Delft, University of Technology

Master Thesis
System Engineering, Policy Analysis &
Management

Assessing the impact of power plant location decisions on the long term development of the electricity sector

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October 10, 2013

Abstract

This research presents a new way to assess the impact of location decisions for new power plants by power producers. It builds on an existing agent-based model that is able to simulate market and investment behavior of power producers in a north western European electricity market (EMlab-generation). This study adds a module that is based on game theory concepts to simulate both the location selection by power producers and the required spatial permit procedure. In the end this model could help to give insights in possible future developments of power plant siting in a specific country (Netherlands in this case). This could help TSOs and policy makers assess their siting regimes and anticipate for potential future new generation capacity. The main research question is formulated as: *How does the set of factors considered in location decisions for new power plants affect the future development of the technological and spatial distribution of power generation in the Netherlands?*.

This research starts to investigate what aspects play a role in the location decision for new power plants. From literature and empirical sources it is found that besides the technical requirement of power generating technologies (Cooling water, feedstock connection etc.), the permit procedure plays a major role in the decision. Permit risk as power producer call it could significantly decrease the profitability of a project by delays and is thus a very important factor. Permit risk is connected with the potential for local activism against the siting of the new power plant. Activism is simplified and conceptualized to three main factors: Population density, wealth and attitude towards a specific power generation technology.

The model addition contains two main parts. First the power producer selects a technology and finds the best locations according to its own selection method. This could be conceptualized and modelled easily with utility functions. The second part of the permit procedure is more difficult as it involves negotiations with the local government and potentially several local parties (activists). The game theory concept of the nucleolus is used to conceptualize the permit procedure. First the government is payed a monetary environmental compensation fee (based on legal obligation), afterwards the local parties are payed a compensation fee, the unhappiest party first. The compensation is payed to ease the negative attitudes towards the new power plant and to lower the chance parties go to court and potentially delay the project, threatening profitability. This in essence is the model and the data input is based on data of potential power plants sites in the Netherlands (SEVIII) and regional statistics by the bureau of the statistics.

The simulation results show that the model is able to produce significantly different results for different location selection methods by power producers, both in geographical distribution of power plants as the technology mix. Additionally the permit procedure and the amount of compensation required by the

local parties also significantly influences the spatial and technological distribution of power plants. Finally other location related factors such as the potential for CCS at a location were also incorporated and showed significantly different results.

The results are subject to some limitations, these mainly have to do with the choices for simplifications and the data used as model inputs. This is something to always consider when reviewing the results of this study and when reviewing agent-based modelling studies in general.

The analysis of the results contain several different types of contributions:

- The current EMlab-generation model is extended and is now able to incorporate location decision and the permit procedure. Additionally the research presents a lot of valuable location data of power plants. The model shows similarities with the described behavior in the literature and empirical data.
- This study contains methodological contributions in the area of agent-based modelling and game theory. The concept of the Nucleolus has not been used in an agent-based environment and have not been used to simulate a specific kind of permit procedure. Under specific conditions and assumptions we showed that it is possible to use the nucleolus and this enables new applications in many different research fields that consider social negotiations.
- A start has been made to show the potential of the model for real world applications. Scenarios of Tennet for the generation capacity in 2030 have been compared with our model results, showing differences and similarities. The amount of data and detail of this research's model could help improve these scenarios and help Tennet anticipate for future generation capacity developments. Additionally some observations with regards to policies are given and the possibilities of this model to policy analysis is discussed.

Acknowledgements

This thesis has been a big challenge and I had to work very hard to to the level it is now. I am very thankful for the support I received during this thesis from everyone. I want to thank a few people explicitly. First of all I want to thank my graduation committee for their expertise and support during this thesis. More specifically I want to thank Professor P.M. Herder for chairing the graduations committee, Dr. E.J.L. Chappin for being my first supervisor and his very direct and valuable feedback given, Dr. S.W. Cunningham for his supervision and especially for helping me with the applications of game theory concepts in my thesis and finally L.A Bollinger MSc. for his feedback and more day to day supervision of my project.

Special thanks go to Ruben Verweij & Kaveri Iychettira. They started their graduation projects in the same field two months earlier and we worked together for several months. They were able to share their experience with the model and guided me through the current EMLab-generation model. Ruben Verweij also shared many of his data analysis R-scripts that were easily adjusted to my case and saved me days of work. It was very pleasant working together with both of them. I also want to thank Wilke van Zelst who reviewed my entire thesis.

Jörn Richstein was able to help me a lot by solving a modelling engine problem that costed me a lot of time to figure out.

Finally I want to thank my family and friends for their support and in special my brother Eric Paling, who is a student in applied computer science. He was able to help me with his knowledge about coding and programming, which was something I had very little knowledge about.

Jeroen Paling

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Chapter 1

Introduction

It is well known that power plant location decisions are very important. In the past power plants were mainly dependent on access to sufficient cooling water, as most of the techniques were based on thermal power plant designs. These power plants were located near major consumption areas, or consumers moved to areas surrounding power plants. The European grids are also designed to this principle. In recent years however with the increasing efforts to incorporate renewable energy sources in the power grids, this changes. For example wind Turbines are build in areas with space, in remote locations and have very different demands for locations than thermal power plants. In Germany the success of the Energiewende, especially the Wind turbines in the north and also the PV cells across the country, cause serious problems because of the intermittent nature of renewables and thus poses a threat to the reliability of the transmission grid(WindPower Offshore, 2012; Oilprice, 2012). This clearly illustrates the tension between the current design of the electricity grid and the impact of the transition towards sustainability.

Besides the problems emerging from the incorporation of renewables in the current electricity grids, there are more problems with regards to power plant locations. Environmental laws in Europe are amongst the strictest in the world, these laws also include requirements for residual heat from thermal power plants. Capacity of rivers, lakes and oceans to absorb heat are limited and have to be taken into account, both for the economic efficiency of the plant, as well as for the environment. Furthermore, the population are more easily activated and could be a big problem in permit negotiations. Societal concerns against nuclear energy were already strong and after Fukushima this activism and the public opinion even caused countries like Germany to shut down nuclear reactors. However activism is not only against nuclear energy or other conventional fueled power plants. Many people are against the conversion of land and the use of open space, the level of activism has proven to increase with educational level and population density (van Dijk & van der Wulp, 2010). This activism also emerged against different renewable energy projects and these activist are seen as very annoying by the project developers (Cass & Walker, 2009). They can cause serious delays and risks in the permit procedure (Groot, 2013). These issues with local activism also have been observed for the planning and construction of transmission lines and because of the long distances of transmission lines their planning and construction, can even take longer than power plants.

1.1 Research Problem

Location Aspects Research Optimization of power plant locations is something scientists have been writing about for decades. Early studies were struggling with qualitative data, but identified there is a need for behavior mapping leading to the location decision of new power plants (Solomon, 1984, p. 76). In more recent years so called multi-criteria decision tools (MCDA) have been frequently proposed by the scientific community to evaluate different locations, especially for sustainable energy (J.-J. Wang, Jing, Zhang, & Zhao, 2009; Scott, Ho, & Dey, 2012; Pohekar & Ramachandran, 2004), but also for modern thermal power plants (T. Wang & Xin, 2011; Choudhary & Shankar, 2012; Barda, Dupuis, & Lencioni, 1990). Besides MCDA techniques there have been numerous studies proposing geo-information-systems (GIS for locating new power plants (Viana, Cohen, Lopes, & Aranha, 2010; Omitaomu et al., 2012; Li, Cockerill, Liang, & Gibbins, 2011). Many of these articles have proposed theoretical frameworks focused on mostly economical optimal locations. Long term effects of the placement of power plants on the development of the electricity sector are hardly considered. Furthermore they focus on a single case (single power plant or single technology). What kind kind of impact a location decision has on the future development of the rest of the electricity sector has not been researched. This could be very insightful, especially for the planning of future transmission grid expansions.

Garrone and Groppi (2012) analyzed the behavior of the power producers after the liberalization of the electricity sector of Italy in 1999. Power producers tended to focus on areas with less locally supported activism and did not go on the most 'optimal' locations. These market imperfection can also cause problems for the planning of the transmission grids. Groot (2013) did research to investment behavior of electricity companies in western european countries. In his interviews it becomes clear that many of the electricity companies took factors related to locations very seriously. Building permit risk, land lease risks, resource availability and grid connection are the main factors that are considered (Groot, 2013). Both studies acknowledge that traditional economic factors like feedstock availability, resources and grid connections play a role in the decision. However permit risk or in other words chance on delays due to permitting (activism) also plays a major role. Power producers tend to avoid risks and thus permitting risks are taken very serious and like the Italian case of Garrone and Groppi (2012) illustrates the areas with the highest amount of local activism are put aside.

The type of risks associated with the location of a new power plant is greatly dependent on the type of generator. Thermal power plant need good access to feedstock and sufficient quality and quantity of cooling water. Renewables have other requirements like for example sufficient wind year round. This connection to the grid is also a factor of importance, especially for off-shore wind. A lot of research has been done to off shore wind energy economics and the transmission grid connection is always a major challenge and source of costs (Dicorato, Forte, Pisani, & Trovato, 2011; Fischlein, Wilson, Peterson, & Stephens, 2013; Green & Vasilakos, 2011). In most countries you are even dependent on third (governmental) parties to provide the transmission connection.

From this initial literature review we can see choosing a location for a power plant is more than just looking for the right technological requirements. As shown by Garrone and Groppi (2012) and Groot (2013) in reality the producers tend to choose for location with the least amount of risk. Power producing companies want to avoid problems with the local population, which could seriously delay the construction or permit procedure. Permit risk and the associated local activism are very dependent on local actor behavior and this makes many quantitative methods less effective and hard to execute. Providing a way to gain insight in the effects of these risks have on the electricity sector, can help developing theories about the spatial distribution of power plants. This can also give insights to TSO for more effective planning of new transmission lines, as planning transmission lines generally takes more time than building new power plants.

Problem Statement The following problem statement is formulated:

It is known that power plant investment decisions take into account the aspects of potential locations, but it is not known how especially the softer risks like permit risk (activism) influence the longer term development of the electricity sector, in both composition of the portfolio as well as the geographical distribution.

This problem formulation is from the perspective of the Dutch transmission system operator Tennet. Solving this problem could help them anticipate for future power plant investments and improve their own long term scenarios for the Netherlands.

Scope Due to the limitation in time and resources this study will focus primarily on modelling the location decision and permitting procedure for new power plants in an agent based model. This model will then be used to evaluate the effects of location decision on the long term development of the electricity sector and tries to find patterns and insights for future planning. The model will be based on the Netherlands, but cannot capture the complete complexity of the location decision and permitting procedure. Simplification and assumption have to be made to keep this study feasible in a reasonable amount of time. Focussing on a single country makes it possible to give the model specific geographical inputs. Furthermore the starting fuel mix of power plants is known and possible locations of big power plants are known (Rijksoverheid, 2009a). Finally, focusing on a single country also helps with the conceptualization of the permit procedure, that precedes the construction and is very important in the final location decision.

Most currently available power plants technologies will be implemented in the model. Future technological developments in new power generation techniques are not taken into account. The model will be based on the EMLab-generation model. This model is an already functional agent-based model that simulates electricity markets. Using this model as a base and adding location decision, will make it possible to focus in depth on location decision and not on modelling the electricity market. Finally possible changes in national policies are not taken into account.

The specific choices for simplification and assumption will be discussed in the rest of this thesis.

Social and Scientific relevance For the scientific community the outcomes of this study could be useful in two ways. This study requires to conceptualize permit procedures and to implement them in an agent-based model, this could help further research to the use of agent-based models for permitting procedures. Additionally it could provide insight in the geographical development of power plants in a specific country and the factors driving this development. Lastly the model could be extended, detailed more and applied to different countries to gain more knowledge to spatial power plant development.

The Ministry of economical affairs could use the result of this study and the model to enhance the effectiveness of its electricity policies and its power plant siting policy (SEV 3). Patterns in the spatial development of the electricity sector could also be used to evaluate current scenarios to the development of the electricity sector in the Netherlands by the Transmission system operator Tennet. Tennet already has developed scenarios about the development around 2030 and this study could be used to evaluate this vision and add new insights gained from this study.

1.2 Research Questions and Approach

The steps presented in the previous paragraph are closely related with the research questions.

Main research question: How does the set of factors considered in location decisions for new power plants affect the future development of the technological and spatial distribution of power generation in the Netherlands?

- *question 1:* - What factors influence the choice for locations of new power plants and what is the role of the transmission grid?
- *question 2:* - How could the permit procedure and subsequently the location decision be modeled in the EMLab-generation simulation model?
- *question 3:* - To what extent does the distribution of power plants differ when considering local activism or not?

- *question 4:* - How does incorporating the permit procedure lead to a different energy mix in the model?
- *question 5:* - What is the implication of limiting CCS capacity to the electricity market?

Research Methodology The first subquestions with regards to the identification of location factors will use interview and empirical data of Groot (2013). These interviews are confidential but the analysis is public. This is a very interesting piece of work and gives valuable insights on how market parties operate and make investment decisions. This will be supplemented with a literature study to get more insight in research done to power plant locations. This is however time consuming and therefore limited.

The modelling technique that will be used in the master thesis is the agent-based modelling paradigm. The agent-based modelling paradigm is a bottom-up modelling technique, which could be used to model different stakeholders, states and interactions between the stakeholders and the environment (Dam, Nikolic, Lukszo, & Afman, 2012). Furthermore it has been shown that this modelling technique can be used to simulate the transition in energy systems (Chappin, 2011). The location decision for power plants are dependent on interaction of the power company with the environment and other actors. Agent-based modelling is a very suitable technique to analyze these interactions and the resulting model behavior.The main drawback of using the agent-based modelling paradigm is that it is time consuming, hard to validate, requires a lot of processing power and is data dependent.

Agentspring will be used as the software for the modelling. Agentspring is suitable for complex agent-based modelling problems (Chmieliauskas, Chappin, & Dijkema, 2012). It uses the Java computer language.

The current EMLab-generation model, based on the agent-based paradigm will be extended to incorporate locational aspects. The EMlab-generation model has been made to investigate the effects of different climate and energy policy on the electricity sector (de Vries, Chappin, & Richstein, 2013). An extensive explaination of the modelling technique and the current EMlab-generation model is presented in chapter 3.

For the data analysis of the simulation results statistical packages like R will be used.

Outline of Thesis To gain insight in the effects of location decision for power plants on the long term development of the spatial and technological distribution of power plants in the Netherlands, several steps have to be done. In figure 1.1 the basic steps of this master thesis are presented. The outline of this thesis will follow these steps closely. In chapter 2 the location decision is analyzed and the most important location aspects are presented. Chapter 3 explains the basics of agent-based modelling and presents the current EMlab-generation model. Chapter 4 presents some game theory concepts that will be used in the conceptualization. These three chapters are all inputs for the conceptualization in chapter 5. The resulting conceptual model will be made into an extension to the EMlab-generation agent-based model in chapter 6. At the same time the input data is gathered and presented in chapter 7. Chapter 8 discusses the verification and validation steps and is followed by the experimental design in chapter 9. The model is than used to generate results and these are presented in chapter 10 and further analyzed in chapter 11. This is followed by the conclusion which will answer the research questions, in chapter 12. This thesis ends with a reflection to the model results and the process, in chapter 13. Additionally there are also appendices and these are referred to in this thesis. Due to the large amount of data, figures and graphs, not everything is in the appendices of this report. Online additional graphs, figures and tables can be found at: https://github.com/jeroenpaling/emlab-generation/tree/LocationAspects/Report .

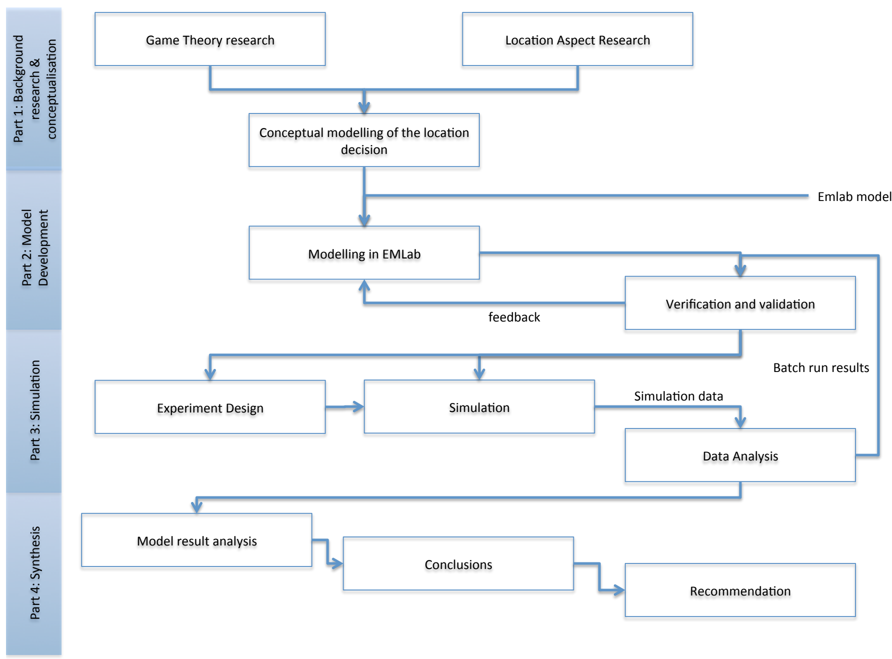


Figure 1.1: An overview of the different parts of this thesis

Chapter 2

Location Aspects of the power plant investment decision

This chapter analyses the location decision for new power plants by power producers in a liberalized Northern European market. Different key aspects in the location decision will be presented. Additionally the investment process and permitting procedures will be discussed. The results of this chapter will form the basis for conceptualization of chapter 5.

2.1 Location Decisions for new power plants

Groot (2013) did research to the investment decisions of power generators in north western Europe. He assessed how they come to a decision to invest and what factors are influencing this. According to interviews with several electricity generating companies, they found a lot of valuable information on how investment decisions are made in the electricity sector. He identified several key risks that were presumed to have high impact on the operations or planning of power plants.

- building permit risks (key risk for power producers)
- power price volatility (key risk for power producers)
- land lease risks (key risk for power producers)
- subsidy risks (key risk for renewables)
- natural resource availability risk (such as wind speed yield risk: key risk for the development of renewables)
- technical risks in the power plant

- grid connection risks
- construction and risks
- fuel price risk
- carbon exposure risk
- risks in partnering

(list from Groot (2013))

It becomes apparent from the list presented above that many of the risks are linked to location aspects. Building permit risks, land lease risks, natural resource availability and grid connection risks are directly linked to locations. However other factors also have links to location aspects. Partnering with local groups and companies is likely needed for a smooth process and is therefor also linked to locations. Natural resource availability is not only valid for renewables, but also for the feedstock supply of conventional plants and the availability of sufficient cooling water is directly linked to this risk. Some companies simplified the location risks to only: cooling water, permit issues, availability of feedstock and supply of feedstock (Groot, 2013). Showing the importance of these 4 main location aspects.

The importance of permit risks is also acknowledged in research by Garrone and Groppi (2012). Italian gas power plant investors did not really care about environmental issues, but did care about local activism against the construction of their power plant and considered this a much bigger risk. When we think about activism we mainly consider environmental activists, but for these Italian power generators local activism is considered a far bigger risk. This means there is a tendency of Italian power producers to move away from high risk areas for opposition and activism. This can cause problems with the planning of transmission lines, because not all power plants are placed in the most (economically) optimal locations, it is hard to anticipate for future investment in power plants.

Another interesting observation is that the power producers, according to Groot (2013), did not really consider environmental issues as major risks, as most factors are captured in the permit procedures. Walls, Rusco, and Ludwigson (2007) also found that in restructured electricity (liberalized) markets companies worry about risks with regards to permit and tend to keep option open for long to select the alternative with the least amount of financial risk.

It becomes clear that for power producers a major part of the location decisions comes from the permit procedure and the risks involved with this procedure. Additionally Groot (2013) provided empirical data which can be used to find relevant location aspects that are used in location decision.

2.2 Permit procedure

A schematic chart of the entire permitting process can be found in figure 2.1 and a detailed description can be found in appendix D. In the Netherlands many previously separated permits are now bundled, this includes environmental, spatial, usage and buildings permits. It bundles over twentyfive permits in total (Rijksoverheid, 2009c). There is an extensive process before the permit is approved. Depending on the size of the project the permit has to be applied for at the relevant government body (municipality, province). The government will assess the plan, value possible environmental mitigation measures and finally decide wether or not to issue a permit. Other parties can give their opinions and a reaction to these opinions by the power producer is mandatory. Other parties have the possibility to go to court if they do not agree with the condition of the permit.

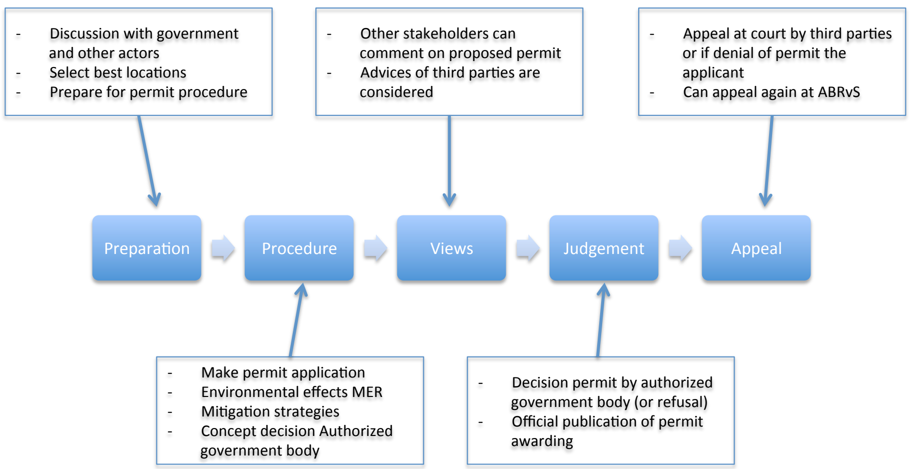


Figure 2.1: Simplified permit procedure for power plants

2.3 Grid connection and power generation

To understand the location aspects of power plants it is required to assess not only the building, environment and surroundings permits, but also the generation and connection permits. The Dutch electricity law of 1998 states all the requirements of the power producers and transporters.

In article 16a, 16b, 16c, 16d of the Dutch Electricity Law (Rijksoverheid, 1998) (appendix D) the transmission system operator is obliged by law to connect power producing parties to the grid and extend the grid where necessary. Although they are obliged to connect everyone and transport electricity, the timeframe for large scale producers is not mentioned. Also for transport they are justified to deny transport if there are problems with capacity and they should have a plan when to solve the problem for a reasonable amount of money (article 23 and 24 of the Dutch Electricity Law). In practice it proves to be faster to build an power plant than to reinforce or build new transmission lines. This means that it could seriously hamper the economic efficiency of the power plant during the first year(s) of operation, due to possible congestion.

Grid connection risks Two main factors involving grid connection risk can be identified. The distance to the nearest high voltage transmission line is the first factor. Capacity of the nearby high voltage grid is the second. To define these in factors is hard. One way would be to combine the previously mentioned factors with expected connection risks and make that a decision variable that will be used in investment decision for a new power plant. Other ways would be just nearby capacity of the lines and distance to the grid in kilometers. However the the capacity could be extended. The precise way of handling this will be detailed later, but these main factors will definitely be important.

So the two main factors are:

- Distance to the high voltage grid
- Capacity of the high voltage grid, under legal obligation (N-1, N-2 etc.)

2.4 Location Factors

Dutch government location decision The Dutch government has recently made a decision (Structuurvisie SEV III) on where electricity generators can put new over 500 MW power plants (Rijksoverheid, 2009a) and all the location are shown in figure 2.2. This document is for all locations on land and locations within the twelve miles zones in sea. For offshore wind there are only places in the twelve miles zone near Egmond aan zee, Ijmond and de Maasvlakte, if ship traffic allows this. Other locations for offshore power generation further out in sea can be found in the National water plan (Rijksoverheid, 2009b).

The possible locations for nuclear energy are a lot more limited, there are three location where nuclear power plants are allowed (Kernenergiewet (Rijksoverheid, 1963)). These location are Borssele, Eemshaven and Maasvlakte.

Tabel 1 – Vestigingsplaatsen

Nummer	Plaats	Opmerking en uitvoering (a)
1	Eemshaven	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
2	Hunze (Groningen)	Vervallen
3	Burgum	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
4	Westelijke Noordoostpolder	Vervallen (b)
5	Ketelmeer	Vervallen (b)
6	Harculo	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
7	Nijmegen	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
8	Dodewaard	Vervallen
9	Lek	Vervallen (b)
10	Utrecht	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
11	Flevo	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
12	Markerwaard	Vervallen (b)
13	Wieringermeer	Vervallen (b)
14	Velsen	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
15	Hemweg	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
16	Diemen	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
17	Maasvlakte I	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
18	Galileistraat (Rotterdam)	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
19	Waalhaven (Rotterdam)	Vervallen
20	Merwedehaven	Vervallen
21	's-Gravendeel	Vervallen (b)
22	Borssele / Vlissingen (haven- en industriegebied)	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
23	Ossenisse	Vervallen (b)
24	Bath/Hoedekenskerke	Vervallen (b)
25	Amer Geertruidenberg	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
26	Maas/Waal	Vervallen (b)
27	Boxmeer	Vervallen (b)
28	Buggenum	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
29	Maasbracht	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
30	IJmuiden	Vervallen
31	Moerdijk	Opname in provinciale structuurvisie of inpassingsplan en gemeentelijk bestemmingsplan
32	Westland	Opname in provinciale structuurvisie of inpassingsplan
33	Geleen	Handhaven in provinciale structuurvisie en gemeentelijk bestemmingsplan
34	Delfzijl (havengebied en industriegebied)	Opname in provinciale structuurvisie of inpassingsplan en gemeentelijk bestemmingsplan
35	Amsterdams havengebied / Noordzeekanaal	Opname in provinciale structuurvisie of inpassingsplan
36	Maasvlakte II	Opname in provinciale structuurvisie of inpassingsplan en gemeentelijk bestemmingsplan
37	Rijnmond / Rotterdams havengebied	Opname in provinciale structuurvisie of inpassingsplan en gemeentelijk bestemmingsplan
38	Terneuzen / Sas van Gent (haven- en industriegebied).	Opname in provinciale structuurvisie of inpassingsplan

Opmerkingen bij tabel 1:

Figure 2.2: Table with all the SEVIII locations (Rijksoverheida, 2009)

Resources Power plants are dependent on specific location aspects depending on the resources needed for electricity generation. In table E.1 in the appendix you find the different requirements for the different technologies. Each location must meet these technology specific requirements to be able to facilitate the specific generation technology. Specific data is available for cooling water requirements, as it differs greatly between different generation technologies. Feeley et al. (2008) analyzed the generation techniques and their water consumption, this could be used to assess cooling water requirements. For feedstock of fossil fuels there is a dependency on either water or railways, or for gas power plants connection to the main national gas grid. Nuclear energy has other requirements, especially when it comes to the transport and handling of nuclear waste. Rense (2004) analyzed the current cooling water quality and sensitivity for temperature increase at location of power plant for Rijkswaterstaat Waterdienst. This could used to compare the different location on the basis of cooling water availability. In section 7.5 the figure with the water quality of all the locations is included.

Local opposition & attitude Permit risk was identified in the empirical study to play a major role in the location decision. But what does permit risk mean? For the power producers it is the risk on delays due to problems in the permit procedures. These can be caused by governments and local inhabitants or activists going to court to appeal against the permit. Their attitude could lead to longer procedures and court rulings, lower permit risk is thus favored by companies that invest in the generating capacity (Garrone & Groppi, 2012). As perviously mentioned in chapter 1 there have been a lot studies done to opposition and activism by local groups against industrial facilities. Interesting findings suggest (van Dijk & van der Wulp, 2010) that the amount of activism is dependent on the wealth and education in the surrounding area. This is both true for renewables as well as for traditional means of electricity generation. Upreti and van der Horst (2004) investigated the failed development of power plants in the UK and concluded that the 'not in my backyard' attitude of the local people and the ' there is no alternative' attitude of the developers were the main causes of failures. Gaining public support was concluded critical in a successful project. This finding is supported by research done by Jones and Richard Eiser (2010), he also concluded that by involving the public you could reduce the opposition of the public, or as they called it: 'reducing the size of peoples backyards'. Another finding was that the distance to a plant does not matter per se. Visibility is far more important. Just involving the population, by explaining your plans is not always enough, people are not necessarily ignorant and their views should be taken in consideration as they might prove very valuable and an extra source of knowledge (Aitken, 2010). Based on these studies we can argue that local activism is based on wealth, education, visibility or quality of landscape and how informed people are.

From the literature the main factors for the threat of local activism can be derived and these can be used be used in the conceptualization to model local activism. In table 2.1 a first overview of factors influencing the likelihood and amount of activism at a location. It is likely a choice has to be made what factors will be used to model activism, this will never capture all the facets of local activism, but using the data of this section a sufficiently supported choice can be made.

Activism category	Key measurements
Level of involvement of population	• Part of process • Get informed • Not part of process (Aitken, 2010; Jones & Richard Eiser, 2010; Upreti & van der Horst, 2004)
Environmental factors	• Density • Quality of landscape (Jones & Richard Eiser, 2010)
Demographical factors	• Education level • Wealth (van Dijk & van der Wulp, 2010)

Table 2.1: A selection of the most important factors that determine the local activism

2.5 Conclusion

This section looked in more detail at the location decisions of new power plants by power producers, to answer the first sub research question.

> What factors influence the choice for locations of new power plants and what is the role of the transmission grid?

Interestingly enough the power producers did not mention environmental factors, while the government find this very important. However these environmental effects are captured in the extensive permit procedure the companies have to follow in order to be able to construct and run a power plant. In these permit procedures the spatial planning is also included. This means that many of the factors related to the environment and permit procedures, spatial planning and construction risks can be aggregated. The permit procedure is also the place where opposition can use influence to delay or cancel the project. Risks in partnering are also closely related to the permit procedure, to ensure a smooth process, partnering up with local groups, governments can speed up the process, but also brings risks of parties leaving and delaying your process.

The second main factor for location is the availability of a natural resource. For thermal power plants this means the availability of sufficient cooling water, but for renewables this could mean enough wind or solar. The location for power plants over 500 MW have all been selected to have enough cooling water available (Rijksoverheid, 2009a).

The third factor of importance to the location decision is the access to the transmission grid. This could be measured in both capacity of the nearby transmission grid and distance to the nearby transmission grid.

To summarize the main location aspects table 2.2 is presented. These location aspects will be used in the conceptualization chapter (chapter 5) to conceptually model the location decisions for power plants.

<table>
<tr><th>Aggregated Factor</th><th>Location factors</th></tr>
<tr><td>Permit procedure</td><td>Building permit risks
Land Lease risks
Activism risks
environmental factors
Construction risks
Risks in partnering
fixed location permit
avoid location risk</td></tr>
<tr><td>Natural resource dependency</td><td>Natural resource availability
Fixed location permit
environmental factors</td></tr>
<tr><td>Transmission grid access</td><td>Grid connection risks
Fixed location permit</td></tr>
</table>

Table 2.2: Overview of the most important location aspects

Chapter 3

Agent-Based Modelling and EMLab-generation

This chapter will briefly discuss the basics of agent-based modelling. Additionally it will present the emlab-generation model and discuss the most important parts where the this study will make additions and changes.

3.1 Agent-Based Modelling

Agent-Based modelling is a bottom-up approach contrarily to most other forms of (mathematical) modelling. According to Dam et al. (2012) agent based modelling is defined as:

> "So agent-based modelling is a method, or approach, which examines the interactions of "things" or "entities" rather than a particular thing or collection of things to be replicated."

Agent-based models do not specifically try to replicate a desired state, but rather focuses on describing entities (agents) and observing how the interactions change the system's possible states (Dam et al., 2012). So basically you define the agents and the rules to which these agents should act. These agents can interact with each other, but also can be influenced by the environment they interact in (the system). The emergent behavior and possible states of the system can be analyzed and patterns, tendencies and frequent behaviors can recognized. These outcomes can not be used to predict the future, but can be relevant to the real world (Dam et al., 2012). In figure 3.1 the concept of agent-based modelling is shown conceptually (Nikolic, 2013). The figure shows very clearly the most important aspects of agent-based modelling from the interactions to the position of the model compared to the modeller.

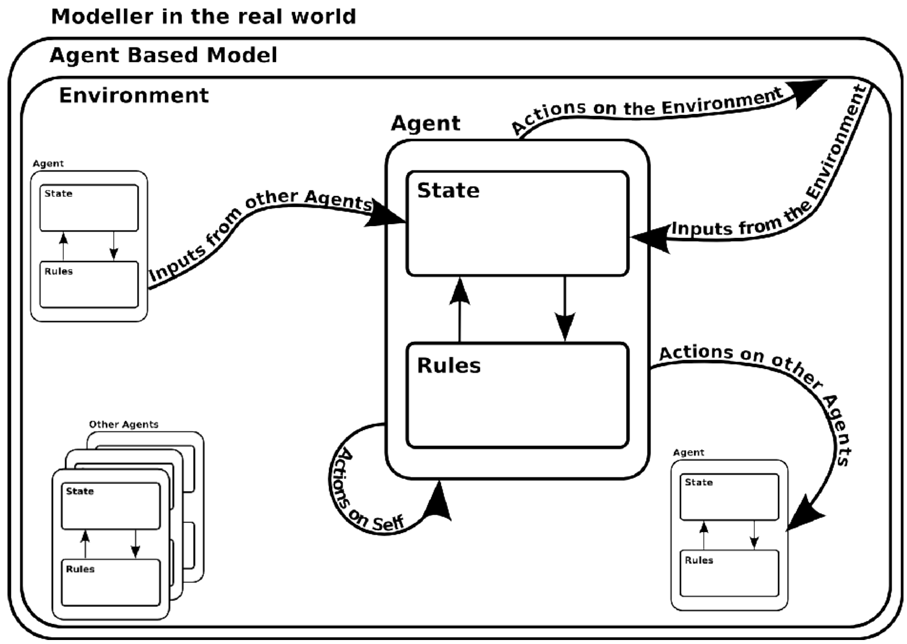


Figure 3.1: Agent-based modelling overview (Nikolic, 2013)

3.2 EMLab-generation

EMLab-generation is an electricity market simulation model with the following objective:

> "The model is designed to analyze the aggregate effects of investment decisions of electricity generation companies under different policy scenarios and market designs in order to assess the possible effects of different policy instruments on the long-term development of European electricity markets " (de Vries et al., 2013)

The model enables us to investigate possible effects of policy measures on the electricity sector of north western european electricity market. The model does not intend to replicate a specific electricity market. However it is possible to adapt the portfolio of power plants to a specific country's power plant portfolio to see the effects of policies on market with the same power plant portfolio. Other inputs for the model are mostly exogenous like fuel price and demand development scenarios, as well as the amount of agents in the model.

The model has several steps in which the agents can interact with one another or with the market. The following steps are precent in the model (de Vries et al., 2013):

1. Dismantling of Power Plants by power producer

2. Submitting of bids to electricity spot market by power producers
3. Spot market clearing, both electricity and CO_2
4. Cash flow updates
5. Power producers pay maintenance and loans
6. Power producers buy fuel and other commodities
7. Power producers can decide to invest in new generation

The next subsections will discuss some important parts of the model that are relevant for this study. Additional information about the EMLab-generation project can be found at www.emlab.tudelft.nl or in the manual of de Vries et al. (2013).

3.2.1 Agents

There are two main type of agents in the emlab-generation model: Power producers and Power consumers. Power consumers have a very simple role and just represent the demand levels that are based on scenarios (de Vries et al., 2013). The power producer's role is much more extensive as the previously defined steps in the model already suggest. There are two basic strategic decisions power producers have to make (de Vries et al., 2013):

- Investment: Decide to invest in new power generation capacity or not
- Technology: Choose the technology of new power generation capacity

Additionally the power producers have operational decisions to make (de Vries et al., 2013):

- Sell electricity: Submitting bids to the power exchange at marginal price (based on CO_2 price and fuel price) and a price markup based on market power
- Purchase fuel: Based on the electricity production of the power producer, it has to purchase enough fuel to deliver the sold electricity.
- Acquire CO_2 emission rights: Depending on the amount of CO_2 emitted, the power producer has to purchase CO_2 emission rights. The price is influenced by the amount of available CO_2 emission rights available.

3.2.2 Investment Algorithm

There are basically two main algorithms: The market algorithms and the investment algorithm. The investment algorithm will be explained here in more detail as it is very important for the addition of locations. In figure 3.2 the investment process of the EMlab-generation model is shown. Basically the power producer will assess market data and make a forecast about the future market. Several constraints, physical and financial (cash position, capacity already under construction) are also considered during the gathering of alternatives. The power producer calculates for every technology, that meets the constraints, a net present value (NPV) and will pick the technology with the highest NPV.

