factories to be located in the Netherlands since payback periods on offshore wind turbine factories are relatively short (5-7 years). More specifically, it is assumed that one factory will be realized in 2015 with a production line that can produce approximately 400-500 offshore turbines per year. The geographical location of the Netherlands is another advantage since offshore wind turbines can also be transported to other countries as the UK or Germany. Another trend is that current onshore manufacturing lines are moved towards lower cost countries such as China and India, as well as to the growing North American market. These factories can be replaced with offshore manufacturing lines, thereby increasing production capacity due to the fact that offshore components are larger and it is therefore more economical to manufacture closer to the sites. It is assumed that these new production lines will fill in the gaps of global offshore wind turbines demand.

The market for the supply of electrical cables is relatively small since only three established players are active within the offshore wind sector. Nevertheless, it is assumed that a new extrusion line will be realized within the Netherlands, also in respect with foreign developments. This would take up to four years since it takes two years to test and certificate new cables. This means, that approximately 200 kilometer of electrical cables is available each year, as from 2015. In addition, the current suppliers asserted that it is possible to expand existing production lines within 12-18 months. Until 2015, it is assumed that existing production facilities provides for the required electrical cables. Therefore, the supply constraint of electrical cables will be remedied. Subsequently, it is assumed that a new electrical cable vessel will be tendered for in the Netherlands, which will be active in 2015. Moreover, it is assumed that the supply of substation transformers will be provided with existing production capacity, which requires only small enlargements.

In this paragraph, the assumptions are given which are made with regard to the take-off era. It is assumed that a serious boom occurs due to the concession round in 2014 followed by the implemented actions undertaken by the Dutch government and the offshore wind supply market. In this era, it is assumed that standardized offshore wind turbines will enter the market coupled with standardized installation methods due to the fact that the offshore wind supply chain shared their practical experiences and executed research programs on these topics. Subsequently, the Dutch government played a facilitating role in this process to fine tune diverging strategies. Furthermore, it is assumed that the reciprocity between governance and business communities enhanced the pool of experienced human capital, provided for testing and demonstration facilities, provided land for new factories and port infrastructures focussed around centers of excellence, and formed a cost-effective supply chain. Therefore, it is assumed that sufficient installation vessels, offshore wind turbine production facilities, electrical equipment production facilities, substructure production facilities, harbor capacity, grid connection capacity, and human capital is available in order to realize the depicted offshore wind deployment scenario in figure 18. Furthermore, it is assumed that two offshore wind clusters will be located in Borselle and IJmuiden. Over time, a new cluster will emerge in Eemshaven. Next, more educated but non-experienced human capital will enter the market as a result of the established educational and training programs in the grounding era, which increases over time. At the end of this era, it is assumed that offshore wind parks will become less dependent on governmental subsidy funds due to the provisioned grid connection sockets and the possibility to loan via the government and banks. In addition, more non-recourse projects[73], like the Prinses Amalia wind farm will be realized. Consequently, some first signs of spatial limitation issues will show up since the lion's share is realized within near shore areas. This decreases therefore the growth rate of offshore wind deployment in near-shore areas. Nevertheless, offshore wind projects will become more interesting in far-shore areas due to technological advances.

Box 14: Providing Sufficient Port Facilities, Substructure Production Facilities, and Human Capital.

The Netherlands has a number of ports from where it is possible to operate. However, it is assumed that the Dutch government provides for sufficient harbor capacity. Subsequently, it is assumed that the 'harbor at sea' concept is realized in 2019 in order to stimulate far-shore wind projects. This island will provide accommodation for personnel, space for workshops, storage for spare parts, and test sites for new foundation and turbines designs. Such an island therefore increases harbor capacity and project revenues due to reduces travel times. It is therefore assumed as a necessity in order to enhance incentives for far-shore wind projects.

There are enough substructure production facilities, which combined have sufficient capacity and reasonable growth or redirection capacity that could be brought in line in less then a year. Moreover, the offshore wind market is mainly a niche for large cap companies and is therefore predominantly carried out by small manufacturers. Multiple Dutch foundation manufacturers and many other foreign companies are active in the offshore wind market. However, the enlargement of these components requires conversely the greatest increase in new factory capacity, new technologies to support larger turbines in mid-depth and deep waters, and new higher volume manufacturing techniques to deliver economies of scale. Nevertheless, it is assumed that required supply enlargements will be realized within this sector in advance.

The implemented educational and training programs by the Dutch government and the offshore wind supply market - in 2011 - have taken care of the first human capital enlargement in 2013. This has to do with the fact that these educational programs are part of an existing education, therefore a range of two years is assumed for this first wave. Subsequently, personnel from other professions are trained and re-educated for the offshore wind market in the Netherlands. Moreover, it is assumed that a negligible share of foreign personnel can be attracted due to the booming markets in their own countries. Per installation vessel approximately 15 units of personnel are required including one project supervisor. Subsequently, approximately 2 units of personnel are required per service vessel. This makes the total required human capital approximately 50 units of personnel per spread of vessels.

According to the CBS (2010 pp.7, 218, 234) approximately 85.000 students graduate each year, among which approximately 11.000 in sciences, mathematics, informatics, technique, industry, and architecture as main educations in the Netherlands for both higher vocational education (HBO) and higher education (WO). Subsequently, Eurostat (2009 p.255) projected that approximately 8500 students graduate in science and technology studies in the Netherlands each year. It is assumed that approximately 0,5% of these graduates can be used for the offshore wind market in the Netherlands. Moreover, this share will slightly increase over time, due to the introduced educational programs. Consequently, it is assumed that a similar amount of personnel can be attained through inter-profession mobility each year. This means that sufficient new human capital can be attained for the depicted deployment scenario in figure 18. Note that a large share of the required human capital also comes from intermediate vocational education (MBO). However, with respect to the experienced offshore wind engineers and experienced project supervisors, this is more difficult to realize. Therefore, apprentice programs should be implemented in 2011, allowing multiple prospective offshore wind engineers and project supervisors to gain experience so that they can realize projects after 4 or 5 years of practice. Furthermore, it is assumed that a small share - circa 6 - experienced project supervisors and experienced offshore wind engineers may be transferred from the oil and gas sector as from 2014. In sum, the lack of human capital can be remedied but must be planned well in advance.

Shifting Era (2019-2020)

Within this era, the potential demand for offshore wind farms within near-shore areas will be fully fulfilled, which requires a shift in focus toward offshore wind farm locations further offshore. Consequently, more knowledge and

[73] This means that loans can be required more easily since banks only entitles repayments from the profits of the project the loan is funding, and thus require no other assets from the borrower. Therefore, a large increase is expected in offshore wind projects.

beneficial experience with far-shore wind parks is now available. This means that far-shore wind parks can be realized more cost-effectively[74]. Nevertheless, shifts in manufacturing lines are also required due to the fact that far-shore wind parks require other foundations and larger wind turbines to compensate for the higher installation investments. Subsequently, more interconnection electricity cables are realized coupled with onshore grid expansion adjustments in the Netherlands. Therefore, the increased capacity of offshore wind can still be implemented into the Dutch electricity grid. In addition, offshore wind deployment is also booming in other countries in order to attain the mandatory EU targets. Therefore, the following assumptions are made:

It is assumed that the newly created supply chain in the Netherlands is not affected by offshore wind development abroad. This reflects that it is very important to make the required investments in advance. Furthermore, it is assumed that the Dutch government provides for the required interconnection electricity cables between neighboring countries in order to implement the generated electricity by offshore wind turbines into the Dutch grid. Moreover, TenneT takes care of the necessary onshore grid adjustments such as grid expansion issues but also balancing issues between base- and peak-load capacity. Next, it is assumed that more far-shore experience is gained due to the results of the FLOW research and demonstration program and developments abroad. Consequently, it is assumed that an artificial island is realized in 2019, which acts as a harbor at sea for far-shore wind projects. Ultimately, see table 3 for a quantitative overview of the made assumptions from 2010-2020[75].

Supply Constraints vs. Solutions	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Offshore Wind Turbines (cumulative)	96	96	96	146	206	266	386	586	906	1265	1706
Offshore Wind in MW (cumulative)	228	228	228	428	668	908	1388	2188	3468	4904	6668
Offshore Wind in MW (annual)				200	240	240	480	800	1280	1436	1764
Offshore Wind Turbines (annual)				50	60	60	120	200	320	359	441
Production Capacity (annual)						450	450	450	450	450	450
Substructures (cumulative)				50	110	120	180	320	520	679	800
Production Capacity (cumulative)				250	525	577	635	698	768	845	930
Spread of Vessels (annual)				0,5	0,6	0,6	1,2	2,0	3,2	3,6	4,4
Production Capacity (annual)				1	2	3	4	5	6	7	8
Electrical Export Cables (cumulative)				0,0	0,7	0,8	1,2	2,2	3,5	4,5	5,3
Production Capacity (cumulative)							2	4	6	8	10
Ports (annual)				0,3	0,4	0,4	0,8	1,3	2,1	2,4	2,9
Port Facility in the Netherlands (annual)				4	4	4	4	4	4	5	5
Human Capital (cumulative)				25	55	60	90	160	260	340	400
Total Capacity (cumulative)				84	182	210	240	276	318	366	422
Education of Students (cumulative)				42	91	105	120	138	159	183	211
Inter-Profession Mobility (cumulative)				42	91	105	120	138	159	183	211
Experienced Human Capital (cumulative)				1,0	1,2	1,2	2,4	4,0	6,4	7,2	8,8
Already Present (cumulative)				6	6	6	6	6	6	6	6
Educated Personnel with Experience (cumulative)									5	10	18

Table 3: Quantitative Overview of Offshore Wind Deployment Assumptions (2010-2020).

[74] Larger turbines generate more electricity, which increases revenues per turbine and balances the higher costs associated with the more complex installation processes further offshore and in deeper water depths.

[75] The production capacity of an offshore wind turbines production facility is 400-500 turbines a year. It is assumed that an offshore wind production facility will be built in 2014. BARD and other production facilities make the remaining offshore wind turbines in 2013-2014. At present, the Smulder Group can manufacturer 250 foundation a year. They have a annual growth capacity of 10%, which is sufficient to supply the required substructures in the Netherlands. It is possible to manufacture two installation vessels a year, which is equivalent to one spread of vessels. However, two installation vessels must be tendered for in 2011. Furthermore, approximately 100 kilometer of electrical export cables is needed per 600MW. It is assumed that a new production facility will be built in the Netherlands and is operative in 2016 with an average production line of 200 kilometer of electrical cables per year. Existing production facilities will supply the remaining electrical cables in 2013-2015. Next, approximately 150 turbines, including foundations, can be stored and assembled in an average port per year. There are sufficient ports until 2020. Subsequently, a harbor at sea will be realized in 2019. In addition, 50 units of personnel are required per spread of vessel. However, with educational and training programs approximately 0,5% of the 8500 graduates with technical backgrounds can be attract to the offshore wind market. This number increases annually with 10%. Subsequently, it is assumed that a similar share of human capital can be attained from inter-profession mobility. Moreover, it is assumed that already 6 experienced offshore wind supervisors are present and will dedicate their selves to the Dutch market. And it is assumed that, by providing apprentice programs, this share will increase as of 2018 with approximately 5-8 units every year.

Far-Shore Era (2021-2030)

Within this period, the transition process from near-shore towards far-offshore wind projects is completed resulting in a steadily increase of offshore wind turbine realization processes. However, installation equipment and human capital enlargements are still required since far-shore projection realization processes take more time on average. In this era, the boundary is reached at which the entire electricity demand can theoretically be fulfilled with offshore wind energy in the Netherlands. However, it is assumed that more offshore wind turbines will be realized, see box 10. Therefore, the offshore wind market in the Netherlands will stabilize but continues to deploy offshore wind turbines. Ultimately, approximately 11.000 offshore wind turbines can be realized as a result of the implemented (major) efforts - started in 2011 - of the Dutch government and the offshore wind supply market, see figure 20.

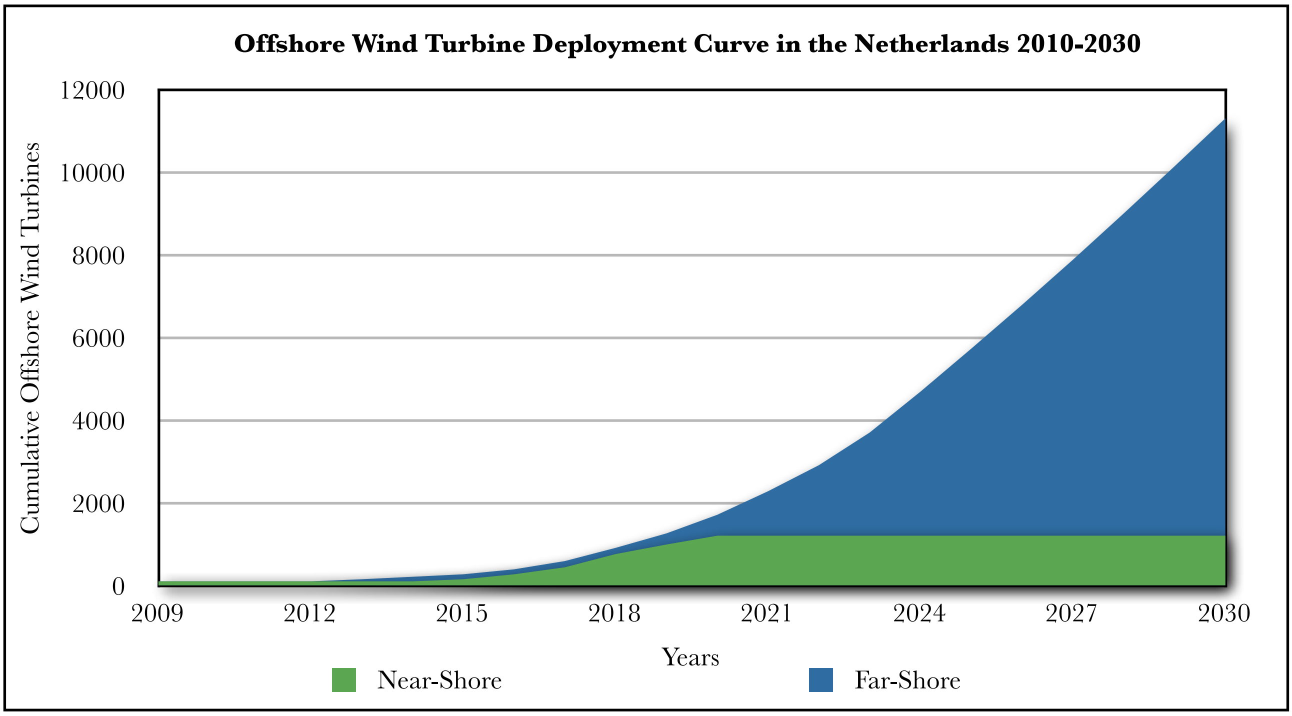


Figure 20: Offshore Wind Turbine Deployment Curve in the Netherlands (2010-2030).