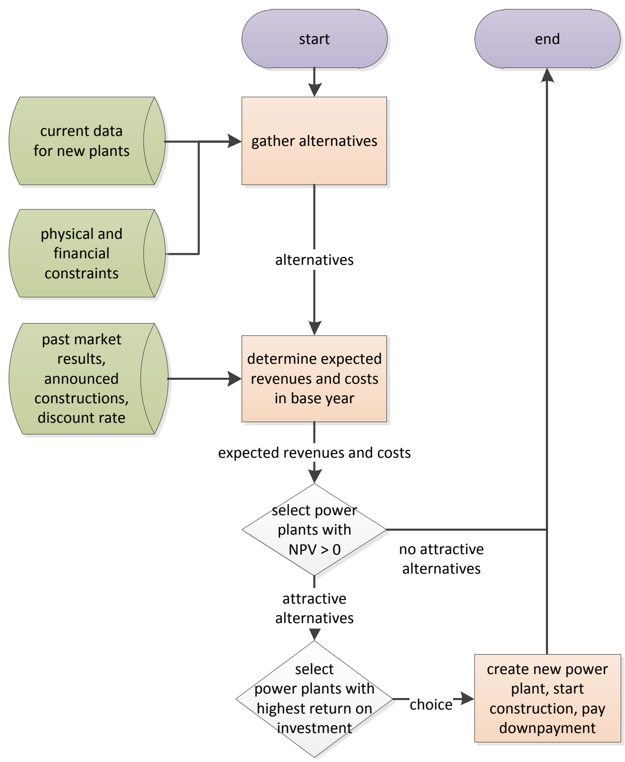


Figure 3.2: Original investment decision chart of the EMlab-generation model(De Vries et al., 2013)

Technologies In the current EMlab-generation model there are several power generation technologies power producers can choose from. The technologies have specific capacities for a new plant, this can be changed according to the preferences of the modeller. The power generating technologies in the model are (de Vries et al., 2013):

- Coal (co-firing of biomass optional) with or without CCS
  - Pulverized super critical
  - Integrated gassification combined cycle
- Biomass
- Gas
  - Open cycle gas turbine (OCGT)
  - Combined cycle Gas turbine (with or without CCS) (CCGT)
- Nuclear power
- Wind
  - Onshore
  - Offshore
- Photovoltaic

3.3 Locations and EMlab-generation

There are regions in the EMlab-generation model, hese regions represent different countries, which can be used to analyze policy effects with inter-connector capacities. However power plants do not have a specific location within such a region (country). To assign a location to each power plant the investment algorithm and initial distribution of power plants has to be adapted.

In chapter 2 the location decision for new power plants has been analyzed. The permit procedure was found to play a major role in the location decision. So in the investment decision not only a location has to be chosen, but also a permit procedure has to be implemented.

In the investment algorithm of figure 3.2 a couple of things have to change. Besides the current constraints other location related constraints for specific technologies, as identified in chapter 2 have to be added. Furthermore there is a limit for the amount of power plants each location can have. After the technology selection, the permit procedure can take place. In which negotiations with the local government of the location will take place, followed by negotiations with local parties. If the power producer found a location for the new power plant and the investment still has a positive net present value (NPV), the power producer can invest in the power plant. If there is no suitable location, the technology can not be invested in.

This process requires a conceptualization of the location selection and permit procedure, which will worked out in chapter 5. Additionally specific data about the location is required. The Netherlands has been chosen as a reference country for the model. Data about possible locations for new power plants in the Netherlands will be used in the model. It has been mentioned by the authors of the EMlab-generation model that the model does not intend to replicate a specific country. Here we will not do this either, we will base the model on a country like the Netherlands. Data about the current power plant portfolio can be used combined with the location data to have a matching technology portfolio and geographical portfolio of power plants.

Due to the fact that the current EMlab-generation model already has a working simulation of the electricity with power plant investments it makes sense to base our study on this model. The only thing to add is the location decision and permit procedure and the market and most of the investment algorithm can be left as it is. This will reduce the time needed for this study.

3.4 Conclusion

This section explained the basics of agent-based modelling and presented the most important details of the EMlab-generation model. This model will be used as a basis and the location choice of power plants will be added to this model. In the investment algorithm the location choice, with its new constraints to the technology selection has to be added. Additionally the permit procedure for a power plant has to be added before an investment can be made. Basing this study on this current model saves a lot of time and the model provides sufficient inputs for the location selection and permit procedure. EMlab-generation is an already working electricity market simulation model based on agent based modelling and could be based on a nations power plant portfolio. This makes the model very suitable as a base platform to model the location decisions of power plants by power producers. Using the ideas of agent-based modelling the location decision will be conceptually modelled in chapter 5. The conceptual model will be made into a working agent-based model in chapter 6.

Chapter 4

Game Theory Concepts

This chapter will give a brief overview of the game theory concepts that will be used in the conceptualization and formalization. Several important theories will be discussed, from basic bargaining to more complex theories about coalition bargaining theory, with special attention to the nucleolus concept. The descriptions are very theoretical and the way these theories will be applied will be discussed in the conceptualization chapter (chapter 5).

4.1 Bargaining games

Two player bargaining games The two player bargaining game is one of the most basic game theory concepts. Osborne and Rubinstein (1990) discusses several forms and extensions of this game theory concept. The bargaining game between two players with outside option is a really interesting one to conceptualize the negotiation process between a government and the electricity generator. Jin and Tsang (2011) continued on the work of Osborne and Rubinstein (1990) and extended the ideas to situations with incomplete information. The way Jin and Tsang (2011) modelled this is very interesting and could be used as a base for our conceptualization needs.

When an outside option β is bigger than utility of the bargaining game, the player should opt out for the outside option. If the offer of the other player is bigger than the outside option β and bigger than the expected utility of their own next bid than they should accept that offer. Mathematically this is written as in equation 4.1, this is based on work of Jin and Tsang (2011). s_i means this is the strategy function for player i. x_j represent the value 1 party would get and $1 - x_j$ is the value the other party will get. The meaning of the lines of mathematical symbols is written after each line of 4.1.

$$s(i) = \begin{cases} if(1-x_j)\delta_i^t \geq MAX(u_i(x_i)^{t+1}\delta_i^{t+1}, \beta_i) & \text{Accept } 1-x_j \\ if\beta_i > MAX(u_i(x_i)\delta_i^{t+1}, (1-x_j)\delta_i^{t+1}) & \text{Opt - out for } \beta_i \\ ifu_i(x_i)\delta_i^{t+1} > MAX((1-x_j)\delta_i^t, \beta_i) & \text{Counter - Offer at } (t+1) \end{cases}$$

This strategy function could be used for both players i and j, although x_i should be placed on the spot of $(1-x_i)$.

N party coalition bargaining game In a N player game we get a considerable level of extra complexity, however the basic strategies of most parties remain the same when making coalitions. The players have several options. They get offered a value from the another party to join the their grand coalition, they can accept this (based on threshold value), they can counter offer or they can flock together with other parties to form an alternative coalition. Their strategies can be summarized with the following basic strategy function S(L):

$$s(L) = \begin{cases} \text{Accept compensation and join the coalition} \\ \text{Opt - out for alternative coalition} \\ \text{Counter - Offer at } (t+1) \end{cases}$$

Especially the concept of outside options in bargaining games is interesting for our case and this can be used in situation with two or more players.

4.2 Nucleolus and Gately point

While the the previous N player bargaining game looks logical and would replicate negotiation the best in real world, getting a computer model to replicate this behavior is very challenging. A different simpler concept is required, although the notion of outside options are very interesting and the basic bargaining behavior will remain valid. The nucleolus and Gately point are possible theories with the assumption that the grand coalition will form. All parties are assumed to be willing to work together and join a grand coalition. The grand coalition has a characteristics function that holds the total value and distribution of costs or payouts of the grand coalition (Schmeidler, 1969).

The Nucleolus concept was originally proposed by David Schmeidler (Straffin, 1993). It tries to minimize unhappiness by side-payments. In reality you could see this as compensation. This is done until all parties are equally 'unhappy'. In our case this could ultimately lead to a situation where you are able to find a location with the least opposition, meaning the lowest permit risk. The problem is that there might be possible cases that a single participant could break up the coalition as there is not to much to gain, thats why Gately (Straffin, 1993) proposes to further minimize the propensity to disrupt the coalition. The resulting outcome is called the Gately point.

The likelihood of stakeholders cooperating depends on the payout they will receive when they cooperate. This should be bigger than their individual value, this is shown in expression 4.3. Outcomes that satisfy this condition are called 'the core' of the computation.

Equation 4.3 is the condition for outcomes to be in core. If an outcome (distribution of costs or payments between agents or actors) does satisfy this condition it is in the core. A solution in the core is regarded as stable and acceptable for all actors.

$$\sum_{i \in S} x_i \geq v(S) for every S \subseteq N. \tag{4.3}$$

In many cases there is no optimal outcome and the nucleolus proposes to satisfy the condition of equation 4.3 as nearly as possible. This can be done by minimizing the largest difference. So the excess is the difference between the expected payout of a coalition and the summed individual outcomes. The difference can be seen as a measurement of unhappiness (Straffin, 1993). Minimizing the unhappiest party with some payments could be a way to reach an optimal outcome. The mathematical formula for excess is given in expression 4.4. e_s is the excess, $v(S)$ is the coalition payout and X_i is the individual payout.

$$e_s(X) = v(S) - \sum_{i \in S} X_i \tag{4.4}$$

If a coalition has a value lower than what the individual would get, it is not rational to go into a coalition this is called *individual rationality* (expression 4.5). This an important constraint as it determines the chance of the coalition forming.

$$x_i \geq v(i) \tag{4.5}$$

Each party has a characteristic function that has a value when not joining the coalition. This characteristics function could be used with the coalition characteristics function, with its distribution of payouts between the parties to calculate the excess. The expression 4.4 should be minimized, to reduce the excess and thus the unhappiness of the coalition. This leads to a distribution of costs or gains (depending on the situation) and this could give insight in the required payments or distribution of costs. The party that is the most unhappy is payed of first until this optimum, of minimal excess, is reached.

Gately point The Gately point is defined in expression 4.6. The gately point is the point that minimizes the maximum change to disrupt. This means in our case that the gately point of the siting of the powerplant is the distribution of costs/gains where the chance the coalition will fail is the lowest. This is very useful as it gives insight in the possibilities that the coalition will fail and helps determine the risk of the permit procedure. $d_i(x)$ is player i's propensity to disrupt coalition X. N represents the grand coalition.

$$d_i(X) = \frac{\sum_{j \neq i} x_j - v(N-i)}{x_i - v(i)} \tag{4.6}$$

Nucleolus applications in literature The concept of the Nucleolus has been applied mainly on single case noxious facility cost distribution problems for governmental parties (like waste burning facilities). Who will pay what if several municipalities decide to build one big noxious (waste) facility together? This is the main question that is answered in these studies (Lejano & Davos, 2002; Erkut, Karagiannidis, Perkoulidis, & Tjandra, 2008). All these studies use the base assumption that the utility of each of the agents is transferable (Lejano & Davos, 2001). What these studies do is to find the most suitable location for a waste burning facility, where three (or more) municipalities (Erkut et al., 2008) or neighborhoods (Lejano & Davos, 2002) can build a facility together or all individually. It is more efficient to build one facility together. However the big facility has to be build at a location and that location will have all the negative effects. The nucleolus is then used to distribute the costs according to the risk impact. So the municipality where the facility is located pays less in comparison with the municipalities where the facility is not located. Other application of the nucleolus are listed here:

- Sie, Bitter-Rijpkema, and Sloep (2010) used the nucleolus to find the best creative work team. They developed a model that recommends the best creative teams based on skill values using the nucleolus.
- Tauman and Zapechelnyuk (2010) showed that in the case of agents bargaining with the holder of an intellectual property right, that if all agents have equal power the solution matches with the nucleolus.
- Massol and Tchung-Ming (2010) investigate the possibilities of Liquid Natural Gas (LNG) exporters to work together to reduce the length of the supply chain and uses the nucleolus principle to find a distribution solution, but the solution is due to market power probably not going to be used in reality.

These applications of the nucleolus show the diverse sectors it can be used in and that the nucleolus has opportunities with regards to bargaining based on (skill) values of parties.

Applications of the nucleolus in permitting procedures have not been found, while in certain permitting situation there are certainly possibilities for the nucleolus. Additionally application with repeated negotiations in an agent-based modelling environments are also not found. The nucleolus is rather computational light and would make it very useable for agent-based modelling applications. Finally all the example discuss negotiations or coalition forming between agents with the same type of goals, e.g. all government parties or all of them countries. One might think that if there is a way to compare values or utilities of totally different agents with one another, than the nucleolus could be applied and be used to conceptually model negotiations involving compensation due to perceived damages caused by other actors.

4.3 Utility Functions

To quantify the attitudes of the involved actors the concept of utility functions is used. The concept of utility function is not new and the current most basic forms are derived from the work of Morgenstern and Neumann (1947). The basic utility function is shown in equation 4.7. The hypothesis is that rational agent will maximize their utility. U is the utility for an agent, with chances p and outcomes A.

$$U = \sum p_i A_i \tag{4.7}$$

This basic idea has been used many times ever since and the applications are very versatile. The basic one dimensional utility function creates an interval for an alternative A with $[x_{worst}; x_{best}]$ (Nikolova, Ahmed, & Tenekedjiev, 2008). This is than multiplied with a weight factor which also makes the value unit-less.

$$U_{agent} = \sum w_i A[x_{worst}; x_{best}]_i \tag{4.8}$$

4.4 Conclusion

This chapter presented various game theory concepts. Concepts of basic bargaining games with various number players and outside options was discussed first. The ideas were interesting, but likely impossible to model, so other ideas of coalition forming were analyzed. These are the nucleolus and Gately point ideas. Last utility functions were explained. All of these concepts will now be used in chapter 5. Here the choices for the different theories will be elaborated as well as their specific application in the location decision for power plants. Together with the next two chapters the sub research question below can than be answered:

> How could the permit procedure and subsequently the location decision be modeled in the EMLab-generation simulation model?

Chapter 5

Conceptualization

Using the theories (chapter 4), modelling techniques (chapter 3), the location aspects and permit procedure data (chapter 2) we now can create a conceptual model of the location decision for new power plants. Some parts of the permit procedure and location decision process will need to be simplified to be able to model it in an agent-based model. First an analysis is made of the agents, behavior and the environment. This is followed by the conceptual model of the location selection and the permit procedure. This has been done in several sections, which together form the complete conceptual model. How all these elements are defined and conceptualized will be presented in the rest of this chapter, however an initial overview of the conceptualized process is given in figure 5.1.

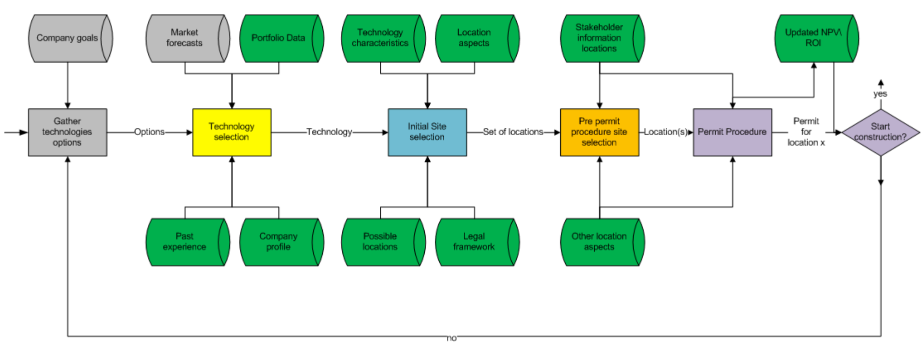


Figure 5.1: Overview of the conceptualization of the location selection and permit procedure

5.1 Agents and behavior

In this section the agents (actors) and their behavior are identified and a selection is made of which actors will be incorporated in the actual model. The actors selection will be based on the permit procedure and the specific roles of actors in this procedure. Some roles of actors are very small and than the decision can be made, where possible, to combine several actors.

Actor behavior In figure 5.2 the most important actors and their relevant behavior is presented. The actors have been identified using the WaBo law and permit procedure (Rijksoverheid, 2008) and by using the associated overview of the process made for companies applying for a permit, which can be found in appendix A. Especially this graph makes all the roles and tasks of different parties clear. Already left out are general activists, they are for this study combined with the local inhabitants, due to relatively similar behavior and interests. Only one government party is included, as the procedure is the same for the different government levels. In reality there are of course difference between the levels, but in theory in this procedure this should not be the case. Provinces and the national government normally decide about large power plants and municipalities about small ones. Here it is assumed that all the decisions are made by the relevant Province. This has been done to reduce the complexity of the model. Additionally government actors should have on a high abstraction level the same goal, a livable society and are subject to same rules and regulations.

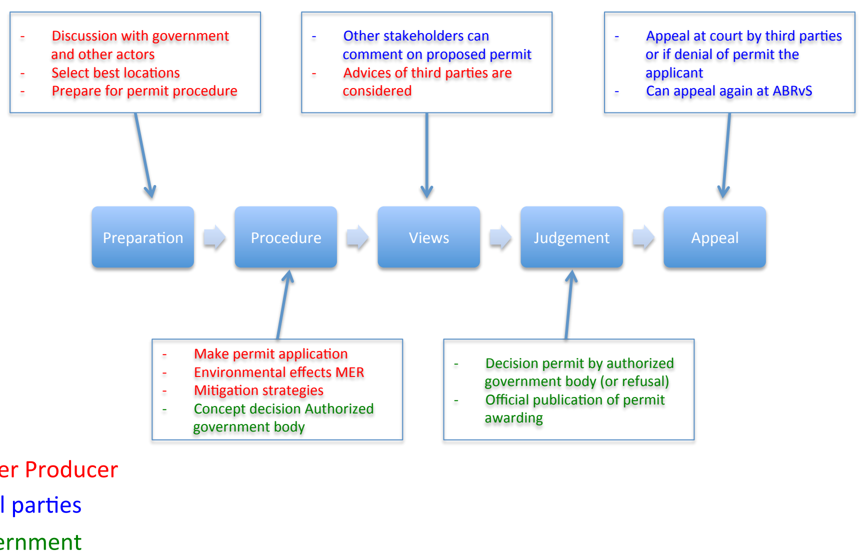


Figure 5.2: Flowchart permit procedure with relevant actors

Environment The environment will be based on data from the Netherlands, the specific data about Netherlands is presented in chapter 7.5. The environment has several roles, which are summed up below:

- There are specific locations for power plants over 500 MW, offshore wind turbines and onshore wind turbines

- Each location has environmental factors influencing the suitability of a location
- Each location contains demographic data, which will be used to determine the level of opposition of local inhabitants
- There is a maximum amount of power plants possible at each location, mainly based on transmission grid capacity and cooling water.

Interactions of Agents Figure 5.3 gives some insight in the most important interactions between the different agents and the environment. All the actors get information from the environment in which they operate. These environmental values could be an input to the rules which could change the states of the actors.

Additionally in figure 5.3 the actors identified in the previous paragraph and their interactions are presented. In the middle the power producer agent is shown. The interactions with other agents are shown with the arrows. The other agents also have their own states and rules, which determine their behavior. The court is not considered as an actor in the conceptualization. The implication of the court could be big, as they can decide about permit issues law suits and seriously delay the project. In the model it will simplified to a chance a court case succeeds, based on data about environmental law lawsuits (will be detailed in the specification). So no complicated interactions have to be modelled and the model can focus on the three main (groups of) agents and their interactions.

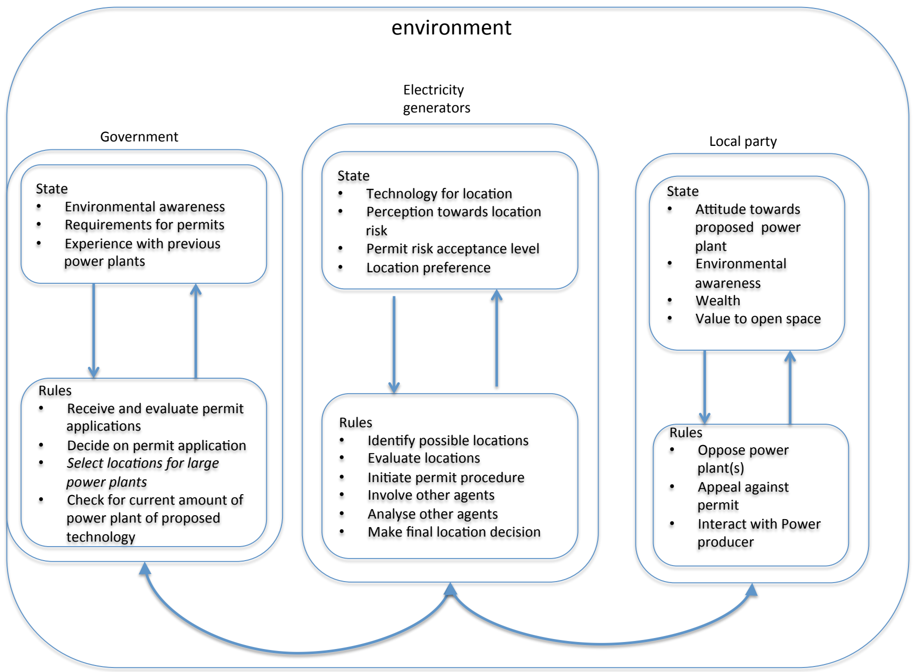


Figure 5.3: Interactions between different agents

Behavior description Power producers that want to invest in a new power plant will search for possible location, this can be seen as an interaction between the electricity producer and the environment. The environments contains possible location for a power plant. When there are several option they need to evaluate them on different criteria. These criteria are technology dependent. The power producers also have interactions with local governments and inhabitants to check out support for the location at hand. The different criteria both technological as social will let the power producer make a location decision for a new power plant. This location will require a permit and the government will issue it if all the criteria for the permit are met. Next local inhabitants can go to court if they do not agree on the permit decision. The court could postpone the construction of the power plant.

The details of how this will be conceptualized and modelled will follow in the rest of this chapter and chapter 6.

5.2 Multi-criteria tool for location selection

The first step to get location decisions in an agent based model will be the conceptualization of the initial location selection. In the interviews of Groot (2013) some companies acknowledged that they simplify the location decision to just permit risk, cooling water availability and feedstock availability. Other factors could also be analyzed depending on the company. This simplification could be interesting for this study. Cooling water and feedstock availability are primarily technology dependent as you can see in table 5.1. Only location that suit the needs of a power generating technology will be evaluated, so feedstock availability does not have to be included in the ranking and selection. Permit risk can be parameterized with population density and wealth of the municipality. Population density represents the value put in open space, the more people in the area the more they value the open space, which was identified a key indicator for local opposition in section 2.4. Wealth combined with education were the other important local opposition indicators identified in section 2.4. Education is highly correlated with wealth so only wealth will be used to represent permit risk. Finally many power producers look at grid connection risks as well, this is conceptualized as distance to the grid. It would be better to also evaluate capacity, but that requires a lot of extra modelling work, so it is kept simple with distance to the grid.

So the four factors that power producer will base their location selection on are:

- Cooling water quality / wind speed data
- Distance to the grid
- Wealth of the municipality
- Population density of the municipality

Due to these simplifications complicated multi-criteria tools are not really necessary. A basic utility function based selection will be sufficient to make a choice between several available locations.

Generation technology	Location Resources
Coal	• Coal feedstock • Cooling Water • (CCS infrastructure)
Biomass	• Biomass feedstock • Cooling Water • (Coal plant)
Gas	• Gas feedstock • Cooling water • (CCS infrastructure)
Nuclear	• Enriched uranium or plutonium feedstock • Cooling water • Specific location law
Wind	• Wind speed • Wind stability
Photovoltaic	• Sun hours • Sun power

Table 5.1: Location requirements for different power generation technologies

Power producers can have their own way they evaluate locations. In the empirical data of Groot (2013) this is also the case, every power producer has their own way to analyze risks and other factors important for the investment decision. Different weight factors to each of the four key indicators (locations that do not have feedstock connection for a technology will not be evaluated) will represent different location selection methods. The location are thus valued and ranked. The best ranked location will be selected for the initial permit procedure, this will be further elaborated in section 5.3. The Utility functions that are used to evaluate locations and represent preferences for certain parameters are presented in chapter 6.

5.3 Permit Procedure conceptualization

This section will discuss the conceptualization the permit procedure. The input for the permit procedure is a ranking of locations suitable for the selected technology, as discussed in section 5.2. First a brief description of the permit procedure is given and where certain game theory elements can be applied. This continues with the conceptualization of the roles of the agents in the permit procedure. Finally the compensation payments are discussed and the assumption this conceptual model uses are summed up.

Description and game theory application First of all, in order to build a power plant, the power producer has to get a permit from the government. According to the regulations, damages to the environment have to be compensated with mitigation strategies. these mitigation strategies are assessed by the authorized government body. In the model these negotiations about mitigation strategies will be expressed in compensation (money) required to get a permit. The negotiation can be seen as a bargaining game. The power company wants to spend the least amount of money, the government wants or needs to be compensated, but also has employment gains in area when a power plant is being build. However the attitude of a government can also change after a few power plants in the area have been buildand they become harder to convince. It is thus assumed that a government body acceptance of a new power plant will decline if it already has several plants in its area (province).

This bargaining game is relatively easy, the power producer and the government negotiate until they reach a situation that is acceptable for both. It becomes more complicated when other local parties get involved in the decision process. A few actors could be satisfied with limited resources, but once they group it can become a major risk and forming a grand coalition is not as straightforward and could be costly.

Local parties (activists) could delay the project with court trials and procedures. Delays in the project impact the NPV severely and could threaten the financial profitability of the project. This could be seen as the permit risk in the empirical data of Groot (2013). The forming of a coalition by the power company is than a function of maximum possible delay, the resulting change in the net present value (NPV) and its risk acceptance level. When the company reaches a certain level of risk, it accepts the risk and moves forward in the procedure with that current coalition, so it could be possible not all local parties are fully compensated and could still appeal at courts against the permit for the power plant.

To conceptualize these negotiations a way has to be found to model this. Game theory could provide nice tools to do this, as discussed in chapter 4. From a game theory perspective the negotiations with more than two parties become significantly more complicated, you basically now have to bargain with more than three players. Group effects arise and together they stand stronger and have perceived higher values. This makes sense as you will not group up if it reduces your bargaining position. The nucleolus is a very interesting concept in finding an optimal outcome. The nucleolus could give an idea of the risks and payments required to get a permit and to get all parties to join the grand coalition. Though computational coalition forming might be problematic and challenging. The nucleolus is based on the assumptions, as described in chapter 4, that all parties will join the grand coalition. So the problem of dynamic coalition forming can be bypassed by using the nucleolus.

It is likely that power companies will prefer location with possible less activism as they only have to negotiate with the municipality. This form of strategic behavior can be mitigated by letting the government attitude depend on the number of surrounding/previous plants. This way they are, in some cases, forced to go into more complex negotiations. In reality there are also limitation to the amount of plants an area can handle due to limited environmental mitigation strategy options, mainly due to other location aspects, as cooling water, feedstock availability and transmission grid capacity.

In the next three paragraphs the utility functions for the previously defined parties involved in the location decision will be given. The theory of utility function can be found in section 4.3. These utility functions will be the main representation of the different agents in the model and for the characteristics function required for the nucleolus.

Local Parties Each agent or actor involved in the permitting process has a utility function to express their attitude towards the new power plant. In section 2.4 the decision is elaborated to make the amount of activism dependent on the visibility or quality of landscape, wealth and education. Wealth and education are in many cases dependent on each other and one of the condition for the use of utility functions is the assumption that all variables in the utility function are independent. So for the utility function of a local party the only value that will be assessed is wealth as this is closely related to education level (trivial: higher education generally leads to higher income). The quality of the landscape,in other words openness, can be represented by the density. The density is the most convenient measurement as highly populated areas generally have less open space. The third factor is the perception people have towards different means of electricity generation.Ansolabehere and Konisky (2009); Aravena, Hutchinson, and Longo (2012); Poortinga, Pidgeon, and Lorenzoni (2006) all did survey based research to the perception people have towards different forms of electricity generation. This perception could be the final part of the utility function of the local party. This makes the utility function dependent on social determinants and perception to technologies, as shown in equation 5.1. The complete literature review and data can be found in chapter 7.

$$U_{Locals} = (Density)w_{density} + (Wealth)w_{wealth} + (Technology)w_{technology} \tag{5.1}$$

To enable the power producer to compensate the inhabitants there also needs to be a factor ranging from 0 compensation to maximum theoretical necessary compensation. This rate can compensate for the negative utility.

To determine the number of local parties involved in a permit negotiation, a random draw from a probability density function is proposed. The outcome should always be positive. Equation 5.1 could also be used as the σ of a normal distribution with average 0. The higher the utility function value the higher the σ meaning that the chance on higher amount of parties increases. This creates a dynamic effect to the permit negotiation and will make locations with high factors related to permit risk or activism far less favorable and more costly for the power producer.

Government The second party is the government and they can issue the permit for the power plant. As explained earlier the government can ask for mitigation strategies in return for the permit. The negative environmental effects will be part of the utility functions and require compensation payments to get the utility function up again. In the literature there are numerous sources defining and investigating externalities and environmental effects of power plants(Georgakellos, 2010, 2012; Kim, 2007; Mirasgedis & Diakoulaki, 1997; Rashad & Hammad, 2000; Road, 1998; Söderholm & Sundqvist, 2003). The intervals used in the utility functions are detailed in chapter 7.

The second part of the utility function of the government are the local economy effects, which will be positive as new industry will give the local economy a small boost. Each technology has different effects on the local economy. In the literature this is in many cases translated in jobs per MW or KWh. The differences are pretty big and especially biomass in some studies provides huge amount of jobs, however these studies tend to incorporate the sources of biomass and do not limit to the local employment only. In chapter 7 you find a literature review about employment effects of different generation technologies and a selection of which data will be used for this utility function.

The final part of the utility function will be a learning effect of previous experiences and application of the technology in the area. When there have been many power plants in the area this value will become more negative (see paragraph 6.4). The utility function of the government is given in equation 5.2.

$$\begin{aligned} &U_{Government} = (EnvironImp)w_{environImp} + \\ &(Employment)w_{Employment} + (PreviousExp)w_{PreviousExp} \end{aligned} \tag{5.2}$$

Power producer The expected NPV of a power generating technology is the base value, this NPV is already in the EMLab-generation model. The maximum value of the utility function of the power producer is when there is no opposition and thus the full NPV will likely be made as a return. The NPV varies between 0 and the maximum set for the technology (given output of the model at this moment), when the NPV is negative the technology will not be selected and not invested in. The NPV is influenced by the chance on delays. The bigger the negative utility of the other parties the bigger the expected delay. In previous empirical studies to behavior and results of activism groups in the Netherlands show interesting results. From the 45 groups investigated about half of them used legal action with an success rate between 50 and 60 percent on environmental laws and nature preservation laws, although environmental laws were more successful (van Dijk & van der Wulp, 2010). The study is limited in its size and probably not all results are therefor statistically valid, but assuming that there is a chance of roughly 50 percent, that a lawsuit successfully delays a project would be interesting and will give the agent an incentive to gain consensus. It is assumed that if a lawsuit succeeds it will delay the project. Other outcomes of lawsuits are not considered.

A possible delay of the construction of a power plant will impact the NPV as the time needed to construct the facility will be longer and thus the power plant will start making money later, which could severely reduce the NPV. The electricity generator tries to minimize the chances and offers compensation to the parties involved to reduce the impact of the power plant on their utility. In reality these side payments can be seen as compensation measures for municipalities to restore nature and compensation for e.g. house value losses of local inhabitants.

These side payments will be added to the construction costs and thus reduce the NPV. It will than make sense for the electricity generator to keep paying side payments until it reaches an optimum level or an accepted risk level. The way side payments (compensation) are done will be discussed later. The utility function of Electricity generator seems relatively simple as it is dependent on the NPV. However the factors all influence the NPV so there are more complications. The idea of a party improving their own position in an n-person game and at the same time improving the position of other parties, closely matches with the concept of Nash's equilibrium theory (Nash, 1950, 1951). By paying side payments to the other parties, their position improves and at the same time the chances on big delays for the electricity generator decreases as well. Ultimately they reach an equilibrium that follows the basic ideas of Nash. Meaning that the electricity company can not continue paying side payments and improve its own NPV as well and thus reaching an optimum.

Due to the randomness of the amount of locals and their requirements it could happen that the best location does not provide a positive NPV. Than the electricity producer decide to move to next location. Osborne and Rubinstein (1990) described this as bargaining games in which players have an outside option. They created mathematical conditions when players will stop negotiating and move to the exit option (or opt-out option as the theory of section 4.1 and 4.1 calls the exit option). This matches with our idea of stopping the process of paying out the locals or the government when the NPV will go below 0 and than move to the next location in the hope more positive results will be achieved there. The outside option in our case is not fixed as it is in the case of the example of Osborne and Rubinstein (1990), but is dependent on previous ranking of location and previous negotiation at other locations. The basic utility function of the electricity producer is shown in equation 5.4.

$$U_{ElecGen} = (NPV)w_{NPV} \tag{5.3}$$

$$\begin{aligned}
&NPV = (NPV_{current} - compensation) - \\
&(NPV_{current} - UtilityP * (\frac{1}{2} * NPV^{start(t+2)})) \\
&UtilityP = \text{Chance on disruption action based on other parties utility} \\
&NPV^{startt+2} = \text{NPV if a delay in construction happens} \\
&\frac{1}{2} = \text{chance of success in court based on (van Dijk \& van der Wulp, 2010)}
\end{aligned} \tag{5.4}$$

Random factor Each local party has a different attitude towards the potential power plant. To achieve this a random factor has to be added to the utility of a local party. The factor will make a random draw from equation 6.9. The mean is 1 as on average the compensation will be the factor, the small standard deviation will put the factor between roughly 0 and 2. The maximum of the utility function for local parties will remain 1 though, because 1 is the maximum outcome of the utility function. The normal distribution is shown in figure 5.4.

$$|\mathcal{N}(1, 0.25)| \tag{5.5}$$

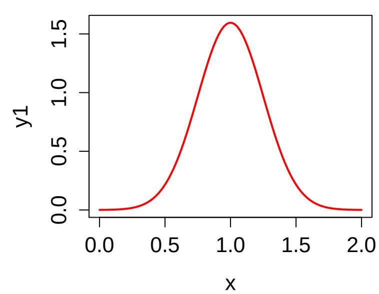


Figure 5.4: Normal distribution for the randomization of local party attitudes, with average 1 and sigma 0.25

Payments using the characteristics function The way side payments (characteristics function) will be done is with the idea of the Nucleolus as defined in the book of Straffin (1993). This method tries to make the most unhappy party a little bit less unhappy to get them or keep them in your coalition. This is done until you reach a situation that all excesses are equalized. In expression 5.6 and 5.7 these formulas of Straffin (1993) are presented (the theory itself is explain in chapter 4). The way they are implemented in our case does not match exactly with the theory. We will be minimizing the most unhappy party until funds run out (NPV) or an acceptable risk level is achieved.

Calculate excess S_i and minimize it (Straffin, 1993):

$$\min e_{s_i}(X) = v(S_i) - \sum_{j \in S_i} x_j \tag{5.6}$$

$$\sum_{i \ni S} \geq v(S) \text{for every S} \subseteq N. \tag{5.7}$$

$v(S_i)$ = payout of a coalition
X = a imputation, distribution of payouts in this case
x_j = payout imputation that is part of coalition S_i
j=all parties of a coalition

There are two points that make the application in this study of the nucleolus different. First of all it applies the basic concept of the nucleolus in agent based model. Secondly the concept of the nucleolus is not used to distribute cost between stakeholders, it is used to compensate actors that have no direct benefit from the power plant. Electricity is assumed to be independent by location by locals as it is easily transferable. Local inhabitants do not like a power plant in their surroundings even though they use electricity every day. The application used here is different from the studies with the nucleolus where there is a certain benefit for a municipality or a county. The interesting thing of the nucleolus is that it pays the most unhappy party first. Straffin (1993) used the expression “The wheel that squeaks the loudest is the one that gets the grease” for this idea. In reality the parties that are the most active find ways to get heard and have their issues addressed (Johnson, 1984). This could be seen as making the most unhappy party a little less unhappy.

The main assumption of the nucleolus is that the payout should be bigger in the coalition than what the party would get when they are on their own. There are two ways to look at this assumption. If we compare the case of no power plants and later a power plant, than the local party will not be better off, as the power producer agent pays compensation until a certain risk level is reached. The average negative utility of all the local parties is the risk that they will go to court. This is an assumption that gives the power producer agent an incentive to compensate local parties. However, the way the permit negotiations are done in reality, the permit is almost issued when local parties can demand that their concerns and views are considered by the government and power producer. The chance that one single local party can stop the construction of the power plant at all is in reality almost zero. So if the power plant will be constructed the main assumption of the nucleolus holds. If the party does not cooperate it will receive nothing and ultimately have a power plant in its vicinity. If they accept compensation, the have money and a power plant in the vicinity so they are better of. So a local party can in the worst case delay a project and this is very costly for the power producer when expressing this in NPV, as the first years of return are generally the highest in the NPV calculation. So there is for both agents a clear incentive to be in a coalition together.

Assumptions The chosen conceptual model, based on game theory is subject to the following assumptions:

- A single local party can at most delay the construction of a power plant
- All parties are willing to participate in a big coalition
- All parties can be compensated in money
- All parties accept compensation
- All (environmental) damages can be expressed in terms of money

5.4 Conclusion

Using the conceptual model presented in the previous sections we can put together a total schematic of the conceptualization of the permit and location process. The conceptualized process is shown in figure 5.5.

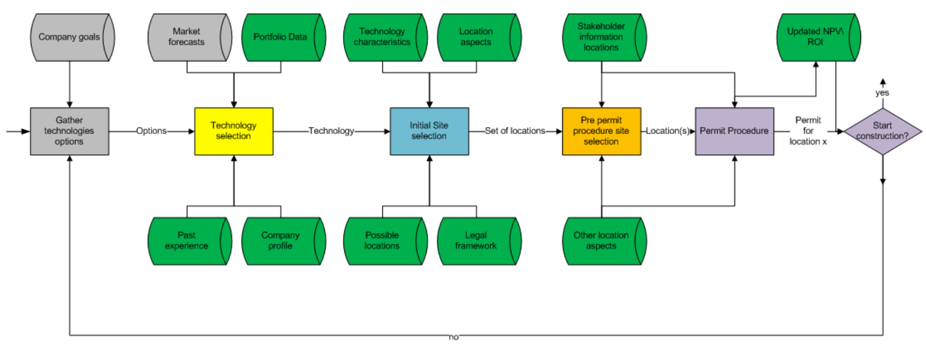


Figure 5.5: Overview of the conceptualization of the location selection and permit procedure

It is now also possible to answer the following subquestion to a certain extend.

> How could the permit procedure and subsequently the location decision be modeled in the EMLab-generation simulation model?

The power producer initially selects several sites for a new power plant according to technology specific requirements and permit risk factors. Than the power producer has to apply for a permit and has to pay environmental compensation, dependent on the technology, to the authorized government. Afterwards the power producer has to deal with local opposition. It is assumed that all parties accept monetary payments and change attitude because of this, furthermore it is assumed that they are all willing to join the grand coalition. Using these two assumptions it is than possible to use the Nucleolus concept to pay the most unhappy party a sum of money and repeating this until a satisfactory risk level of local opposition is achieved. If the NPV of the electricity producer is still positive it will invest in the power plant at the location the permit is issued for.

The next chapter (chapter 6) will go into more detail about the modelling, but most concepts and the way it should be modelled has been explained in this chapter. The input data for utility functions and the location data will be presented in chapter 7.

Chapter 6

Formalization

In this chapter the conceptual model, of chapter 5 will be translated in an actual simulation model. This chapter focusses on the structure of the model and chapter 7 focusses on the data inputs. The model is an extension to the current emlab-generation model which is based on AgentSpring platform. AgentSpring has its own conventions for coding (Chmieliauskas et al., 2012). These building blocks will be used to formalize the conceptual model in the rest of this chapter.

6.1 EMlab-generation building blocks

There are four main building blocks for the coding: Domain classes, Role classes, Repository classes and scenarios files (xml-files). From the EMlab-generation report the following definition of these modelling components can be given (de Vries et al., 2013):

- Domain classes are the definition of things and their properties. For instance it contains the classes Agent and PowerPlant.
- Role classes capture pieces of behavior, such as InvestInPowerPlantRole, that can be executed by specific types of Agents.
- Repository classes contain functions that deal with the interaction of typical model code and the database. Repositories also assist in updating current information or storing new information
- Scenario xml files contain all data to define and initiate a simulation run. A scenario contains data, but also relations between objects.

In figure 6.1 the most important domain classes in EMlab-generation for this study are shown. The class Location, LocalGovernment and LocationLocalParty are added in this study. The EnergyProducer (or Power Producer in this thesis) agent has a powerplant and this power plant usually one power generating technology (sometimes more with biomass). Additionally a power plant has a location. In each of the classes the main parameters or properties are listed. These classes will be referred to in the rest of this chapter.

Figure 6.2 shows the objects of classes related to the role InvestInPowerGenerationTechnologiesRole. This role contains the investment process for a new power plant by the power producer agent (EnergyProducer class). The role already existed in the original EMlab-generation model, but here the Province of class LocalGovernment, location of Class Location and localParty of class LocationLocalParty are added. The role is initiated by an power producer that wants to invest. It checks all the technologies for certain conditions and calculates NPV. Afterwards it will go look for available location for that technology. When locations are found, it will start the permit procedure involving the province and local parties. When the permitting was a success a new power plant will be build and this power plant is saved in the repository. If the permitting fails the technology is updated with the fact that the last time the technology is used it failed to result in a new power plant. This will be further elaborated in section 6.3. The location selection will be detailed in section 6.2.

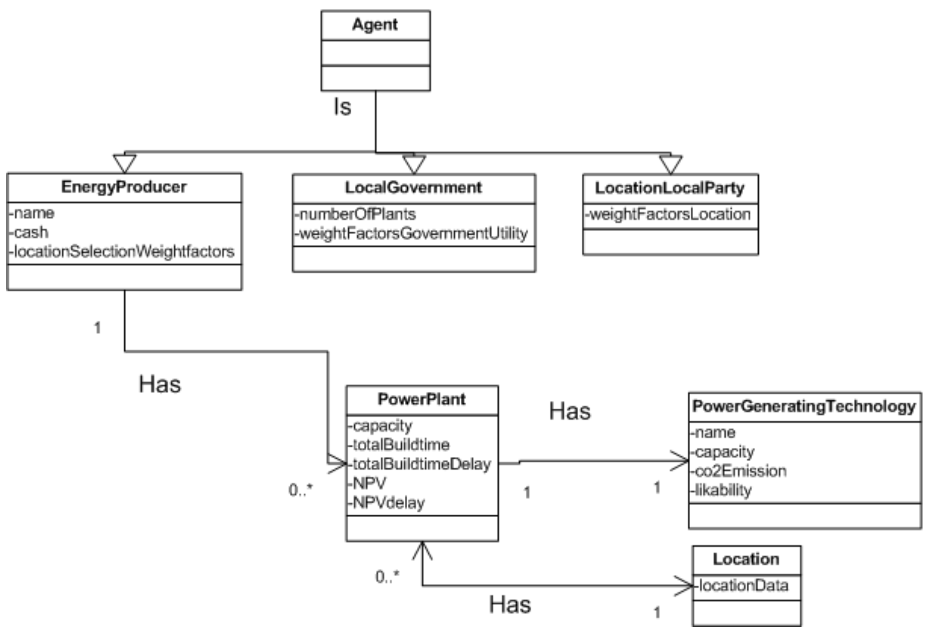


Figure 6.1: Domain classes used in the formalization, arrows indicate reading direction

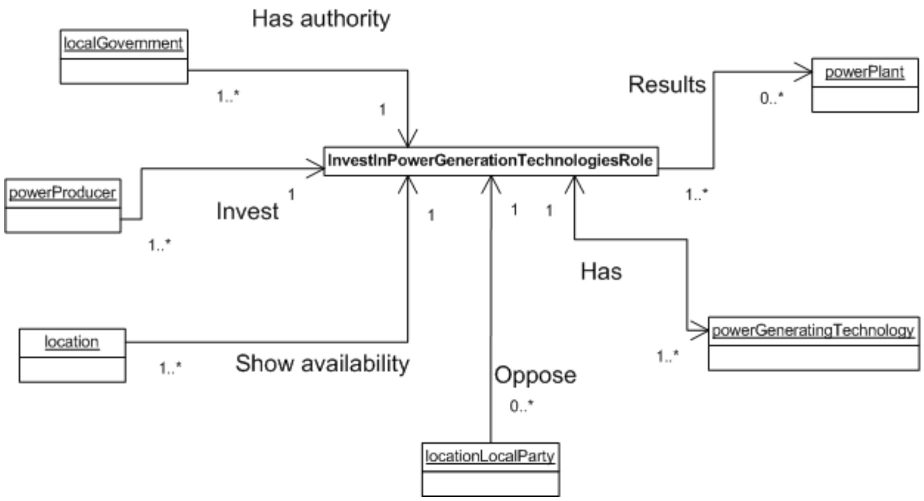


Figure 6.2: InvestInPowerGenerationTechnologiesRole schematic with the required object inputs, arrows indicate reading direction

6.2 Location selection

In section 5.2 the main criteria for locations have been discussed. From the empirical research it became apparent that feedstock connection, cooling water and permit risk were the main variables. To a lesser extend grid connection risks were taken in consideration. Permit risk will be operationalized by population density and Wealth. Grid risk will be operationalized in distance to nearby transmission grid. For Wind and solar basic figures about sun-hours and average wind power will be used to evaluate different locations. The location class has parameters for all these different parameters. In the scenario files (xml) different location have to be created, with the location specific input data. The location specific data is discussed in chapter 7.

Assumption It is possible for power plants with cooling towers to discharge less cooling water. However this is more expensive and it is than assumed that the quality of cooling water can just be measured in three categories. Even in the worst category it is still assumed that is it possible to build directly cooled power plants, however in reality this will most likely require a cooling tower or hybrid cooling systems.

Wind Offshore The transmission system operator (TSO) is obliged to connect new power plants on land, however on sea this is the responsibility of the project developer. Vattenfall values locations according to the distance to the main land (grid) , soil conditions, water depth and of course wind speed (Wind Energy Update, 2013). For this study we reduce this to the distance to the land

and wind speed. Soil conditions and water depth are left out because of time constraints, as this requires a lot of research for probably limited added value. Permit risk is not incorporated, as most location are not visible from the shore and using our conceptualization it is impossible to have local activists emerge in the ocean.

Utility function different technologies The following utility functions are used to rank locations for the different types of technologies.

$$\begin{aligned} &Utility(location)_{Thermal} = Utility(Density) + Utility(Wealth) \\ &+ Utility(DistanceGrid) + Utility(QualityWater) \end{aligned} \tag{6.1}$$

$$\begin{aligned} &Utility(location)_{WindOn-Shore} = Utility(Density) + Utility(Wealth) \\ &+ utility(DistanceGrid) + Utility(Windspeed) \end{aligned} \tag{6.2}$$

$$\begin{aligned} &Utility(location)_{WindOff-Shore} = (Utility(Density) + Utility(Wealth)) \\ &+ utility(DistanceGrid) + Utility(Windspeed) \end{aligned} \tag{6.3}$$

$$\begin{aligned} &Utility(location)_{Solar} = Utility(Density) + Utility(Wealth) \\ &+ utility(DistanceGrid) + Utility(solarhours) \end{aligned} \tag{6.4}$$

Pseudo-code In short the the location selections starts when a technology is selected. Each location has an indicator for which type of fuel it is suitable, e.g. the location has a gas grid connection or coal storage facility in reality. For carbon capture and storage (CCS) power generation technologies an additional check has to be done, whether or not a location is suitable for CCS. The model loops through all the location, defined in the scenario file. For each location that satisfies the conditions mentioned before, the utility is calculated with the utility function that matches the technology type. If a technology ranks higher than the previous locations it will be listed at the current best location. The best three locations are saved and when all the location are looped through the best location is the first that is used in the permit procedure. In algorithm 1 in appendix C the entire model process is presented and in figure 6.3 this is visualized in a flow diagram.

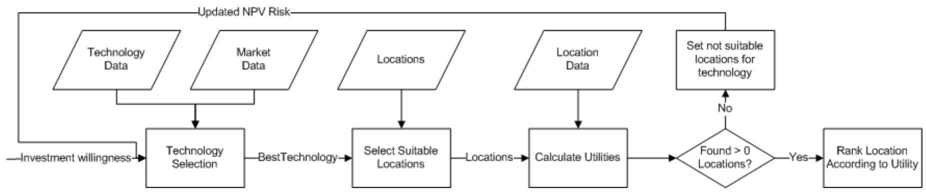


Figure 6.3: Flow chart Algorithm 1, the location selection

6.3 Permit procedure

In the chapter 5 the permit procedure is conceptualized, here we present the way it will be modelled in EMlab-generation. The input for the permit procedure are the three highest ranking locations of the location selection, discussed in the previous section. First the highest ranking location is used, if the permit procedure fails, the second highest is used etc. .

Local Government For the first location the authorized government will be selected from the repository. Each location has a province, which is the authorized government body for the permit. As discussed in the conceptualization the province is assumed to be the authorized government in all cases in this study. All the provinces are looped through until a matching province with the location's province is found.

Next from the repository power plants of the same type as the selected technology are counted. This is an input for the parameter 'previous experience' in the utility function of the government, shown in equation 6.5. After this has been done, the utility of the government is calculated.

Now the negative utility of the government represents the damages to the environment that need to be compensated. The electricity producer now starts paying compensation (which is of course counted) until the utility of the government reaches 0.

If the NPV is still positive the process moves to the next phase, the negotiations with the local parties. If the NPV is negative other locations are tried.

$$\begin{aligned} U_{Government} = (EnvironImp)w_{environImp} + \\ (Employment)w_{Employment} + (PreviousExp)w_{PreviousExp} + \\ (EnvCompen)w_{EnvCompen} \end{aligned} \tag{6.5}$$

Negotiations with local parties Local parties have the possibility to submit their views and opinions about the permit the province can issue. The locations data is used to calculate a sigma for a normal distribution. The sigma calculation is shown in equation 6.6. The utility of parameter is multiplied with a weight factor, which can be changed to increase the amount of activists that arise on average. The sigma is the input for equation 6.7. A random draw from this equation will be done, which will be the number of local parties that will be part of the negotiations.

$$\sigma = (Density)w_{density} + (Wealth)w_{wealth} + (Technology)w_{technology} \tag{6.6}$$

$$amountOfLocalParties = \lfloor |\mathcal{N}(0, \sigma)| \rfloor \tag{6.7}$$

Now the utility of each party is calculated in a loop. A random draw from a distribution based on equation 6.9 will be done and multiplied with the utility value, to prevent that all parties have the same utility. The utility functions for each party are based on the location data and the inputs are thus equal. Randomizing this will result in more unpredictable behavior. Next compensation is payed by the power producer to increase the acceptance of the power plant by the local population and to reduce the chance they will go the court. Compensation will not impact the utility in a linear way. A logistic function is used, as shown in equation 6.10 and more specifically in equation 6.11. This results in a distribution as shown in figure 6.4, which looks like an S shape curve. This makes the first payments and last payments less effective. The first amount of compensation is accepted with skepticism by the local party and when it receives more their attitude starts to shift. When it reaches around 95 percent of the maximal increase utility, the party is almost completely compensated, but the last changes in attitude are harder as they still do not like the power plant. The compensation change is based on the weightfactors used for the utility functions.

Using the Nucleolus concept the compensation payments to the different parties are made. The most unhappy party is payed first until a accepted risk level is reached. The risk level is defined in the scenario file as a property of the power producer. The risk that the parties go to court is calculated as the average utility of all the parties. This is assumed to be a chance. The payments thus stop when the chance the parties go to court is acceptable or NPV becomes negative.

$$\begin{aligned} U_{Locals} = (Density)w_{density} + (Wealth)w_{wealth} + \\ (Technology)w_{technology} + (compensation)w_{compensation} \end{aligned} \tag{6.8}$$

$$|\mathcal{N}(1, 0.25)| \tag{6.9}$$

$$y = \frac{1}{1 + e^{-x}} \tag{6.10}$$

$$UtilityChange = \frac{1}{1 + e^{-\frac{CompensationPayed}{CompFraction*InvestmentCosts}*20-10}} \tag{6.11}$$

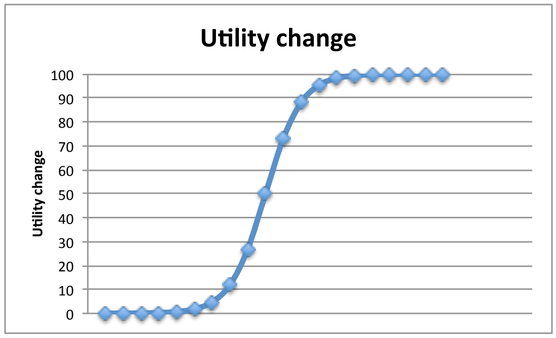


Figure 6.4: Distribution to represent effectiveness of compensation payments and the impact on the utility

Power producer and final investment decision The NPV of the power producer is now updated with the compensation and if the NPV is still positive the investment in the power plant X of technology Y at location Z is made. This is done using equation 6.13. The compensation is added to the total costs of the power plant.

$$U_{ElecGen} = (NPV)w_{NPV} \tag{6.12}$$

$$\begin{aligned}
&NPV = NPV_{current} - UtilityP * (\frac{1}{2} * NPV^{start^{t+2}}) \\
&UtilityP = \text{Chance on disruption action based on other parties utility} \\
&NPV^{startt+2} = \text{NPV if 2 year delay in construction happens}
\end{aligned} \tag{6.13}$$

When the negotiations fail, the second highest ranking location is chosen for the permit negotiations. When there was not a possibility to get a permit at any of the locations, or there were no locations available for this technology. The technology will not be assessed for investment by power producers for the next two ticks, representing learning effects. A module has also been made to reduce or increase the NPV slightly when limited or a lot of local parties are encountered with the technology.

Pseudo-code In figure 6.5 the flow chart of the algorithm for the permit procedure is presented. A detailed pseudo code of the algorithm can be found in appendix C

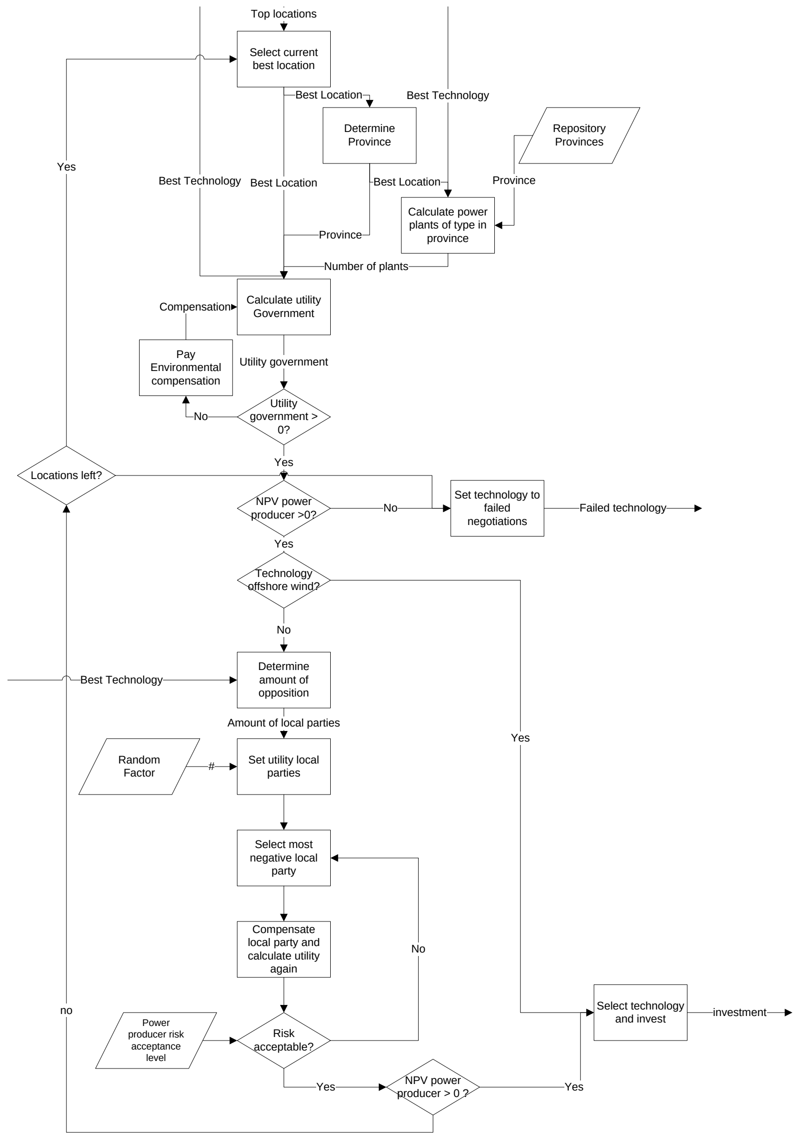


Figure 6.5: Flow chart Algorithm 2, the permit procedure

6.4 Other required model changes and inputs

Compensation environmental effects government On average mitigation measures for the climate are roughly 10 percent of the construction costs, this differs of course for the application (Sharma, 2011). We assume that 10 percent is the maximum of compensation required by a government, for the worst technology.

Previous experience When there are more plants the preference of a local government decreases. With none the factor is 0, however with four plants this will be -100 meaning that the requirements will be a lot higher.

Transmission grid data RIVM (2013) has a detailed map with all the transmission grid connection in the Netherlands. The distance to the main net from the location of the power plant is than calculated. In the end Capacity is not used in this study as it proved to complicated to model under the time constraints. It would be an interesting addition though.

Available Locations The amount of locations available at a location will be calculated with the current capacity at the location. The model assumes that 1 free spot equals 500 MW. So e.g. eight free spots would represent 4000 MW, however not all power plants are 500 MW so the 4000 MW cap is not fixed and can be passed by a bit. New investments ones the cap has been past will be impossible though. This matches with reality as it is possible to have slightly higher capacity at a location than the grid can handle (could lead to congestion though). The precise caps for each location will be discussed in chapter 7.

Power plant Size The current model uses static values for the size of power plants, of which most are above 500 MW. Assuming all thermal power plants need to be in a location of SEVIII solves the problem we are facing and makes it possible to keep the model simpler. SEVIII is the regulation that defines where power plants bigger than 500MW can be situated in the Netherlands. Wind turbine capacity can be lowered to 50 for onshore- and 100 MW for offshore wind turbines , down from 500 MW. This makes it possible to have a more realistic spread of wind turbines, as most sites on land are between 50-150 (Rijksoverheid, 2013a) and offshore 100-500 (4C Offshore, 2013).

Carbon capture and storage (CCS) In chapter 7 literature about the amount of possible CCS in the Netherlands is presented. In the code each technology that uses CCS will check if there is still capacity for another power plant that stores carbon dioxide. If this is not the case there is no new investment in CCS possible until a CCS plant is dismantled. So there is a cap on the number of CCS that is possible in the Netherlands and at what location.

Dismantling Another Addition is to clear location when a power plant is dismantled. The solution for this is rather simple. The amount of power plants at a location is checked using a query. This query can be limited to only operational and under construction power plants.

Model Start The model itself did not consider geographical locations and location decision. It has options for countries, named as locations. This is especially a problem with the startup of the model and the investment in new power plants. Currently the model creates power plants in the first tick until it reaches the energy mix given in the scenario file. These power plants also need to be given a location, but this cannot be done as random as the creation of the power plants and assigning the electricity producer to each plant. Each technology has only a few location suitable for that type of power plant.

This problem is solved by incorporating technology specific location choices for the initial power plant portfolio. The presented Pseudo-Codes will make use of scenario file input. In the scenario file for each technology it is defined which location can be used in the beginning.

Algorithm 1 Assigning initial location to power plants

```
Get available locations from scenario file
if location is suitable for technology then
    add location to locationlist
end if
draw random location from locationlist
Assign Location to Powerplant
```

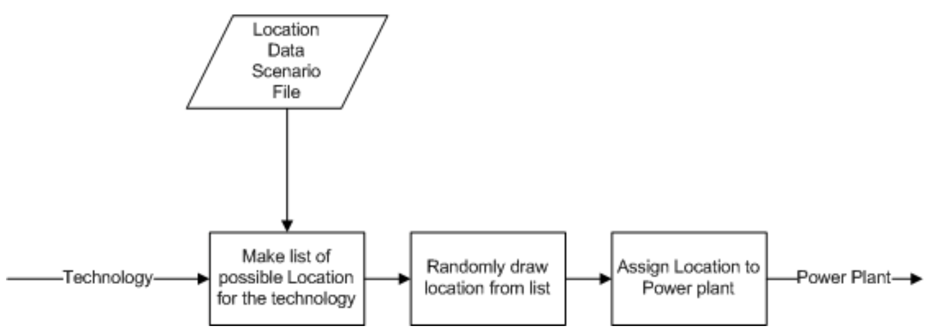


Figure 6.6: Flow chart Algorithm 3, the initial spread of power plants

6.5 Conclusion

This chapter gave a model implementation for the conceptual model discussed in chapter 5 and used the notion of agent-based modelling and the base EMlab-generation model as discussed in chapter 3. This chapter enables us to answer the final part of the the sub research question:

> How could the permit procedure and subsequently the location decision be modeled in the EMLab-generation simulation model?

The conceptual model discussed the application of several theories. This chapter used the conceptual model to build an extension to the existing agent-based model EMlab-generation. The resulting model should now be able to answer the main research question and the remaining sub questions. The data inputs for the different utility functions will be gathered and discussed in chapter 7. The weight factors of the utility functions will be further elaborated during the experimental design of chapter 9.

Chapter 7

Model Input Data

In this chapter the the intervals of the utility functions are created based on literature. Furthermore it elaborates on other model inputs like the amount carbon capture and storage (CCS) possible and municipality statistics for population data required to estimate the level of activism. The resulting data that is used in the utility functions is presented in table 7.7. Additionally location specific data for both thermal power plants location and wind turbines location is presented in this chapter. With the data that will be presented in this chapter and the model of chapter 6, simulations can nowbe done to generate results.

7.1 Parameters utility functions

Some of the data required for the selection of locations, evaluating perceptions of different agents and evaluating the environmental effects have to be found in literature. A literature study has been done to get these input parameters. The setup of the literature study is to find several studies investigating the same parameters. By comparing the ranges of the different studies a choice can be made on what range of parameters can be used for the model. A lot of the factors have different values for different technologies, when some studies do not have all the technologies included they can be estimated from the ranges of other similar studies. The rest of the section will present the outcomes of this literature study.

Power generation technology preferences In section 6.3 the utility functions that determine the attitude of local parties and the amount of locals activists are given. These utility functions need an input of the perception local people have towards power generation technologies. Several surveys have analyzed perceptions of people towards power plant technologies. In table 7.1 three surveys and the perception values are presented. CCS is not yet included and it is assumed that local people have the same attitude towards CCS than to their non CCS counterpart. There are less environmental problems, but it is a new technology and in the Netherlands CCS has proven to be a very sensitive topic. The different survey studies that are used in table 7.1 come from different countries. Aravena et al. (2012) did surveys in Chili, Ansolabehere and Konisky (2009) research is based on the US and Poortinga et al. (2006) researched british people their attitudes. All of these countries have liberalized electricity markets and democracies. They are assumed to be representative for the Netherlands.

Generation technology	**Aravena et al. (2012)**	**Ansolabehere and Konisky (2009)**	**Poortinga et al. (2006)**
Coal	4% prefer	2.7% strongly support 45% strongly oppose	16% good for community
Biomass	8% prefer		
Gas	12% prefer	3.7% strongly support 25.7% strongly oppose	
Nuclear	11% prefer	5% strongly support 55.3% strongly oppose	11% good for community
Wind	57% prefer	25.7% strongly support 11.2% strongly oppose	40% good for community
Photovoltaic	61% prefer		

Table 7.1: Attitudes towards power generation technologies

The data of Aravena et al. (2012) is comparable with the other two studies in the ordering of acceptance of power generating technologies. There are differences and these are due to the amount of technologies considered and perhaps the regional origin of the study, but the order of the technology preference is the same. So a range from 4 to 61 percent acceptance of a technology can be used as an interval and all power generation technologies fit in this range.

Environmental Impact Lots of research has been done to the environmental damage caused by different power plants. Many studies attempted to put monetary values to the damages caused to the environment. These monetary values are very helpful in our case, as the local government needs to be compensated to mitigate negative effects on the environment, while in reality the power producer e.g. builds parks and nature areas. The model assumes we can express these mitigation measures in terms of money and the amount has to be negotiated with the local government. Having monetary values for damage caused by a technology is thus important for the functioning of the model. A selection of research to monetary (external) environmental damages caused by power generation has been presented in table 7.2

Generation technology	**Berry, Holland, Watkiss, Boyd, and Stephenson (1998)**	**Georgakellos (2010, 2012)**	**Mirasgedis and Diakoulaki (1997)**
Coal	54.6 mECU/kWh	24,30 euro/MWh	29.88 mecu/kWh
Biomass	5.5 mECU/kWh	2,73 euro/MWh	
Gas	16.5 mECU/kWh	9,42 euro/MWh	8.49 mecu/kWh
Nuclear	2.6 mECU/kWh		2.59 mecu/kWh
Wind	1.4 mECU/kWh	0.16 euro/MWh	1.50 mecu/kWh
Photovoltaic		2.02 euro/MWh	

Table 7.2: Environmental effects of different power generation technologies based on several studies

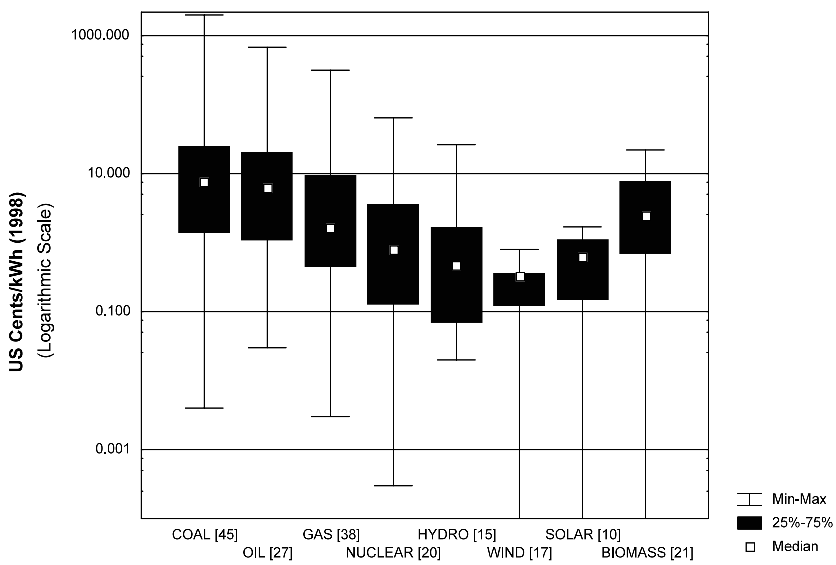


Figure 7.1: Box plot showing the results of a literature study by Soderholm and Sundqvist to the environmental costs of power generation technologies (2003)

From table 7.2 and figure 7.1 an interval can be created for the utility function of the government expressing the impact on the environment by different power generation technologies. Especially figure 7.1 is useful, as the graph nicely shows the results from a literature study to environmental costs of different technologies (Söderholm & Sundqvist, 2003). For the utility function it is most important to have a preference list and a certain fixed gap between the different technologies. This is shown nicely in the figure 7.1 as the average costs to the environment differ per technology. Also we see that especially the research of Georgakellos (2010, 2012) can be matched well in these plots. For this reason the data from these studies will be used. A monetary value for Nuclear power is missing though and by using the other research and the figure we see that the average is slightly lower or equal to solar energy. We can than assume the costs to be around two euro per MW in the units of Georgakellos (2012). $[0.16 - 24.30]$ Will be the interval used in the utility function and all technologies have a value in this interval. It has to be noted that Nuclear has a huge spread and is highly dependent on what factors are taken in to consideration, other choices are also valid and it would be interesting as a future research extension to investigate the sensitivity and impact of these environmental monetary values on the development of the electricity sector.

Employment Local economies are assumed to benefit from having a nearby new power plant. The model considers the employment effects caused by the new power plant as the main indicator for this. That employment influences wealth in a region has been shown in research done by Brown, Pender, Wiser, Lantz, and Hoen (2012). They did research to the effects wind power generation has on a regions wealth. They concluded from data and a model that per MW of wind power installed the population will become 11.000 dollar richer in roughly eight years and on a county level each megawatt will create 0.5 jobs. From this we assume that employment is a suitable indicator for economical benefits of new power plants. In table 7.3 outcomes of different studies with regards to the amount of jobs each technology creates is presented.

Generation technology	Chatzimouratidis and Pilavachi (2008) Jobs/ MW	Cai, Wang, Chen, and Wang (2011) Job / MW	Tourkolias and Mirasgedis (2011); Tourkolias, Mirasgedis, Damigos, and Diakoulaki (2009) man power year/ MW	Moreno and López (2008) MW / Job	REPP (2002) MW / Job
Coal	5	1.322			
Biomass	70	3.222	1.27	0.4-2.3	
Gas	4.9	0.770			0.1
Nuclear	5	0.615			
Wind	10	0.378		0.1-0.3	0.3
Photovoltaic	10	0.497		0.1-1.2	0.3

Table 7.3: Jobs per capacity unit for different power generation technologies

Defining a range is hard, first it has to be mentioned that (Chatzimouratidis & Pilavachi, 2008) is a lot higher than most other studies, this is because the whole lifecycle is taken into consideration and not just local employment or operation and maintenance effects. (Cai et al., 2011) did a simulation study and used these data as inputs for the jobs per technology for operation. Its order almost the same with most other ranges, or close to it. It is therefor assumed that these ranges could be used as the basis for the employment utility function of the government. $[0.379 - 3.222]$ is the utility interval that is established for the employment utility function.

7.2 Regional Statistics

Population Density From Dutch bureau of statistics (CBS) the population density for all municipalities have been obtained (CBS, 2012). In figure 7.2 the histogram of all population densities of Dutch municipalities is shown. For the utility function population density the lowest and highest population density determine the interval. The utility interval will be $[21 - 6131]$. The data for each power plant location can be found in section 7.5.

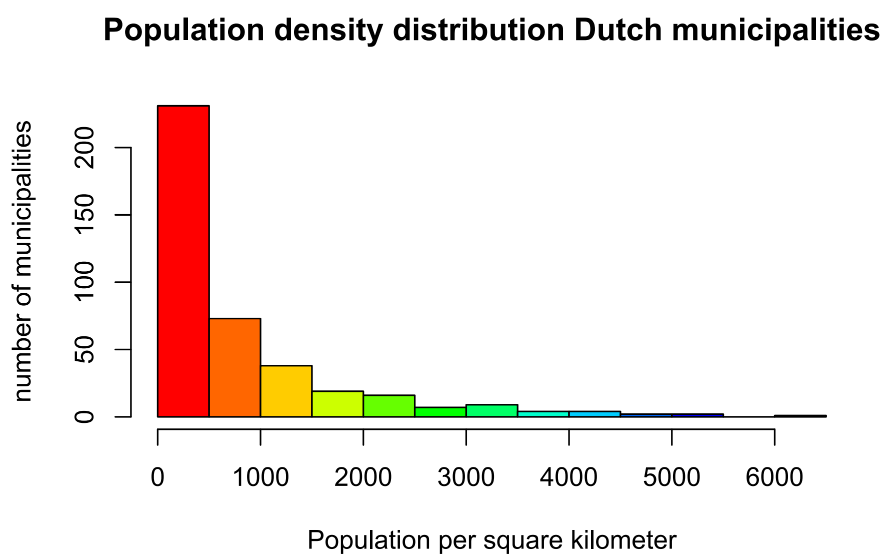


Figure 7.2: Histogram of the population density of Dutch municipalities

Wealth From the Dutch bureau of statistics (CBS) the average income for all municipalities has been obtained(CBS, 2010). In figure 7.3 the histogram of the data is shown. The utility function can be created from the data and the interval of the utility function will be $[10.8 - 23.2]$. The value is per resident of the municipality and not per household. Furthermore you can see from figure 7.3 that there is a nice spread and there are big differences in wealth among municipalities. This means that there are differences enough between them to make it worthwhile to use wealth as an indicator. The data for each power plant location can be found in section 7.5.