5.4 Conclusion

According to Breton & Moe (2009 p.648) and Tambke *et al.* (2005 p.15), the average offshore wind speeds are very good at the North Sea, which increases with the height of the hub. Subsequently, based on the current developments and the conclusions of Breton & Moe (2009 p.649), Larsen (2010 p.24), and Markard & Petersen (2009 p.3546), major advances are expected to change the offshore wind turbine technology in order to push the capacity far beyond the current 5 MW capacity-level in the future. Besides the projected technological change, further developments are expected in the installation, operation, and maintenance procedures, especially when offshore wind farms will be developed far offshore. Therefore, offshore wind technology is considered as a possible constraint that hampers deployment. In addition, the offshore wind market in the Netherlands is also still in its infancy since there are only two offshore wind projects realized so far.

At present, the most important identified supply constraints are the availability of sufficient installation equipment for turbines, foundations and electrical equipment as well as sufficient manufacturing capacity for offshore wind turbines (especially large turbines), and electrical cables. Subsequently, human capital - particularly for installation processes but also for operation and maintenance and contracting procedures - will be a serious bottleneck. Next, the supply of of foundations, the availability of sufficient ports, and connection to the grid will be important supply constraints.

Furthermore, spatial issues will hamper the maximum deployment potential of offshore wind energy projects. Subsequently, there are sufficient possible projects in the current project pipeline, however it is important to realize these projects successfully in order to trigger more initiatives and larger offshore wind farm designs. At this moment, practical knowledge is insufficiently exchanged among organizations within the offshore wind supply chain and needs to improve in order to create an experienced pool of human capital and cost-effective supply chain. The projected offshore wind projects in other countries are a subsequent bottleneck for the Netherlands. Nevertheless, by refining and streamlining the current policy measures and thereby attracting a financial climate, organizations within the supply chain can seek investment in key elements resulting in lower risks and capital costs. Consequently, consistent and long-term supportive policies form the basis for the deployment of offshore wind energy in the Netherlands.

Furthermore, this research showed - supposing the Dutch government, first, gives clear signals in their coalition agreement that offshore wind will be stimulated with consistent long-term policies, second, designates more dedicated offshore wind areas and provides the basic data, third, couples the subsidy tender to the construction permit procedure, fourth, participates in public-private partnerships, fifth, establishes a central committee for offshore wind procedures, sixth, approves TenneT as the offshore grid operator, seventh, provides for the grid connection sockets, eighth, invests in public RD&D, ninth, acquaints the new concession round in advance, tenth, introduces dedicated educational programs, eleventh, provides for extra harbor capacity, and twelfth, takes precautionary measures related to interconnection issues; the offshore wind supply markets reacts by first, providing initiatives for research programs, second, exchanging attained experiences, third, developing consortia, fourth, taking precautionary measures in order to solve anticipated supply constraints in advance, and fifth organizing meetings with other related sectors - that approximately 1700 offshore wind turbines may be realized in 2020.

6. ANALYSES

6.1 Lessons Learned

The premeditated cases provided adequate insights, first, for large-scale renewable energy technology interrelated deployment bottlenecks in the Netherlands, second, for policy measures and their effects on the renewable energy targets, and third, for innovation system theory development.

6.1.1 Cross Comparison of Deployment Bottlenecks

The deep geothermal and offshore wind cases are both examples of large-scale renewable energy technologies. The deployment of large-scale renewable energy technologies has presumably other deployment bottlenecks than small-scale renewable energy technologies such as solar PV or heat pump technologies. In box 15, observed similarities and differences are presented.

Box 15: Observations

Both cases have similarities in supply constraints. First, the deployment of offshore wind energy in the Netherlands is mainly hampered by the availability of sufficient installation equipment. This is equivalent to the main hampering constraint of deep geothermal energy, which is the availability of sufficient drilling equipment, in the Netherlands. Second, the pool of experienced human capital requires major efforts to enlarge, particularly given the long lead times associated with education and gaining experience. Third, both cases are eventually limited by spatial issues that often primarily occur in regional aspects, for instance deep geothermal projects stumble against overloading scenes in Zuid-Holland and offshore wind projects stumbled against the availability of near-shore locations.

Other similarities are, first, that both cases have complicated permit license procedures. But this is presumably linked to the fact that deep geothermal and offshore wind both are large-scale renewable energy technologies and therefore require complicated permit procedures in order to ease all related interests. Second, both sectors are strongly interrelated with the oil and gas sector. The oil and gas industry has gained much experience in onshore drilling- and offshore installation processes and is therefore an interrelated industry from which knowledge can spill over. Subsequently, equipment and human capital can either be borrowed or transferred from the oil and gas industry to offshore wind and deep geothermal markets in the Netherlands over time. Third, steel is a commodity that is used in many main components, for instance the towers and foundations of wind turbines and the casings of wells, and therefore its substitution to carbon fiber will reduce manufacturing costs enormously in both renewable energy technology cases, although such a substitution was not addressed in the timeframe of this analysis.

However, some typical differences are identified between both cases. The most obvious is, first, that deep geothermal technology for direct use is far more matured in comparison with offshore wind technology, which is only partly matured. Therefore, deep geothermal energy, theoretically, may be more easily deployed on the short run than offshore wind since the latter case requires more additional efforts from the Dutch government before it can be efficiently deployed. Conversely, the second observed difference is that offshore wind policy measures are better organized in terms of required renewable energy targets and supporting instruments. Third, the excellent gas infrastructure in the Netherlands is an advantage for offshore wind as back-up capacity where it is a bottleneck for deep geothermal energy deployment. Favorable gas conditions in the Netherlands diminish the advantages of deep geothermal energy utilization, especially in the horticultural sector since CO2 is often required for enhancing crop growth next to heat. Fourth, demand and supply of energy is different in both cases since the peak capacity of deep geothermal energy is determined by demand and peak capacity of offshore wind energy is determined by the supply of wind.

Inter-Supply Constraints Resolved

Below, three interrelated supply constraints are presented, including the required remedying measures which, ideally, should be implemented in order to stimulate both cases simultaneously.

Production Facilities and Installation Equipment

Manufacturing and installation processes of large-scale (renewable energy) technologies require adequate production facilities and sufficient installation equipment (Carlsson & Stankiewicz 1991 p.99; Lundvall *et al.* 2002 p.218). The availability of production facilities and installation equipment is an outcome of three influential factors: (technological) expectations, current policy, and demand (Lam *et al.* 2010 p.782; Sandén & Azar 2005 p.1566; van Lente 2010 p.104).

As shown in both cases, a shortage of sufficient installation equipment is already present but long-term, stable, and consistent policy will eliminate a lot of uncertainties on the long run (Foxon & Pearson 2008 p.152). As a result, this improves the match between supply and demand of renewable energy technologies, thereby creating an impetus for companies to make the habitually large investments in production facilities and installation equipment (Geels 2004 p. 898; Kemp *et al.* 2007 p.179).

Human Capital

Scientists, engineers, and entrepreneurs play a key role in the innovation process towards industrialization of renewable energy technologies (Edquist 2004 p.192; Lundvall *et al.* 2002 p.221). As shown in both cases, a shortage of experienced and skilled human capital is already present, which suggests a great risk of shortages in future years. The largest part of the supply of required human capital for the renewable energy sector is educated and trained in national institutions of higher education, mainly in science and technology studies (Foxon & Pearson 2008 p.157; Ponomariov & Boardman 2010 p.613). However, the actual availability of human capital depends on inter-profession mobility, and international mobility, which both can act as positive or negative mechanisms, but by creating the right boundary conditions with the right incentives of both the government and business communities, more human capital can be attracted from other professions and to a lesser extent from other countries (Mosey & Wright 2007 p.930). The upgrading of technicians and the converting or retraining of graduates with non-scientific degrees can also enhance the supply of scientists, engineers, and entrepreneurs for renewable energy project.

Spatial Limitation

Geographical restriction, as in potential available areas, is often the last limitation aspect that determines the maximum potential of a renewable energy technology (Hoogwijk *et al.* 2004 p.892; Smeets *et al.* 2007 p.62). However, this research has shown that there are different types of spatial limitation since spatial issues can occur in certain regions where other regions still have enormous spatial potentials. For deep geothermal energy this had to do with the availability of good subsurface conditions and heat demand, where for offshore wind energy technological limitations (near vs. far offshore sites) determined regional overloading scenes. The Dutch government is therefore an important actor that has to direct the environmental planning as efficient as possible, thereby trying to diminish spatial hampering factors as much as possible.

6.1.2 Insights for Policy

This section, first, briefly describes the renewable energy targets for the Netherlands, second, considers whether the renewable energy technology targets are ambitious or lacking ambition, and third, relates the deployment potentials with the mandatory targets of the European Commission and the consequent targets of the Dutch government.

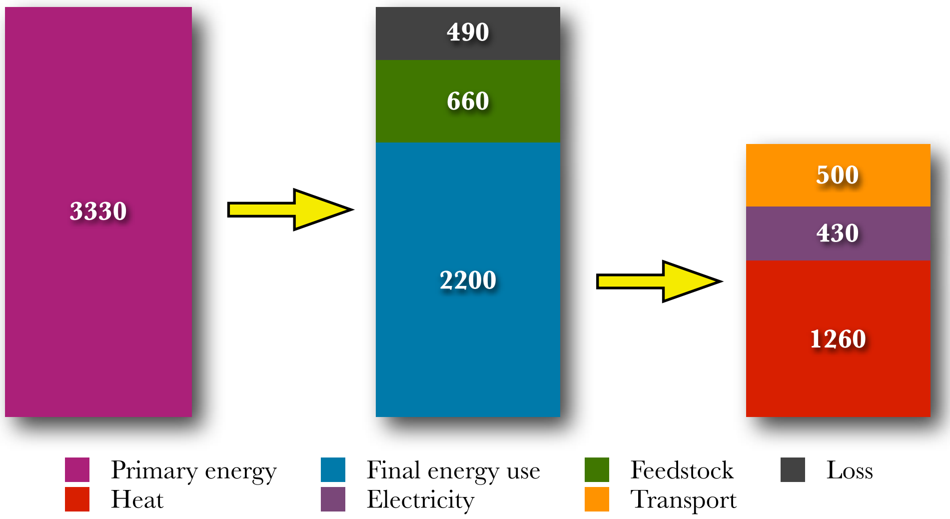
Renewable Energy Targets

In 2008, the European Commission introduced the Renewables Directive, which require each member state to attain a certain share of renewable energies to raise the overall share to 20% by 2020 (European Commission 2008 p.2). In addition, a share of green fuels, such as biofuels or electrical vehicles, of 10% is also included within the overall EU target. In order to achieve the objective, every member state is required to increase their share of renewables that is calculated on the basis on an index of the gross domestic product (GDP) per capita, which is 14% of final energy use for the Netherlands. In addition, the Dutch government has also set a national target in its 'Clean and Efficient' program, which is a share of 20% of primary energy use in 2020. The following sections will further elaborate the difference in approaches between the EU and the Netherlands. Furthermore, box 16 gives an overview of the current energy use in the Netherlands.

Box 16: Energy Use in the Netherlands in 2008

In 2008, the total primary energy consumption in the Netherlands was approximately 3330PJ. Primary energy includes sources of energy, such as crude oil, natural gas, coal, uranium, and renewable sources such as wind, biomass, and sunlight (Ediger & Akar 2007 p.1703). A share of the primary energy consumption is used as feedstock, which means that it is used as raw material, e.g. the use of crude oil for the production of plastics. The rest is transferred into more convenient forms of energy, such as electricity, refined fuels, and heat, where a part is lost.The part of energy that is 'lost' is transferred into unusable heat due to conversion processes (Landwehr & Jochem 1997 p. 693). The final energy in the Netherlands was, therefore, approximately 2200PJ, and is divided into transport (500PJ), electricity (430PJ), and heat demand (1260 PJ), see figure 21.

Energy Use (PJ) in the Netherlands in 2008



Scenario Targets Compared with Deployment Potentials

Within the Dutch Renewable Action Plan, the offshore wind target of 6000MW is converted to 69PJ and a projection is given of 11PJ, which is based on the reference-assessment of ECN, for the direct use of deep geothermal energy in 2020 (E&A 2010 pp.104-105). These projections are depicted on the determined deployment curves of deep geothermal and offshore wind in the Netherlands, which are calculated by means of the average performances of deep geothermal doublets and offshore wind turbines, see box 16 and 17.