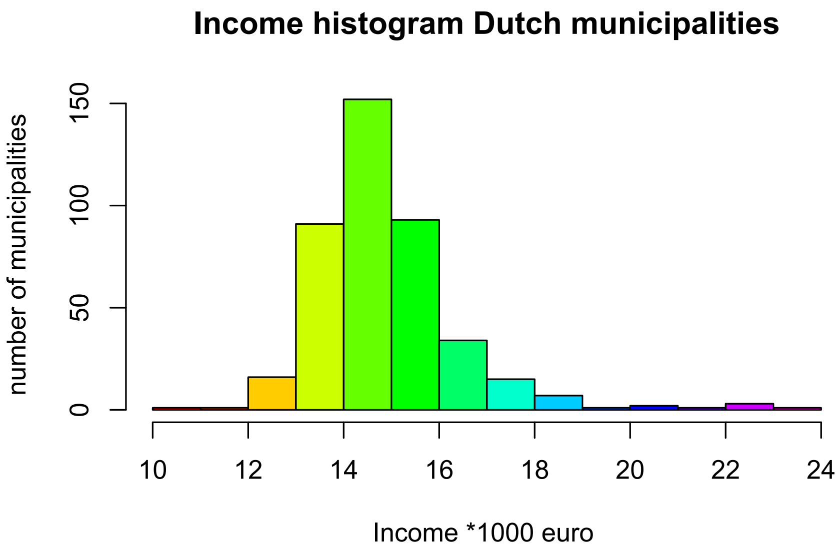


Figure 7.3: Histogram of the average income of people in a Dutch municipalities

7.3 Carbon Capture and Storage (CCS)

TNO researched the potential for CCS in the Netherlands (TNO, 2012). The Northern part of the Netherlands is well suitable for storage, however other parts have limited storage capacities. Onshore storage has proven extremely difficult due to public support problems and the government has withdrawn support for onshore storage and is focussing on off-shore carbon storage. In research done by TNO it shows that offshore storage has a theoretical maximum injection capacity of roughly 20-30 Mt CO_2 for around 20 years (Neele, Wilschut, & Hofstee, 2012). This equals five to seven coal power plants in the Emlab model (the amount of plants is doubled for gas based plants (Rubin, 2009)). This theoretical maximum is used in the model to limit the amount of CCS to five to seven plants (ten to fourteen incase of gas fired power plants). Furthermore the report argues that it is most likely that only Eemshaven and the port of Rotterdam will be connected for storage, so all other location are not suitable for CCS in the model. As a final note, the amount of power plants is based on full year operation and that a single plant in the model is about 500MW.

7.4 Available room for Power Generation at Locations

Specific data about the amount of room that is available for future power plants at the locations is not available. What is available is the capacity of the nearby transmission grids and transmission stations. This could server as a base case. Additionally the quality of the cooling water can help determine how realistic it would be to have extra capacity at the location, given that the transmission capacity could be extended and cooling water availability allows the construction of an additional power plant at the location. The precise definition of the caps will be discussed in chapter 9

7.5 Location aspects data in the Netherlands

In this section an overview of all the location and data for each location is presented. Thermal power plant locations have been selected by the National government of the Netherlands in the SEVIII report. The location data is from the bureau of statistics of the Netherlands (CBS). Location for wind parks onshore will be based on current siting decisions for each province (IPO, 2012) shown in figure 7.5. Data here will also come from the bureau of statistics of the Netherlands and weather specific data from the national weather and climate agency (KNMI) (KNMI, 2013c). In table 7.5 you find the data of the SEVIII location data, with the characteristics of the municipality they are situated in (Population Density and Wealth). Additonally the distance to the nearest transmission grid station and the quality of water based on Rense (2004) (figure 7.4) is presented for each location in table 7.5. The location data for onshore wind is presented in table 7.6.The distance to the nearest transmission grid has been calculated with the help of google earth. Data for Population Density and Wealth is taken from the databases of the central bureau of statistics of the Netherlands CBS (CBS, 2010, 2012). Note for table 7.5: Waalhaven currently has big power plants, however the location has been renamed in the latest SEVIII documents to Rijnmond/harbor area (Rijksoverheid, 2009a) .

For the offshore wind locations information of 4C Offshore (2013) is used. This is an european database with all past and current offshore wind projects. This is used to get data of possible location in the dutch part of the Northsea and subtract wind and waterdepth data. The data can be seen in table 7.4.

Table 7.4: Offshore location and data based on 4C Offshore (2013)

Name	Wind (m/s)	Capacity (MW)	Depth (m)	Distance (Km)
Hoek van Holland I	10.06	300	24	30
Hoek van Holland II	9.91	450	27	45
Hoek van Holland III	9.88	705	27	55
Scheveningen Buiten	9.91	450	21	30
Rijnveld Zuid	9.95	504	23	30
West-Rijn	9.95	212	20	45
Scheveningen 5	9.91	123	22	48
Rijnveld Oost	9.95	135	20	35
Rijnveld Noord	9.95	81	21	48
Beaufort	9.97	279	22	25
Scheveningen II	9.97	450	21	30
Eneco Luchterduinen	9.93	129	20	20
Breeveertien	9.9	150	22	45
Q7 West	9.9	244	22	35
IJmuiden thetys	9.93	159	21	25
Prinses Amalia Windpark	9.93	120	22	25
Q4	9.87	78	22	30
Egmond aan Zee	9.96	108	17	15
Callantsoog oost	9.8	244	25	38
Callantsoog zuid	9.83	327	26	42
Callantsoog west	9.8	244	24	45
Gallantsoog Noord	9.84	300	30	35
Den Helder I	9.75	468	28	60
Den Helder II	9.75	468	28	60
Den Helder III	9.69	500	26	65
Den Helder IIII	9.69	500	28	65
Tromp oost	9.72	367	24	70
Tromp west	9.72	385	25	75
Brown Ridge Oost	9.72	282	25	75
Breeveertien II	9.8	349	22	58
Osters bank I	9.97	450	32	50
Osters bank 3	9.99	450	33	53
Osters bank 2	9.98	310	36	56
Osters bank4	9.99	450	38	60

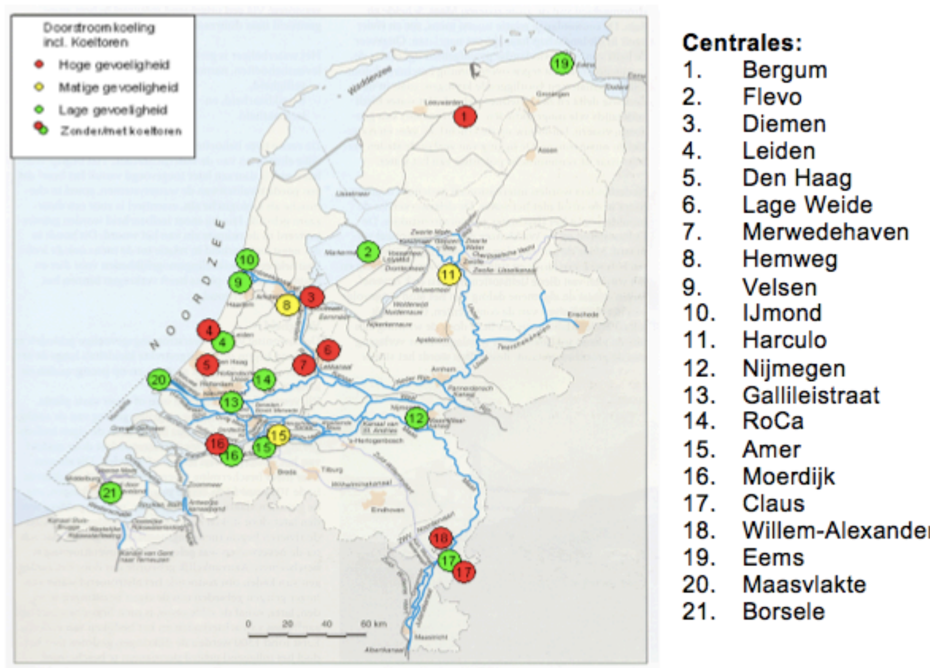


Figure 7.4: Sensitivity of the surface water for temperature increases at power plant locations (Rense, 2004)

Table 7.5: SEVIII Locations and their location data

Location	**Density (Population / Km^2)**	**Wealth (average income /1000 euro)**	**Distance grid (Km)**	**Quality water (ranked)**
Eemshaven	86	13.1	1	3
Burgum	215	13.6	1	1
Harculo	1091	14.6	10	1
Nijmegen	3081	14.2	15	1
Utrecht	3353	15.2	9	1
Maxima-centrale	325	13.8	0.5	2
Velsen	1503	15.5	5	2
Hemweg	4767	15.5	5	2
Diemen	2080	15.2	0.5	2
Maasvlakte I	2952	14	0.5	1
Galileistraat, Rotterdam	2952	14	10	1
Borselle/vlissingen	160	14.4	1	3
Amer Geertruidenberg	806	15	0.1	2
Buggenum	923	14.4	2	2
Maasbracht	526	15	2	2
Moerdijk	229	15.3	3	2
gemeente westland	1282	15.2	5	1
Geleen	1196	14.5	25	2
Delfzijl	198	13.5	10	3
Amsterdams havengebied	4767	15.5	8	2
Maasvlakte II	2952	14	3	3
Rijnmond, Rotterdam	2952	14	12	1
Terneuzen/sas van Gent	218	14.7	15	1

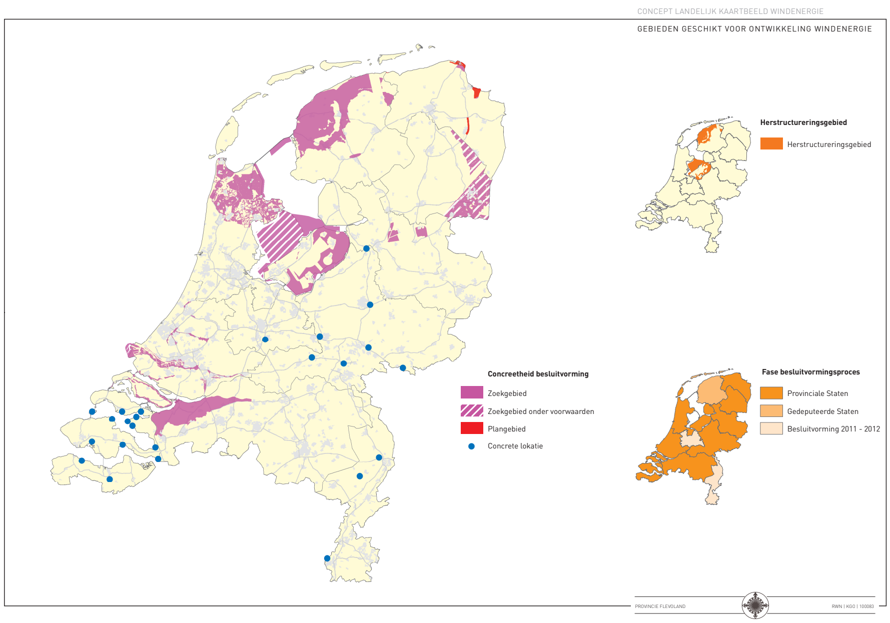


Figure 7.5: On-Shore wind power locations in the Netherlands

Table 7.6: On Shore wind generation locations and their location data

Location	Wind (avg m/s)	Capacity (plants)	Wealth (Euro/ year)	Density (people/ km2̂)
Hattum	5	1	15.1	511
Apeldoorn	4.5	1	15	462
Didam	4	1	13.9	332
Doetinchem	5	1	14.3	711
Elst	4.5	1	14.5	423
Ede	3.5	1	14.4	342
Wageningen	4.5	2	13.6	1215
Houten	4.5	2	16.4	872
Afsluitdijk	7	3	13.7	191
Veluwemeer	5	3	13.8	121
Markermeer	6	3	14	1490
Flevopolder	5	10	13.8	121
Den Helder	5.5	4	14.2	1261
Kop Noord Holland	6.5	10	14.5	133
Oosterscheldekering	5	4	15.1	165
Vlissingen	4.5	2	14.2	1302
Rotterdam Haven	5	4	14	2952
Noord West Brabant	4.5	8	14.9	159
Tholen	5	4	13.2	174
Zierikzee	5	4	15.5	148
Bergen Op Zoom	4.5	4	14.7	826
Reimerswaal	5	4	13.1	213
Panningen	3.5	1	14.1	271
Venlo	3.5	1	13.9	800
Maastricht	3	2	14	2131
Amsterdam	3.5	3	15.5	4767
Bunschoten	4	2	14.1	664
Dronten	4.5	4	13.8	121
Harselaar	4.5	1	13.5	304
Lemmer	5.5	1	13.9	149
Herbayum	6	2	13.2	200
Middelburg	5	1	14.7	984
Westwout	5	1	14.9	327
Winsum Ranum	5	1	13.8	138
Zeewolde	5	1	14.8	86
Delfzijl	5.5	1	13.5	198
Terneuzen	4.5	1	14.7	218
Velsen	5.5	1	15.5	1503

7.6 Conclusion

This chapter provided all the data needed to create the data intervals for the utility functions and enables the model to function with this data. The normalization used for the utility function intervals is straightforward and shown in equation 7.1. The resulting utility functions can be found in table 7.7. The direction column indicates whether the value will be multiplied by -1 of 1 to reflect negative or positive impact to the utility function.

There is no direct data available about the environmental impact of CO_2 storage and possible perceptions of people to this kind of technology, therefor the three types of CCS are assumed to have the same level of acceptance and environmental impact as their non-CCS counterparts. This is probably unrealistic and not true, but this way they can be added to the model as they are expected to have a large impact on the future electricity sector and are very important in renewable current policies and outlooks for the Netherlands. Furthermore this chapter found that the amount of CO_2 that can be stored in the Netherlands is limited due to policies and geological features. This could seriously affect the amount of CCS plants possible in the Netherlands. Besides the utility function intervals and CCS caps, this chapter also presented all the locations used in the model, with their respective geographical data, which will serve in many cases as the input of the utility functions and fits in the interval defined in this chapter. With the data of this chapter the model can now be verified and validated in chapter 8 and afterwards experiments can be designed (chapter 9) to come to an answer to the remaining sub research questions and ultimately to the main research question.

$$Normalization = \frac{\Delta(V(x), V_{min})}{\Delta(V_{max}, V_{min})} \tag{7.1}$$

utility sub function	**Interval**	**Utility formula**	**Direction + *or* -**
Employment	$[0.379 - 3.222]$	$\frac{Employment_{tech}-0.379}{2.843}$	+
Environmental Impact	$[0.16 - 24.30]$	$\frac{Environmental_{tech}-0.16}{24.14}$	-
Population Density	$[21 - 6131]$	$\frac{Density-21}{6110}$	-
Technology Preference	$[4 - 61]$	$\frac{Pref_{tech}-61}{57}$	-
Wealth	$[10.8 - 23.2]$	$\frac{Wealth-10.8}{12.4}$	-
NPV	$[NPV_{maxdelay} - NPV_{tech}]$ [1]	$\frac{NPV_{tech}(X)-NPV_{maxdelay}}{\Delta NPV_{tech},NPV_{maxdelay}}$	+

Table 7.7: Units and normalization of all the utility sub functions

Chapter 8

Verification & Validation

This chapter discusses the verification and validation of the model presented in chapter 6. First the steps that have been done to verify the model will be discussed. Next the model validation will be discussed, including the way it has been validated with its shortcomings. With the validation the results of the batch runs are discussed, these are used to check for internal validity, but also as a sensitivity analysis to identify interesting combinations of parameters for the experimental design of chapter 9.

8.1 Verification

Continuing the Formalization phase the resulting model has to be verified and checked for modeling and programming errors. The verification has been done in several phases. First of all the code needed to be made running in the AgentSpring environment. Secondly the model is evaluated step by step and manually checked for calculation or referring errors. The third phase, which is also already part of the validation are the first initial batch-runs of the model. In these batch-runs some extreme scenarios are run to see if the model responds as expected.

Model Structure tests Like with many models it took a while to completely troubleshoot the model to get it to run. Using the descriptions of the errors the model was step by step made to run and checked for new errors. The most common errors in this phase where typing errors and bracket errors. Although some more substantial errors where are also discovered and corrected. Especially some lists related to objects proved to be problematic. Ultimately the model ran without run time errors.

Unit check After the model was able to run, the model was evaluated using lots of loggers. These loggers display the outcomes after almost every line in the model. In this way each step in the model could be manually calculated and checked for the correct outcomes. It is possible to automate this process with J Unit tests, creating special classes that check input and output. However the model extension made in this study adapted the general investment role. It added hundreds of lines of code with an almost equal amount of parameters. Time wise it was smarter to do this check manually, than by checking it computationally. It has to be acknowledged though that J Unit tests are more thorough and more failproof, but the method used here resulted in a model that shows the right expected outcomes. Errors found during this phase where incorrect references, variable mixups, operator errors etc. . For a complete overview of specific problems encountered in the verification see appendix G.

8.2 Validation

This section discussed the steps and results of the validation phase of this study. Validating an agent-based model is rather hard and a model can never fully reflect the real world system. The validation can be split in two parts: Internal and External validation. In this section the main focus is on internal validation. Are the causalities between two variables properly modelled and does the model give the expected behavior?

Tests have been conducted with only one technology to check the functioning of each technology. This resulted together with the batch run analysis in the fixing of several issues, especially with CCS and wind turbines.

Initial portfolio of the Netherlands The initial spread of power plants in the Netherlands has to be included in the model. The model does not intend to exactly replicate the Netherlands. This is computational impossible and will result in expectation that are impossible to realize. The IEA (2012) has the current fuel mixes in GWh and the prospected. This data and data from all dutch power plants from the database of enipedia are used to determine the exact fractions of technologies for the Netherlands. Each time the model starts running it starts creating power plants until the fraction in the power mix of the scenario file is reached. For each powerplant a location is than picked from a list, that is specific for each technology. Several runs of a hundred repetition of this initial power plant creation have been conducted. This has been done to verify that the geographical distribution of power plants over all these runs is roughly similar to that of the Netherlands. Specific runs could differ a lot though. The total amount of MW available at a location in the Netherlands is statistically compared with the power plants generated at the location in the model. The results for the big thermodynamic power plants can be seen in table H in the Appendix. There are some location that have too much generation capacity and are significantly different from the actual average. This is due to the fact that power plants under a hundred MW are not modelled and thus there is a bit more generation especially for gas at the location. Location with big power plants suffer more as the chance they will get a powerplant during the setup of the model is higher. This explain e.g. the slightly higher average for Eemshaven. This is something to keep in mind when reviewing the results of the model.

This initial setup can result in different spreads, as mentioned. The question is wether that is important for the final model behavior. Investment in new power plants are done according to the algorithms and data, if the initial spread is different, perhaps some more favorable location fully used earlier, but especially later model behavior will likely not be impacted a lot. This study looks for patterns in the siting of new power plants and the effects location aspects can have on the electricity system. If the same patterns are visible for different initial spreads of power plants, we could even argue that the pattern is less affected by different paths of investment and developments, possibly making the value of these patterns even higher. However still due to the differences a sufficiently large amount of runs will be required to be sure the average is close to the desired spread of power plants for a single scenario.

8.3 Batch-Runs & Sensitivity Analysis

To further investigate the causal relations in the model some batch runs have been done. The parameters that have been added to the model will have one or several scenarios to check if the expected behavior from changing these parameters is realized with the model. This does not only give clues about possible errors or strange behavior, but could also give ideas for interesting combination of parameters changes for the experimental design. Furthermore we will present in the discussion of these batch run results also the main outcome indicators that will be used in the result chapter.

Nine scenarios have been created to test several important additions to the current emlab-generation model, the scenarios are presented in table 8.1. Each scenario has one variable or parameter that is varied. The definition of parameters and the specific values of these parameters is discussed in chapter 9 the experimental design. For the stacked location or capacity figures, such as figure 8.2 the average is taken at each time step for the specified scenario.

Table 8.1: 9 batch runs scenarios

Scenario	Parameter	Description
AmountOfComp1	Compensation	Changes the amount of compensation required from 0.01% to 0.1% per local party
AmountOfLocals1	weights amount locals	Changes the weights which determine the amount of locals that oppose the plant
AmountOfLocals2	weights amount locals	Changes the weights which determine the amount of locals that oppose the plant
Highcapv2	spatial cap	High amount of sites per location for powerplant
Medcapv2	spatial cap	Medium amount of sites for location for powerplant
Lowcapv2	spatial cap	Low amount of sites for location for powerplant
LocationSelec1	weights location selection	Weights change: high importance of feedstock (cooling water, wind etc.)
LocationSelec2	weights location selection	Weights change: high activism parameter importance (wealth, density)
LocationSelec3	weights location selection	Weights change: high grid importance and equal spread for rest

All these scenarios from table 8.1 have been run for a limited amount of repetitions (ten). The reason for this is that one repetition takes roughly 6-8 minutes. To verify completely different parameters spaces and their effects it is likely that there are already differences and patterns visible with only ten repetitions. For the experimental design more runs are required to reduce the effects of randomness. The effects of randomness will be discussed in chapter 9. For initial validation and verification purposes the scenarios, with only 10 repetitions, should be sufficient to check whether the model behaves as expected. In the next paragraphs the behavior of the scenarios for some key indicators will be discussed to show it functions as it should.

Location building start time During the model run at each tick the amount of investments for a given location is recorded. This allows us to analyze the order of investments at locations. The outcome for all nine different scenarios is presented in figure 8.1. This figure shows a boxplot for each location in each scenario, the data is filtered for when there are no investments (0). So the boxes show when the majority of the investments in a single scenario at that location take place. The tails of the boxplot show 95 percent of the observations for that location.

We can clearly see that for the different LocationSelec scenarios, with the different location selection criteria for new power plants gives a different spread for new power plants. If we look at Hemweg, Geleen, Harculo, Galileistraat, Diemen, Delfzijl, Borgum, Rijnmond, Terneuzen we see very different sizes and placement of the boxes. This makes it possible to assume that the locationselec gives a different spread. A nice example for this is MaasvlakteII, which has a good quality feedstock (coolingwater), but rather high activism parameters. This results in the scenario where feedstock location selection is done, in very early investments at MaasvlakteII, but in the second case where activism is only considered the investments are made a lot later.

The scenarios based on the amount of Locals and the amount of compensation do not show a lot of changes from the high cap (their base scenario). This is expected, if permit negotiations fail a technology will not be used for next two ticks. Each technology has specific locations suitable, but with a general order of likability only influenced by permit failures. With more runs there is probably a slight difference with the base scenario, but nothing big. It will be interesting to combine these scenarios with different selection criteria and see the combined effects on locations.

The high, med, low -capv2 scenarios (see table 8.1 for details of the scenarios) have different amount of plants that are possible at each location. You can see that between medium and low cap the spread is roughly equal, but the time of investment is slightly lower in the low cap scenario, the same goes for the high cap scenario versus the low and medium cap, however the high cap does not use some locations.

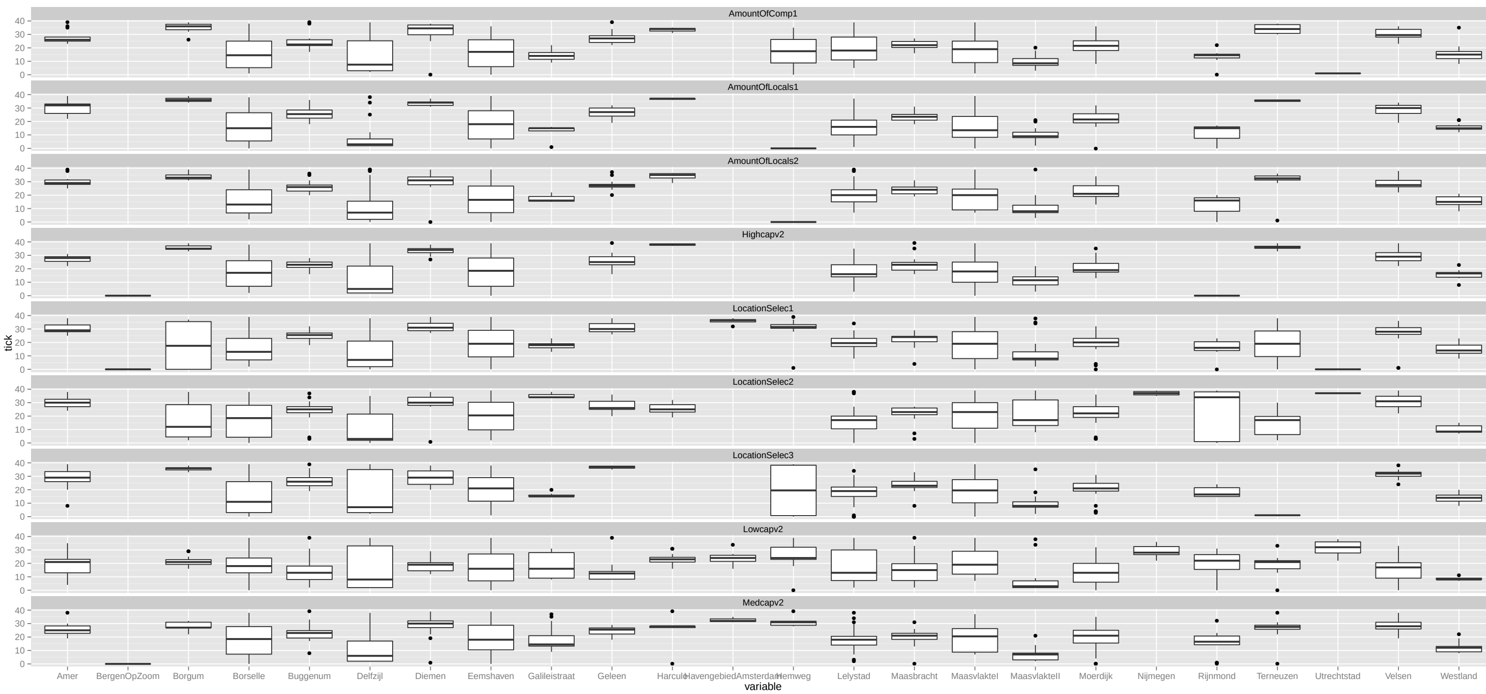


Figure 8.1: Boxplot of the distribution of construction start times for thermal power plant locations

Generation capacity and generation development In figure 8.2 the generation capacity in the different scenarios is shown (and in figure I.2 in the appendix the generated electricity by source for different scenarios is shown). The influence on the generation portfolio should be fairly limited as the only real impact is that the if a permit negotiation fails the technology is not used and if in previous cases a lot of resistance was there the NPV is slightly reduced. The scenario with the biggest impact on the portfolio is the scenario with a different CCS cap. Current storage options and policies limit this to about ten gas plants or five coal plants. This might explain the return of nuclear in many scenarios, however the locations for nuclear are also limited and that is why you see that in lowcap and medcap scenarios the nuclear generation is lower. So big direct impacts are hard to see, but smaller indirect effects like the cap on CCS and the following expansion of nuclear capacity makes is worthwhile to assess the technology capacity development figures.

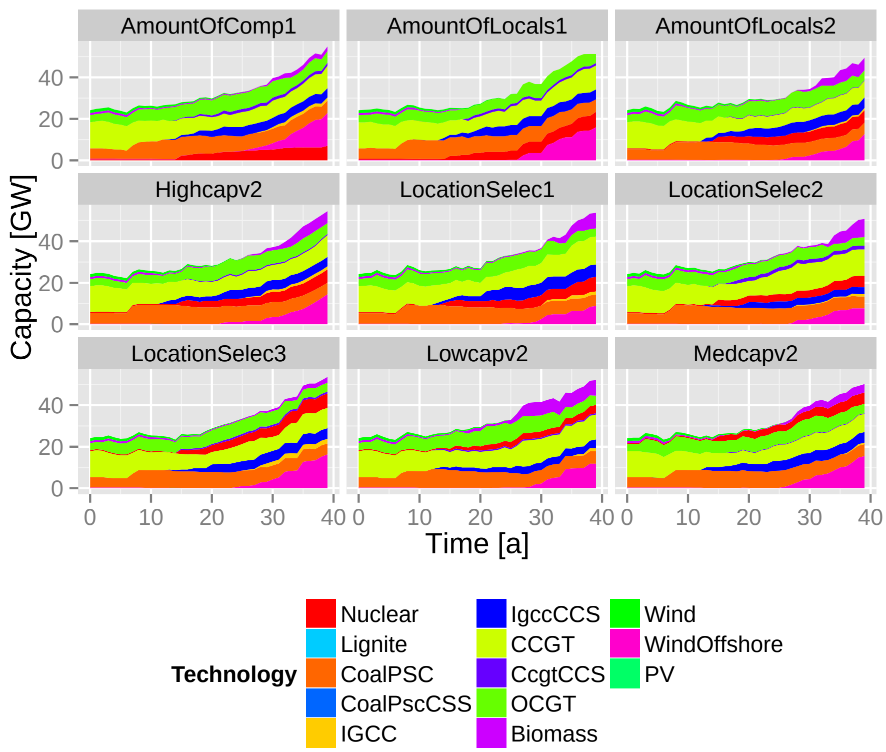


Figure 8.2: Available generation capacity per technology for each scenario

Electricity Price & CO_2 price Figure 8.3 shows the average electricity price development. The CO_2 price development looks very stable and the figure can be found in appendix I. The scenario with a low amount of possible plants at each site shows some more spikes above the CO_2 cap, but is still following the line closely. Due to the low impact this figure is not shown here, but only in appendix I.

The electricity prices show more interesting behavior. The cash position in AmountOfComp1 where the amount of compensation that needs to be paid to local parties is ten times higher, was worse than all the others, still the price of electricity does not seem to be influenced by this. This is interesting as it is then not possible to price in compensation in the electricity price explaining the cash position graph for this scenario. This also makes sense in the model and real world where the electricity price is dependent on bidding based on the marginal price. Again we see that especially in the lowcap that there are more price spikes, especially around tick twenty, which matches with the time that all location are full. Due to the high prices wind parks become more favorable and slowly makes the price go down again. It is interesting to see that the location selection scenarios show price spikes near the end. LocationSelec1 only looks at cooling water quality for thermal power plants and the price volatility could have something to do with the amount of compensation that needs to be payed to local parties, although more runs are needed to verify that. The same goes for LocationSelec2 where permit risk is the main factor determining the location and the price volatility seems to be later, perhaps due to high prices for compensation. Although we previously mentioned that compensation has limited impact on the electricity price directly, however if it causes permit procedures to fail and therefor stopping investment it could lead to shortages and than higher electricity prices. A combination between the scenarios is a nice way to investigate the combined effects and make this more visible.

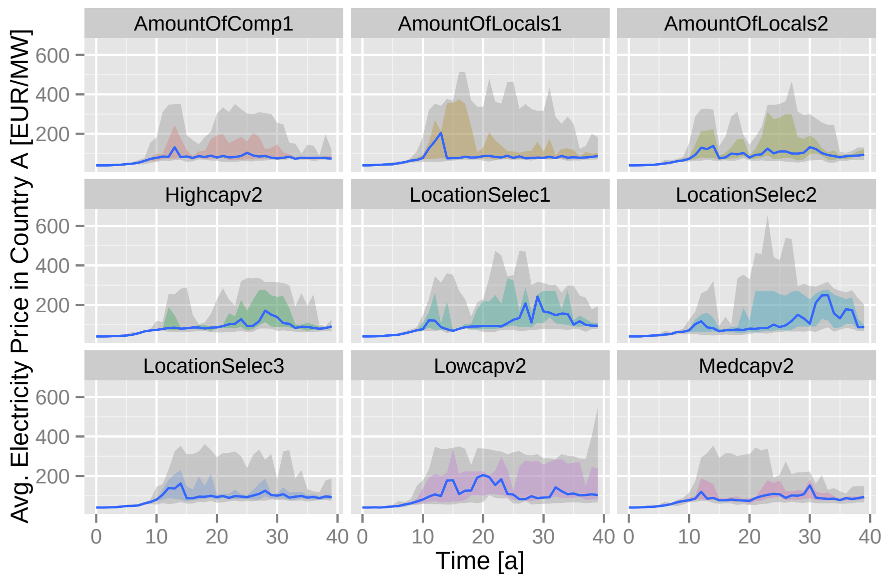


Figure 8.3: Average electricity price per scenario

Individual Location MW development In Figure 8.4 the thermal power plant locations and their MW at each tick are shown. Each color represents a different scenario. The location capacity cap again show to influence the results of this indicator a lot (scenarios low med high cap2). However we also see big changes in different ways of selecting locations (blue lines). This is behavior we would expect, from the conceptual model and the formalization.

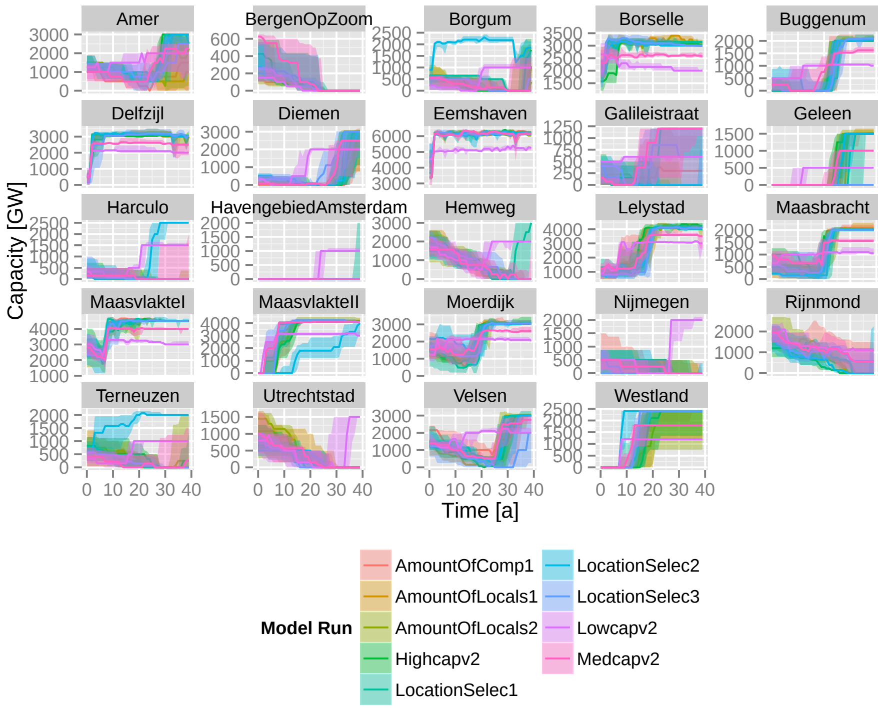


Figure 8.4: The development of generation capacity at each location, with the colors representing different scenarios

Wind Power development In figures I.4 & I.5 in appendix I we see small variations in the placement of wind turbines both on land as on sea. Using these graphs a modelling error was found. The amount of MW per location is way to high in these graphs and this had to do with the amount of plants that can be placed at each location. The amount spots for wind plants was already adapted to their actual size and the size of wind parks in the model (50 MW for onshore and 100 MW for offshore). However the model used the thermal power plants calculation for free spots, assuming that each spot equals 500 MW. This has been changed and now the model should work as intended for the experiments.

Problems fixed During the (internal) validation a number of problems surfaced that were not identified during the verification. The first problem that surfaced was that there were never investments in carbon capture and storage technologies (CCS). After a lot of runs it became apparent that there was an error and it never found location for CCS, although it was the best option with regards to NPV. This has been fixed.

The second major problem was with wind power investment. The way the free spots at a location were calculated was the same as on land, but this was not the case and needed to be more specific for wind only. The result was a lot of wind power at a single location as the cap was to high and unrealistic.

The batch runs have rather different parameter settings to represent different investment behavior, this helps us identify proper differences between the different forms of location selection and assess the impacts. Also the values for the amount of compensation and the amount of activism vary greatly and this mainly to help see impacts on behavior and check whether the model is working properly.

8.4 conclusion

This chapter discussed the steps done to verify and validate the model. A significant amount of errors have been found and corrected using the methods discussed in the chapter. The behavior of the sensitivity analysis (batch runs) shows expected behavior and interesting combination of different parameter settings can be used for the experimental design. Some errors were still found in the batch runs, CCS investment did not work properly and there was a bug in the amount of wind turbines that could be build at a single location. The validation was mainly focused on internal validity, showing that the model behaves as we would expect based on the conceptualization, external validity is problematic for agent-based models to prove.

The model with the error and bug fixes should now be capable of running interesting scenarios which can be used to test the effects of location decisions and the permit procedure on the electricity market in a country like the Netherlands, answering the remaining research questions. First the experiments will designed in chapter 9, this is followed with the simulation results in chapter 10.

Chapter 9

Experimental Design

To answer the main research question defined in section 1.2, experiments have to be carried out with the designed model of chapter 6. The experiments have to be created in such a way that they give insight in the following aspects (derived from the research questions in section 1.2):

1. Impact of Location selection on fuel mix of power plants
2. Impact of Location selection on geographical representation of power plants
3. Impact of permit procedure on the geographical representation and fuel mix of power plants
4. Effects of certain geographical related factors concerning renewables and CCS

These aspects will be used to create hypothesis. Scenarios will be designed using the hypothesis and from the results of the batch runs of the validation in section 8.2. These runs gave some initial insight in the sensitivity of certain parameters in the model. Each scenarios will have a specific parameter space and will be discussed in this chapter. The choice for the set of scenarios with their parameter space will discussed briefly, followed by arguments why certain parameters are kept stable or why they are not considered.

9.1 Hypotheses

To answer the research question, hypotheses have to be created to conduct experiments. Falsifying hypothesis is rather difficult due to the fact that it is a created model, meaning basically that what you put in the model will come out of the model. This makes analytical statistics less powerful. Only statistical test are insufficient and descriptive statistical tests will be needed to convincingly falsify the hypotheses. Dam et al. (2012) state that there are basically two type of hypotheses. The first are hypotheses that identify macroscopic regularities under given conditions and the second type of hypothesis finds clearly distinguishable behavior or regularities from the agent based model. All the hypotheses fit the first definition, as the conditions for which the outcomes are analyzed will be set. All the hypothesis will use three caps to the amount of power plant each location can handle, the reason for this will be discussed later in this chapter. The hypotheses will be focused on increasing the internal validity of the model and each hypothesis should give insight in the subresearchquestions. The following hypotheses are created, all with a short description of the type of experiments required:

Hypothesis 1:

> Scenarios that have power producers incorporate activism criteria in the location selection have a different fuel mix than scenarios that have power producers only evaluate location based on technical aspects.