Box 16: Deep Geothermal Doublet Performance

The total amount of energy that an average geothermal doublet can produce in one year can be calculated by means of the following equation:

$$E = P\,(q * p * c_v * \Delta T) * s$$

Where E is the total amount of energy (in J), P is the thermal capacity (in W_{th}), q is the flow rate of the doublet (in m^3/s), p the water density (in kg/m^3), c_v the specific heat of the formation water (in J/kg/K), ΔT the temperature interval (in degrees (K or °C)), and s the operation time (in seconds of a whole year).

A flow rate between 100-200m^3/h is necessary for a project in order to be profitable (Hagedoorn 2009 p.1; Van den Bosch 2009 p.3). The flow rate of the geothermal doublets of the horticultural firm A+G Van den Bosch in Bleiswijk is approximately between 85-220m^3/h, it depends on the demand for heat which is higher in winter than in summer (Van den Bosch p.19; Platform Geothermie meeting 2010). This also means that the thermal capacity will not entirely be used in summer, therefore a capacity factor is used in order to determine the total amount of energy for a deep geothermal doublet per year.

Based on an average flow rate between 100-200 m^3/h, a constant value, and a temperature interval of 30°C, the average capacity of a d deep geothermal doublet is approximately 6-8MW. Furthermore a capacity factor of 50% is used to determine the amount of energy in PJ per year.

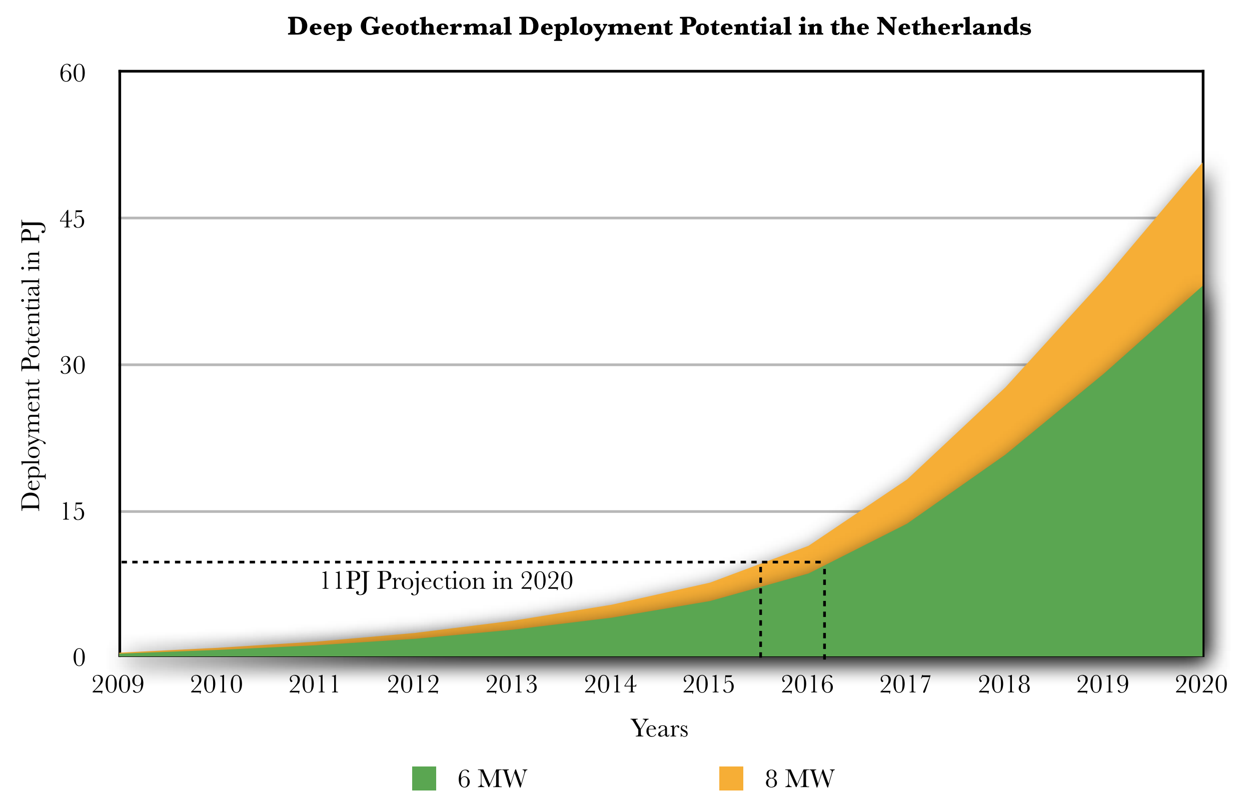


Figure 21: Deep Geothermal Deployment Potential in the Netherlands 2010-2020.

Figure 21 depicts that the projected level of 11PJ of direct use of deep geothermal energy within the Dutch Renewable Action Plan can be attainted at earliest around 2016. Therefore, it is concluded that the deep geothermal projection within the renewable action plan is quasi ambitious. More specifically, 11PJ of deep geothermal energy in the Netherlands can be attained in 2020, however, this will require additional efforts from the Dutch government and business communities to overturn the current deployment rate.

Box 17: Offshore Wind Turbine Performance

The total amount of energy that an average wind turbine can produce in one year can be calculated by means of the following equation:

$$E = P\,(\tfrac{1}{2} * p * A * V^3) * s$$

Where E is the total amount of energy (in J), P is the wind power capacity (in W), p is the air density (in kg/m^3), A is the exposed area (in m^2), V is the velocity (in m/s), and s is the operation time (in seconds of a whole year).

The energy production of a wind turbine depends on many factors, for example wind climates of a potential site, the hub height, the rated wind speed, the cut-in and cutout wind speed of wind turbines, and the generator design (Li & Chen 2009 p.1175). It is therefore difficult to generalize offshore wind turbine performances since local wind resources can vary significantly (Ackermann & Söder 2002 p.96). In addition, failures and repairs also affect the annual performance of offshore wind turbines, which is, again, also characteristic for each (newly) designed turbine (Joselin Herbert *et al.* 2007 p.1126).

Therefore, in order to determine the annual performance of an offshore wind turbine, the load factor is brought into use, which is the ratio of the actual output of a wind turbine over a period of time and its output if it had operated at full capacity (Schenk *et al.* 2007 p.1964). The load factor is also site specific, but a load factor of 3350 hours is used as a guideline for offshore wind turbines in the Dutch part of the North Sea (ECN 2004 p.41). A power capacity of 4MW is chosen for average offshore wind turbines, since turbines of 3-5MW will be installed the coming years until 2015 (Larsen 2010 p.25). After 2015, an average power capacity of 5MW will be used as an average value for offshore wind turbines, since Vestas and Siemens are currently developing a 6 and 7MW turbine at this moment (Offshore Wind 2010a p.7), which will probably become the standard in the years to come.

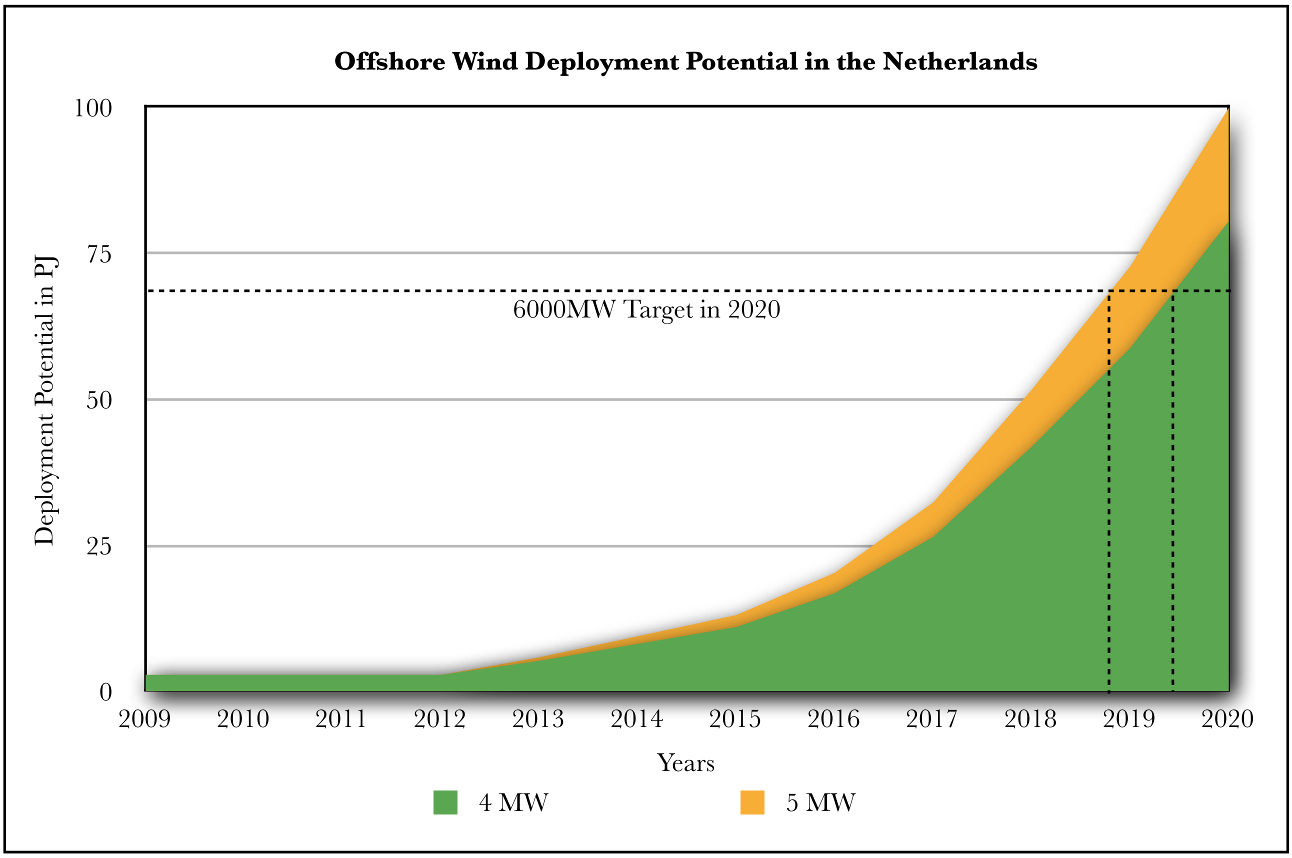


Figure 21: Offshore Wind Deployment Potential in the Netherlands 2010-2020.

For offshore wind energy, this level can be attainted at earliest around 2019. Therefore, it is concluded that the offshore wind target within the Renewable Action Plan is very ambitious. More specifically, 69PJ of offshore wind energy in the Netherlands can hypothetically be attained in 2020. However, this would require major efforts from the Dutch government and business communities in the Netherlands. Moreover, ECN does also not expect that the 6000MW target of installed capacity will be reached in 2020 (E&A 2010 p.104).

Attainment of Renewable Energy Targets

The total primary energy use is still roughly 3300PJ in 2020, according to the reference assessment based on the global economy scenario, including intended and executed Dutch and European climate policy, of the Dutch Energy Research Centre (ECN) and the Netherlands Environmental Assessment Agency (PBL) (Daniëls *et al.* 2010 p.156). Subsequently, the final energy demand is approximately 2100 PJ in 2020 (E&A 2010 p.14). There are two renewable energy targets, which both are based on different calculation methods. The European target is based on the 'final energy' method, which is the energy transformed from primary energy and thus refers to the energy delivered to the final customers (Daniëls *et al.* 2010 p.130). The total share of renewable energy is thus the part of renewable energy contribution within the total final energy use. The Dutch target is based on the substitution method, which looks at the amount of primary fossil energy that would have been required when no renewable energy has been used (E&A 2010 p.11). Renewable energy is valued in the terms of the fuel input required by a hypothetical conventional primary energy source.

The EU target is thus based on 2100PJ of final energy demand in 2020, which means that 294PJ (14%) must be generated with renewable energy technologies. Again, the projections of the Renewable Action Plan of the Netherlands are used. More specifically, the total share of renewable energy is divided into electricity (181PJ), heat (91PJ), and transport (38PJ) (E&A 2010 pp.103-106). Subsequently, the additional share of renewable energy for offshore wind (31PJ) and deep geothermal (40PJ), which can be deployed under the 'pull out all the stops' scenario, is attached in

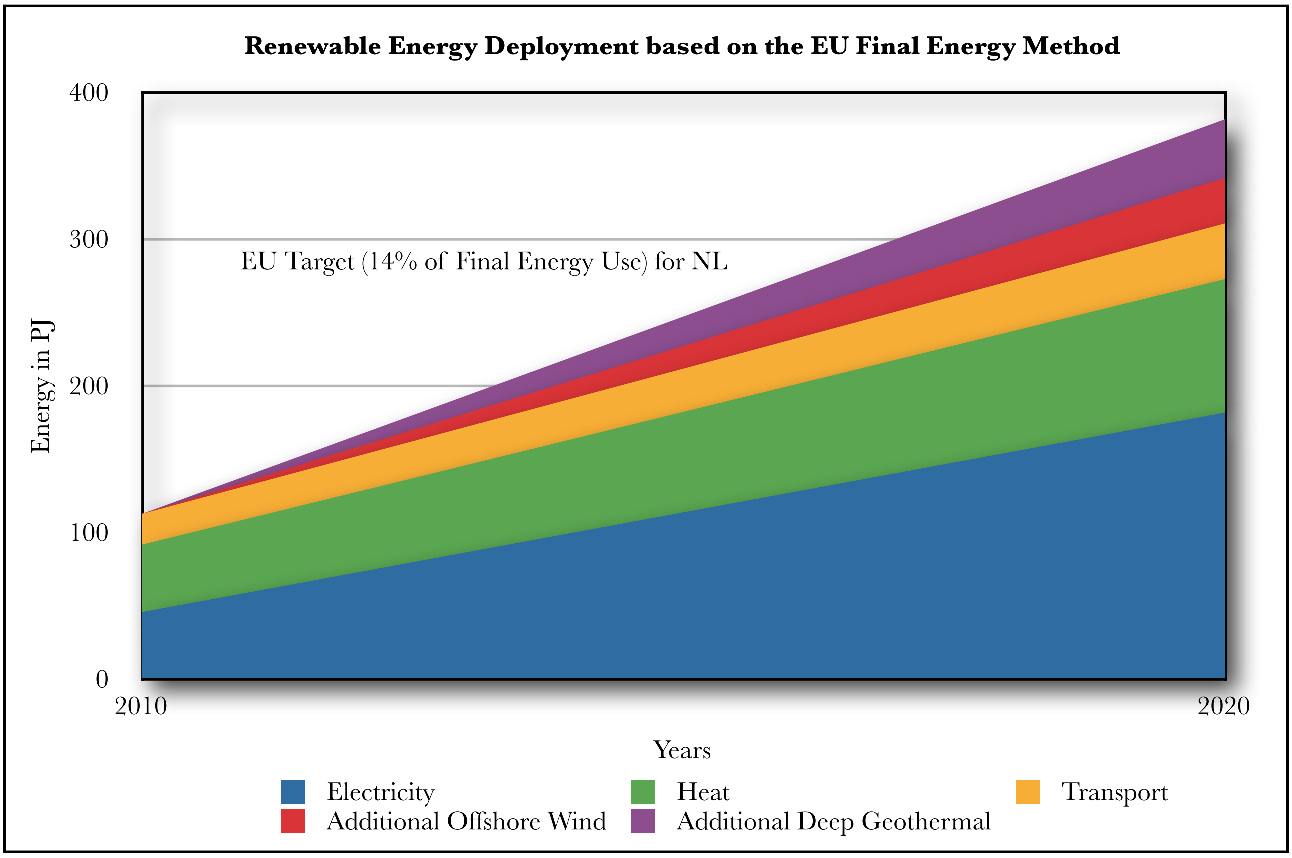


Figure 22: EU Target for Renewable Energy in the Netherlands 2010-2020.

figure 22. It shows that the EU renewable energy target will can be reached much earlier if additional major efforts, as described in sections 4.2.4 and 5.2.4, are made within both renewable energy technology deployments processes.

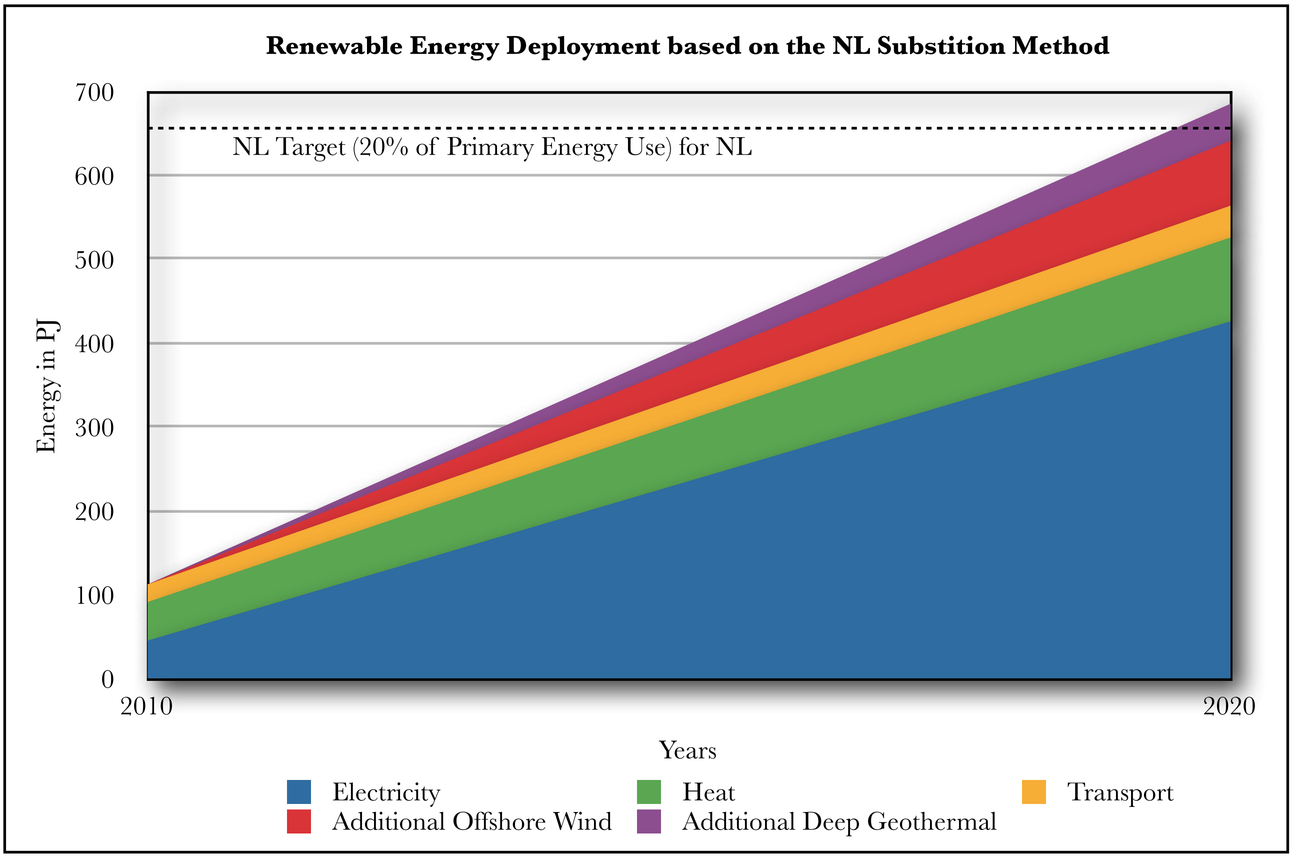


Figure 23: NL Target for Renewable Energy in the Netherlands 2010-2020.

The NL target is based on 3300PJ of primary energy use in the 2020, which means that 660PJ (20%) must be generated with renewable energy technologies. Again, the projections of the Renewable Action Plan of the Netherlands are used. However, these values must be converted to the amount of primary fossil energy that would have been required when no renewable energy has been used. For electricity contains that 1PJ of renewable energy is approximately 2,5PJ of avoided fossil energy, and for heat contains that 1PJ of renewable energy is approximately 1,1PJ of avoided fossil energy (Daniëls *et al.* 2010 p.130). Therefore, the total share of renewable energy is divided into electricity (453PJ), heat (100PJ), and transport (38PJ). Subsequently, the additional share of renewable energy for offshore wind (78PJ) and deep geothermal (44PJ), which can be deployed under the 'pull out all the stops' scenario, is attached in figure 23. It shows that the NL renewable energy target can be attained, when additional major efforts, as described in sections 4.2.4 and 5.3.4, are made by the Dutch government and business communities for both renewable energy technologies.

6.1.3 Insights for Innovation System Theory Development

This section briefly summarizes the usefulness and strength of the innovation systems framework. Subsequently, insights are given which can contribute to the development of this framework.

System Failure Focus

In recent years, science and policy community recognize even more that technological change and its resulting innovations are best understood as the outcome of innovation systems (Sagar & Holdren 2002 pp.465-466). Within emerging innovation systems, renewable energy technologies develop from their early phases of fundamental research and experimentation in niches towards products that be installed and utilized by the industry. Consequently, the TIS framework has particularly proven itself in explaining why and how sustainable energy technologies have, or haven't, developed and diffused in society (Hekkert & Negro 2009 pp.584-585). The process towards implementation and successful deployment of renewable energy technologies is often characterized by high uncertainties, risks, and late returns on investment (Alkemade *et al.* 2007 p.140). Therefore, in order for a smooth implementation of renewable energy technologies, firstly, these barriers have to be overcome, secondly, continuous development and maturing of the technology has to take place, and thirdly, an institutional and physical infrastructure needs to be shaped in which the respective renewable energy can be embedded (Mans *et al.* 2008 p.1375; van Alphen *et al.* 2010 pp.396-397).

The Role of Deployment Potential Assessments

The innovation systems framework is primarily an analytical construct with its main strength that it pinpoints influencing factors, which affect the development, diffusion, and utilization of new technological knowledge, from a system perspective. When insight is gained about the inducement and blocking mechanisms, specific policy can be formed to remedy the identified barriers and thereby accelerate the deployment of the respective renewable energy technology. Consequently, policy should strengthen inducement mechanisms and remove blocking mechanisms. However, the innovation system theory has one important deficiency: its outcomes are often predominantly based on qualitative assessments due to the process approach, or sequence, analysis[76]. Therefore, deployment potential assessments could strengthen the outcomes of innovation system analyses by providing more explicit recommendations - based on quantitative assessments - for policy. To illustrate, it can provide more explicit policy requirements in detailed timeframes or give accurate projections of, for instance, the required human capital and coupled policy measures to realize this share in advance. To sum up, first, it provides insight in possible supply market upscale bottlenecks, and second, anticipates required policy measures to remedy these bottlenecks in advance for an optimal deployment process.

[76] "The process approach conceptualizes development and change processes as sequences of events. It explains outcomes as the result of the order of events. It encompasses continuous and discontinuous causation, critical incidents, contextual effects and effects of formative patterns" (Hekkert *et al.* 2007 p.427).

7. CONCLUSION

7.1 Conclusion and Discussion

This section describes the findings of this research. First, a summary of the results and analysis is presented to answer the main research questions. Second, the implications of these findings are described for current policy and theory. And third, some limitations of this research and further research opportunities are described.

7.1.1 Conclusions

This research has investigated the following research questions:

What is the deployment potential of deep geothermal- and offshore wind technology based on supply constraints in the Netherlands in the period from 2010 till 2020? What kind of insights will there be for policy? And what kind of insights will there be for innovation system theory development?

For this, an exploratory approach has been chosen which included an extensive desktop research complemented by interviews with experts in the deep geothermal and offshore wind sector in the Netherlands. The results have been analyzed and led to the answers on the main research questions.

Deep Geothermal Energy Deployment Potential 2010-2020

The deep geothermal results show that the Netherlands has good subsurface conditions for the utilization of deep geothermal energy but that the current deep geothermal market is still in its infancy. The technology for the direct-use of deep geothermal energy is matured and is therefore not considered as a possible bottleneck for the deployment of deep geothermal energy in the Netherlands. The main supply constraints are the availability of sufficient drilling equipment, the availability of experienced human capital, and spatial limitations in the subsurface. Consequently, consistent and long-term supportive policies form the basis for an optimal deployment scenario of deep geothermal energy.

Moreover, this research shows - supposing that that the Dutch government in 2011, first, provides for long-term policies in their coalition agreement with a specific target for deep geothermal energy, second, implements the new deep geothermal application procedure, third, refines the existing deep geothermal guarantee scheme, fourth, provides for deep geothermal energy educational programs, and fifth, provides for more acquaintance about deep geothermal possibilities in different sectors; the deep geothermal supply market reacts by first, developing specialized training programs, second, providing initiatives for deep geothermal research programs, third, exchanging attained experiences, and fourth takes precautionary measures in order to solve anticipated supply constraints in advance - that approximately 400 deep geothermal doublets may be realized in 2020.

Offshore Wind Deployment Potential 2010-2020

The offshore wind results showed that the Netherlands has good offshore conditions for the utilization of offshore wind energy but that the offshore wind market in the Netherlands is still in its infancy. The technology for offshore wind energy has not fully matured and is therefore considered as a possible bottleneck for the deployment of offshore wind energy in the Netherlands. The main supply constraints are the availability of sufficient installation equipment, the availability of sufficient turbine production facilities, the availability of experienced human capital, and grid inlet inlet limitations. Consequently, consistent and long-term supportive policies form the basis for an optimal deployment scenario for offshore wind.

Moreover, this research shows - supposing that the Dutch government in 2011, first, gives clear signals in their coalition agreement that offshore wind will be stimulated with consistent long-term policies, second, designates more dedicated offshore wind areas and provides the basic data, third, couples the subsidy tender to the construction permit procedure, fourth, participates in public-private partnerships, fifth, establishes a central committee for offshore wind procedures, sixth, approves TenneT as the offshore grid operator, seventh, provides for the grid connection sockets, eighth, invests in public RD&D, ninth, acquaints the new concession round in advance, tenth, introduces dedicated educational programs, eleventh, provides for extra harbor capacity, and twelfth, takes precautionary measures related to interconnection issues; the offshore wind supply markets reacts by first, providing initiatives for research programs, second, exchanging attained experiences, third, developing consortia, fourth, taking precautionary measures in order to solve anticipated supply constraints in advance, and fifth organizing meetings with other related sectors - that approximately 1700 offshore wind turbines may be realized in 2020.

Policy Insights

The results of the deep geothermal deployment potential assessment show that the projection by the Dutch Energy Research Center for the direct-use of deep geothermal energy of 11PJ in 2020 is quasi-ambitious. Subsequently, the results of the offshore wind deployment potential assessment show that the target of the Dutch 'Clean and Efficient' program of 6000MW in 2020 is very ambitious. Furthermore, it shows the effects of new-dedicated policy measures for deep geothermal and offshore wind deployment in the Netherlands until 2030. Subsequently, it shows that the mandatory EU renewable energy target of 14% of the final energy use in the Netherlands in 2020 can be attained much earlier if the proposed actions in this report are undertaken by the Dutch government as well as the deep geothermal and offshore wind industry. Moreover, it shows that the Dutch renewable energy target of 20% of the primary energy use in the Netherlands in 2020 can merely be attained if the proposed actions in this report are undertaken by the Dutch government as well as the deep geothermal and offshore wind industry.