This hypothesis requires scenarios with different caps of the amount of power plants possible at a location. Additionally the way locations are selected have to be varied to assess the impact.

Hypothesis 2:

> Scenarios that have power producers incorporate activism criteria in the location selection have a different geographical spread (MW / location) than scenario that have power producers only evaluate location based on technical aspects.

This hypothesis requires the same scenarios as hypothesis 1, so scenarios with different caps to the amount of power plants possible at each location, combined with different ways of location selection by power producers.

Hypothesis 3:

> Limiting CCS capacity results in a significantly different fuel mix.

Scenarios with different caps for the amount of power plants possible are required. This has to be combined with scenarios with a theoretical cap for CCS and scenarios with a significantly higher CCS cap.

Hypothesis 4:

> The amount of desired compensation demanded by local parties to be willing to accept a power plant significantly influences the location decision and technology mix.

In hypothesis 1 and 2 we investigate the general impact location selection methods have on the distribution of power plants and their technology. Here we go one step further and see if the permit negotiation itself impact the distribution of power plants and the technology mix. Again there is a need for scenarios with different caps to the amount of power plants that can be constructed at a location. This has to be combined with scenarios that have different levels for the amount of activism construction of a power plant causes.

9.2 Scenarios

To be able to falsify the hypotheses, scenarios have to be created. First the parameter space will be discussed continued with the experimental setup. In the experimental setup the scenarios that are based on the parameter spaces will be presented

9.2.1 Overview parameters

The scenarios are based on a certain parameter space. In table 9.1 the different parameters that can be used in the scenarios are presented. A short description of each parameters is also added in this table.

Table 9.1: All parameters used for the scenarios and the parameter descriptions

Parameter	Description
Location Cap	Amount of power plants that can be constructed at a location
Selection method	The way power producers select locations for new power plants, can vary between only technical aspects to only permit risk factors
Selection method Wind	The way power producers select off-shore wind locations
Amount of Activism	The amount of locals that need to be compensated, random factor but with mean 0, but the standard deviation can be increased
Amount of Compensation	The amount of compensation required to increase the happiness of a local party
Activism Utility function	The distribution of weight to factors determining the level of activism at a location
Locals Utility	The distribution of weight to factors determining the perception of local parties to power plants
Government Utility	The distribution of weight to factors determining the perception of the government to power plants
Power producer Utility	The distribution of weight to factors determining the perception of a power producer for an investment
Fuel prices	Price scenarios for all power plant fuels
Demand	Demand scenarios for the single country in the model
Initial fuel mix	The percentage of each type power plant in the beginning of the model
CCS cap	The amount of CCS plants that can be constructed

Fuel Prices and Demand In table 9.2 the fuel price development parameters are given. These are from the base EMLab-generation scenarios (more specifically ScenarioOneCountryB). The biomass price development parameters are based on research of Faaij (2006). The price development parameters for the other fuels is based on IEA (2011). The fuel price development parameters are an input for triangular distributions with a minimal value, maximum value and top value. These triangular distributions are used to draw a random number each tick to determine the fuel price development of a specific fuel.

Table 9.2: Demand and fuel price development parameters

Name	Top	Min	Max
Demand Growth	1.02	0.99	1.05
Coal Price	1.01	0.97	1.05
Gas Price	1.01466	0.94466	1.0846628
Uranium Price	1.01	1	1.02
Biomass Price	1.01	0.97	1.05

Power plant mix In table 9.3 the fractions of each power generating technology are presented. These are based on data of the International Energy Agency (IEA, 2012) and Enipedia data. Using the total amount of generation capacity and the data of all the power plants in the Netherlands of Enipedia the shares of different technologies were calculated. These have been tested in the validation section 8.2, whether they reflect the real distribution of power plants in the Netherlands. This was not entirely the case and most of the difference was explained by the lack of very small generators (< 150MW).

Table 9.3: The initial fractions of each type of power plant

Type of Power plant	Fraction
Coal Pulverized Super Critical	0.20
CCGT	0.53
OCGT	0.15
Biomass PGT	0.03
Nuclear PGT	0.02
Wind onshore	0.06
Wind Offshore	0.01

Location Caps Table 9.4 locations and the three different cap scenarios are presented. There is no data about caps. In reality this is determined by factors like cooling water, capacity of the grid, feedstock availability, attitudes of surrounding area and space in general. The amount of plants are thus rather arbitrarily and therefor three setups are made. The first is based on the current amount of plants, grid capacity and space available. The second and third are more based on capacity and cooling water quality. Maasvlakte I and II have a huge amount of capacity of the grid, but have to share this and space is rather limited, so therefor the amount of possible plants is not extremely high. The capacities of the grid cannot be directly translated in MW and are likely a bit lower, furthermore it does not incorporate nearby other power plants and usage of the grid so that is why other factors are also used. Medium and High cap scenarios are in many cases 1 or 2 more spots for power plants at a location. With data of TENNET (2008) the capacities of the transmission lines can be found.

Inter-connectors capacity is not used in the model so it is left out as possible connection for the power plants. Planned new capacity is taken in to account as far as possible. Special cases with regards to grid capacity at a location is noted in the capacity column of table 9.4.

More attention to the transmission grid and environmental facts could improve the caps, but that is out of the scope of this research and the caps now used are just to assess the effects of caps in general. It would be a valuable addition to the model if the transmission grid could be modelled more precisely and the environmental factors around a power plant location.

Table 9.4: Locations for thermal power plants and the amount of possible power plants at that location for different caps. Number of plants is based on the notion that one plant is roughly 500 MW.

Location	**Grid Capacity (MAV)**	**Low Cap (power plants**	**Medium Cap (power plants)**	**High Cap (power plants)**
Eemshaven	3575 (will be increased)	10	12	12
Burgum	1906	2	3	4
Harculo	5925 (interconnector)	3	4	5
Nijmegen	3290	4	5	6
Utrecht	1645	3	4	5
Maxima-centrale	3290(will be increased)	6	7	8
Velsen	1900	4	5	6
Hemweg	1900	4	5	6
Diemen	5190	4	5	6
Maasvlakte I	7915	6	8	9
Galileistraat, Rotterdam	5290	1	2	2
Borselle / vlissingen	1645 (will be increased)	4	5	6
Amer Geertruidenberg	4935	4	5	6
Buggenum	1645	2	3	4
Maasbracht	6580 (interconnector)	2	3	4
Moerdijk	1645	4	5	6
gemeente westland	5290	2	3	4
Geleen	6580 (interconnector)	1	2	3
Delfzijl	2645	4	5	6
Amsterdams havengebied	1900	2	3	4
Maasvlakte II	7915	6	8	8
Rijnmond, Rotterdam	5290	4	5	6
Terneuzen/sas van Gent	1645	2	3	4

Utility Functions Besides the way power producer select locations there are more utility functions with weight factors that can be varied. The amount of variation have been kept to a minimum due to time constraints. The choices for each individual utility functions weight factors will be discussed. Data about the weight factors is very hard to come by and thus most of them are based on assumptions.

The activism weight factors originally had two levels of activism in the batch runs of the validation (table 9.5). The technology itself is presumed to be the most important driver for activism closely followed by the two other activism level indicators identified in section 2.4. The high amount of activism is double the low level but based on the same spread. In the high amount of activism case, using these weight factors, more local parties should emerge during the permit process. However to reduce the number of runs it is a choice to only vary the demanded amount of compensation and not the weight factors in this equation, because it does not matter for the permit negotiations if there are e.g. hundred parties asking all one euro or ten parties asking ten euro. This also makes the computational process faster.

Table 9.5: Amount of activism weight factor levels

Name	**Weight factor wealth**	**Weight factor perception**	**Weight factor density**
Low amount of activism	3	4	3
High amount of activism	6	8	6

Table 9.6 shows the weight factors for the utility function that determines the attitude of local parties. Only one case has been created and again it is assumed that technology determines most of the attitude. If it is a big polluting coal plant or a wind turbine will both cause activism, but on a different level. The other indicators of activism are assumed to be equally important and significantly less important than technology perception. The difference is bigger than in case with the weight factors of the number of activists that spawn shown in table 9.5. It is assumed that people attitude is more dependent on the technology and that appealing is more dependent on social factors and value to open space.

Table 9.6: Attitude local parties weight factors

Name	**Weight factor wealth**	**Weight factor perception**	**Weight factor density**
Base	0.2	0.6	0.2

Table 9.7 also has only 1 base case. The government needs to be compensated for environmental effects, according to laws and regulations (environmental mitigation strategies). Thus this will influence the attitude of the government the

most. Local economical factors are assumed to play a minor role. If there are already several power plants of the same type in a local government's area, the local government's perception goes down as it thinks it has contributed enough, this is maximized when there are around five power plants of the same general fuel type.

Table 9.7: Attitude government weight factors

Name	**Weight factor technology**	**Weight factor employment**	**Weight factor previous experience**
Base	0.7	0.1	0.2

Amount of compensation In table 9.8 the different levels and types of compensation that will be used in the scenarios are presented. According to (Sharma, 2011) the environmental compensations demanded by governments for compensation measures equals to roughly 10 percent of the investment costs. In the model it is assumed that this is the maximum amount of compensation and if the environmental effects of a technology are not as bad as the worst technology a lower percentage is demanded.

Data about what local parties demand for compensation is hard to come by. 0.001 percent of the investment costs of a power plant equals roughly 100.000 euro with an investment of 1 billion and 0.0001 percent of the investment costs of a power plant equals 10.000 euro. These percentages are likely not realistic, but they are at a level that could represent e.g. property value loss. The comparison between the two could give insights in the effects the amount of compensation has in the permit procedure and the resulting geographical distribution of power plants.

Table 9.8: Amount of compensation for the government and the local parties

Compensation Type and indicator	**Level**
Government Environmental compensation	Max 10% of investment costs of a power plant (Sharma, 2011)
Local party low compensation	0.0001% per party
Local party high compensation	0.001% per party

Location selection method Three different scenarios have been made to assess the impact of location selection methods on the geographical distribution of power plants. According to the empirical data of Groot (2013) permit risk is an important factor. So in all cases the base determinants of permit risk (Wealth and population density) are taken into account. However in case of 'Permit' , as seen in table 9.9, these will almost completely determine the location choice. In case of 'Feedstock' the permit risk will only account to 0.2 of the weight and

0.75 of the weight goes to feedstock (or cooling water availability). 'Spread' is somewhere in between with a roughly equal distribution between the different factors.

Table 9.9: Different location selection weight factors for power producers

Name	**Weight factor wealth**	**Weight factor density**	**Weight factor feedstock**	**Weight factor distance grid**
Permit	0.45	0.5	0	0.05
Spread	0.3	0.35	0.3	0.05
Feedstock	0.1	0.1	0.75	0.05

Location selection offshore wind In table 9.10 the three different selection methods for wind offshore locations are presented. The different methods of selection are pretty straightforward and have different weights for wind power , depth of the water and distance to the shore.

Table 9.10: Wind power location selection method weight factors for power producers

Name	**Weight factor wind power**	**Weight factor distance to the shore**	**Weight factor depth water**
High wind	0.8	0.1	0.1
Medium wind	0.4	0.3	0.3
Low wind	0.1	0.45	0.45

CCS cap In section 7.3 the theoretical cap for CCS in the Netherlands under current conditions is discussed. This theoretical cap is roughly 6 coal power plants or 12 gas power plants (both of 500 MW). To assess the impact of a CCS cap on the development of the power sector a cap that is double the current cap is implemented. So 12 coal power plants and 24 gas power plants is the high cap for CCS.

9.2.2 Randomness and Experiment setup

Randomness There are several sources of randomness in the model. A few were already present in the base EMLab-generation model, but also some are added. The distribution of power plants amongst power producers is done randomly before the first simulation tick, it will randomly assign a power plant to a power producer until the fractions of each technology, as specified in table 9.3, have been reached. The order of investments by power producers is also random at each tick. This is done to prevent a power producer to always have the first choice of investments at a given time. The fuel price development and demand development are based on triangular distribution and are stochastic, thus also a source of randomness. Finally for the base EMLab-generation model the initial power plants are given a random age at the beginning of the model.

In the extension to the base EMLab-generation model, as discussed in chapter 6, there are some more sources of randomness added. First of all the geographical locations of the power plants are randomly given to the power plants. The chance a geographical location is picked is based on the amount of actual generation capacity at that location in the Netherlands, the more MW capacity , the higher the chance an initial power plant will be situated at that location. Secondly in the permit negotiations a random element is added to make the amount of local activists that emerge when the power producer is applying for a permit unpredictable. Additionally the attitudes of the activists are all calculated the same way, but are multiplied by a random number to make it worthwhile having several actors in the model. If all actors have the same value it would make sense to just integrate them into one actor. Both the amount of activists that emerge and their attitude chance distribution are based on environmental factors, wealth and population density and the attitude towards a certain technology. In reality it is also unsure, regardless of local statistics, how many local people will appeal against the issuing of a permit and how persevering the local people are.

Experimental setup Due to the initial geographical spread of the power plants and the other sources of randomness the scenarios have to be repeated a certain number of times to reduce the effect of the random behavior. Additionally agent-based models are likely to produce different outcomes each run, so repeated scenarios are always required. Due to the amount of time each run takes, the amount of experiments and repetitions is limited and a choice has been made to run all the scenarios fifty times. Each run takes roughly six to eight minutes to run, so the twenty scenarios times fifty repetitions takes roughly a week. Some parameters would be interesting to assess in more detail with more different sets of parameters (ideally full factorial design), but due to this computational limitation a selection of interesting combination has to be made.

For all scenarios EMLab-generation is regarded as the population. This is important as we will be comparing runs and no comparison can be made with real world data. The model does not intend to replicate the real dutch power sector, but is based on the dutch sector's data.

The different scenarios are presented in table 9.11 . Choices have been made in combination of different parameter settings, based on the sensitivity analysis of the validation, section 8.2. The amount of activism is kept stable as discussed in paragraph 9.2.1. Because offshore wind selection methods are completely independent in the model from the other location selection methods, random combination could be made with other scenarios, significantly reducing the amount of scenarios. Furthermore most selection methods have a high and low compensation scenario to assess the impact of the permit procedure. Three scenarios have been added to verify the effects of different CCS caps for different location capacity caps. Together these scenarios should give enough data to falsify the hypotheses.

Table 9.11: The resulting scenarios

Name	**Weight location selection**	**Amount activism**	**Amount compensation**	**Wind selection**	**CCS**	**MW cap**
Scenario 1	Permit	High	High	High	normal	High
Scenario 2	Permit	High	Low	High	normal	Med
Scenario 3	Permit	High	Low	High	normal	Low
Scenario 4	Spread	High	High	Low	normal	High
Scenario 5	Feedstock	High	High	Med	normal	High
Scenario 6	Spread	High	Low	Low	normal	Low
Scenario 7	Spread	High	Low	Low	normal	Med
Scenario 8	Feedstock	High	Low	Med	normal	Low
Scenario 9	Feedstock	High	Low	Med	normal	Med
Scenario 10	Spread	High	Low	Low	normal	High
Scenario 11	Spread	High	High	Low	normal	Med
Scenario 12	Spread	High	High	Low	normal	Low
Scenario 13	Feedstock	High	High	Med	normal	Low
Scenario 14	Feedstock	High	High	Med	normal	Med
Scenario 15	Feedstock	High	Low	Med	normal	High
Scenario 16	Spread	High	High	Low	High	High
Scenario 17	Spread	High	High	Low	High	Med
Scenario 18	Spread	High	High	Low	High	Low
Scenario 19	Permit	High	High	High	normal	Low
Scenario 20	Permit	High	High	High	normal	Med

9.3 Exogenous Variables

Demand and fuel prices have proven to be very important exogenous factors in the base EMLab generation model . The question is though whether they are that important in this study? If there are already effects visible with the current experiments we could argue that testing for different fuel price and demand scenarios is out of the scope of this research as we only try to get long terms effects of location decision on the electricity market. Nonetheless fuel price and demand are very important and worthy assessing its impact, but for now they are not considered.

9.4 conclusion

This section presented the hypotheses that will be evaluated in chapter 10. Additionally the scenarios are defined of which the data will be used to evaluate the hypotheses. The parameter space is discussed extensively and choices have been made for certain combination of parameters for the scenarios. The resulting scenarios are shown in table 9.11. With these scenarios all the remaining sub research questions and ultimately the main research question can be answered.

Chapter 10

Results

The hypotheses defined in chapter 9 will be falsified in this chapter. The scenarios have been ran using the model defined in chapter 6 and the resulting data will be analyzed. First a brief overview of the most important indicators and graphs that are used to falsify the hypothesis will be given. This is followed by the hypotheses and whether or not they can be falsified or not. The falsification of the hypotheses in this chapter will serve as an input for the result analysis chapter (chapter 11).

10.1 Indicators and graphs

There are several indicators that are very important to falsify hypotheses. Statistical test are used, both T-tets and Mann-Whitney U tests. However the value of statistical test is limited in the agent based environment due to the very random behavior of each run. The amount of runs conducted helps us to reduce the overall randomness in the outcomes, as discussed in section 9.2.2. Still the power of statistical tests is rather low and thus they are supplemented with capacity trajectory graphs, means and individual run comparisons with the mean. The figures and methods used to visualize the falsification process will be explained in this section.

Tests result graph The scenarios have fourty time steps each and are repeated fifty times per scenario. At each time step the technology capacity or capacity at a location will be compared with another scenario. This will result in a huge amount of tests and the decision has been made to present these results in histograms. The colors will represent either a technology or a location, depending on the variable that is tested. A red dotted line represents the significancy level of 0.05. The X-axis contains the P-values or test values. The Y-axis the amount of observation of P-values in each bin. The bin size is 0.05. This graph helps to gain insight in the amount of significant differences and the source of the significant difference (certain locations or technologies). An example of such a graph is given in figure 10.1. Here you find that a majority of the significant differences are in the CCS technologies and the carbon-dioxide free technologies.

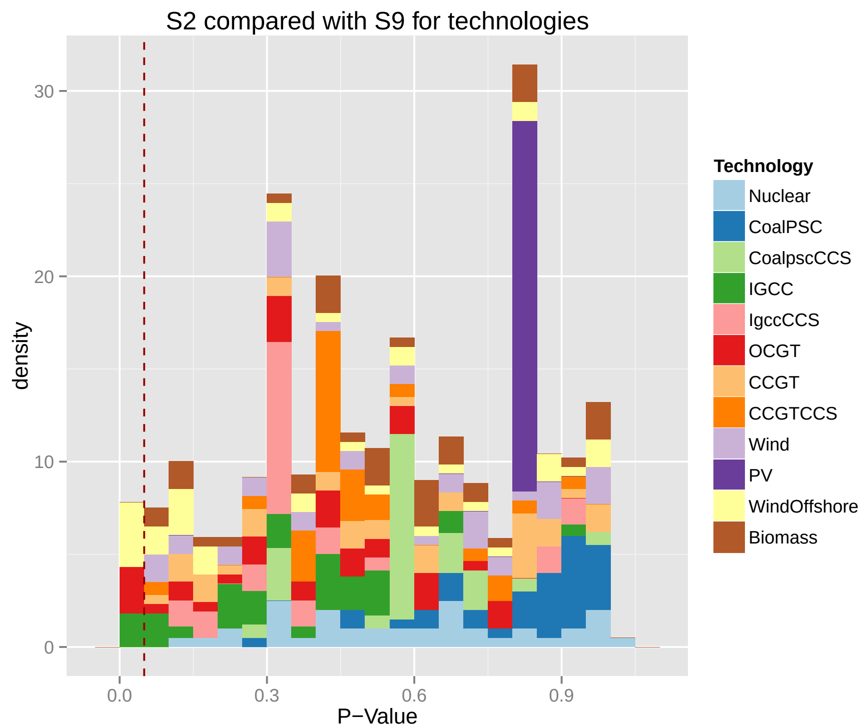


Figure 10.1: Example statistical test result histogram figure

Descriptive statistics Additionally graphs will be presented in the text or in the appendix showing the trajectory of a given technology or location capacity over time with an colored area around the line representing the variance. This helps validate the test results, because the test results themselves have questionable power and should be supported by further data and graphs.

An example of a location capacity figure is shown in figure 10.2. To make the graph easier to read, a decision has been made to let the colored area represent 50 percent of the runs, instead of all or 95 percent of the runs. In cases with 95 percent runs the colored area became to filled up with colors, as there are always outliers presents (agent-based modelling property). The colored line represents the mean of each scenario. Using the 50 percent spread and this mean we can clearly identify differences between scenarios. In figure 10.2 some locations have completely different capacity curves and thus we can say that the statistical tests, if tested that there are significant differences between the scenarios, seem valid. In figure 10.2 these locations are graphs for two locations and two scenarios are shown. Only the scenarios and locations or technologies mentioned in the text will be presented in the figures in this chapter, the other figures of all the other technologies, locations and scenarios can be found in the appendix J.

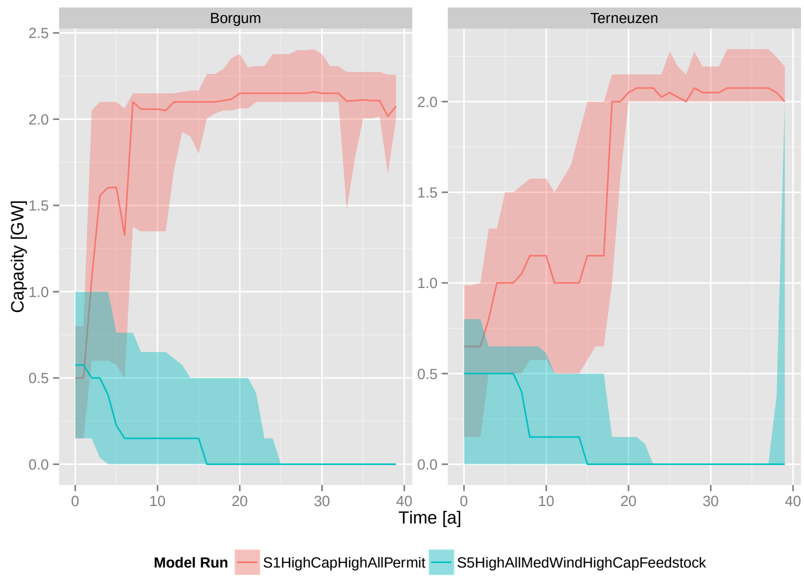


Figure 10.2: Example graph with the different capacities at individual locations for each scenario

The third way to assess the outcomes of the scenarios with regards to the hypothesis is to analyze the means and the amount of runs of both scenarios that are higher than a reference scenario's mean. The mean is taken from one of the two scenarios of the scenario comparison. By counting the amount of runs higher than a fixed reference mean for both scenarios, we can assess if there is a scenario with more runs above the reference mean. This analysis is done at several different time steps (10, 20, 30, 40), because the difference between the scenarios could be at any given simulation ticks so this selection has been made. Additionally we can assess the means at different time steps and see if the difference is more than a single power plant, lowering the chance that the difference is due to an error. To illustrate this table 10.1 is presented. Here you find all the items discussed in the paragraph. For each technology this means that there is a reference scenario mean and an alternative scenario mean. Underneath these means you find the percentage of runs higher than the reference mean. This all for the four different simulation ticks.

Table 10.1: Comparison of means and amount of runs higher than reference mean (scenario 2) for technologies OCGT IGCC and Wind offshore

Time	**Year 10**	**Year 20**	**Year 30**	**Year 40**
Wind Offshore				
Mean reference scenario 2 (MW)	181	143	3370	8796
Mean alternative scenario 9 (MW)	214	322	3837	8793
% runs scenario 2 higher than reference mean	58%	26%	36%	70%
% runs scenario 9 higher than reference mean	70%	42%	48%	72%
IGCC				
Mean reference scenario 2 (MW)	631	836	1958	2731
Mean alternative scenario 9 (MW)	758	1200	2274	3600
% runs scenario 2 higher than reference mean	40%	28%	38%	34%
% runs scenario 9 higher than reference mean	36%	34%	42%	56%
OCGT				
Mean reference scenario 2 (MW)	5543	6350	7375	4550
Mean alternative scenario 9 (MW)	5228	5896	6228	4037
% runs scenario 2 higher than reference mean	44%	42%	44%	52%
% runs scenario 9 higher than reference mean	40%	40%	34%	34%

The methods discussed in this section should together provide sufficient power to falsify a hypothesis. In some cases other figures will be used as well, these we will explained in the relevant section.

10.2 Hypothesis 1

This section will attempt to falsify hypothesis 1, defined in section 9.1. The graphs used are explained in section 10.1. From the scenarios defined in section 9.2.2, different combination have been made and these are shown in table 10.2. The scenario combination have the same level of compensation and location capacity cap, but have different location selection methods (permit selection & feedstock selection). These combinations are statistically tested and visualization are presented to investigate differences between the two scenarios, with respect to the technology mix of power plants.

Table 10.2: Scenario combinations used for hypothesis 1, scenario numbers can be found in section 9.2.2.

Scenario Combination	Scenario A	Scenario B
High cap high compensation	1	5
Low cap low compensation	3	8
Medium cap low compensation	2	9
Medium cap high compensation	20	14
Low cap high compensation	19	13

> *Hypothesis 1:*
>
> Scenarios that have power producers incorporate activism criteria in the location selection have a different fuel mix than scenarios that have power producers only evaluate location based on technical aspects.

The tests and figures In figure 10.3 you find the results of the statistical tests for the first hypothesis, for one scenario combination. To compare the different technologies the student t test has been done for each technology at each tick and compared to other scenarios. Three base scenarios (with different location space caps) with permit risk in the location selection are compared with three scenarios (with different location space caps) with only technical requirements in the location selection. The data of the generation capacities is assumed to be normally distributed, based on normal distribution tests at several time steps and for different technologies.

To support figure 10.3 the generation capacities for a selection of technologies is shown in figure 10.4.

The following H0 and H1 have been defined using the hypothesis.

> H0: The means of permit risk scenarios and technical requirement scenarios are the same
>
> H1: The means of permit risk scenarios and technical requirement scenarios are not the same

Result In figure 10.3 it is clearly visible that the first bin of the histogram left of the red dotted line is not empty. Meaning that there are significant differences between the two scenarios. These differences come from wind offshore, OCGT and IGCC technologies. In figure 10.4, when we analyze the graphs of these three technologies we observe that indeed there are relatively big differences between the two scenarios. For IGCC, OCGT and wind offshore we indeed see small differences, with less overlapping areas than with the other technologies. Interestingly wind offshore tends to develop earlier when considering feedstock as the main location selection criteria.

To verify the graphs and the statistical tests, the means and amount of runs higher than scenario 2's mean are given. This data for OCGT , wind offshore and IGCC can be found in table 10.3. Especially around tick thirty and thirtynine there are large differences for OCGT and IGCC. Also the mean capacities differ greatly and for OCGT with a plant capacity of just 150MW in the model, differences of over 1000MW are rather big and it is likely that this is not a random error. For Wind offshore there are at tick twenty and thirty a lot more observations above scenario 2's mean. The differences in the amount of runs higher than the average of scenario 2 tells us that the significant test results and the observed differences in the graphs are likely true and there is an impact of location selection methods on the technology mix of the power sector.

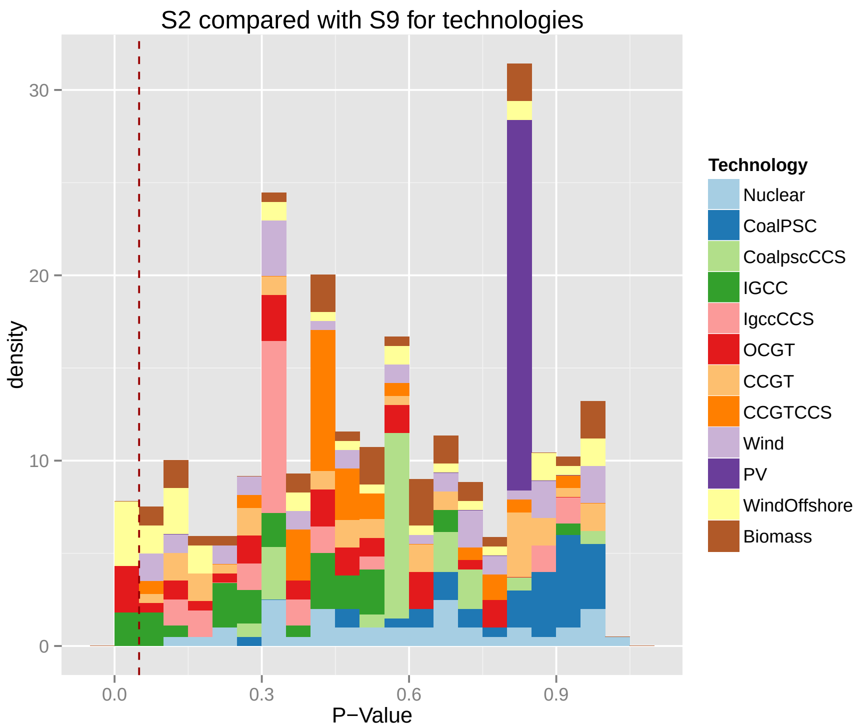


Figure 10.3: Histogram showing the amount of significant runs for two scenarios with medium caps and permit or feedstock location selection methods

Finally to make this difference more clear, figure 10.5 is presented and shows the stacked capacity graph of the technologies for three different scenarios, all based on low cap scenarios. It is clearly visible that certain technologies have a bigger surface area (color) than others, thus also suggesting that the location selection method influences the power plant technology capacity in a country.

All the other combinations of scenarios tested show significant differences, the graphs for the other scenario combinations can be found in appendix J. When assessing the specific graphs of the capacity of the technologies, these significant differences can also be observed. Additionally when analyzing the individual run outcomes differences are still observed especially for OCGT, although the other significant outcomes are more questionable. To conclude this section, H0 has to be rejected, as at least one technology (OCGT) shows significant different outcomes in all cases. Meaning that the location selection method leads to a different power plant technology mix.

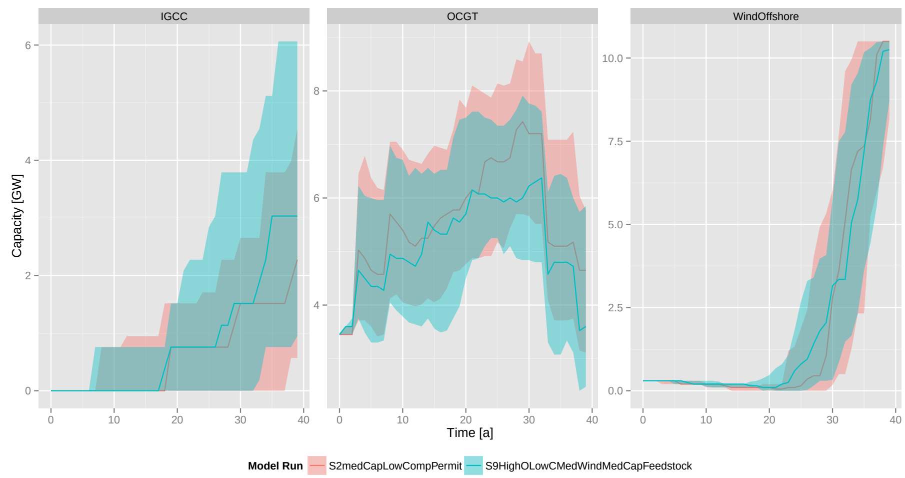


Figure 10.4: A selection of interesting generation capacities graphs, for two scenarios with medium caps and permit or feedstock location selection methods

Table 10.3: Comparison of means and amount of runs higher than reference mean (scenario 2) for technologies OCGT IGCC and Wind offshore

Time	**Year 10**	**Year 20**	**Year 30**	**Year 40**
Wind Offshore				
Mean reference scenario 2 (MW)	181	143	3370	8796
Mean alternative scenario 9 (MW)	214	322	3837	8793
% runs scenario 2 higher than reference mean	58%	26%	36%	70%
% runs scenario 9 higher than reference mean	70%	42%	48%	72%
IGCC				
Mean reference scenario 2 (MW)	631	836	1958	2731
Mean alternative scenario 9 (MW)	758	1200	2274	3600
% runs scenario 2 higher than reference mean	40%	28%	38%	34%
% runs scenario 9 higher than reference mean	36%	34%	42%	56%
OCGT				
Mean reference scenario 2 (MW)	5543	6350	7375	4550
Mean alternative scenario 9 (MW)	5228	5896	6228	4037
% runs scenario 2 higher than reference mean	44%	42%	44%	52%
% runs scenario 9 higher than reference mean	40%	40%	34%	34%

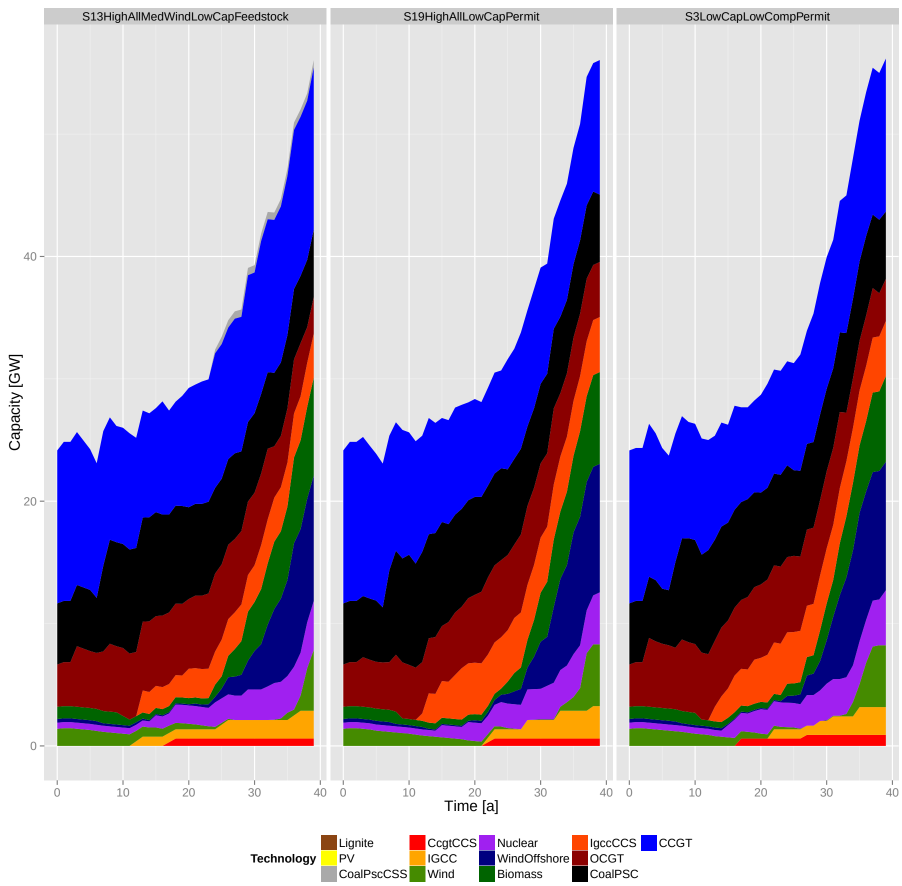


Figure 10.5: Stacked power generation capacity versus time for low cap scenarios with high compensation

10.3 Hypothesis 2

This section will attempt to falsify hypothesis 2, defined in section 9.1. The graphs used are explained in section 10.1. From the scenarios defined in section 9.2.2, different combination have been made and these are shown in table 10.4. The scenario combination have the same level of compensation and location capacity cap, but have different location selection methods (permit selection & feedstock selection). These combinations are statistically tested and visualization are presented to investigate differences between the two scenarios, with respect to the distribution of power plant capacity at locations.

Table 10.4: Scenario combinations used for hypothesis 2, scenario numbers can be found in section 9.2.2.

Scenario Combination	Scenario A	Scenario B
High cap high compensation	1	5
Low cap low compensation	3	8
Medium cap low compensation	2	9
Medium cap high compensation	20	14
Low cap high compensation	19	13

> *Hypothesis 2:*
>
> Scenarios that have power producers incorporate activism criteria in the location selection have a different geographical spread (MW / location) than scenario that have power producers only evaluate location based on technical aspects.

The tests and figures Here we want to proof that the way locations are selected will change the distribution of plants across different sites. The capacities (MW) at the locations do not have a normal distribution and therefor the student T-test is not suitable. The Mann-Whitney U test or Wilcoxin rank sum test is a non parametric test that does not require the data to be normally distributed and is less sensitive for breaking the conditions for the test than the student t-test is. We have to acknowledge though that this test has less statistical power than the student t-test. The tests have been done for all the scenario combinations of table 10.4. The resulting histogram of one of these combination (High cap high compensation) is shown in figure 10.6.

To support figure 10.6 the generation capacities for each location are shown in figure 10.7.