Innovation System Theory Development Insights

The deployment of renewable energy technologies is often characterized by high uncertainties, risks, and late returns on investments in their early phases of development. Therefore, these barriers have to be overcome, where continuos development and maturing of the technology has to take place, and an institutional and physical infrastructure needs to be shaped in which the respective renewable energy can be embedded. Innovation systems assessments provide insights about inducement and blocking mechanisms and provide detailed recommendations for policy. However, these outcomes are often predominantly based on qualitative assessments. Therefore, deployment potential assessments could strengthen these outcomes with quantitative arguments in order to improve policy recommendations. This may result in more explicit recommendations such as specific policy requirements in detailed timeframes to, for instance, enhance the pool of human capital in advance. In sum, deployment potential assessments provide insight in possible upscale bottlenecks of the supply market and these results may be used in innovation system analyses in order to improve policy recommendations for an optimal deployment process.

7.1.2 Discussion

The findings of this research need additional and more extensive empirical research in order to test the fruitfulness of the introduced deployment potential method due to the exploratory approach of this research design. This conceptual model, which was used in order to determine the deployment potentials, needs to be further elaborated. Firstly, more similar studies need to be executed with other renewable energy technologies in the Netherlands. The specific focus on the Netherlands will provide more insights in comparable market upscale bottlenecks because these can differ between countries or other system contexts and over time. Secondly, more studies have to be executed with similar renewable energy technologies but in different countries or regions in order to reveal similarities and differences. These subsequent studies are required in order to validate a comprehensive model of deployment potentials for renewable energy technologies.

In addition, a wide array of documents is used such as peer-reviewed articles, scientific books, national statistics, national policy documents, professional literature and other publications in order to gather the required data. Subsequently, this gathered data is validated through interviews with experts in the deep geothermal and offshore wind industry in the Netherlands. And finally, two experts within the deep geothermal and offshore wind industry in the Netherlands have given feedback on the executed case studies within this report. Therefore, it is considered that the data used in this thesis is of sufficient quality. Nevertheless, assumptions had to be made in both case studies to determine the deployment potentials.

Moreover, the executed research method is the most suitable approach in order to answer the stated research questions since case studies are predominantly used in exploratory research settings in order to draw conclusion for theory development. The desktop study approach complemented with interviews of experts in the deep geothermal and offshore wind fields provided a comprehensive view on the influencing deployment factors within both sectors in the Netherlands. Therefore, it is considered that this research method is the most suitable approach in order to provide for the necessary data and assumptions on which the outcomes of this thesis are based.

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Interviewees

Deep Geothermal Sector

11 February	Saskia Hagedoorn - Business Developer at Brabant Water
16 February	Victor van Heekeren - Chairman at Platform Geothermie
19 February	Leslie Kramers - Geologist at TNO Built Environment and Geosciences
25 February	Dick Swart - Managing Director at Petrogas Minerals International BV
	Kornelius Boersma - Drilling Engineer at Petrogas Minerals International BV
03 March	Guus Willemsen - Director Business Development at IF Technology

05 March Eric Quinlan - Sales Engineer Drilling at Huisman Equipment BV

12 March Pieter Jongerius - Directorate Energy Market at Ministry of Economic Affairs

Offshore Wind Sector

27 April Pieter van Breevoort - Consultant at Ecofys

10 May Jan Pasteuring - Manager Reliability & Maintenance Group at XEMC-Darwind

31 March Bob Meijer - Managing Consultant at Ecofys

17 June Frank Wiersma - Consultant at Ecofys

1 July Gerard van Rijn - Senior Consultant at Ecofys

22 July Jan Kranenburg - General Manager IHC Offshore Wind at IHC Merwede

24 July Ernst van Zuijlen - Director Offshore Wind Energy at Evelop

Visited Conferences

Symposium Geothermie Update 2010, 31 March from 13:00-18:00 hour, Amsterdam, The Netherlands.

Platform Geothermie meeting at the Westergasfabriek in Amsterdam on 31 March from 11:00-13:00 hour.

Seminar Offshore Wind Installation and Maintenance 2010, 29 April from 13:00-18:00 hour, WTC Rotterdam, The Netherlands.

APPENDICES

APPENDIX A: ADDITIONAL FIGURES

A1: DEEP GEOTHERMAL

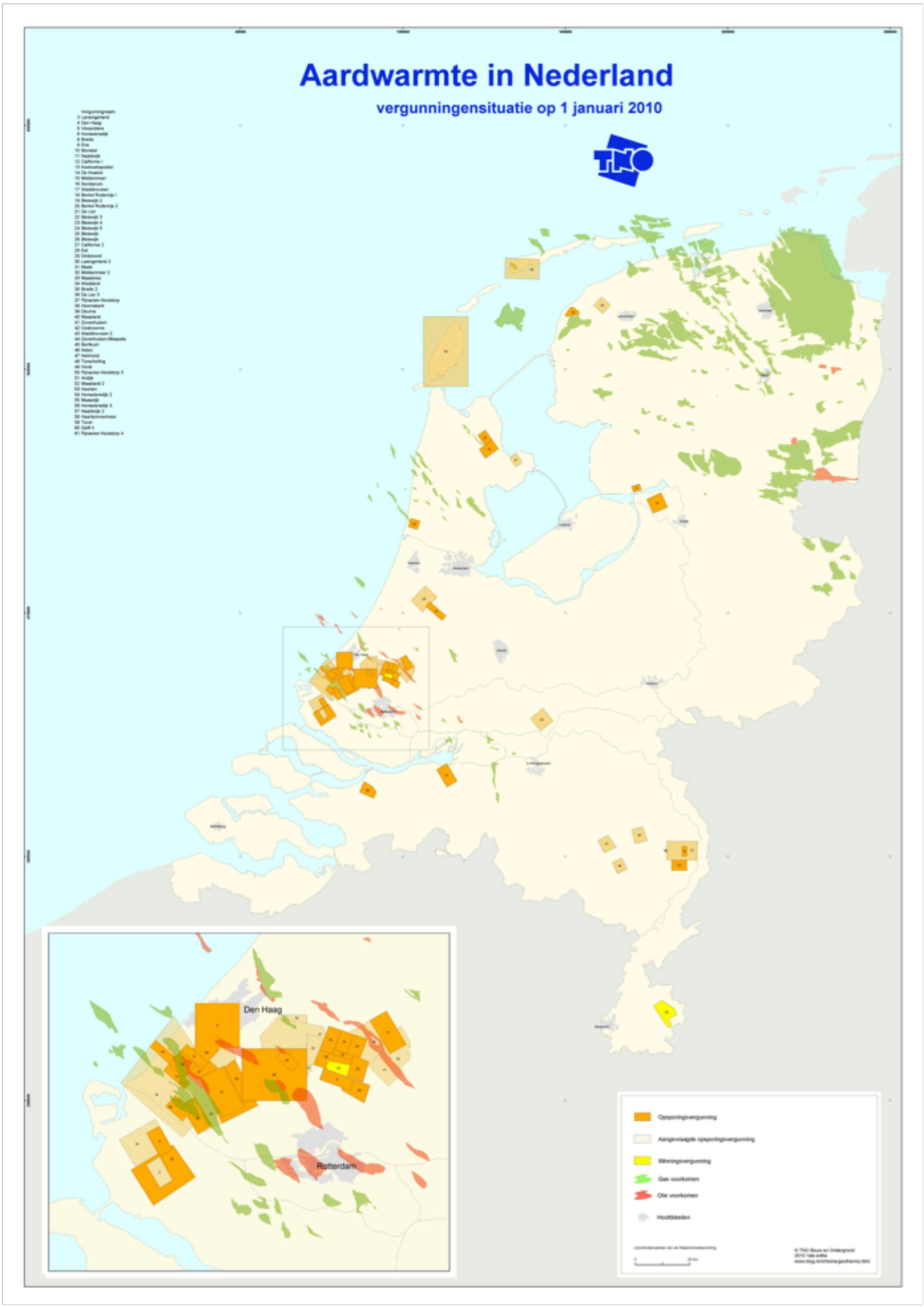

Figure 24: Overview of the Applied and Approved Deep Geothermal Permits on 1 January 2010.

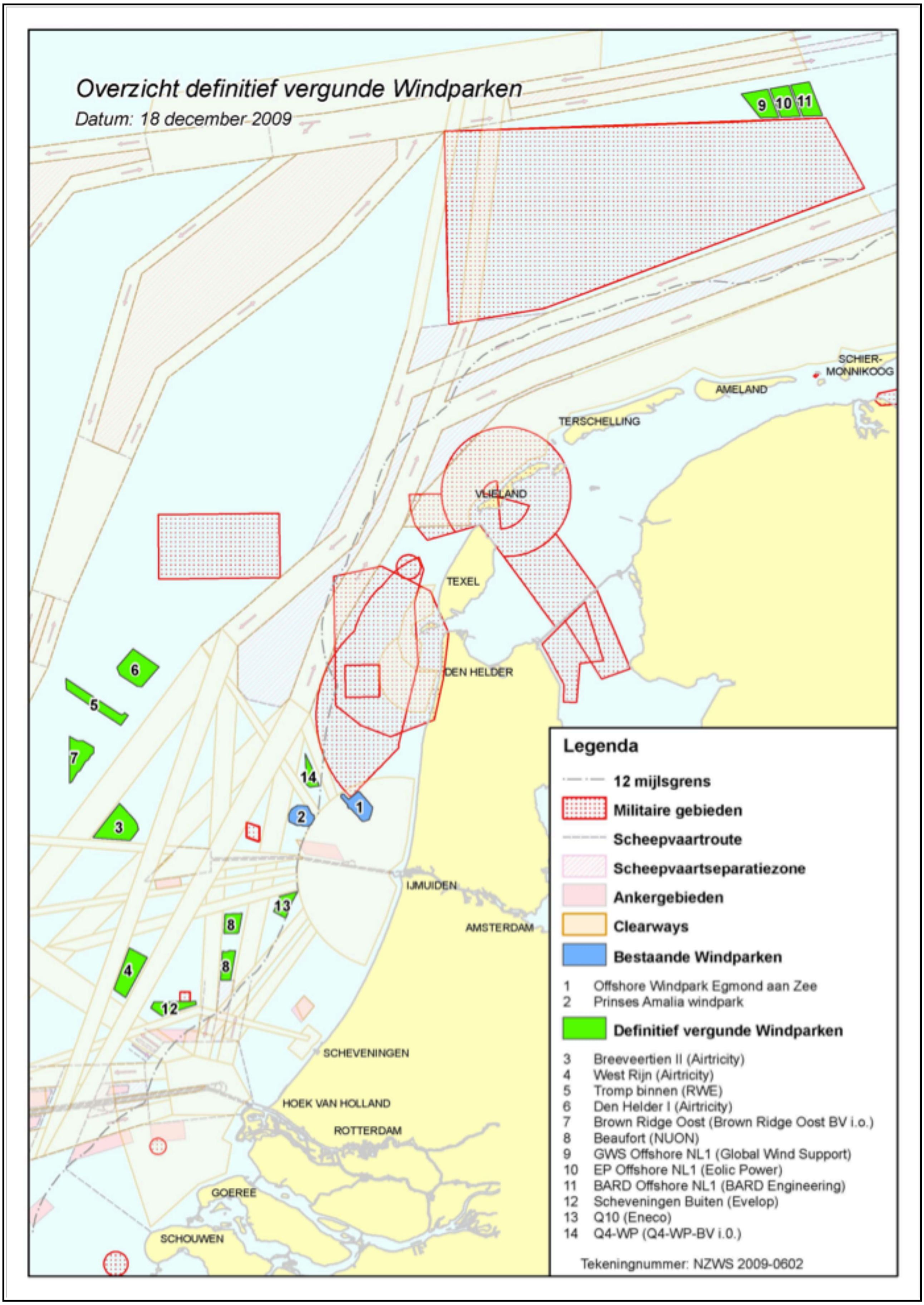

Figure 25: Overview of the Approved Offshore Wind Farm Permits on 1 January 2010.

Appendix B: Background Information

B1: Deep Geothermal

Geothermal Energy Technologies

Geothermal energy technologies can be split in shallow (heat and cold storage) and deep (deep geothermal energy and EGS) geothermal energy, see figure 26. This section also summarizes the shallow geothermal energy technology.