The following H0 and H1 have been defined using the hypothesis.

> H0: The scenarios for permit risk based selection and feedstock based selection have the same means in MW capacity for all the locations.
>
> H1: The scenarios for permit risk based selection and feedstock based selection have different means in MW capacity for all the locations.

Result In figure 10.6 a large amount of the U test results are left of the red dotted significancy line and this means that there are a lot of significant differences between the scenarios. This is also true for all the other scenario combinations defined in table 10.4 and the graphs for these scenario combinations are found in appendix J. When we further analyze this with figure 10.7 we indeed see location with completely different capacity curves, e.g. Borgum, Harculo, Maasvlakte II and Terneuzen. Thus the high amount of significant differences found with the statistical tests are supported by the individual location capacity charts of figure 10.7. These differences are also clearly visible in figure

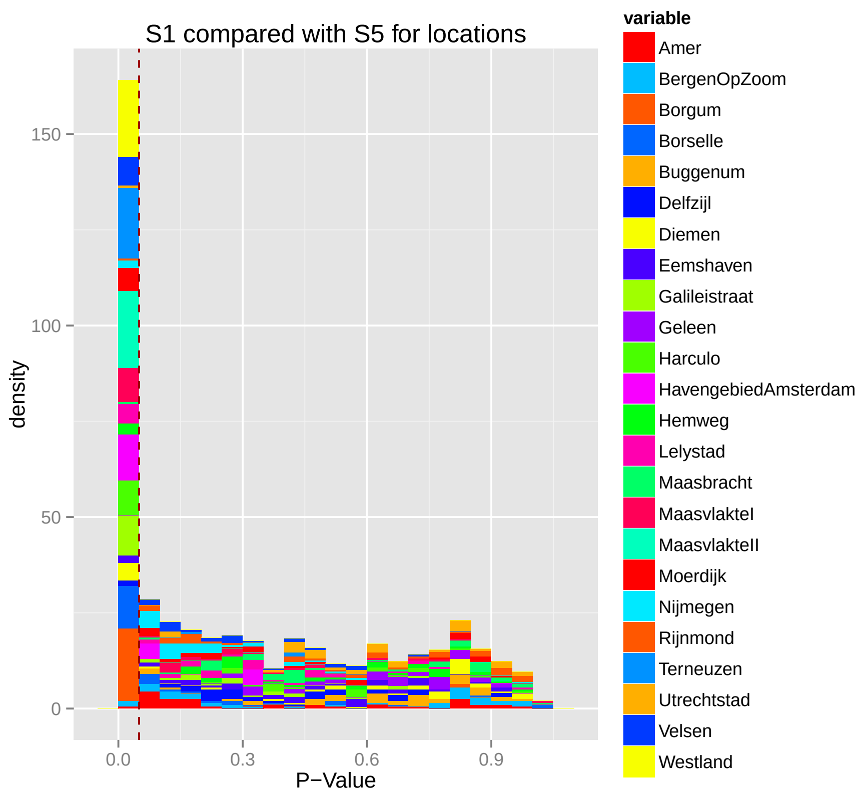


Figure 10.6: Histogram location capacity comparison between two scenarios with high location capacity caps and permit or feedstock location selection methods

10.8. Here three different location selection method scenarios are plotted next to each other, all with the high location capacity parameters. The amount of area covered in the graph of certain colors (locations differ greatly. Finally for Borgum and Terneuzen a table is presented showing the mean capacities (MW) at these locations for the scenarios 1 and 5 and the amount of runs that are above scenario 1's mean capacity. In table 10.5 the huge differences between the scenarios are clearly visible, both for means (difference of over 1000MW , meaning several power plants), as well as the amount of runs that are higher than scenario 1's mean capacity.

This all makes that H0 has to be rejected. This means that different location selection methods will cause a different geographical distribution of power plants. On it self this sounds obvious, but it shows that the model works as intended, increasing internal validity. Further analysis will follow in the end of this chapter.

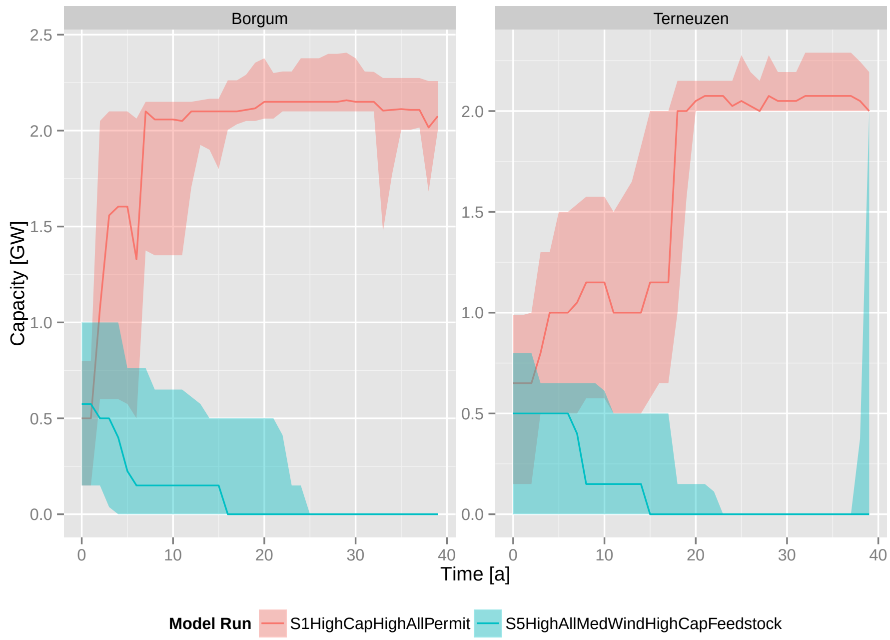


Figure 10.7: A selection of interesting generation capacity graphs for different locations for the two scenarios with a location capacity cap and permit or feedstock location selection methods

Table 10.5: Comparison of means and amount of runs higher than reference mean (scenario 1) for technologies OCGT IGCC and Wind offshore

Time	**Year 10**	**Year 20**	**Year 30**	**Year 40**
Borgum				
Mean reference scenario 1 (MW)	1726	2173	2197	2000
Mean alternative scenario 5 (MW)	291	256	256	319
% runs scenario 1 higher than reference mean	66%	32%	40%	76%
% runs scenario 5 higher than reference mean	2%	0%	2%	1%
Terneuzen				
Mean reference scenario 1 (MW)	1088	1990	2142	2139
Mean alternative scenario 5 (MW)	247	193	352	343
% runs scenario 1 higher than reference mean	48%	80%	32%	32%
% runs scenario 5 higher than reference mean	6%	0%	2%	0%

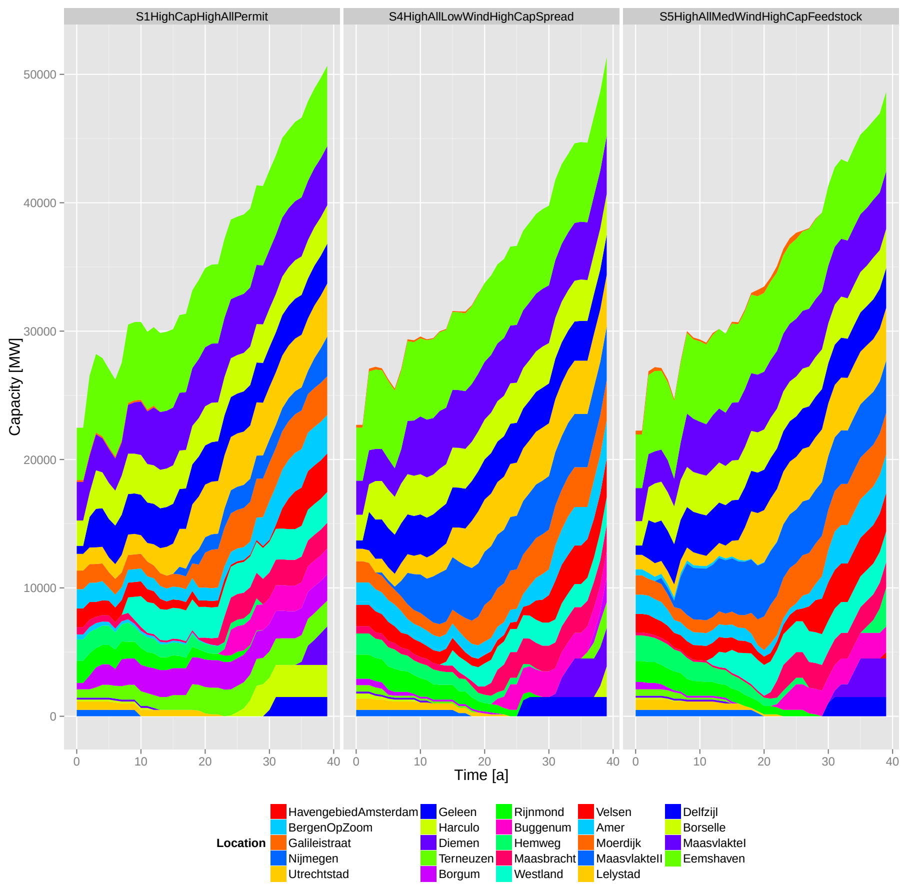


Figure 10.8: Stacked location capacity versus time diagram for High Cap high compensation scenarios

10.4 Hypothesis 3

This section will attempt to falsify hypothesis 3, defined in section 9.1. The graphs used are explained in section 10.1. From the scenarios defined in section 9.2.2, different combination have been made and these are shown in table 10.6. The combinations are based on a balanced location selection (equal weight to permit and feedstock) and with low and high caps for the amount of possible CCS. The scenario combinations are statistically tested and visualization are presented to investigate differences between the two scenarios.

Table 10.6: Scenario combinations used for hypothesis 3, scenario numbers can be found in section 9.2.2.

Scenario Combination	Scenario A	Scenario B
High cap high compensation	16	4
Medium cap low compensation	17	11
Low cap low compensation	18	12

> *Hypothesis 3:* Limiting CCS capacity results in a significantly different fuel mix.

The tests and figures These scenarios are tested if the resulting fuel mix significantly differs from the scenarios with identical other parameters. The scenarios are compared using independent sample T-tests. Normal distribution tests have been done and in most cases the data was comparable with a normal distribution.

> H0: The capacities of the different power generation technologies are equal
>
> H1: The capacities of the different power generation technologies are not equal

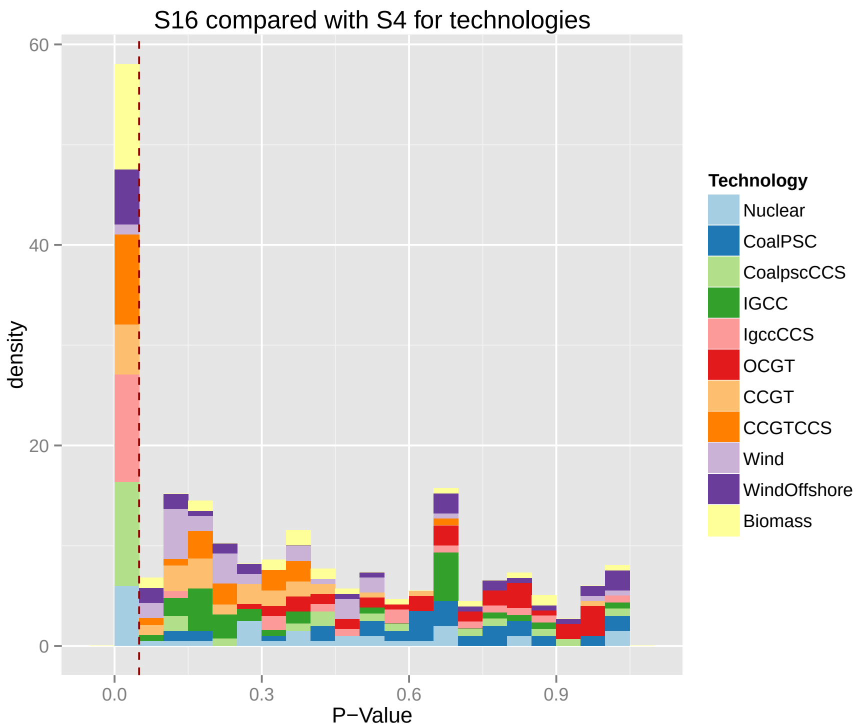


Figure 10.9: Histogram t-test results of the impact of CCS caps (scenarios with high location capacity caps)

Result Figure 10.9 contains a large number of observations in the bin left of the red dotted line. Besides the CCS technologies other technologies are also significantly different, likely as a replacement for the CCS plants. When we examine figure 10.10 this is confirmed. The CCS capacities are a lot higher in the scenarios with the high caps and in the scenarios with the low caps, offshore wind, wind , biomass and nuclear have a higher capacity. These are thus considered replacements for CCS. The same type of observation can be made in the Low cap and medium cap cases , which can be found in appendix J. The differences between the two scenarios for Biomass, Nuclear and Igcc CCS are also presented in table 10.7. It is clearly visible that the difference in means especially at later time steps is far bigger than about one (about 500MW) power plant and that this is also visible in the amount of runs that are higher than scenario 16's mean capacity for the technology.

We have to reject H0 and conclude that scenarios with different caps for CCS leads to different fuel mixes. The implication of this will be discussed later in this chapter.

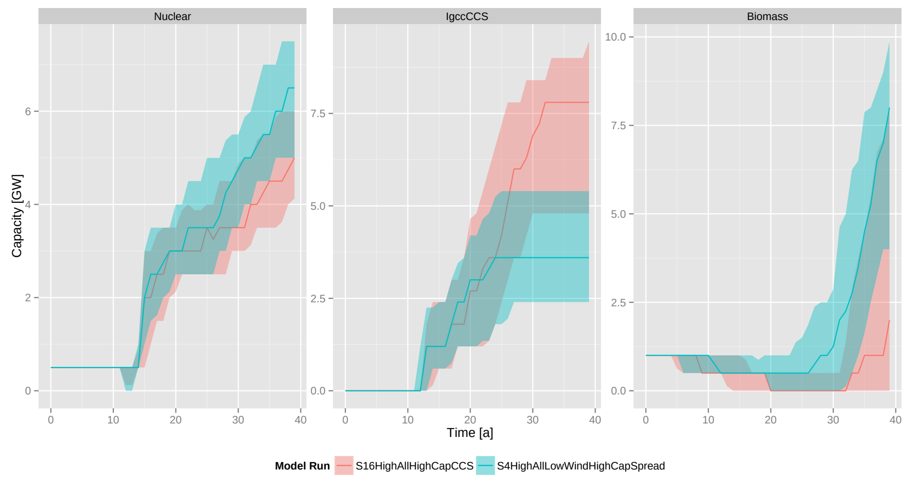


Figure 10.10: A selection of interesting technology capacity graphs for the two CCS scenarios with high location capacity caps

Table 10.7: Comparison of means and amount of runs higher than reference mean (scenario 16) for technologies Nuclear, Biomass and IgccCCS

Time	**Year 10**	**Year 20**	**Year 30**	**Year 40**
Nuclear				
Mean reference scenario 16 (MW)	420	2910	3810	4990
Mean alternative scenario 4 (MW)	420	3120	4750	6540
% runs scenario 16 higher than reference mean	80%	58%	44%	54%
% runs scenario 4 higher than reference mean	80%	64%	66%	94%
Biomass				
Mean reference scenario 16 (MW)	700	310	900	4000
Mean alternative scenario 4 (MW)	750	600	2050	7060
% runs scenario 16 higher than reference mean	48%	48%	24%	38%
% runs scenario 4 higher than reference mean	58%	72%	62%	72%
IgccCCS				
Mean reference scenario 16 (MW)	0	2976	6468	7212
Mean alternative scenario 4 (MW)	0	2976	3744	3744
% runs scenario 16 higher than reference mean	0%	50%	54%	56%
% runs scenario 4 higher than reference mean	0%	54%	0%	0%

10.5 Hypothesis 4

This section will attempt to falsify hypothesis 4, defined in section 9.1. This section is divided in two parts. The first part will investigate if there are significant differences in the technology mix of power plants and the second part will investigate the impact on the geographical distribution of power plants. The graphs used are explained in section 10.1. From the scenarios, defined in section 9.2.2, different combination have been made and these are shown in table 10.8. These combination will be used for both the technology part and location part. The scenario combinations are based on equal location selection methods and location capacity caps, but have different levels of compensation. By looking at the possible impact of the amount of compensation, we can assess the impact of the permit procedure.

Table 10.8: Scenario combinations used for hypothesis 4, scenario numbers can be found in section 9.2.2.

Scenario Combination	Scenario A	Scenario B
High cap spread selection	4	10
Medium cap spread selection	7	11
Low cap spread selection	6	12
High cap feedstock selection	5	15
Medium cap feedstock selection	9	14
Low cap feedstock selection	8	13
Medium cap permit selection	2	20
Low cap permit selection	3	19

> *Hypothesis 4:* The amount of desired compensation demanded by local parties to be willing to accept a power plant significantly influences the location decision and technology mix.

10.5.1 Technology

The tests and figures All the scenario combinations of table 10.8 have been tested using independent sample T-tests. Additionally the capacity graph of each technology is used to support the T-test outcomes. In figure 10.11 the histogram with the T-test outcomes can be found and in figure 10.12 the technology capacity graphs can be found. These figures are based on scenarios with high location capacity caps and the spread location selection method.

> H0: The amount of compensation has no impact on the technology mix of power plants.
>
> H1: The amount of compensation has a significant impact on the technology mix of power plants.

Result Figure 10.11 shows that there are significant test results, as the first bin left of the red dotted line is not empty. While looking at 10.12 we indeed see differences for IGCC , CCGT and Biomass. Interestingly you can see that

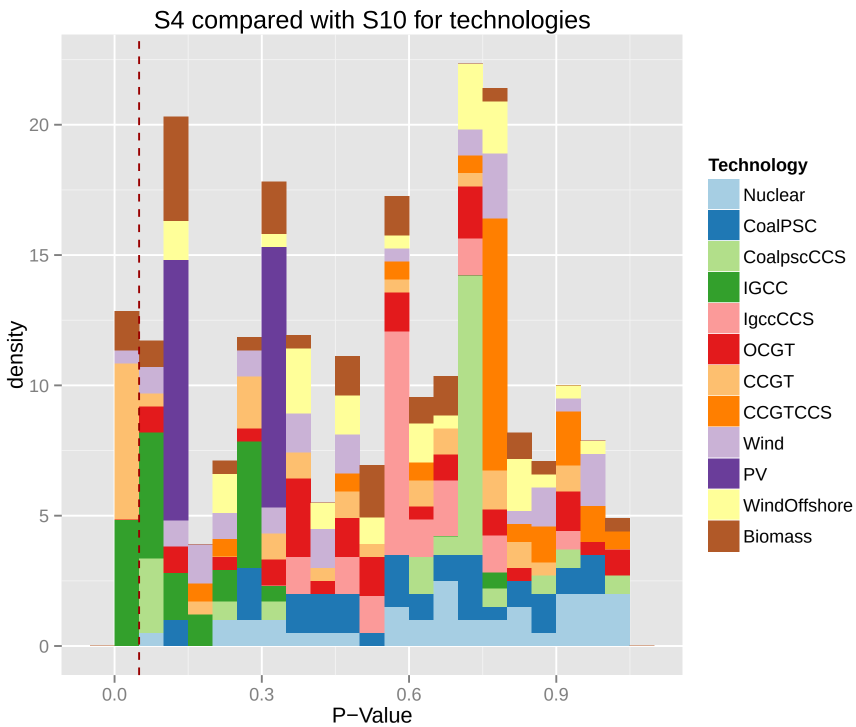


Figure 10.11: Histogram of scenario comparison high location cap and spread location selection method

CCGT is higher for runs with low compensation and IGCC is higher for runs with high compensation. Biomass is also higher in runs with high compensation. In basically all runs we see more biomass instead of CCGT in the high compensation scenarios. This is also visible in table 10.9, after tick thirty we see that the total capacity of biomass in scenario 4 starts to differ from the capacity of biomass in scenario 10. The same happens for CCGT, but the other way around. Additionally already from tick ten (year ten) onwards a big difference is visible between the amount of runs each scenario has above scenario 4's mean. This means that the difference is likely significant. Furthermore for all three technologies in the table, we observe differences in the area of at least 1000 MW. This means the differences is bigger than a few power plants and thus reducing the chance the difference is caused by random errors. These results are supported by all the other scenario combinations tested and for which the graphs can be found in appendix J.

There is thus certainly an impact and H0 has to be rejected.

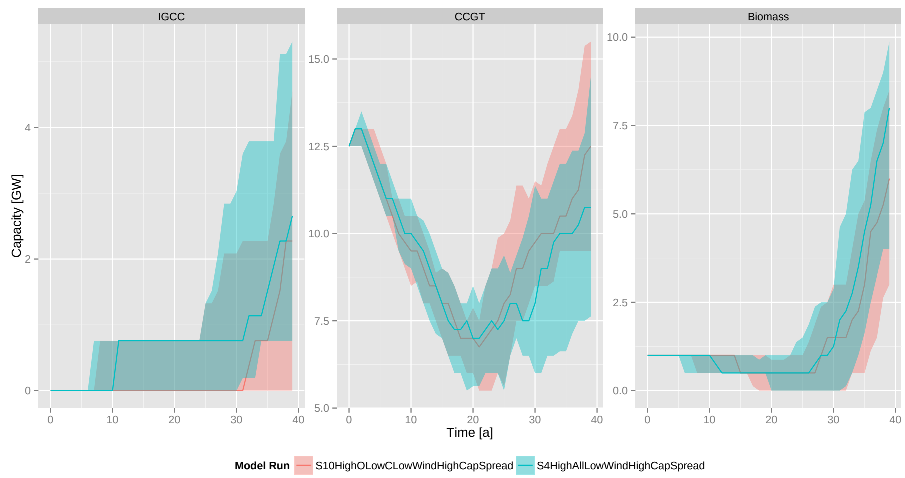


Figure 10.12: A selection of interesting technology capacity graphs of scenarios with high location caps and spread location selection method

Table 10.9: Comparison of means and amount of runs higher than reference mean (scenario 4) for technologies CCGT, Biomass and IGCC

Time	Year 10	Year 20	Year 30	Year 40
IGCC				
Mean reference scenario 4 (MW)	567	773	1849	3153
Mean alternative scenario 10 (MW)	394	500	985	2349
% runs scenario 4 higher than reference mean	48%	18%	32%	44%
% runs scenario 10 higher than reference mean	32%	16%	26%	34%
Biomass				
Mean reference scenario 4 (MW)	750	600	2050	7060
Mean alternative scenario 10 (MW)	800	510	1760	5870
% runs scenario 4 higher than reference mean	58%	32%	34%	52%
% runs scenario 10 higher than reference mean	64%	26%	40%	36%
CCGT				
Mean reference scenario 4(MW)	9940	7100	8470	11130
Mean alternative scenario 10 (MW)	9590	6840	10070	12990
% runs scenario 4 higher than reference mean	56%	46%	46%	46%
% runs scenario 10 higher than reference mean	44%	34%	80%	60%

10.5.2 Locations

The tests and figures All the scenario combinations of table 10.8 have been tested using Mann-Whitney U test. Additionally the capacity graph of each technology is used to support the T-test outcomes. In figure 10.13 the histogram with the Mann-Whitney U test outcomes can be found and in figure 10.14 the location capacity graphs can be found. These figures are based on scenarios with high location capacity caps and the spread location selection method.

> H0: The amount of compensation has no impact on the geographical distribution of power plants.
>
> H1: The amount of compensation has significant impact on the geographical distribution of power plants.

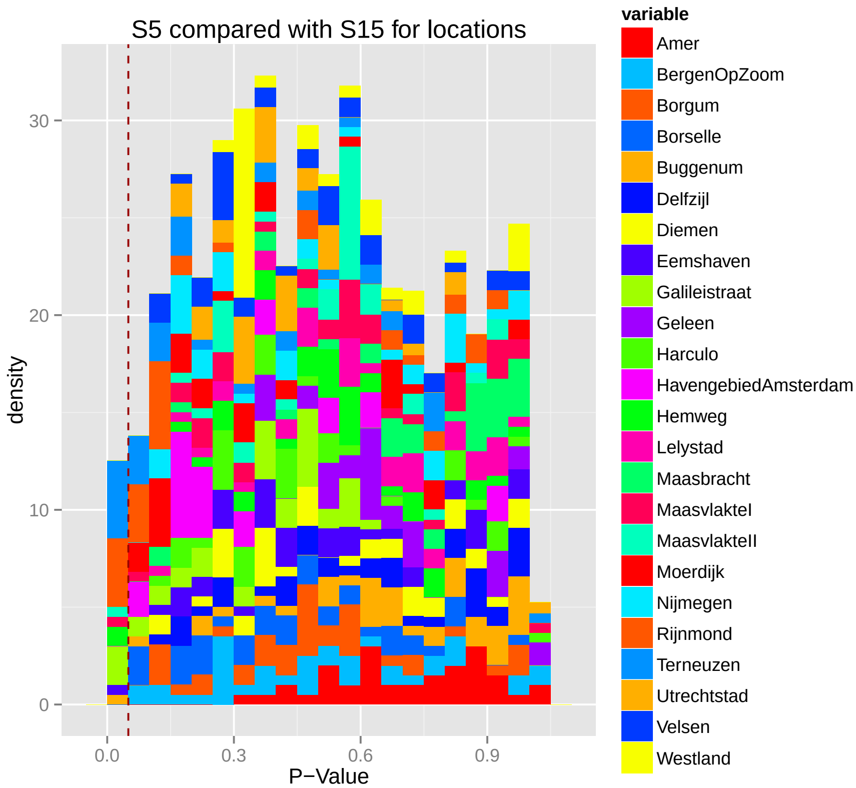


Figure 10.13: Histogram of scenario comparison high cap and spread location selection method

Result Figure 10.13 shows that there are significant runs, this is the case for all the different scenario combinations tested (in appendix J). It is very hard to see these differences in the location capacity graph of figure 10.14. We see that Rijnmond and Galileistraat have the low compensation scenarios higher than

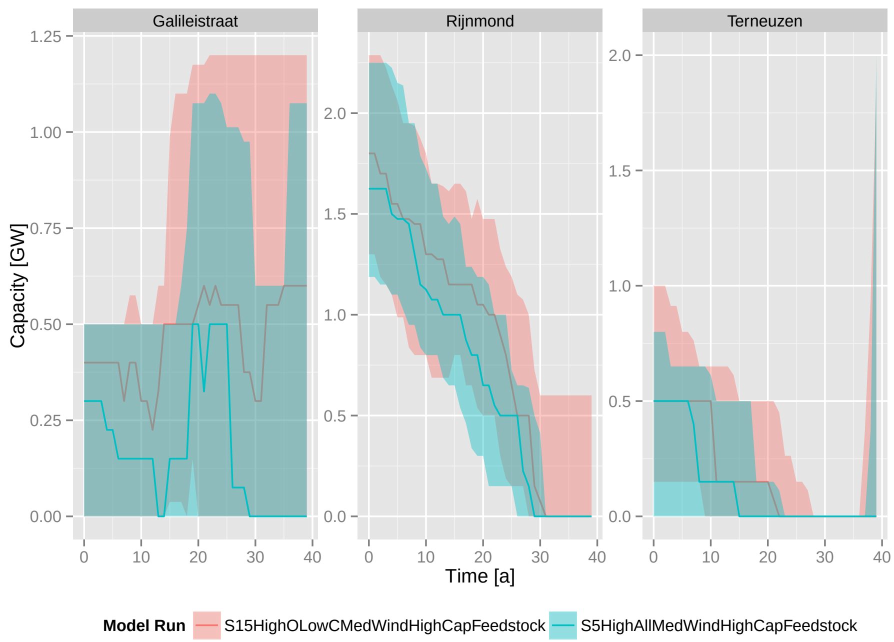


Figure 10.14: A selection of interesting location capacity charts of scenarios with high location caps and spread location selection method

the high compensation runs. Some of scenario combination in the appendix J show similar results, but depending on the location selection method there are different locations significantly different. In the next section the model technical explanation will be given why there are differences and why it makes sense. In table 10.10 the means and differences between individual run outcomes and scenario 5's mean are presented for three different location, Rijnmond, Galileistraat and Terneuzen. These all were significantly different in the U test and were also visually different in figure 10.14. Additionally at certain time steps these three location have different mean capacities and also the amount of runs above S5 mean for each locations is different for each of the three locations at different time steps. This helps confirm the previous observations. However these three locations are relatively small and can only have between one and three power plants, thus the margin for errors is bigger. Still there is a difference visible also in mean capacities and amount of runs above or below this number. These results are supported by all the other scenario combinations tested and for which the graphs can be found in appendix J. The small differences between the scenarios are tested and argued significant.

In the end H0 has to be rejected and we have to conclude that the amount of compensation impacts the geographical distribution of power plants.

Table 10.10: Comparison of means and amount of runs higher than reference mean (scenario 5) for locations Galileistraat, Rijnmond and Terneuzen

Time	**Year 10**	**Year 20**	**Year 30**	**Year 40**
Galileistraat				
Mean reference scenario 5 (MW)	234	496	421	458
Mean alternative scenario 15 (MW)	326	578	488	538
% runs scenario 5 higher than reference mean	38%	54%	46%	48%
% runs scenario 15 higher than reference mean	52%	60%	50%	58%
Rijnmond				
Mean reference scenario 5 (MW)	1271	836	270	314
Mean alternative scenario 15 (MW)	1355	1080	432	538
% runs scenario 5 higher than reference mean	42%	40%	26%	20%
% runs scenario 15 higher than reference mean	58%	56%	40%	34%
Terneuzen				
Mean reference scenario 5 (MW)	375	146	20	664
Mean alternative scenario 15 (MW)	431	248	49	660
%runs scenario 5 higher than reference mean	42%	36%	4%	34%
% runs scenario 15 higher than reference mean	52%	56%	14%	36%

10.6 conclusion

This chapter extensively discussed the falsification of the four hypotheses defined in the experimental design chapter 9.

1. Scenarios that have power producers incorporate activism criteria in the location selection have a different fuel mix than scenarios that have power producers only evaluate location based on technical aspects.

2. Scenarios that have power producers incorporate activism criteria in the location selection have a different geographical spread (MW / location) than scenario that have power producers only evaluate location based on technical aspects.

3. Limiting CCS capacity results in a significantly different fuel mix.

4. The amount of desired compensation demanded by local parties to be willing to accept a power plant significantly influences the location decision and technology mix.

All the hypotheses were confirmed. The falsification was based on statistical tests (analytical statistics) and supported by descriptive statistics. These methods were extensively explained in section 10.1. A basic answer to the remaining sub research questions can be formulated using the results of this chapter. The next chapter (chapter 11) will further analyze the results of this chapter and look for reasons why the hypotheses are falsified and how that can be explained using the model mechanics. Additionally the potential of the model, possible applications of the results and the contribution of this study will be discussed. This allows us to completely answer the sub research questions and the main research question.

> *question 3: To what extent does the distribution of power plants differ when considering local activism or not?*

It has been shown with the agent-based model that power producers who incorporate permit risk (thus local activism) in their location selection criteria have a significantly different spread of power plants than in case power producers only consider at technical aspects. The amount of compensation required by local parties (or activists) has also a significant effect on the geographical distribution of power plants.

> *question 4: What are the implication of incorporating the permit procedure for the energy mix in the model?*

The way locations are selected by power producer also significantly changed the resulting fuel mix of the power plants in the model. This is again also the case for the amount of compensation that is being required by the local opposition.

> *question 5: What is the implication of limiting CCS capacity to the electricity market?*

Based on spatial and geographical information CCS capacity has been capped to a theoretical maximum. This has been compared with simulation runs with a higher cap and the result shows a significant different fuel mixed. In the scenarios with the theoretical cap nuclear energy developed more along side with offshore wind generation and biomass.

Chapter 11

Analysis of the results and contributions

In chapter 10 four hypotheses were falsified based on model outcomes. This chapter will go one step beyond the results of the falsification of the hypotheses. First the model outcomes are extensively discussed, showing the (internal) validity of the results and identifying various interesting research directions. The second part of this chapter goes even one step further and looks at the possibilities this models has to offer for the real world and discusses the contribution of the outcomes of this study.

The hypotheses investigate rather different outcomes of the model, this results in a wide spread of results and contributions. This chapter will show how some of these results are linked and how they ultimately lead to contribution to the model, science and society. To make the interactions more insightful and this chapter easier to grasp figure 11.1 is presented. Here the flow from model results, to hypotheses, to model functioning, model contributions and real world contributions is shown. Most blocks in figure 11.1 contain the section numbers in which the specific contribution or result is discussed.

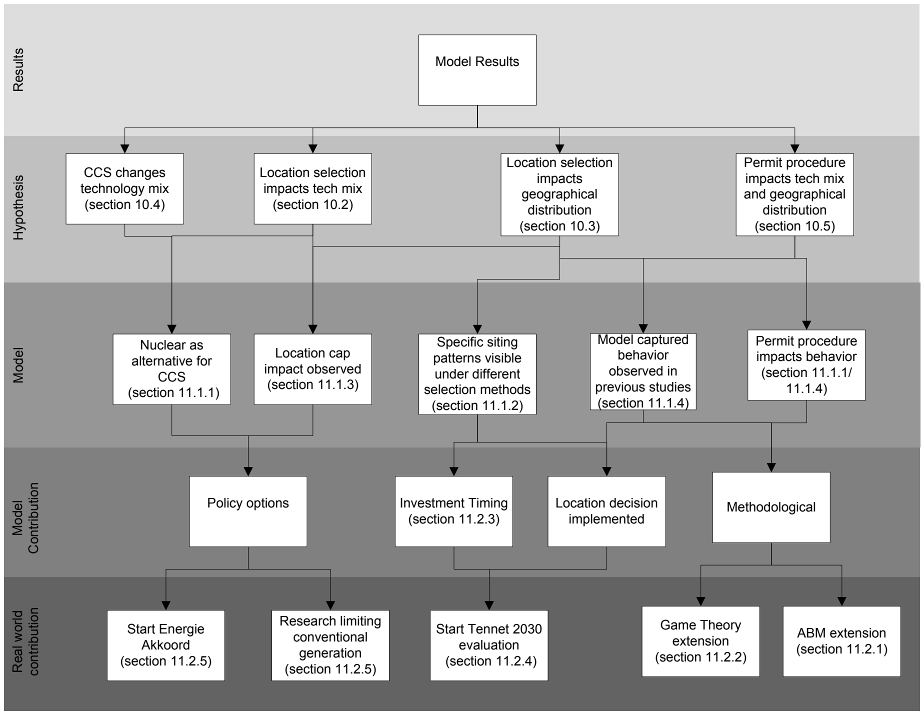


Figure 11.1: Overview of the results, from the model to real world contributions

11.1 Discussion of model results

This section will analyze the results of the falsification of the hypotheses and link them with the model structure and dynamics. This will be done in three parts, first the impact to the technology mix is discussed, continued with the geographical distribution impacts and finally the location capacity caps are discussed.

11.1.1 Technology mix impact and permit procedure

A surprising result was the falsification of hypothesis 1, location selection methods and the resulting permit procedure result in different power plant portfolios. At first this might sound strange, but agent-based models are very path dependent and this can help explain the behavior. When a permit negotiation fails and there is no investment, power producer will not use the technology for two years. The local parties and government that cause permit failures do not change their views on a technology. So selecting locations that have a high chance on permitting problems, with the power producer only checking for technological requirements can result in technologies not being used for a while. This in return creates a different path of other technologies. Thus explaining the significant differences between the two. The main differences are in technologies with a more likable profile in the model, in case of the high cap and medium cap scenario results, gas , biomass and wind offshore are significantly different. The amount of significant differences is rather low so we can assume a movement towards more accepted (not necessarily more sustainable) technologies. The low cap case is far more sensitive towards path dependency. Around year 20 the cap is reached and investment have to wait until a plant have been dismantled. That is why there are a lot of differences, especially in technologies that will be invested in from year 10 onwards (CCS and other low CO_2 emission technologies).

In the scenarios tested for hypothesis 3, to assess the impact of different possible amounts of CCS in a market, we see that in scenarios with lower caps, nuclear capacity significantly increases. This has to do with the fact that nuclear capacity and Biomass capacity are in the model the only alternative for carbon free baseload generation. Biomass increases significantly as well. It can be explained by the model, but this also can have big implication for policy making, which will be discussed in section 11.2.

Hypothesis 4 also found a significant difference in the technology portfolio resulting from higher compensation. A technology is still selected based on the NPV. After this technology decision the model starts the permit procedure. When the NPV is rather small and the compensation payed to the government and local parties makes the NPV negative, the permit negotiations will fail and the power plant technology will not be invested in. The power producer agent can now invest in other technologies and the other power producer agents will also learn from this failure. What can be observed from the capacity figure of hypothesis 4 (figure 10.12) is that there is significantly more biomass and less CCGT at later time steps. Biomass in the model has a higher acceptance and generally generates less activism and thus in case the compensation rates are a lot higher, biomass becomes more favorable.

11.1.2 Geographical distribution impact and siting patterns

That different location selection methods result in a significant difference in capacities at location is not a surprise. The model has been constructed to see effects of selection methods. However what is more interesting than just the fact that there is a difference, is the behavior at individual locations. There are regularities in the placement of power plants. Locations as Eemshaven, Delfzijl and Borssele are basically in all cases very favorable. This is due to the combination of low permit indicators and high quality cooling water access. Other locations e.g. Hemweg are very unfavorable. This could be used to rank locations to favorability under different location selection methods and could give insights for policy makers, this will be further discussed in section 11.2. With hypothesis 4 the differences in geographical distribution are rather limited and especially in lower capacity locations. When a permit application fails the power producer tries a new procedure at two other locations. So this should result in differences, however in many cases when a permit fails, it is likely to also fail at other locations. Although sometimes it fails due to a very high number of local activists and then applying for a permit at another location indeed helps. However other power producer also invest in new power plants and it is possible that at the same tick investment is done at the location the other power producer could not get a permit for. This is basically a limitation of the model and a possible extension to add learning effects, just like technologies, that a location will not be favored by power producer agents when it had a recent failure due to local activism.

11.1.3 Location capacity caps and path dependency

Another interesting observation is the high impact of the amount of power plants that can be situated at each location (location capacity caps). For the model this is a hard cap and the power producer agents do not anticipate for this cap, this results in high path dependency related behavior after the cap is reached and there is no space for new (thermal) power plants until one is dismantled. In reality power producer will anticipate on such problems and might even lobby for new locations. In low cap scenarios the differences are very big in power generation technology capacities. There are a lot of significant differences between low cap scenarios. There is thus a certain path dependency effect here or even a certain lock-in effect. As there is no more space for new thermal power plants, the current power plants have to do the job. The point at which the cap is reached will lock the market with the current portfolio of thermal power plants, until a power plant is dismantled. This path dependency does influence the amount of significant difference between scenarios, but no if one combination between two equal location capacity cap scenarios showed significant differences, the two other location capacity cap were also significantly different. So the location capacity caps are important, but the specific variable varied and tested determines significant differences.

What is interesting is that after the cap is reached investments in renewable technologies are increased, This can be seen in Figure 11.2. You see that investments in biomass, wind and wind Offshore for the Low cap case start earlier than for medium and high cap runs. The explanation is easy, when all traditional technologies do not have investment opportunities anymore, wind is one of the only options left to invest in. What you can also see is that the price development as shown in figure 11.3 is higher and more volatile for the low cap scenario, but the differences are not as big as we might expect. All scenarios are run with the EU-ETS system turned on and by postponing investment in renewables the impact of this emission trading system is larger. So yes earlier caps cause higher prices, but the prices will in the end rise anyway, perhaps a little less with a cap that is a lot higher. So capping thermal power plants could lead to an investment lock-in for wind turbines and other types of power plants not linked to thermal power plant locations.

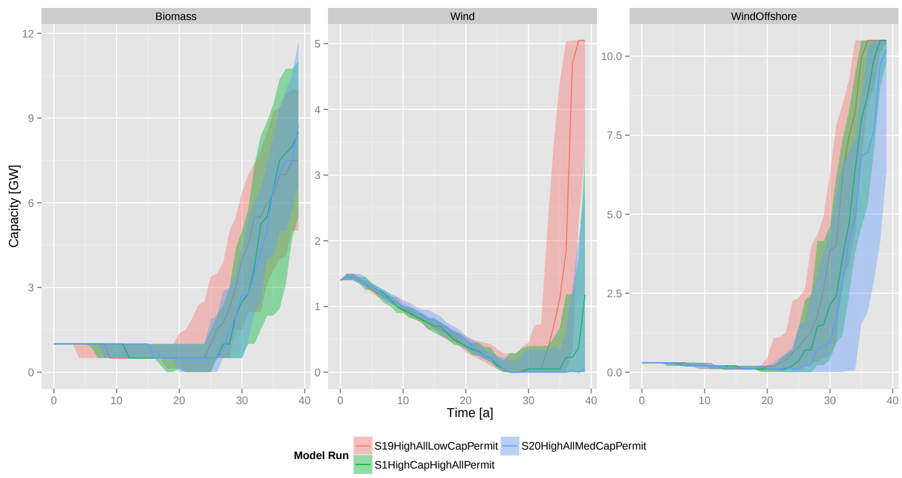


Figure 11.2: Generation capacities of different power generation technologies for low , medium and high location cap scenarios

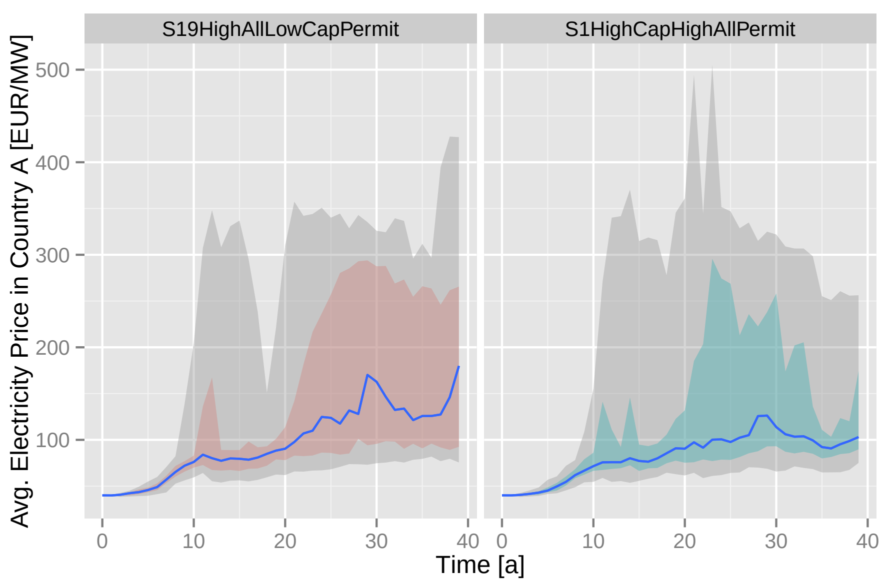


Figure 11.3: Price development high and low cap scenarios

11.1.4 Real world investment behavior

We started this research with research done by Garrone and Groppi (2012); Groot (2013). They found that the location choice is very important and that permit risk (or activism risk) plays a major role in the power plant investment decisions by power producers. Current electricity market simulation models, like the base EMLab-generation model this study is based on, did not include specific locations of power plants. This study tried to improve the investment behavior of power producer by incorporating the location decisions, which also needed the addition of the permit procedure. The results to all the hypotheses suggest that our model is capable of adding the location decisions and incorporating permit risk in the power plant investment decisions. Both the way location are selected, as well as the permit negotiations, were found to significantly influence the investment behavior. Moreover the model results show signs that the location decision and permit procedure could even impact the technology choice of a power plant. In a world where people have more means to protest and express their opinion, having a electricity market simulation model that accounts for the local activism risk will help future research to electricity market developments and electricity market policies. Additionally by adding location aspects to the electricity market simulation model EMLab generation, investment could be limited to certain locations. E.g. in the Netherlands nuclear power plants are by law only acceptable at three locations. Also CCS is likely to be only available at two areas in the Netherlands and with a limited capacity limited, as explained in section 7.3. This proved in hypothesis 3 to significantly impact the technology mix of power plants in the model.

11.1.5 Conclusion

This section discussed the results of the falsification of the hypotheses and tried to explain them in the model structure and dynamics. The results were explainable using the model dynamics and therefor strengthen the internal validity of the model. Interesting observation have been done which will be discussed more in section 11.2. Some possibilities to improve the model were also found and will be recommended for future research.

11.2 Applications of the results

This section will make clear in what way our model and the results contribute to both science and society. First two clearly scientific contributions to both the agent-based modelling paradigm and game theory are discussed. The second part of this section will the great possibilities of the model to assess the geographical development and how this can be used for the creation or evaluation of scenarios. To illustrate this Tennet's 2030 scenario study is evaluated using the results of our model. Finally we discuss how some of the results of the previous sections, especially with regards to CCS, wind power and Nuclear energy, could be linked to policy making.

11.2.1 Agent-based modelling contribution

Abdollahian, Yang, and Nelson (2013) used the agent-based modelling paradigm to plan a transmission line and also took into account compensation payments to local parties. Additionally the local parties could form coalitions in their model. This is one of the few examples of studies that use agent based modelling to simulate negotiations for the siting of energy infrastructures. Abdollahian et al. (2013) applied the model for only one trajectory of a transmission line, by letting the model negotiate with local parties for compensation to find the best possible route for the transmission line from A to B. The model proposed in this study uses agent based modelling to repeatedly simulate investment decisions in new power plants, additionally the permit procedure for the siting of power plants, although simplified, is simulated. The way the permit procedure is modelled is new for agent based modelling and could be further extended and used in a variety of fields. The permit process is based on the european environmental assessment regulations, requiring mitigation strategies for environmental damages caused, before a permit can be issued. Local people have the opportunity to give their views and opinions. A reaction to the concerns and views of the local parties is required by the party applying for the permit. The model of this study deals with these mitigations strategies in a simple monetary way, based on data about the damages to the environment of different power generation technologies. The local people that get involved in the permit procedure can get compensation to increase the acceptance of the power plant, this can be seen as the reaction the party that applies for the permit has to give to each concern of the other parties involved. The approach used is very data dependent and there are several points for improvement. Blocking power and environmental protection parties are not incorporated. Additionally alternative coalition forming is not supported. These aspects would be interesting additions for future research.

The way the permit procedure is modelled in this study is in essence a way to model complex social interactions of groups of people/agents. This opens a lot of opportunities for other agent-based modelling applications, both inside as outside the energy sector.

11.2.2 Game Theory contribution

In chapter 4 some game theoretical concepts were discussed, with some current applications of these concepts. In chapter 5 these concepts were used and modified to fit our purpose. The main concept used in this study is the nucleolus with some elements of bargaining theory. The nucleolus is used and adapted to simulate the environmental compensation payments to the local governments. More interestingly it is used to pay compensation to local parties to prevent them from going to appeal at court against the issuing of the power plant permit, which could delay the project. The most unhappy local party is payed until an acceptable risk level is reached for the power producer agent. If the NPV goes negative the power producer agent will not invest and uses an outside option to look for alternative locations, this is an application of bargaining theory.

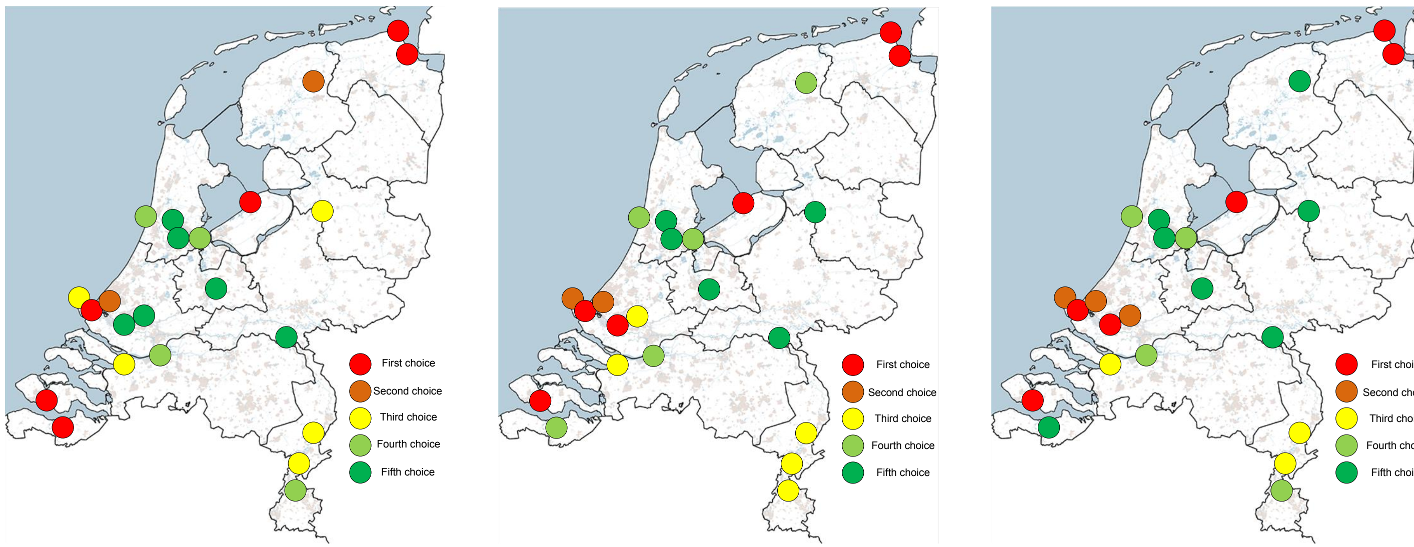
The payments of compensation proved to significantly influence investment behavior of the power producer agents (hypothesis 4). The technology choice was impacted by the compensation payments and to a lesser extend some changes in the distribution of power plants were found. This suggests that the addition of the permitting process changes investment behavior. This shows the effectiveness of using these game theoretical concepts in an agent based modelling environment to represent the specific permitting procedure. The nucleolus is a relatively computational light concept and can thus be repeated a lot of times. Surprisingly no application of the nucleolus in agent based modelling was found, while as shown by the results of hypothesis 4 it certainly offers great possibilities. The concept used here could easily be adapted to other cases (models) with similar type of permit procedures, like the chemical industry or energy infrastructure planning.

The way the nucleolus is implemented is very basic and is argued sufficient in the conceptualization (chapter 5). Still there are interesting extensions to the current application possible. Like mentioned in the previous section the creation of alternative coalition by e.g. several local parties is not in the model. It has been researched, but proved theoretically very complicated. With alternative coalitions, concepts as blocking power and more powerful negotiation positions could be added. This will make the concept more applicable for complicated coalition games, besides the relatively simple permit procedure case used here.

11.2.3 Location preferences

The way locations are chosen can affect the spatial representation of the power plants, this was an obvious observation. More interestingly is to analyze the timing of investments at each location. By comparing the timing of investment at a location with other selection methods, we could get an idea under what circumstances which location is preferred for investments. This has been done for the three selection methods and the results are presented in three maps. The circles represent the power plant locations and the colors indicate the preference of a location. Red is the most preferred and dark green the least preferred. Figure 11.4 presents these maps for the three different location selection methods of power producers in the model. The most preferred locations are mostly shared between the different location selection methods. This means that in all cases these location will be the first to be selected for new power plants. When these locations are full, the locations in the second group are selected. The order is not as strict as shown here, there are differences possible (variance), but in general this is the order of investments in locations. The groups have a relatively equal spread in the timing of investments. In appendix J the boxplots of all the locations are shown to give an idea of the spread of investment timing at the different locations. A large spread means that the location is invested in at a lot of different time steps and this suggest that, when space comes free, these locations are preferred over other locations. When the spread is low and only around a few ticks, the investment is likely to take place around that time under the specified scenario conditions.

The maps of figure 11.4 can help think about the likelihood of new investments at certain location. It is very unlikely that new power plants in the coming years will be situated at locations in the last groups. It shows the possibilities of the created model to add a new layer of detail to electricity market simulation models. With this model it is possible to research both the technological portfolio of power plants, as well as the geographical distribution of power plants. This enables more detailed creation of scenarios, to anticipate future congestion and plan grid expansions. To illustrate the possibilities of our model, a start will be made to evaluate Tennet's 2030 scenarios for the dutch electricity sector. This will be presented in the next section.



(a) Order of investment for location selection method based on permit risk

(b) Order of investment for location selection balanced

(c) Order of investment for location selection based on technical requirements

Figure 11.4: Maps of the Netherlands, with the circles representing power plant location and the colors indicating the preference power producer have for a certain location. Background map source: Jan-Willem van Aalst www.imergis.nl

11.2.4 Tennet's Vision 2030

An interesting comparison can be made with the report about Tennet's (the Dutch TSO) projections for 2030 (TENNET, 2008). In figure 11.5 you find their scenarios for the four main coastal location. The fact that Maasvlakte is found a good location in their models, while in our model it starts to develop later is likely a bias in our model. Maasvlakte has its permit risk based on the Rotterdam municipality data and it is situated far from the city itself. In the scenarios with investments based on feedstock both Maasvlakte I and II are favorable and thus more in line with the scenarios of Tennet.

What does come as a surprise is the rather high capacity of generation at Borselle. Current grid capacity is only 1650 MAV and this is being upgraded, but still 5 GW or even up to 7 GW of capacity including offshore wind generation is rather high. The capacity in Borssele for conventional power plants in our model is capped at little more than 3 GW, without taking in to account offshore wind power generation. Another interesting finding is that the Eemshaven has very little conventional power generation in 3 out of 4 scenarios of Tennet. Eemshaven is always the first location used in our model. It is one of the few locations suitable for CCS, so one might expect even in scenarios with a lot energy saving and a green revolution, that it would still be used a lot. No specific green or storage scenarios are taken in to account in our model, so that could explain part of difference in generation capacity, but still it is surprising. This might be something for Tennet to reevaluate.

In the scenario 'Geld Regeert' the conventional generation Capacity comes fairly close to the conventional capacity in this study's model for the low cap scenarios. With Borssele thus a bit higher in Tennet's case and Ijmuiden (or Velsen) and Maasvlakte a bit higher in our case. In appendix J in figure **??** you can find the low capacity cap data (red lines) and can see that for the location of Tennet's study, the capacities match relatively well with the scenario 'Geld Regeert'. For Maasvlakte and Ijmuiden the different off shore wind power capacity graphs are shown in figure 11.6 and figure 11.7 (the scenario definition is shown in table 11.1. Both Eemshaven and Borssele did not develop before 2040 in our model. So this is a difference with Tennet's model, Borssele can be explained by the fact that are very little locations for offshore generation in our model. For Eemshaven the offshore wind location are located rather far from the shore and are less favored compared to the location close to Maasvlakte and ijmuiden, explaining why these did not develop before 2040. Both Maasvlakte and Ijmuiden start to develop between year 20 and 25 , meaning 2030-2035. This is slightly after 2030, the year the study of Tennet analyses. This could just be bias in our model. Tennet's model suggests that around 2030 there is around 0.5 GW capacity at Ijmuiden and Maasvlakte, in our model this same capacity is reached a little bit later but before 2035 as shownin figure 11.6 and figure 11.7.

Our model thus comes close to the outcomes of Tennet's scenario 'Geld Regeert', which increases the validity and the opportunities for real world applications of our model. The other scenarios of Tennet use different policies, incentives, storage technologies etc, explaining the big differences. Additional research with more detailed scenarios that match the demand and fuel developments used in Tennet's scenarios could lead to more comparable results. This would be a good opportunity for future research.

	Groene Revolutie			Duurzame Transitie			Nieuwe Burchten			Geld Regeert		
	Conv.	Wind	Totaal	Conv.	Wind	Totaal	Conv.	Wind	Totaal	Conv.	Wind	Totaal
Borssele	5,7	1,0	6,7	0,9	0,0	0,9	1,5	0,0	1,5	3,7	1,0	4,7
Maasvlakte	2,9	2,5	5,4	3,0	1,0	4,0	7,6	1,0	8,6	4,6	0,5	5,1
IJmuiden	0,0	2,5	2,5	4,0	2,5	6,5	0,0	0,0	0,0	1,0	0,5	1,5
Eemshaven	0,0	0,0	0,0	0,9	0,0	0,9	1,4	0,0	1,4	5,0	0,0	5,0
Totaal	8,6	6,0	14,6	8,8	3,5	12,3	10,5	1,0	11,5	14,3	2,0	16,3

(waarden in GW)

Figure 11.5: Tennet's Vision 2030 scenario outcomes (Tennet,2013)

Table 11.1: Overview of the used scenarios with different wind power location selection methods and location capacity caps (Based on same scenarios as in chapter 9)

Scenario	Wind based selection	Capacity caps
1	High	High
2	High	Medium
3	High	Low
4	Low	High
5	Medium	High
6	Low	Low
7	Low	Medium
8	Medium	Low
9	Medium	Medium

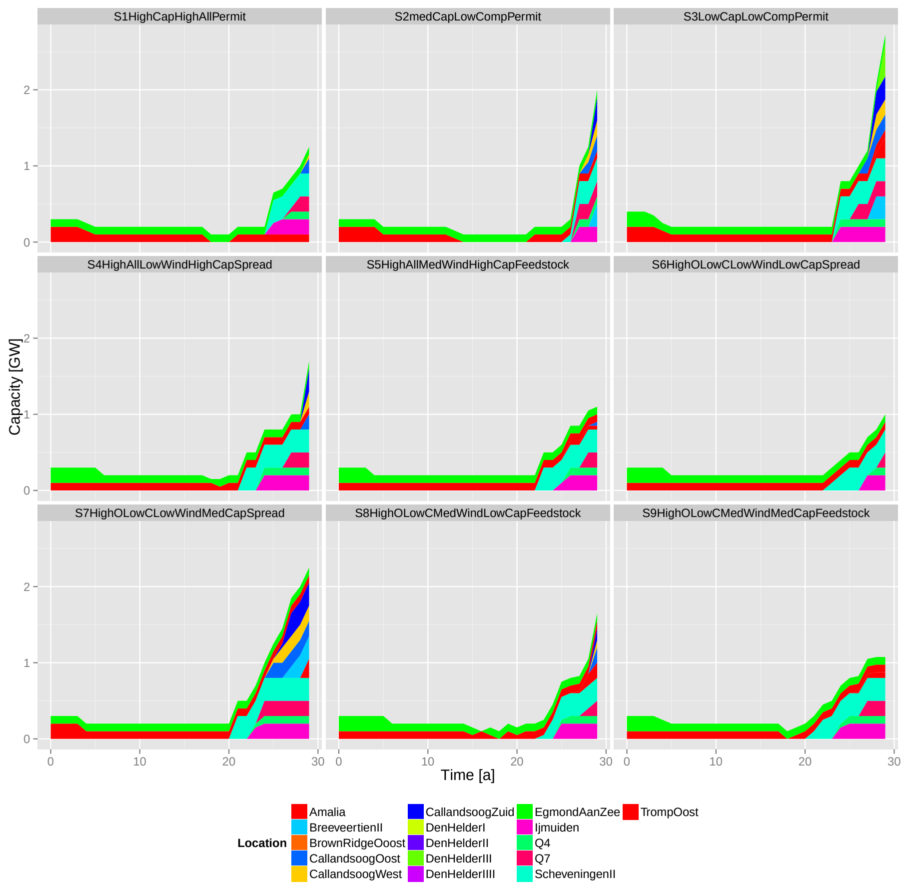


Figure 11.6: Stacked capacities of wind power locations connected to Ijmuiden

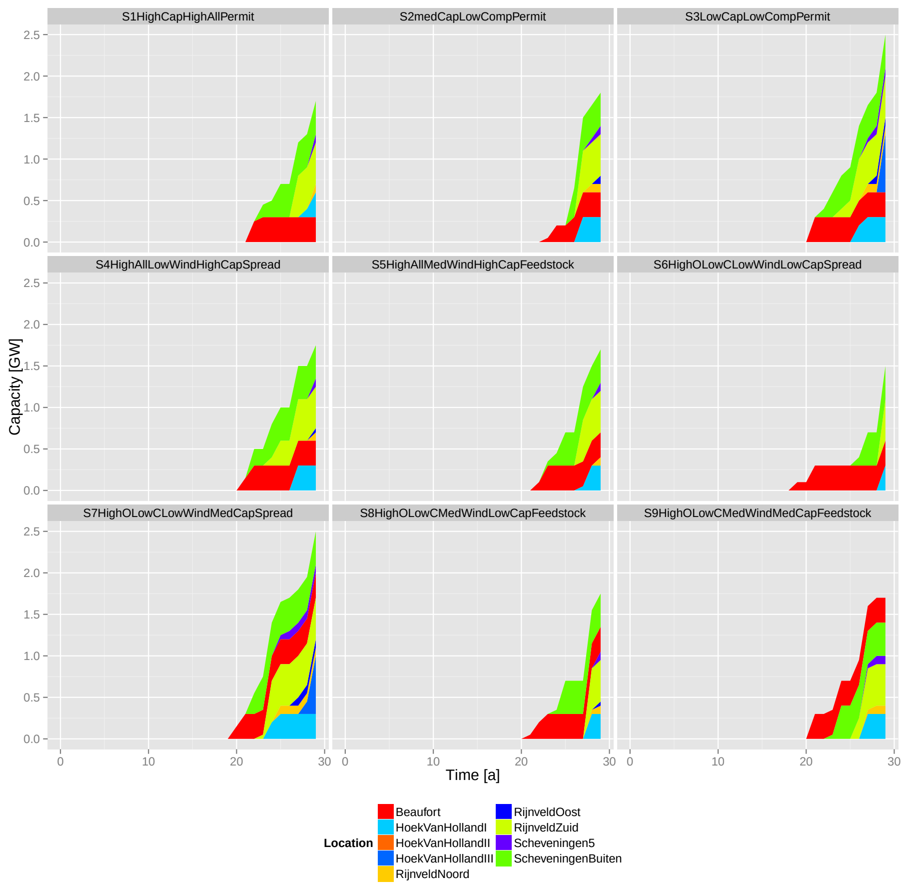


Figure 11.7: Stacked capacities of wind power locations connected to Maasvlakte

11.2.5 Generation portfolio, policies & energie akkoord

In figure 11.8 the capacities per technology for High location capacity, but different CCS cap scenarios are presented. The theoretical CCS cap varies between 2500-5000 MW capacity which is between 5-10 percent of the total generation capacity, depending on the timestep. In figure 11.8 nuclear capacity is a lot higher in the scenario with a lower CCS cap. The same goes for Biomass and wind offshore. This suggests that Nuclear, Biomass and wind offshore are the alternatives for CCS on the long term. In scenarios with the medium location cap this is less visible, which could have to do with the limited locations available for nuclear available (only three) and the high desirability of these locations. Having a lower cap and thus situations in medium and low location cap scenarios where all location are full, than nuclear has more trouble to find new locations, as there are simply less available location. This creates a certain path dependency in the model, or even a lock-in. Without room for new nuclear power plants, no investment is possible.

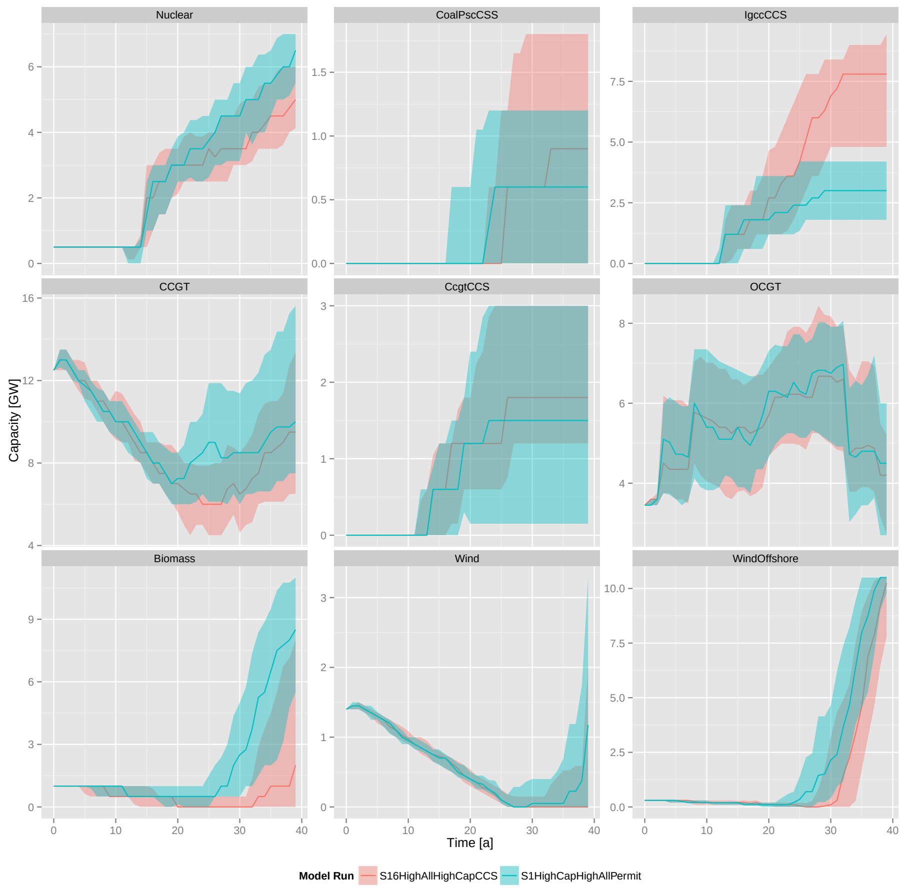


Figure 11.8: High location cap comparison of the technology mix between scenarios with a high CCS cap and a low CCS cap

Still the lower capped CCS scenarios causes nuclear capacity to expand in all cases. This can be explained by the EU-ETS emission trading system and the incentive this gives to power producers to invest in CO_2 free technology. Biomass and Wind Offshore also increase in the low CCS scenarios more than in the high CCS scenarios. Nuclear and Biomass will be the only alternatives for base-load generation without CO_2 emissions. So is it possible to reduce CO_2 levels, while keeping electricity prices affordable without nuclear energy in a situation with limited CCS storage available? Basically the answer is no, without significant advances in other technologies and storage, nuclear is the only alternative for CCS to get to a low carbon economy, without considering storage technologies and the limitation of Biomass. Peoples attitude towards nuclear energy is very negative, due to recent events in Fukushima and if this is justified or not is not going to be discussed here. This study can not give a definitive conclusion that increasing nuclear capacity will be unavoidable, because of the limitation of this study and the impact of location capacity caps, but it gives strong clues that in the situation of the scenarios, nuclear capacity will expand in order to reduce CO_2 emissions. Finally it seems that real renewable generation capacity is even delayed, due to the higher cap of CCS. So more CCS plants reduce the amount of off shore wind turbines and on shore wind turbines.

It has been mentioned in this chapter that the cap on the amount of thermal power plants at a certain location, has an effect on the timing of investment of renewable technologies. This might than also be a possibility for policy action. A lower cap will result in higher prices, like you can see in figure 11.3 , but the difference with the high location capacity is not as big as you might expect. It can thus be a choice to limit new locations for thermal power plants or limit new permits for specific type of power plants and force the markets to renewables. This is an interesting suggestion that could be further analyzed using this model with different sets of scenarios, with perhaps even lower caps (even the current low cap scenarios have room for new investments in most locations). There is of course a big risk in relying on renewables and that is the development of storage options. Renewables are intermittent and this is incorporated in the model, however with storage, renewables could become more or less stable base load and this could change the behavior and also price levels. The development of storage technologies is on going and large scale storage solution are not there yet. It is also hard to predict when they will be available. Storage is not currently implemented in the model, but it would be a great addition to the model that would help assess the impact of storage on the transition towards a more sustainable electricity sector.

Energie Akkoord 2013 Some of the portfolio effects discussed in this section are really interesting to compare to the recent Dutch Energie Akkoord (Rijksoverheid, 2013b). That has been agreed on by the Dutch government and a large number of other national stakeholders, to make the energy supply of the Netherlands more sustainable. Surprisingly it hardly pays attention to CCS, nuclear energy and electricity storage. The results of this study suggests that CCS and nuclear will have to play a major role in the future electricity system. Nuclear energy is not even discussed at all in the report and CCS will be decided on later. It is likely that this is due to consensus making in the negotiation process, but if there is e.g. hardly any wind and you have over 10GW of wind power how do you want to sustainably generate electricity? Research of TNO showed the limited storage capacity for CO_2 (TNO, 2010) and the reports suggests to make use of CO_2 and use electricity storage options like power to gas. However these are technologies are extremely infantile, how they are going to develop is very unsure. Also the closure of old coal plants that could be used for biomass reduces the base load generation option drastically. In our model that simulated a market with the only policy implemented was the EU-ETS emission trade system all the items the 'Energie Akkoord' gave very little attention to, Nuclear energy, Biomass (only 25PJ) (ECN & PBL, 2013) and CCS were very important in the long term. Furthermore wind turbines both onshore as offshore did not seem to develop early on, especially not during the first 10 ticks of the simulation.

In chapter 7 we presented the current location available for wind onshore and offshore. For onshore wind this is only about 2000-2500 , so that means that there is a need for 4000 MW more. It is possible, but it is a lot of capacity that needs to be installed and with activism problems also against wind turbines it could prove problematic. ECN and PBL (2013) also mentioned some of the points mentioned here, also about the missed opportunities to make deals about electrical energy storage. The simulation model presented in this study, adapted to regulation and measures proposed in the 'Energie Akkoord' could give insights not only in the portfolio developments, but also in the geographical effects and the permit negotiations. This could help policy makers to see possible results of their actions and could also make the effects of closing some type of power plants more insightful.

11.3 Conclusion

This chapter extensively discussed the results of chapter 10. This shows the internal validity of the model, as well as interesting application of the results. This gave rise to several contribution to EMLab-generation model and moreover resulted in several contribution beyond the EMLab-generation model. An overview of how the different results are interrelated is shown in figure 11.9 in the beginning of this chapter. The chapter basically followed step by step most of the points of this figure. The layer, model contribution, got less attention in this chapter, most of these contribution are easily deduced from different applications of the results of section 11.2. The specific contributions to the model itself will be discussed in more detail in the reflection (chapter 13).

The model results suggest that the model was able to simulate power producer's location decision of new power plants. Additionally it the model has a functional permit procedure for the location, that influences investment behavior of power producers. The model also shows patterns under different location selection methods by power producers, which can be of great value for the creation and evaluation of scenarios. A first step has been made to evaluate Tennet's 2030 scenarios, to illustrate the added value of our model.

The model also shows interesting effects that require further attention. Lower location caps were responsible for earlier investment in wind turbines, at first glance with limited extra costs. Additionally it showed the need for base load generation and the increase of Nuclear and CCS. The amount of CO_2 that can be stored is limited and this, in time, increases the amount of nuclear energy. Interestingly CCS and nuclear energy only get minor attention in the new 'Energie Akkoord' of the Dutch government. This model with new scenarios and

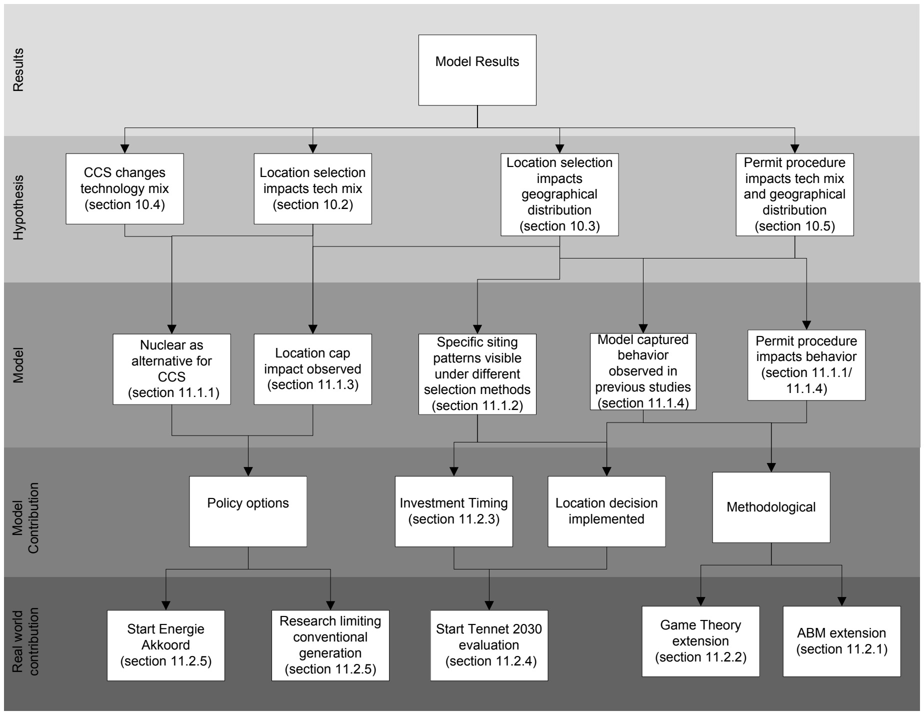


Figure 11.9: Overview of the results, from the model to real world contributions

policies implemented would be able to help reflect on the decision of this deal.

Finally the way the permit procedure is implemented is a new way of dealing with complex social negotiations in agent-based modelling. Furthermore the way the game theory concepts are applied to represent the permit procedure is a completely new application and shows great potential for other applications and further research.

Now all the sub research questions and the main research question can be answered and this will be done in chapter 12.