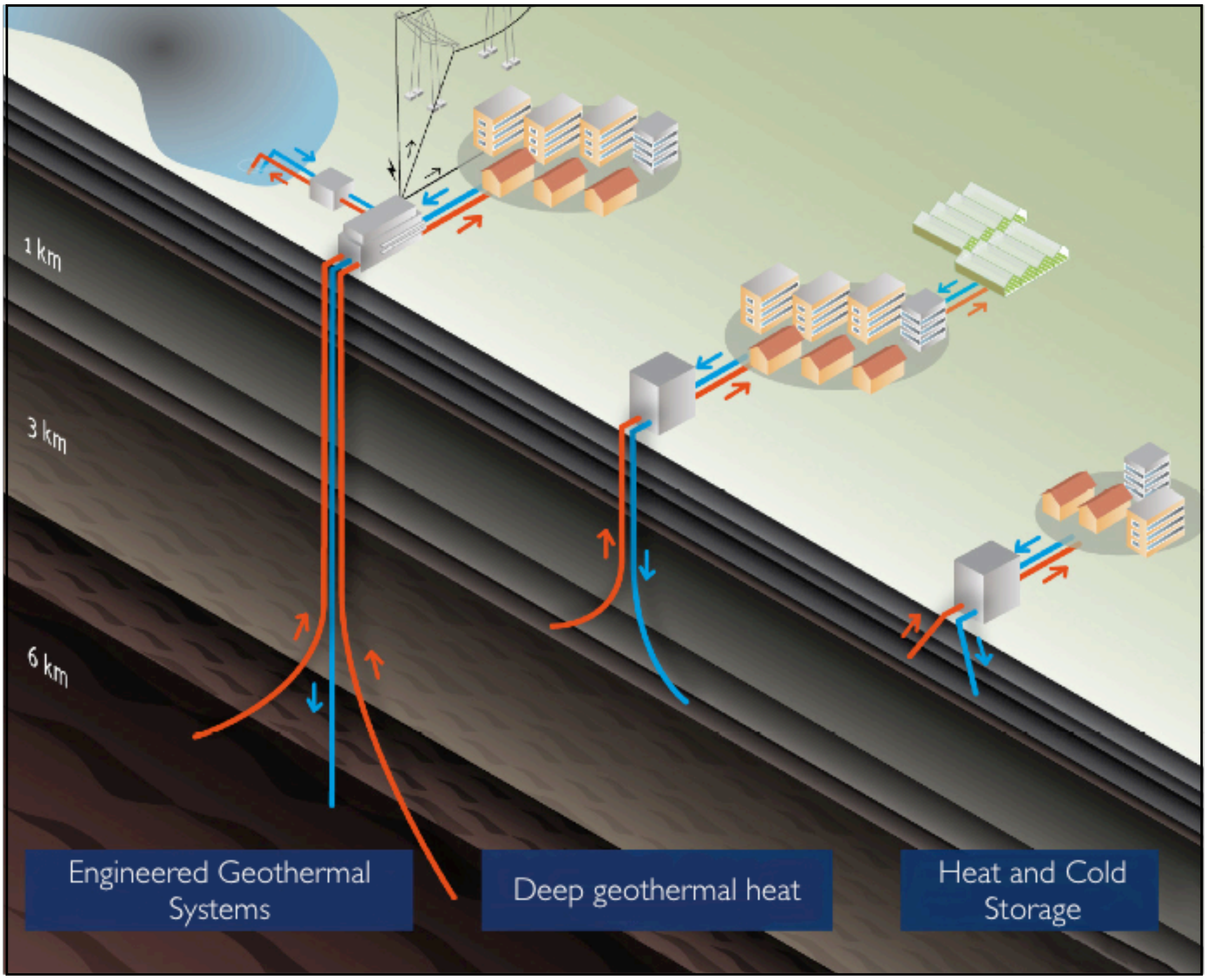

Figure 26: Geothermal Energy Technologies.

Shallow geothermal energy uses the heat from solar energy - absorbed at the surface and stored in the subsurface - for heating (in winter) and cooling (in summer) of buildings with heat pump applications (Sanner *et al.* 2003 p.578). The water in the subsurface has a constant temperature that is roughly equal to the average temperature for a specific location (Hoppe *et al.* 2008 p.179). This means that the subsurface has a higher temperature in winter and lower in summer. A heat pump circulates water - in an open or closed system - and extracts the required temperature for heating (and cooling) purposes (Kulcar *et al.* 2008 p.323). The two most common types of geothermal heat pump applications are: Aquifer Energy Thermal Storage (ATES) and Borehole Heat Exchangers (BHE) (Sanner *et al.* 2003 pp.581-583).

Geological Background

Three concentric zones form the earth: crust, mantle, and core, see figure 27. The earth's is commensurable with the skin of an apple compared to the other two concentric zones. The earth's radius is 6370 km where the thickness of the earth's crust is on average 7 km beneath ocean basins and 20-65 km beneath continents (Barbier 1997 p.3). The earth's mantle has a radius of 2900 km and largely consists out of igneous rock mainly made up of ferromagnesian minerals (Barbier 2002 p.9). The earth's core has a radius of 3470 km and its temperature is about 4000°C (EGEC 2009 p.3).

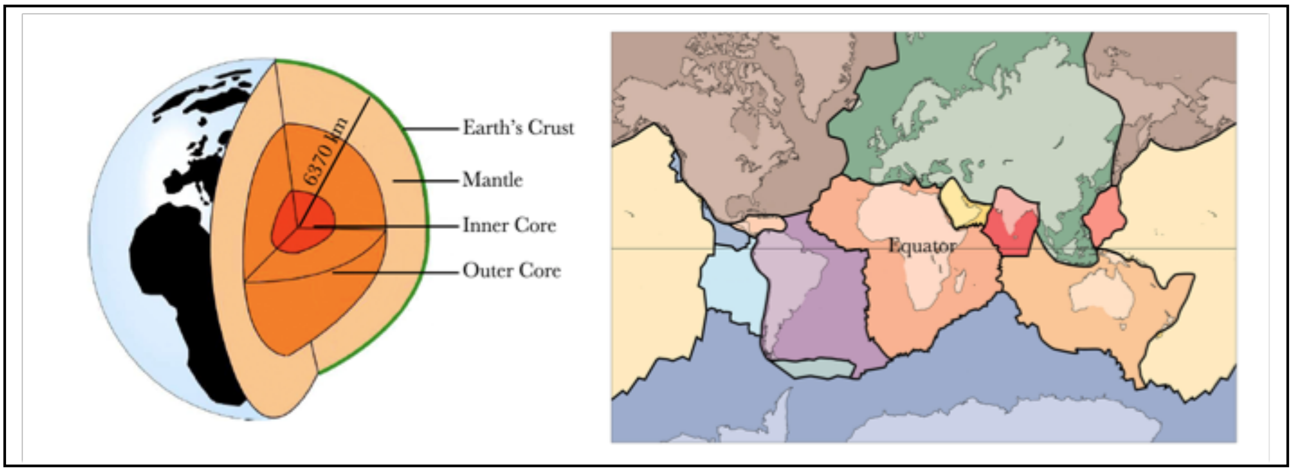

Figure 27: The Earth's Interior and Tectonic Plate Location in the World

The 'heat beneath our feet' reveals itself through the presence of volcanoes, hot springs, and other geothermal phenomena (Dickson & Fanelli 2004 p.1). The first systemic measurements of temperatures underground are ascribed to Robert Boyle, who was a British chemist, in 1671 (Barbier 2002 p.11). He discovered that the temperature increases with depth. The average increase in temperature with depth - geothermal gradient - in the earth's crust is 2-3°C per meter (EGEC 2009 p.3). However, the geothermal gradient can fluctuate between 1-10°C per meter (Barbier 2002 p. 13). The higher geothermal gradients can be found in areas of active volcanism and can be explained by the tectonic plate theory.

The earth's crust and uppermost part of the earth's mantle form the lithosphere, which is the outer shell of the earth and is relatively inflexible and breakable (Barbier 2002 p.9). The lithosphere is made out of a number of large blocks at a continental scale or more, which are called tectonic plates. These plates move slowly across the earth's surface with a speed of a few centimeters per year (Dickson & Fanelli 2004 pp.13-15). The margins of the plates match up to weak and densely fractured zones of the crust where there are high terrestrial flows (Barbier 2002 p.11). So, higher geothermal gradients are often located around plate margins.

The transfer of heat in the earth occurs via conduction and convection (Dickson & Fanelli 2004 p.24). Conduction means that moving molecules strike neighboring molecules, causing them to vibrate faster and thus transfer heat energy (Barbier 2002 p.12). Whereas convection means that gasses or fluids transfer the heat from one place to another, which is an enormously more efficient process of heat transfer than conduction (Barbier 1997 p.9).

Geothermal Resources

A natural geothermal system mainly consists out of three elements: a heat source, a reservoir, and a fluid that transfers the heat (Dickson & Fanelli 2004 p.15). The heat source can be a magmatic intrusion at shallow depths or the earth's normal temperature, which increases with depth. A reservoir is made of a large body of permeable rocks and must contain large amounts of fluids, in the form of steam or water, which carry heat to the surface (Barbier 2002 p.12). Such a reservoir is often connected to a recharge area and overlain by a cover of impermeable rocks (Dickson & Fanelli 2004 p.16). The fluids within the reservoir circulate, the hot fluids are abstracted through spring or well discharge and cold meteoric waters refill the reservoir and are warmed up in the recharge area via conduction and convection processes (EGEC 2009 p.4). A simplified representation of a natural geothermal system is depicted in figure 28.

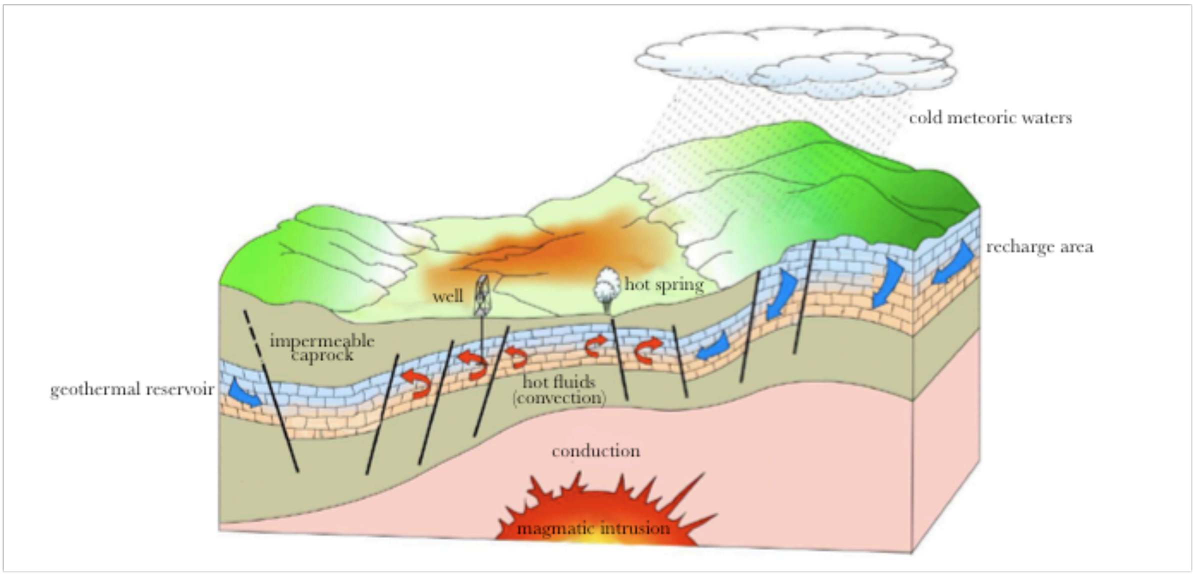

Figure 28: Simplified Representation of a Natural Geothermal System.

Geothermal energy is seen as a renewable energy source that can fulfill a major role in a sustainable energy system (MIT 2006 pp.26-27). For geothermal heat the term renewable means that "the energy removed from the resource is continuously replaced by more energy on time scales similar to those required for energy removal and those typical of technological societal systems" and sustainable means that "the production of system applied is able to sustain the production level over long times" (Rybach & Mongillo 2006 p.1083). The most important factor that justifies geothermal heat as a renewable energy source is the rate of energy recharge, which have to occur through advection of thermal water on the same time scale as production from the resource (Dickson & Fanelli 2004 p.25). And when the extraction rate of geothermal reservoir does not exceed its replenishment rate, than it is labeled as sustainable (Barbier 2002 p.19).

The average lifetime of a geothermal doublet is estimated to be about 30 years[77], which is called the breakthrough time where it reaches the equilibrium (MIT 2006 p.29). After this period interference occurs, which means that the cold injected water will reach the production well and that the extracted temperature will slowly decline (Mijnlieff & van Wees 2009 p.4). A solution here fore is to drill another production well and let the other original production well rest in order to recharge (Rybach & Mongillo 2006 p.1089). The regeneration of a geothermal reservoir is site specific but is estimated that new water in a respective aquifer need approximately 40 years to reach the old temperature (Barbier 2002 p.22). However, it is difficult to predict the exact geothermal doublet lifetime since most of the time there is a lack of knowledge of the formation since it is never a homogeneous layer qua depth and composition (SGP 2009 p.2) And the total amount of hours that a geothermal doublet is in operation per year do also affect the lifetime of the geothermal reservoir.

Geothermal Drilling Process

When all preparations are finished and the equipment is at site, the rig is set up. Generally, a drilling rig exists out of the following main components: power system, mechanical system, rotating equipment, circulation system, a derrick and a blowout preventer (Teodoriu & Falcone 2008b p.228). All these components are developed to work seamlessly together; see figure 29. The power supply consists out of a large diesel engine and electrical generators to provide the electrical

[77] The average lifetime - reservoir longevity - of a geothermal doublet depends on its doublet well spacing (EGEC 2009 p.2). So, an average lifetime of more than 30 years is also conceivable. For instance, the 34 geothermal doublets in Paris - that serve 100.000 residences of 70m^2 each year - are periodically (every 25-30 years) (re)completed and drilled at adequate reservoir locations, which extends the lifetime of the Paris Basin geothermal district heating system over 75 to 100 years (EGEC 2009 pp.3-4; SGP 2009 p.2).

power. A mechanical system consists out of a hoisting system and a turntable that are used for lifting. The rotating equipment exists out of a turntable, a drill string, and a drill bit. The circulation system pumps drilling mud under high pressure through the drill pipes. A derrick supports the structure that holds the drilling machinery. And a blowout preventer seals the high-pressure drill lines and relieves pressure when necessary to prevent a blowout.

The drilling process for geothermal heat is almost the same; one big difference is that the last casing string - production casing - of a geothermal well is commonly larger than for oil and gas wells (Augustine *et al.* 2006 p.3; MIT 2006 p.191; Teodoriu & Falcone 2008a p.1). This is because the amount of fluids that have to be pumped through the geothermal well require a larger thickness[78]. Besides this difference, the drilling process is essentially the same for oil, gas, and geothermal wells (Augustine *et al.* 2006 p.3).

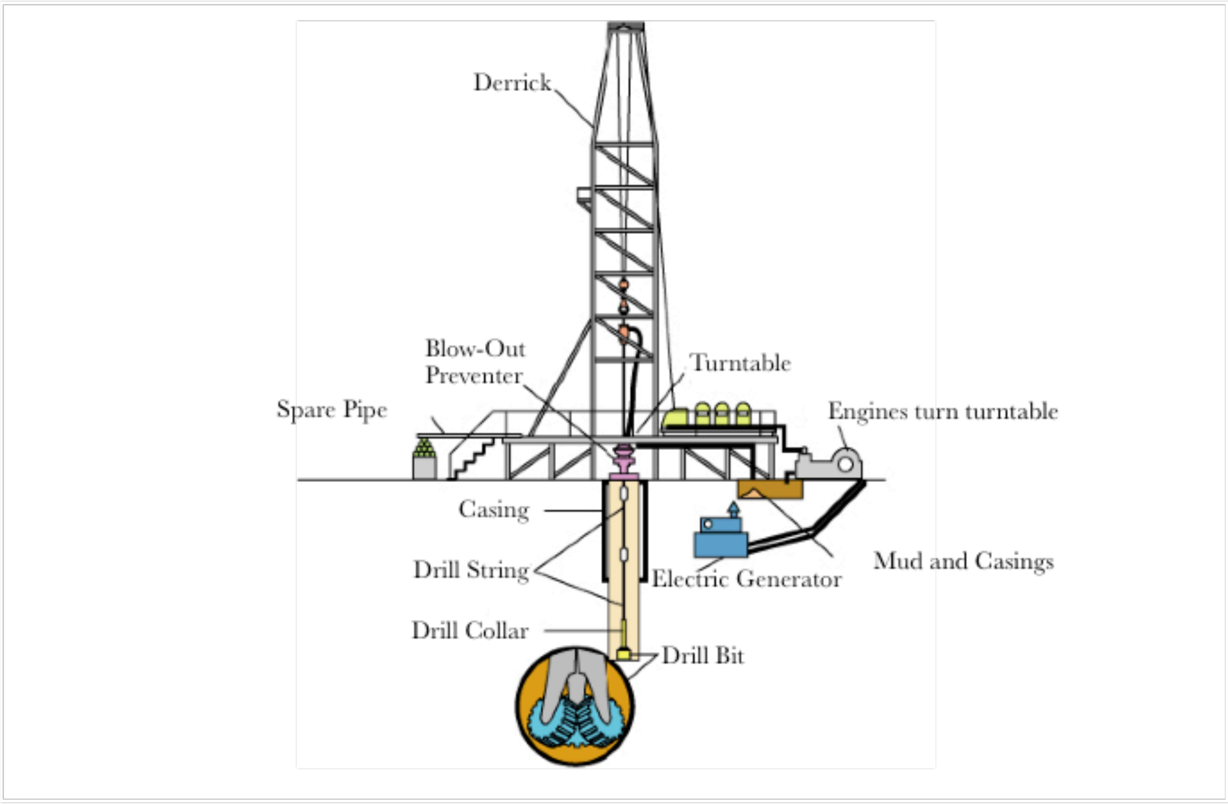

Figure 29: Composition of a Deep Geothermal Drilling Rig.

The most common drilling method for geothermal wells is rotary drilling (Culver 2006 p.131). This method rotates the drilling bit - where a heavy drill collar applies weight - and fluids clean cuttings from beneath the bit to the surface. Another technique that is often used is directional drilling in order to enhance the distance between both wells[79] (MIT 2006 p.194). However, there are also other drilling methods - each with their own benefits and disadvantages - that can be used for geothermal wells (see Culver 2006 pp.129-135).

[78] "Typically, oil and gas wells are completed using a 6 ¾" or 6 ¼" bit and then lined or cased with 4 ½" or 5" casing which is almost always cemented in place, then shot perforated. Geothermal wells are usually completed with 10 ¾" or 8 ½" bits and 9 5/8" or 7" casing in liner which is generally slotted or perforated, not cemented. The upper casing strings in geothermal wells are usually cemented all the way to the surface to prevent undue casing growth during heat up of the well, or shrinkage during cooling from injection. Oil wells, on the other hand, only have the casing cemented at the bottom and are allowed to move freely at the surface through slips" (Augustine *et al.* 2006 p.13)

[79] "Modern controlled drilling is accomplished by using a down hole motor driven by drilling fluid pumped down the drill string. The motor is attached to the string and by a bent sub and non-magnetic sub. The drill string and subs do not rotate. The bent sub is angled one to three degrees and is oriented to guide the drill motor and bit in the desired direction" (Culver 2006 p.134)

B2: Offshore Wind

Physics of Wind

Winds are the result of solar radiation. The movement of air masses, due their different thermal conditions, cause winds as a natural source (Ackermann & Söder 2000 p.330). The motion of the air masses has global, i.e. jet streams, and regional, i.e. orographic conditions, phenomena. Jet streams are fast flowing air currents in the atmosphere and are caused by a combination of the earth's rotation and by solar radiation (Sahin 2004 p.507). The earth's surface and atmosphere rotates the fastest around the equator and virtually not rotates at all at the poles. This causes pressure buildups that cause jet streams (west to east winds[80]), which are located at 30-60º latitudes of middle hemispheres (Sahin 2004 p.507). Orographic conditions are for example the surface structure of the area, since wind speeds are more turbulent near the ground of a rough landscape (Ackermann & Söder 2002 p.83). Regional winds occur through pressure gradients that cause temperature gradients, which leads to strong winds (Sahin 2004 p.507). Summarizing, wind speeds depends on latitude, longitude, position and time.

The highest efficiencies can be reached when the wind turbines use the designed wind speed, which is usually between 12-20 m/s (Ackermann & Söder 2000 p.335; BWEA 2005 p.3). At these wind speeds, the full capacity is reached by the power output. Above the designed wind speeds, the power output must be limited in order to keep the power output close to the rated capacity and, thereby, reduce the total load on the rotor hub and the whole wind turbine structure (Sahin 2004 p.521). Hence, the control and safety system of a wind turbine can adjust the angles of the blades, which is known as pitch control, or even stall the wind turbine when a certain high wind speed is reached, for instance in a storm (Ackermann & Söder 2000 p.336). See figure 30, for a typical power curve of an offshore wind turbine.

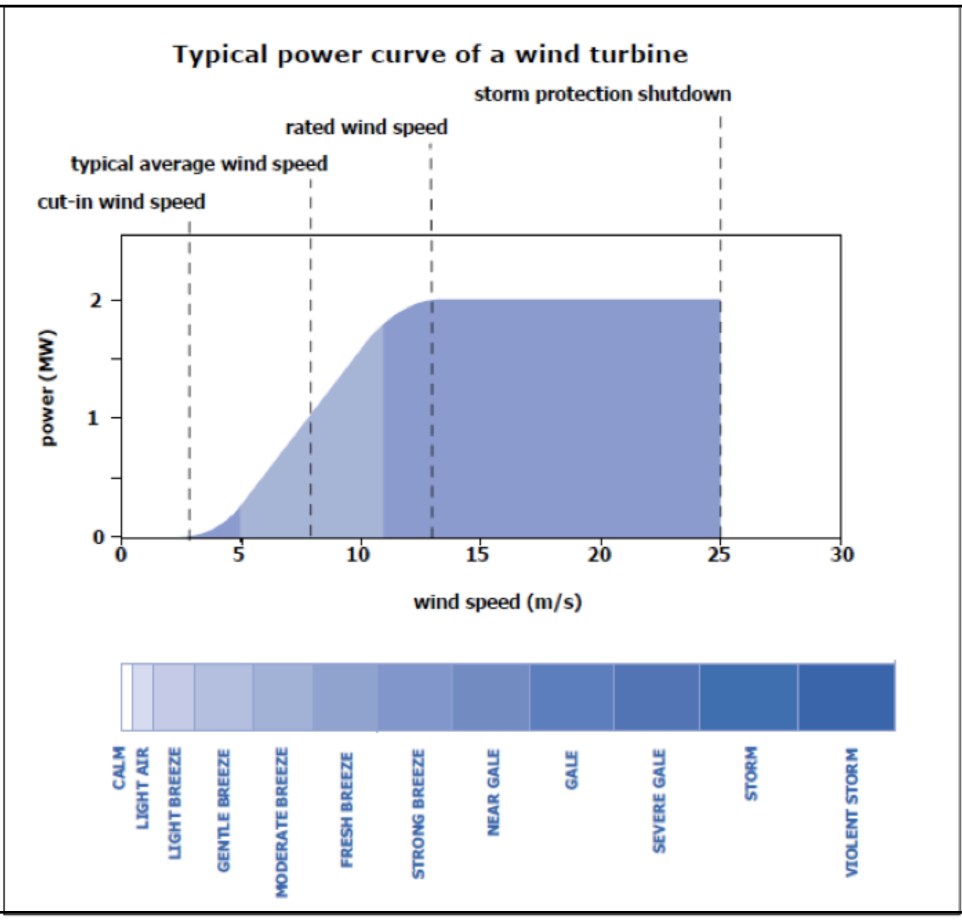

Figure 30: Typical Power Curve of a Wind Turbine (BWEA 2005 p.3).

[80] During the northern summer, east to west jet streams can also form in tropical regions (Sahin 2004 p.507).

Appendix C: Project Realization Processes

C1: Deep Geothermal

Feasibility Study Phase

The first phase is a preliminary research phase where geological and feasibility studies are carried out. It starts with a geological quick scan, which is more or less a literature study on existing available geological data, in order to determine whether it is necessary to conduct a larger geological study. If the geological quick scan provides the desired outcomes then a larger geological study has to be executed. Such a large geological study will expose site-specific geological data about the sandstones, for instance their transmissivity (Kramers *et al.* 2009 p.3). This data can then be used to design a suitable well doublet.

Next to the geological studies, feasibility studies have to be conducted on how to chose the right business plan regarding insurance, external finance, and/or cascaded use issues. Deep geothermal energy projects require high initial investments in advance, so a sound business plan including risk insurance is therefore strongly recommended since there is always a chance that the geothermal doublet performs less than estimated in advance. When both the geological and feasibility studies turn out to be positive, then, first, an exploration and, second, an exploitation permit has to be granted by the Dutch Ministry of Economic Affairs since any energy mining exceeding 500 meters falls under the Mining Act[81], introduced in 2003, for which the Ministry of Economic Affairs is the permitting authority (SPG 2008 p.14).

An exploration license gives the right to explore for deep geothermal energy by one or more drillings in a specific area and a defined period. It requires a comprehensive and thorough document, including descriptions of the local geological situation, the proposed installation and operation methods during drilling activities[82], the effects on the sub-soil, the interference with other applications, the definition of the license area, the expected planning, the financial details and the envisaged results (SPG 2008 p.14). Altogether, the geological and feasibility studies, including the composition of the exploration license the document, can last between 2 and 6 months, depending on the depth and quality of the research. However, it is highly recommended to spend sufficient time to conduct qualitative geological and feasibility studies, which especially will yield a profit on the longer run. Therefore, the average time spent on the preliminary research phase is set to 4 months in this analysis.

Permit Application Phase - part I

The second phase is the first part of the permit application phase for the utilization of deep geothermal energy: the application process for an exploration license[83]. First, the request, in the form of a thorough document, has to be submitted to the Dutch Ministry of Economic Affairs. When the application is received it is placed in the Staatscourant[84] where an invitation is placed for counter-applications. Interested parties can submit a competitive application within 13 weeks from the date of publication. After this period the Dutch Ministry of Economic Affairs requests the advice of TNO Built Environment and Geosciences, Netherlands Energy Management (EBN), the

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[81] The Mining Act regulates the basic rules for the exploration, exploitation, and technical modus operandi during the total chain of mining activities of minerals, such as crude oil, natural gas, salt, and terrestrial heat, and offers the main rules and concepts connected with mining (SPG 2008 p.14). All Dutch mining products, including terrestrial heat, belong to the State when still below the surface. Once produced the ownership of the product, which is the extracted heat, is transferred to the license holder (exploitation license). The legal procedure for deep geothermal energy is an exact copy of the oil- and gas permit procedure.

[82] Including the safety precautions and methods to prevent pollution and nuisance.

[83] An exploration license regulates: the allowed activities, the targeted mining product, the covered period, and the covered geographical area. Basically, it determines the terrain and period in which drilling and testing processes for geothermal energy are allowed.

[84] This is the Dutch governmental newspaper.

National Mines Inspectorate (SODM), and the Provincial Executive (GS) of the province in question. Within 6 weeks these parties will give recommendations concerning various aspects of the exploration license application. Consequently, the Dutch Ministry of Economic Affairs solicits the advice of the Mining Advisory Council, which meet once every 2 to 3 months. After these procedures, the Ministry of Economic Affairs has a maximum of 6 months, after the period for submitting counter-applications ended, wherein they must issue a decision on the application for an exploration permit. However, the minister can extend the decision process period but by no longer than 6 months. The decision will then be announced in the Staatscourant and if it is not contested it becomes irrevocable after 6 weeks.

The exploration application procedure can, hypothetically, be accelerated. The reserved time (13 weeks) for counter-applications is defined by the European Commission and cannot occur any faster[85], however, the next phase can start much sooner when no counter-applications are expected. But when a counter-application is applied for, even on the last possible day, all the work has to start all over again, which is not desirable. The next period, in which the government must issue a decision, can also be accelerated but depends on the advice of Mining Advisory Council, who meet only once every 2 or 3 months. Besides these issues, quality insurance of the decision is also very important and needs time to execute. Therefore, the average time spent on the exploration license application phase is set to 8 months in this analysis.

Contracting and Installation Phase

The third phase is the contracting and installation process of the geothermal doublet, which mainly consists out of setting up contracts, and a drilling and installation process. During the end of the exploration license application process, drilling and consulting firms are requested to submit an offer for the drilling and installation process of the designed geothermal doublet. On the basis of the submitted offers, further negotiation occurs until contracts are set up where insurance and financial issues are clearly regulated. Hereafter, the actual installation process begins.

First, some on-site preparations are needed in order to clear and level the respective terrain and to provide electricity or a water source that both are required in order to start the drilling process. The required temporary drilling area uses approximately 30 by 20 meters up space, whereof 100m^2 is permanently used for the drilling rig, a building for the crew, and the storage of components and equipment (van den Bosch 2009 p.4). The drilling process to depths of 2 to 3 kilometers is, nowadays, routine based since much experience is already acquired via the oil and gas industry (Bottai & Cigni 1985 p.309; MIT 2006 p.191; Teodoriu & Falcone 2008a p.1).

The construction and dismantling of the drilling rig lasts approximately 1 to 4 weeks, depending on the relocation. The drilling of deep wells lasts approximately 15 days per 1000 meter, with a significant increase in drilling time for depths greater than 3 kilometer. The testing of the geothermal wells lasts approximately one week each. This brings the total realization time for two geothermal wells of 2 to 3 kilometers to about 14-20 weeks, depending on the actual situation and materials used. Hereafter, the pumps can be installed and tested. The last task is to install the heat exchanger and connect it to the supply. The drilling process can, hypothetically, be accelerated but that is not desirable since the drilling process is the most important part of the throughput process of deep geothermal projects. Therefore, this phase is set to 4 months on average, without contracting or installation delays, in this analysis.

Permit Application Phase - part II

The fourth phase is the second part of the permit application phase for the utilization of deep geothermal energy, which is the application process for an exploitation license. In order to grant an exploitation license, the applicant must be able to show that the geothermal resources are economical and environmentally viable. Once again, the Dutch Ministry of

[85] It is, already, very tough to apply for a counter-application within 13 weeks, so shortening this period will create a 'first come, first serve' climate, which is not desirable for the quality of geothermal projects.

Economic Affairs requests the advice of TNO Built Environment and Geosciences, Netherlands Energy Management (EBN), the National Mines Inspectorate (SODM), and the Provincial Executive (GS) of the province in question. Within 3 to 6 months these parties will give recommendations concerning various aspects of the production license application. Consequently, the Dutch Ministry of Economic Affairs solicits the advice of the Mining Advisory Council, which will take about 6 weeks. Within the subsequent month the Dutch Ministry of Economic Affairs will issue the permit. When everything is according to wish than the permit will be granted and goes into effect 1 day after sending. This last phase will last 8 months on average without any delay in this analysis.

Operation and Maintenance Phase

The last phase is the operation and maintenance phase, which covers all operation and maintenance activities undertaken once the geothermal doublet is operational. The required maintenance activities can be periodical or accidental, however, these are negligible for geothermal doublets since maintenance is required ideally only once per year.

C2: Offshore Wind

Permit Application Phase

The first phase is the permit application process for the utilization of offshore wind energy: the application process for a construction license[86]. This procedure is applied under the Public Works and Water Management Act (WBR) and requires a mandatory Environmental Impact Assessment (EIS). First, a project initiative[87] has to be submitted to the Directorate Water Management North Sea (DNZ), which is part of the Ministry for Transport, Public Works and Water Management. If more parties apply for the same overlapping area, DNZ informs them and tries to organize discussions to fine-tune the initiatives. DNZ replies by sending the specific guidelines for the permit request and make the initiative public, e.g. in the Government Gazette. Hereafter, the Committee for Environmental Impact Assessment (CEIS) has the opportunity to give advice, and anyone else concerned can also comment on the project initiative. Within 13 weeks, the DNZ gives the final guidelines for the EIS to the applicant.

The applicant can then start executing the EIS, this process does not have a time limit and there is also an opportunity to supply a draft version to the DNZ for review. During the same time, the applicant does also have the opportunity to supply a draft version of the construction license request, however, this is also optional.

When both the environmental impact assessment and the construction permit request are completed, it can be send to the DNZ. The DNZ is obliged to judge the EIS on the basis of the guidelines and legal requirements on completeness and correctness within 6 weeks. When the DNZ considers the EIS acceptable and the construction license request is complete, the DNZ notifies other applicants that also requested for the same area. From then on, no other applications will be processed for the same area. Within 10 weeks, the DNZ sends the EIS and the construction license request to the CIES and the statutory advisory bodies. The DNZ publishes the construction license request and deposits the EIS and

[86] A construction license regulates: the allowed activities, the covered period, and the covered geographical area. Basically, it determines the terrain and period in which construction and producing activities for offshore wind energy are allowed. The Netherlands has a so-called exclusive economic zone offshore, which covers an area of 60.000 km^2. However, parts of this zone are already reserved for other activities, such as military areas, shipping routes, disposal sites, sand resources and cable routes. Nevertheless, the entire exclusive economic zone (excluding the 12-mile of coast zone) is, in principle, open for permit application requests. In addition, the Ministry will only grant construction permits for individual wind farms that do not cover more than 50km^2 (Rijkswaterstaat Dienst Noordzee 2006 p.2).

[87] The minimum data to be provided by the applicant for a construction permit are: border coordinates of the projected wind farm, type and design of the wind farm, information about the utility and necessity of the wind farm in the NEEZ, impact of rightful use of the sea by others, an environmental impact, a construction plan, a maintenance plan, a safety plan, a marking and signaling plan, an emergency plan, an indication on the period of intended commercial operation, a decommissioning plan as well as a design assessment certificate of the wind turbines (Rijkswaterstaat Dienst Noordzee 2006 p.2).

construction license request for public inspection. Within 6 weeks, anyone concerned can make remarks on the EIS. Hereafter, the CIES reviews the EIS both for completeness and scientific quality, taking into account the comments from advisers and public participation, and gives advice on the EIS within five weeks.

Upon receipt of the CIES's advise, the DNZ produces the decision for the draft construction license as soon as possible. Within two weeks after informing the applicant and other administrative bodies concerned, the DNZ is obliged to post the draft construction license and EIS for public perusal and notifies the public. Appeals against the decision can be made within 6 weeks. After the reception period, the DNZ has to decide about the construction license request within 4 weeks, since it is obligatory to make a final decision within 6 months after the first official request notice. This phase will lasts 18 months on average with no delays[88].

After the request for a construction permit has been accepted, the developer has a claim on the location given for a limited time. During this period, the developer has to get the remaining consents, such as a permit for cables running through the territorial waters and permission to cross the cables through the dunes, and arrange for the attainment of subsidies[89]. These processes overlap and occur during the following phases.

Front-end Development and Contracting Phase

The second phase is the habitually complex front-end development and contracting phase where development and contracting processes are carried out. First, the specific design of the offshore wind park needs to be further elaborated, resulting in a final working plan based on optimalization and feasibility studies. After the specific equipment and operational- and decommissioning procedures have been determined, these activities will be outsourced. External parties are requested to submit an offer for mainly three processes. First, to supply the designed offshore wind turbines and required foundations, second, to install these foundations together with the offshore turbines, and third, to construct and install the entire electrical infrastructure. On the basis of the submitted offers, further negotiation occurs until final contracts are set up and signed by all parties. This phase lasts approximately 12 months, however it heavily depends on the designed offshore wind farm, its coupled foundations, and required installation equipment.

Manufacturing and Installation Phase

The third phase is the manufacturing and installation phase, in which the entire offshore wind park has to be manufactured and installed. The manufacturing of foundations and offshore wind turbines require several orders for different materials, such as steel or concrete, in order to assembly the different structures of the offshore wind turbine at a factory. Hereafter, the different parts have to be transported to an available port closely to the offshore wind park. At the quay, the different components are assembled and are made ready for transport to the offshore wind park location. First, the foundations have to be installed on site. Second, the transition pieces and turbines need to be installed on top of the foundations. Third, the remaining blade has to be attached to the nacelle, although some installation vessels can also transport entire assembled offshore wind turbines. As a last, the electrical infrastructure needs to be installed, which includes connecting the different wind turbines to a substation. Other activities, which can be executed simultaneously, are to manufacture and install the electrical substations and the electrical cables, and to connect these to the onshore grid.

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[88] However, in practice this phase can last much longer. Note that the depicted timeline is under normal circumstances without complicated issues such as appealing procedures, which can result in enormous delays.

[89] Subsidies are available for parties in possession of a construction license according to the WBR and are supplied in the form of a tender in the Netherlands. The operator who offers the best price per kilowatt-hour receives the subsidies. Therefore, the size of the subsidy is linked to the current market price for electricity. Adding to, the costs of the grid connection must also be borne by the wind farm operator, which means that that the grid connection has to be provided by the operator.

The offshore installation process is very dependent on weather conditions. Hypothetically, these can be executed during the whole year but are more sensitive to bad weather conditions during the months October until April. This is therefore also a financial issue, since non-operational activities are not preferable for investors. Another restriction is the piling season restriction, which means that no foundations can be installed[90]. Therefore, the manufacturing and installation phase lasts approximately 48 months on average without any major delays.

Operation and Maintenance Phase

The fourth phase is the operation and maintenance phase, which covers all operation and maintenance activities undertaken once the offshore wind park is operational. The required maintenance activities can be periodical or accidental. These activities are also weather dependent and last the whole lifetime of an offshore wind park, which is 20 years on average. After this period, according to the Public Works and Water Act, an offshore wind park needs to be entirely decommissioned.

[90] Most types of foundations require piling procedures, which is restricted in the Netherlands from 1 January until 1 July. However, there are other methods to install foundations, for instance drilling methods, but it is preferable to change the current seasonal restriction into a maximal noise level for piling procedures throughout the whole year, as is already implemented in, for example, Germany (Taskforce Windenergie 2010 p.41).

Appendix D: Historical Backgrounds

D1: Deep Geothermal

Historic Deployment

Deep geothermal energy exploitation interests started in the Netherlands after the rise of oil prices in 1973. The governmental-established 'Discussion Group Geothermal Energy' was soon founded and conducted a number of inventory and feasibility studies in the 1980s (SPG 2008 p.4). However, these studies did not lead to actual projects. In 1987, a first test well was drilled in Asten that turned out unsuccessful since the yielded water was too low for the heating of greenhouses (Lokhorst & Wong 2007 p.341). But this location was chosen with the wrong incentives. A local market gardener was willing to purchase the extracted heat from the test well. But from a geological point of view, this location was not ideal for a first demonstration project.

Deep geothermal received renewed interest after the introduction of the Kyoto Protocol, which was introduced in 1997 to reduce worldwide reduction of CO_2-emissions, and the continually rising oil prices (SGP 2008 p.4). This led to the foundation of the Platform Geothermie on initiative of SenterNovemin 2002. The Platform Geothermie is a non-profit organization (NGO) with the core objective to foster the development of geothermal energy in the Netherlands.

In March 2006, the drilling process of the first deep geothermal project started in Heerlen in the Netherlands. Officially, this project belongs to the deep geothermal definition since it was the first time that geothermal drillings were executed to depths of more than 500 meters in the Netherlands. However the geothermal project is somewhat different since it extracts heat from water out of the galleries and shafts of former coal mines at 700-meter depth (Lokhorst & Wong 2007 p.343). The project was brought into production on 1 October 2008.

In the fourth quarter of 2006, the drilling process of the second deep geothermal project (but actually the first real deep geothermal project) started in Bleiswijk. The horticultural firm A+G van den Bosch was the first that recognized the potential of deep geothermal energy for the heating of greenhouses. Rik van den Bosch even received the prestigious Creative Energy Award from the Minister of Economic Affairs (SPG 2008 p.24). The project was brought into production in the fourth quarter of 2008.

In December 2008, the drilling process for the third deep geothermal project started in the Netherlands. Again the horticultural firm A+G van den Bosch decided to execute another deep geothermal project but now in Lansingerland for their second horticultural greenhouse. The project was brought into production in the fourth quarter of 2009. Consequently, 3 projects are realized until 2010.

D2: Offshore Wind

Historical Deployment

Wind energy exploitation in the Netherlands interests started after the oil crisis in 1973, when the Ministry of Economic Affairs published its first White Paper on Energy. In 1985, an ambitious goal has been formulated to realize a target of 1000 MW onshore wind energy in 2000 (Agterbosch *et al.* 2004 p.2049). Until the introduction of the Electricity Law in 1989, grid connection of wind turbines was very complicated since it was not mandatory (Mast *et al.* 2007 p.6). Wind energy received even more interest after the introduction of the Kyoto Protocol in 1997, which was introduced to reduce worldwide reduction of CO_2-emissions[91].

[91] See Schenk *et al.* (2007 p.1969) for an overview of onshore wind development in the Netherlands until 2005.

Subsequently, interests started to move the wind sector in the Netherlands offshore; mainly due to the higher wind speeds that are positioned offshore and the NIMBY issues that affected onshore wind deployment (Gibescu *et al.* 2009 p. 241; Toke *et al.* 2008 p.1135). In 2004, the Ministry of Economic Affairs organized a policy workshop about the development of offshore wind energy in Europe which resulted in the Egmond Policy Declaration, describing a number of measures and actions required by the European Commission, Member States, TSO's, and market parties in order to stimulate offshore wind deployment (IEA 2005 p.161). On 29 December 2004, the policy rules to issue construction permits for the construction of offshore wind farms were published in the Netherlands under the Public Works and Water Management Act.

The first Dutch offshore wind farm was realized after a long-preparation period of approximately 10 years, which is the Egmond aan Zee wind farm and is fully operational since 2007. Subsequently, the Dutch government has set an ambitious target in its 'Clean and Efficient' program to create an offshore capacity of 6000MW in the North Sea by 2020[92] (EA 2009 p.7). In the meantime, the second wind farm was realized in the Netherlands, which is the Prinses Amalia wind farm and is fully operational since 2008. In addition, the Prinses Amalia wind farm is the first Dutch offshore wind project that is constructed beyond the 12-mile off coast zone and the first wind farm that is financed on a non-recourse base in the Netherlands (Offshore Wind 2010b p.19. Consequently, 96 turbines are installed with a combined capacity of 228 MW until 2010 (Offshore Wind 2010a p.43).

[92] The 6000MW has to be committed in 2020, not necessarily built. However, the target needs to be realized in order to attain the mandatory EU target of 14% of renewable energy in the final energy use.