Chapter 12

Conclusions & Recommendations

This research presented a new way to assess power plant investments, including the location decision, based on agent-based modelling. The outcomes of this study are diverse. From more methodological contribution with regards to the use of game theory concepts in the agent-based modelling environment. To model contributions showing the potential of the model in assessing the impact of power plant location decisions on the development of the electricity market. The scenarios that are used in this study are simple and more detailed scenarios could help making the model more relevant for the real world applications. This is the short answer to the research question:

> *How does the set of factors considered in location decisions for new power plants affect the future development of the technological and spatial distribution of power generation in the Netherlands?*

The rest of this chapter will go in to more about the conclusion with regards to the main research question. First the subquestions (12.1) answers will be discussed, followed by the different contributions of this study (12.2) and finally ending with the limitations (12.3) and recommendations for future research(12.4).

12.1 Subquestions

> *What factors influence the choice for locations of new power plants and what is the role of the transmission grid?*

From literature and empirical research it has been shown that besides the obvious technology related requirements for locations other factors also play a big role. Permit risk and grid connection risks are taken very seriously by power producers (Groot, 2013). Permit risk defined as the chance on delays during the construction of power plants and is found to be mainly influenced by wealth, education levels and the perceived value of open space in a region. Grid connection was found to be influenced by the distance to the grid, the capacity and legal requirements. All these point come back in the location selection and permit procedure of new power plants.

> *question 2: How could the permit procedure and subsequently the location decision be modeled in the EMLab-generation simulation model?*

To model the permit negotiations the game theory concept of the nucleolus has been found to be the most suitable way to conceptualize these negotiations. This concept assumes that all parties are willing to be in a grand coalition and using the characteristics function value can be redistributed to make the most unhappy parties with the situation less unhappy. This concept has been adjusted to be able to use it for the permit negotiation of new power plants. First the government will be payed off until it is no worse of than in the situation that no power plant will be build. This represents the legal environmental compensation that is required for plans that have negative effects to the environment. The second part is to compensate local parties. The local parties are being payed (the most unhappy first) until the power producer thinks the permit risk is acceptable. If the value of the project becomes to negative, the power producer cancels the negotiations and moves on to another location or technology. This method closely matches with the nucleolus theory, with the exception that there are outside options and the redistribution of the characteristics functions does not continue until a stable outcome is found, but until the power producer is satisfied with the permit risk. The input for this permit procedure is a location selected by the power producer. Power producers can select locations based on utility functions, where different weight factors represent different location selection methods.

> *question 3: To what extent does the distribution of power plants differ when considering local activism or not?*

It has been shown with the agent-based model that power producers who incorporate permit risk (thus local activism) in their location selection criteria have a significantly different spread of power plants than in case power producers only consider at technical aspects. Some locations that are preferred in one selection method are used a lot later in other selections methods. Also there are some locations that are in all selection methods more favorable than other power plant locations. The amount of compensation required by local parties (or activists) has also a significant effect on the geographical distribution of power plants. Some location with higher activism values were used less often, however the effects were rather small.

> *question 4: What are the implication of incorporating the permit procedure for the energy mix in the model?*

The way locations are selected by power producer also significantly changed the resulting fuel mix of the power plants in the model. This is again also the case for the amount of compensation that is being required by the local opposition. What this means is that certain technologies get more favored over others, because of the high chance of permit negotiation problems. The reason why this happens is that some technologies are more preferred by the public. For example coal has a relatively bad reputation. In the model this reputation partly determines the amount of opposition against the proposed power plant. If a permit application fails, the power producers will avoid trying to build a power plant of that technology for a while.

> *question 5: What is the implication of limiting CCS capacity to the electricity market?*

Based on spatial and geographical information CCS capacity has been capped to a theoretical maximum. This has been compared with simulation runs with a higher cap and the result shows a significant different fuel mixed. In the scenarios with the theoretical cap nuclear energy developed more along side with offshore wind generation and biomass. This is an interesting observation of which the desirability of the increase of nuclear energy is something policy makers need to decide on.

12.2 Contributions

This study extensively discussed the different contribution in chapter 11. Here the contributions will be briefly discussed and are divided in three main groups.

12.2.1 Model contributions

Location selection The model enables power producers in an electricity market simulation model not only to invest in power generation technologies, but also choose a location. The way power producers initially select locations has a great impact on the resulting geographical distribution of power generation. This makes it possible to assess investment behavior in more detail and to incorporate location specific limitation with e.g. cooling water and carbon capture and storage (CCS).

Permit procedure In reality a big part of the location decision for new power plants is determined by the permit procedure. In the model the permit procedure significantly impacts both the technological and geographical distribution of the power generation capacity. This again makes it possible to make investment behavior more realistic, as in reality power producer take permit risk very seriously when thinking about new investments in power generation capacity (Groot, 2013; Garrone & Groppi, 2012).

Location Data An extensive analysis has been made about the possible location for power plants in the Netherlands. For onshore wind, offshore wind and conventional power plants all currently known locations are listed and the main surrounding parameters are linked to these locations.

12.2.2 Methodological contributions

Game Theory To model the permit procedure the game theory concept of the nucleolus is used. The way it is implemented has not been done before. It is used for negotiations between different type of parties, where most other application focused on cost sharing between several identical parties. Here the power producer pays the most unhappy local party until it reaches a desirable level of permit risk. The local parties are better of by cooperating with the power producer as they can be compensated, as it is highly likely that the power plant will in the end (perhaps with delays) be build. It sounds relatively simple, but by using this last notion the nucleolus becomes applicable in these kind of negotiation processes.

Agent-based modelling The addition to agent-based modelling is highly related with the previous paragraph about the contribution to game theory. The way the negotiations between the parties are modelled is new for agent-based modelling and shows interesting impacts on the geographical and technological distribution of power plants. The method is relatively computationally light and this makes it very usable for agent-based modelling. Additionally it is likely that the way the permit negotiations are modelled in this study are applicable to other cases. It is basically a new way to model social interactions, involving compensation payments between agents. There are also some drawback and limitation to the use of the concepts discussed in this section, which will be discussed later.

12.2.3 Policy Implications

Transmission line planning In chapter 11.2 an example of a possible applications of this study's model is given, by evaluating Tennet's 2030 scenario results. The model shows the amount of capacity and the year it is created at each location. This allowed us to compare the results with Tennet's three locations studied. In one of the Tennet's scenarios (focussing on the market) the differences were very small, showing validity of our model. There were differences and these could be used to improve Tennet's scenarios and our results. New scenarios runs with the same conditions of Tennet's scenarios could help Tennet to increase the value of its scenarios and perhaps anticipate more on possible future investment patterns.

Location capacity caps and the Dutch 'Energie Akkoord' From the analysis some interesting unexpected results were observed. Limiting conventional generation capacity did not lead to extreme increases in prices and renewable investments were observed to take place earlier. More research is needed, but this could lead to interesting policy options of limiting conventional capacity in favor of renewables.

By adding location aspects it was also observed that with the current available knowledge about CCS and its possible locations that the potential is not that big. The only real alternative for CCS was a combination of biomass and Nuclear energy. Surprisingly both CCS and nuclear got very little attention in the recent 'Energie Akkoord' in the Netherlands. While they were in almost all cases responsible for a significant part of the generation portfolio. This shows the versatility of our model and the usefulness of adding locations to electricity market simulation models. It could also help to evaluate current policy alternatives, although it is highly dependent on scenarios you put in the model.

12.3 Limitation of this Study

Some limitations were shortly mentioned before, but one of the biggest limitation is the dependency on data and specific scenarios. Agent-based modelling is a very interesting technique but very data intensive and the model results are sensitive to data changes. An example for this is the way location data is gathered in this study. The data of the municipality of a power plant location is used to calculate permit risk factors. In most cases this is fine, but with the Maasvlakte it is problematic. The Maasvlakte is 60km from Rotterdam and partly build on reclaimed land with no inhabitants, but it is still in the municipality of Rotterdam which is very densely populated.

Different scenario parameter could change the outcomes significantly. The amount of scenarios that could analyzed was very limited due to the long run time of one scenario (6-8 hours). To be able to say more about real world applications the scenarios need to be matched with e.g. the scenarios of Tennet. Due to the limited amount of possible scenarios, different fuel price development parameters are not used. Previous studies using the base EMLab model showed significant effects of fuel prices (Verweij, 2013). So fuel price scenarios will lead to different model results, but we did not research a specific portfolio. We focussed on the impact of location decisions. The technology choice is impacted by fuel prices, but the way locations are selected and the permit negotiations are done, is not affected by fuel price developments. While these two factors are argued the main causes of the significant differences in the geographical and technological distribution of generation capacity.

The utility functions used to express attitudes of the agents and determine the opposition are incomplete. They cannot include all the factors that impact the attitudes of the agents in the real world. It is argued that the parameters used are sufficient, but when analyzing the results it always have to be acknowledged that the input is limited.

Future development in e.g. electrical energy storage, new generation technologies and distributed generation are not included in the model. These will likely have big effects on the future electricity market and this should thus be acknowledged when reviewing the results of this model.

The permit procedure is based on several assumptions to make it work. There is no possibility of alternative coalition forming, which proved mathematically and computationally very difficult. It would be a way to improve the permit negotiation and to better match it with reality.

Finally there are a few basic model mechanics that limit or impact the results of the model. The model works with yearly time steps. To further expand the permit negotiations and make them more detailed it would be an idea to add time dependency to create a sense of urgency, however due to the yearly time steps this will be rather difficult to achieve. Another limitation of the model is the lack of consumers. The consumer agent just buys everything. In reality large consumers can negotiate deals with power producers and small consumers can buy from other power producers. So reputation and consumer choice is not incorporated in the model and this could impact the choice for technologies and locations. Perhaps even making locations close to populated areas even less attractive.

12.4 Recommendations for future research

There are lots of possible direction for future research. Four of them will be presented here.

First there is a possibility to further improve the permit negotiations in the model. Introducing dynamic coalition forming, with an alternative coalition could result in very interesting results and would be very useful in many research fields that use agent based modeling and complex negotiations.

Secondly there is a great opportunity to improve the scenarios and to match the scenarios with e.g. Tennet's 2030 scenarios to help improve their scenarios. The same goes for the new 'Energy Akkoord' of the Dutch government. It would be very valuable to evaluate the effects of their new policies on the development of the electricity sector and locations could provide further detail and help to make models more easier to understand. This is harder than it might sound, Tennet's scenarios e.g. already take into account limited electrical energy storage, which is not included in the current EMlab-generation model. It might be very hard to model this, but could be worthwhile.

Grid connection risk has been oversimplified, due to time constraints. It proved very hard to let transmission grid capacity expand over time. A coupling to a transmission grid expansion model would improve the results and the representation of grid connection risk, which is now rather poor. This is also a current limitation to this study. Another point related to the simplification is the way cooling water quality is assessed. It is static and it would be a really nice addition to make power plants impact the cooling water quality at a location.

Finally the current model is based on currently known locations. It will be very difficult to think of future possible locations. However perhaps there are opportunities to assess the development of power plant locations in the

Netherlands in the past and use GIS data and perhaps a map structure to develop future locations for power plants. Locations for power plants are not static, but at the moment they are assumed to be static. So enabling new location, would be a very interesting addition.

Chapter 13

Reflection

The goal of this master thesis was besides graduating, also to try and find a really challenging and interesting subject. This certainly succeeded, but of course this also had some downsides. Planning and Demarcation were rather difficult and the project was hard grasp in the beginning. Additionally the conceptualization gave some problems, but in the end I am really pleased with the results of this master thesis. This chapter will first reflect on the results of this study. This is than followed by an evaluation of the process.

13.1 Reflection on results and methodology

It was very nice to finally analyze model results after months of modelling. The way the hypotheses are created is basically to show internal validity of the model and to give an impression of the possibilities of this model. It would have been great to already had matching scenarios with Tennet's 2030 scenarios, but that proved impossible. That said the model results are very useful and the idea to match the model with Tennet's scenarios illustrates that. Potentially this model could help validate these kind of scenarios and improve them, proving very valuable for the anticipation of future market developments.

Validation proved very hard because it is not known where power plants would be build if other selection methods are used and that the liberalization of the electricity sector is not yet in place for decades in Europe. Nonetheless the model offers a way to give insights in potential geographical spread of power plants. Other organization like again Tennet try to develop scenarios that help them anticipate to future grid expansion, this model could help improve their scenarios, as these scenarios have the same type of problems.

Locations have been overlooked and have been primarily assessed in literature for individual siting of power plants. Incorporating location decisions in the EMlab-generation model and showing that the permit procedure and location selection have an impact on both geographical and technological distribution of power generation is very valuable. It matches with observed behavior of Groot

(2013); Garrone and Groppi (2012), however we have to acknowledge that there was no hard data of these effects. These studies only observed some patterns and found that power producers tried to avoid activistic communities. So we cannot compare the results with real world data. It would have been nice if more research to spatial investment patterns in liberalized energy markets was available, but still it is likely impossible to compare results. External validity is a problem of agent-based models, as the models can never fully grasp the real complexity of a system. So comparing results with the real world is problematic even if data is available, as there are always parameters that are not in model.

Being able to analyze other location aspects like quality of cooling water, CCS possibilities and feedstock availability (coal harbor e.g.) are very welcome additions to the current model. Having model runs with e.g. forty percent CCS capacity is with current knowledge of TNO impossible. The same goes for nuclear energy, as there are only three location available and even if you could build unlimited power plants at each location there is still a limitation to the cooling water. Which brings me to another limitation due to time. Cooling water quality is modelled statically. It would be nice to extend this and make it dynamic, reducing the quality with the amount of generation capacity at a location. This would change the likability of some locations drastically when more power plants have been build there.

An omission in the model was found, that was overlooked during the modelling process. Technologies that are selected by power producer, but failed to make it through the permitting process are not selected for the next two years. The same might also have been a good idea for locations. This has not been done and would have been a nice addition. That said the implications of incorporating this omission in the model would have been minor, although the results to hypothesis 4 would likely be more clear and the differences between the different level of compensation scenarios bigger. Another omission which could also be seen as an interesting addition is to let the power producer evaluate several locations and choose the location with the best permit negotiation outcome. Now it is based on the NPV after the first negotiations and only if it the first location fails, the second location will be tested. It is likely more interesting to evaluate several locations and this would also result in perhaps different results. Bigger differences between several locations is expected, especially when comparing scenarios with different amounts of compensation. This is because the amount of activism is based on a normal distribution and it could differ. This would perhaps be a more accurate implementation of the permit procedure, but due to time constraints this has not been implemented. These omissions were known and could have been corrected, but due to some modelling issues they were not incorperated. A piece of advice is to always list these omissions and keep track of them, so you do not forget them when you are struggling on another part of the model.

Besides the direct impacts of the developed model there are also more methodological contributions that also have been mentioned in the conclusion. The way the permit procedure is modelled is a new for agent-based modelling and the game theory concept of the nucleolus has never been used in this way either. It took a considerable amount of time to find a way to model this permit procedure. I have to say that I am pleased with the way it is modelled and that I was able to understand and use these rather complex game theory concepts. Is the application perfect? No, of course not. Ideally alternative coalitions of local parties, with even the local government could form. This proved mathematically and computational extremely difficult. Still the possibility of alternative coalition forming fascinates me, but finding a way to apply this was too much for this thesis, or perhaps even a complete master thesis. Though I am confident that the permit negotiations, as modelled in this study, suit the needs of this study and perhaps also for other situations with complex multi actor negotiations. I have struggled a lot with the game theory concepts. Later I found out that many of the authors of the main game theory concepts won Nobel prices, which made it a lot more clear why I was having a lot of difficulty understanding their papers and books.

13.2 Reflection on the process

Demarcation The initial subject was very big. It took a lot of reading and time to get it more focussed. In the end I should have done even more to reduce the amount of work. Especially during the conceptualization, formalization and the actual modelling, I got excited and kept adding nice ideas. However during the experimental ideas it proved impossible to test all the combinations with enough type of runs (twenty scenarios already took five full days of running), so some features have to be turned of or kept stable in order to have a feasible amount of runs and be able to graduate in a reasonable amount of time. In the appendices some examples of modules that are not used can be found. These modules are fully operational, but were not used in the experimental design. That said there is thus enough work left for future students to extend the work I have done.

Tools, Methods & Techniques I have previously mentioned that I was looking for a real challenge, a subject that could keep me interested during the entire process. This certainly was the case, but it was not easy. I had very limited modelling experience, only an introduction course to agent-based modelling and some experience with modelling studies in my bachelor Technische Bestuurskunde. Java, Springsource, Graph repositories (neo4j), query languages (gremlin etc.), R-scripts, linux, bash-scripts and LaTeX were the computer related skills that I needed to get myself acquainted with. The main advantage I had was that there were two other students that were slightly ahead with modelling in EMlab-generation and I could learn a lot from them and especially their mistakes and problems. Basically I have done a lot of reverse engineering when it comes to code and used and adapted a lot of code that was already written in the model. Thinking in an object oriented matter also proved harder than first anticipated and still the code needs to be adapted to fully reflect the object oriented programming philosophy. I am very happy I chosen a master thesis subject that required me to learn a lot of new things and I think without it I would not have been able to continuously work on it for more than six months.

13.3 conclusion

This master thesis combined many skills attained in my masters and bachelors, but required me to learn many new tools, languages, theories etc. . This made it challenging and resulted in a thesis with contributions to the model and potentially society, I am proud of. Of course I wanted to do more, as there are many things that could be extended or improved. I wanted to do more scenarios, input parameters matched with e.g. Tennet's scenarios, but still the potential of the model is visible and one might question what the added value of these new scenarios would be for this master thesis. A final note for the graduation committee, grouping a couple students that graduate in the same research field and advising them to work together on a daily basis proved to be very valuable for me.

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Appendices

Appendix A

WaBo Scheme

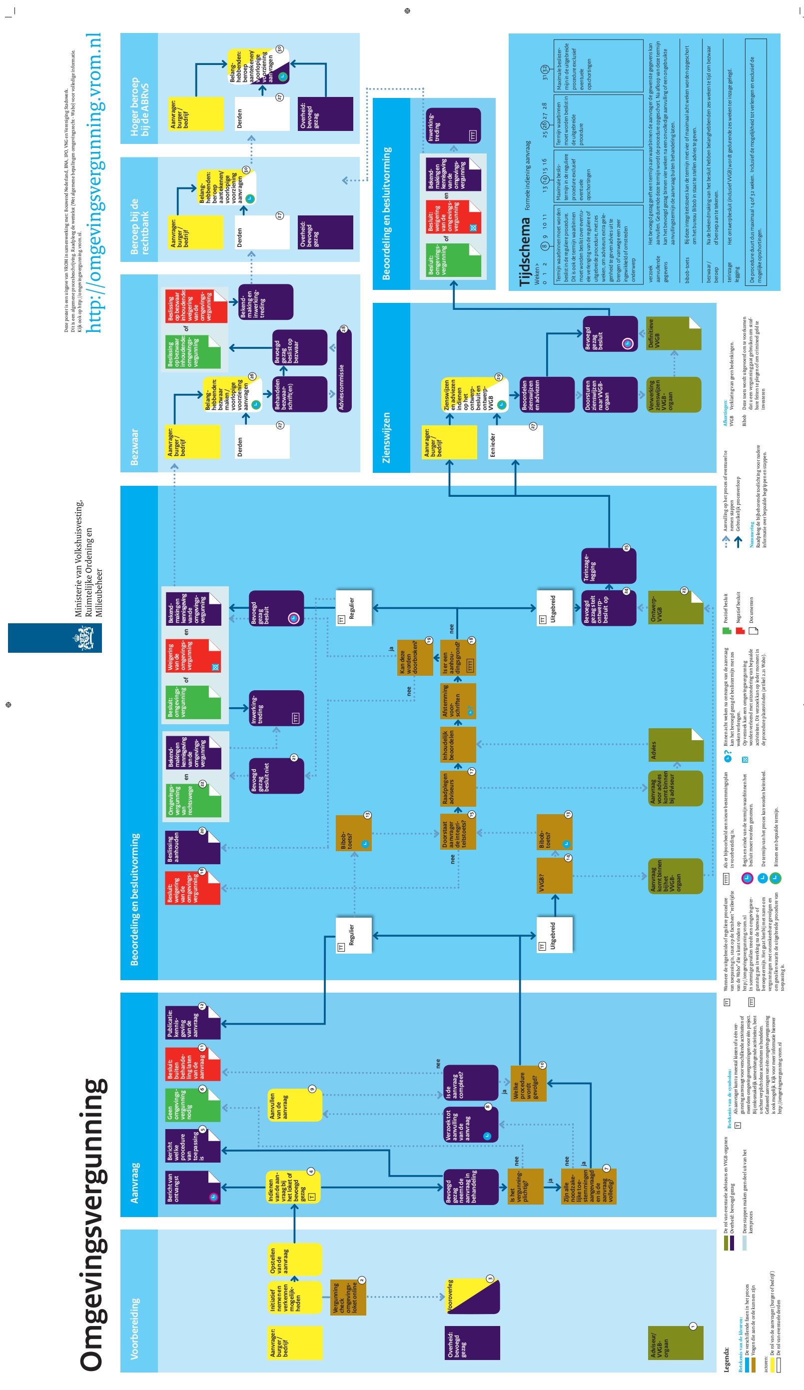


Figure A.1: Procedure WaBo permit

Appendix B

Unused: technology preference addition

Experience Lock-in & Net present value factors to include learning effects

Theories The Dutch electricity sector is very dependent on fossil fuels and the percentage of renewables is around 4-5 percent (source...). For the location selection it is needed to select a technology upfront. Foxon (2007) described reasons for technological lock-ins. Several pretty interesting and could be used to explain the Dutch situation. An important one are sunk costs, investments in new technologies are unlikely if they threaten the position of previous investment with sunk costs. Renewables are generally at zero variable costs and therefor precede all thermal power plants in the merit order. Due to the large scale of these plants and that partial operation will reduce its efficiency, companies are tended to protect thermal power plants. Other effects are so called learning effects and adaptive expectations. The first reduces costs when the technology has been used more often, the other adaptive expectations arise when the user becomes used to a technology and its quality and performance. It has been shown in research that sunk costs alone could cause an indefinite technological lock-in (Balmann, Odening, Weikard, & Brandes, 1996). This is interesting as it shows that path dependency and lock-in do not necessarily happen when there are increased returns over time (learning effects) and increased returns to scale. This could help explain the current lock-in the power sector.

This learning curve can also be used in the model to influence the NPV calculation by other factors, such as previous permit experience on that location and technology specific risks (detailed in formalization chapter).

Empirical data Groot (2013) has obtained a lot of empirical data about investment decisions in the Dutch electricity grid by performing interviews with power producer executives. These empirical data could be used to evaluate the theories described in the previous paragraph for the electricity sector and more specific the Dutch electricity sector. The most interesting findings from the empirical data are presented below:

- Avoidance of opportunity costs, leads to mirroring of the market
- Some companies have strict environmental goals and do not use certain feedstocks
- Goal reasoning is present, if shareholders public, social desirable behavior or outperform competing departments
- Companies with large generation portfolio consider merit order cannibalization effects
- Higher risk considered for new technologies, development risk
- Local employment could be important driver when municipalities are shareholders
- information access

  Size and characteristics asset base (economies of scales)

  Size company (economies of scales)

  Experience in lifecycle and insights (lessons learned, learning effects)

  Size enables better processing and gathering of information

The argument brought forward by Foxon (2007); Balmann et al. (1996) that sunk costs could lead to lock-ins is supported by the empirical data. The electricity generators tend to follow others in the market and fear cannibalization effect of new power plants on current power plants. Learning curves also described in the literature are also present in the empirical data, the same goes for adaptive expectation. The larger a company and the more experience it has with a technique the more knowledge and expertise is available and the more information and accurate forecasting is available reducing risks (which are one of the key investment criteria). Lock-in because of sunk - costs is very interesting, but will not be taken in consideration in this study.

Implementation plan From the empirical data it comes forward that the main driver for the investment decision is the business plan with its NPV and return on investment (ROI) (Groot, 2013). The portfolio and size of the company should be assessed and be used to influence the discount rate. This is an easy implementation of learning effects, as the risk could also reflect risk and impact on other power plants performance. Furthermore goals are also identified as a driver so the different companies should have a different focus. The exact implementation will be detailed in chapter B.

Technology preference

Implementation In the model each company has a Weighted Average Costs of Capacital (WACC) based discount rate. The WACC depends on the costs of debt and the expected returns. A check if a companies portfolio for the selected technology is over a certain threshold (40 percent) than the discount factor reduces by a multiplication factor. The same goes the other way around, when a company has no prior experience with a technology. This should create a bigger barrier for a company to invest in a new technology reflecting the actual behavior from the empirical data.

After all the checks in the investment algorithm has been done for a certain technology the NPV is calculated. The NPV is calculated based on the investment costs, construction time and WACC. To make the NPV portfolio dependent it is needed to check the marketshare of the technology for this investor. If the market share is above 30 percent a multiplication factor TP (technology portfolio) will go below 1 and thus reducing the discount rate and thus increasing the NPV. When a company has no prior experience, meaning a market share of 0 percent than the TP factor will be above 1. The precise value of the TP factor and the market will be determined by experimentation.

In the conceptualization chapter it has been mentioned that the implementation of technology preferences could easily be extended with factors about the previous experience on that site with permit applications. Furthermore the factor should drastically increase for a few years in the case no location have been found suitable for a particularly power plant type.

Pseudo-code The pseudo code will be translated into actual code for the InvestInPowerGenerationTechnologiesRole.

Algorithm 2 Technology portfolio dependency and permit problem impact

if Technology went through previous constraints **then**
    set $Marketshare = 0$
    get $NumberOfPlantTech = agent(x).powerplant.technology(y)$
    get $TotalnumberofPlants = agent(x).powerplant$
    set $Marketshare = NumberOfPlantTech/TotalnumberOfPlants$
    if $Marketshare >= 0.4$ **then**
        $TechnologyPortfolioFactor = 0.9$ (Or other parameter in scenario)
        if $Marketshare = 0$ **then**
            $TechnologyPortfolioFactor = 1.1$ (Or other parameter in scenario)
        else$TechnologyPortfolioFactor = 1$ (Or other parameter in scenario)
        end if
    end if
    if FailureTechnology(Technology) = 1 **then**
        $FailFactor = 10$ (Or other parameter in scenario)
    else$FailFactor = 1$
    end if
    $WACC = WACC * TechnlogyPortfolioFactor * FailFactor$
end if

Appendix C

Pseudo Code

Algorithm 3 Rough Selection and ordering of locations

```
Location utilityLocationRank1 = null
Location utilityLocationRank2 = null
Location utilityLocationRank3 = null
for location Repository:Location do
    if bestTechnology.getName.equals(location.getFeedstock()) then
        if bestTechnology.getCCS() == True && location.getFeedstockCCS() != True then
            Location not suitable for CCS
        end if
        location.setUtility = Utility(bestTechnology X)
    else
        Location not available for Technology X
    end if
    if location.getUtility > utilityLocationRank1.getUtility then
        utilityLocationRank3 = utilityLocationRank2
        utilityLocationRank2 = utilityLocationRank1
        utilityLocationRank1 = location

        if utilityLocationRank1 == null then
            No location found for technology x
        else
            start Permit Procedure
        end if
```

Algorithm 4 Pseudo Code Investment decision location decision

```
boolean locationChosen = false
boolean permitFailure = false
Location chosenLocation = null;
while (locationChosen == False && permitFailure == False) do
    if (utilityLocationRank1 != null) then
        double compensationGovernment = 0d
        double compensationElectricityProducer = 0d
        double utilityElectricityProducer = 0d
        LocalGovernment authorizedGovernment = null
        for (LocalGovernment localgov : RepositoryLocalGovernment) do
            if localgov.getName().equals(utilityLocationRank1.getProvince()) then
                authorizedGovernment = localgov;
            end if
        end for
        plantsOfTechnology = count number of power plants in province
        localgov.setUtility = calculate(U_government)
        while (localgov.getUtility =0) do
            compensationGovernment += #
            compensationElectricityProducer -= #
            localgov.setUtility = calculate(U_government)
            utilityElectricityProducer = calculate(U_ElecGen)
        end while
        Random rand = new Random()
        double normalDistribution = rand.nextGaussian()
        Sigma Equation
        double amountOfLocals = math.abs(math.floor(normaldistribution * sigma))
        arraylist LocationLocalParties listlocals = new Arraylist
        investmentCost = bestTechnology.getInvestmentCost(getCurrentTick()) * bestTechnology.getCapacity
        for (int i = 0; i¡ amountOfLocals; i++) do
            LocationLocalParties local = new LocationLocalParties()
            Set utility local party with formula and multipli with random value
            listlocals.add(local)
        end for
        double averageUtility = -1
        if (listLocals.isEmpty()! = true&&utilityElectricityProducer = 0) then
            while (agent.getRiskAcceptance() = averageUtility) do
                LocationLocalParties minLocalUtility = null
                for (LocationLocalParties local : listLocals) do
                    find most unhappy local party
                end for =0
```

Algorithm 4 Pseudo Code Investment decision location decision (continued)

```
                for (LocationLocalParties party : listLocals) do
                    if (party.getName().equals(minLocalUtility.getName())) then
                        party.setCompensationLocalParty += #
                        compensationElectricityProducer -= #
                        party recalculate utility
                    end if
                end for
                double averageUtilityLocals = 0d
                averageUtilityLocals = calculateAverageUtilityByTakingAverageOfAllLocalParties
                utilityLocationRank1.setAverageUtility(averageUtilityLocals)
                update UtilityElectricityProducer
            end while
        end if
        if (utilityElectricityProducer ¿ 0) then
            locationChosen = true
            chosenLocation = utilityLocationRank1
        else(utilityLocationRank1 = utilityLocationRank2)
        end if
    elsepermitFailure = true
    end if
    invest in bestTechnology at location chosenLocation
```

Appendix D

Permit procedure description

Detailed Permit procedure In the Dutch spatial planning law, the 'Wabo' there is specified a general procedure for big facilities (Rijksoverheid, 2008). The procedure has numerous steps and included all permits needed for the construction of a facility. To build a power plant the so called extended procedure is needed, as power plants are can have considerable impact on the environment and spatial planning in a region. The permit procedure contains 7 steps, each step different actors are involved as shown in table E.3. In the end of the procedure in the so called steps 'views' and 'apeal at court' third parties are allowed to state their opinions and go to court if they think their interests are being neglected. At this stage the official permit is already given, however the court could decide to stop the project for a while or withdraw the permit if the claims of the third parties are considered valid. This has happened before in the Eemshaven where the permit for RWE/Essent was considered invalid by the judge (NRC, 2011), because of an incomplete or incorrect analysis of important environmental aspects. This could have serious consequences for the construction of the plant, causing delays and budget overruns. In the Wabo law the authorized authorities are in this case the municipality councils, although for especially the bigger power plants over 500 MW there is significant involvement of both provinces and the national government, as the effects on the surrounding are considered more significant and its effects broader than just the municipality borders.

Other important parties in the permit procedure are advising parties or consultancy and the municipal council (or higher authorized governments to give out a so called vvgb (verklaring van geen bezwaar *english: Declaration of no objection*). These parties determine the possible negative effects on the surroundings and the environment and give advice for mitigation strategies. Most legal procedures attack the effects on the environment and that makes this phase and these parties very important for a smooth permit procedure. An aggregated overview of the actors involved in each phase is given in figure E.3

To simplify the permit procedure it is important to analyze the different outputs of each phase. In the preparation phase the applicant does some orientational meetings with the authorized government body. After it decides how or if to continue. This is an important phase as location are sorted out here and the best option is chosen and continues in the permit process with advice of the (local) government. The next phases, application and judgement are mostly procedural and do not involve many actors, basically the municipality takes a decision with regard to the permit applications. However the 'views', final decision and possible appeal at the court are interesting. These will have to be modelled in a way that third parties could influence decision making or construction / permit times. Schematically the permit application can be simplified from the ver complicated detailed plan of the ministry (appendix) to only a few steps, as shown in figure D .

electricity law

> Electriciteitswet 1998 artikel 16
>
> c. de netten aan te leggen, te herstellen, te vernieuwen of uit te breiden, waarbij in overweging worden genomen maatregelen op het gebied van duurzame elektriciteit, energiebesparing en vraagsturing of decentrale elektriciteitsproductie waardoor de noodzaak van vervanging of vergroting van de productiecapaciteit ondervangen kan worden
>
> d. voldoende reservecapaciteit voor het transport van elektriciteit aan te houden
>
> e. op de grondslag van artikel 23 derden te voorzien van een aansluiting op de netten
>
> f. op de grondslag van artikel 24 ten behoeve van derden transport van elektriciteit uit te voeren

Appendix E

location aspect tables

Generation technology	**Location Resources**
Coal	• Coal feedstock • Cooling Water • (CCS infrastructure)
Biomass	• Biomass feedstock • Cooling Water • (Coal plant)
Gas	• Gas feedstock • Cooling water • (CCS infrastructure)
Nuclear	• Enriched uranium or plutonium feedstock • Cooling water • Nuclear waste storage • Specific location law
Wind	• Wind speed • Wind stability
Photovoltaic	• Sun hours • Sun power

Table E.1: Location resource dependencies different technologies

Source	Location factors
Company	• Building permit risks • Land Lease risks • Natural resource availability • Grid connection risks • Construction risks • Risks in partnering
Government	• Environmental factors • Permit procedures • Fixed locations permit • Sustainability goals
Sector Research	• Activism risks • Environmental factors not decisive • Avoid location risks

Table E.2: Summary of the factors influencing the location choice

Permit procedure phase	Involved actors
Preparation	• Company • authorized government • Advisors and City council
Permit Application	• Company • authorized government • Advisors and City council
Judgement and decision making	• Company • authorized government • Advisors and City councel
Views	• Company • authorized government • Advisors and City council • Third parties
Judgement and decision making	• authorized government • Advisors and City council
Appeal at court	• Company • authorized government • Third parties • Court
Appeal at Algemene bestuursrechter raad van staten	• Company • authorized government • Third parties • Court

Table E.3: permit phases and actors

Appendix F

Wind and Solar maps Netherlands

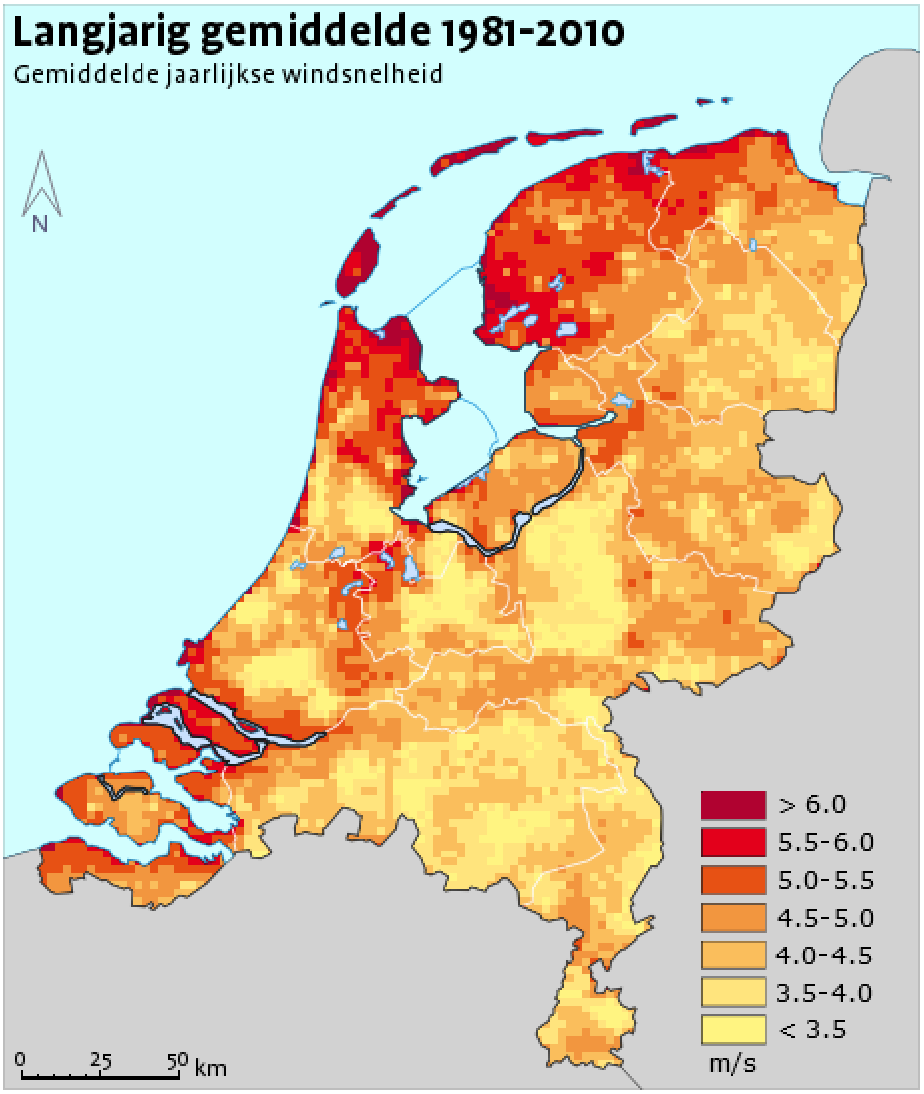


Figure F.1: Average wind speed over 30 years

(KNMI, 2013c)

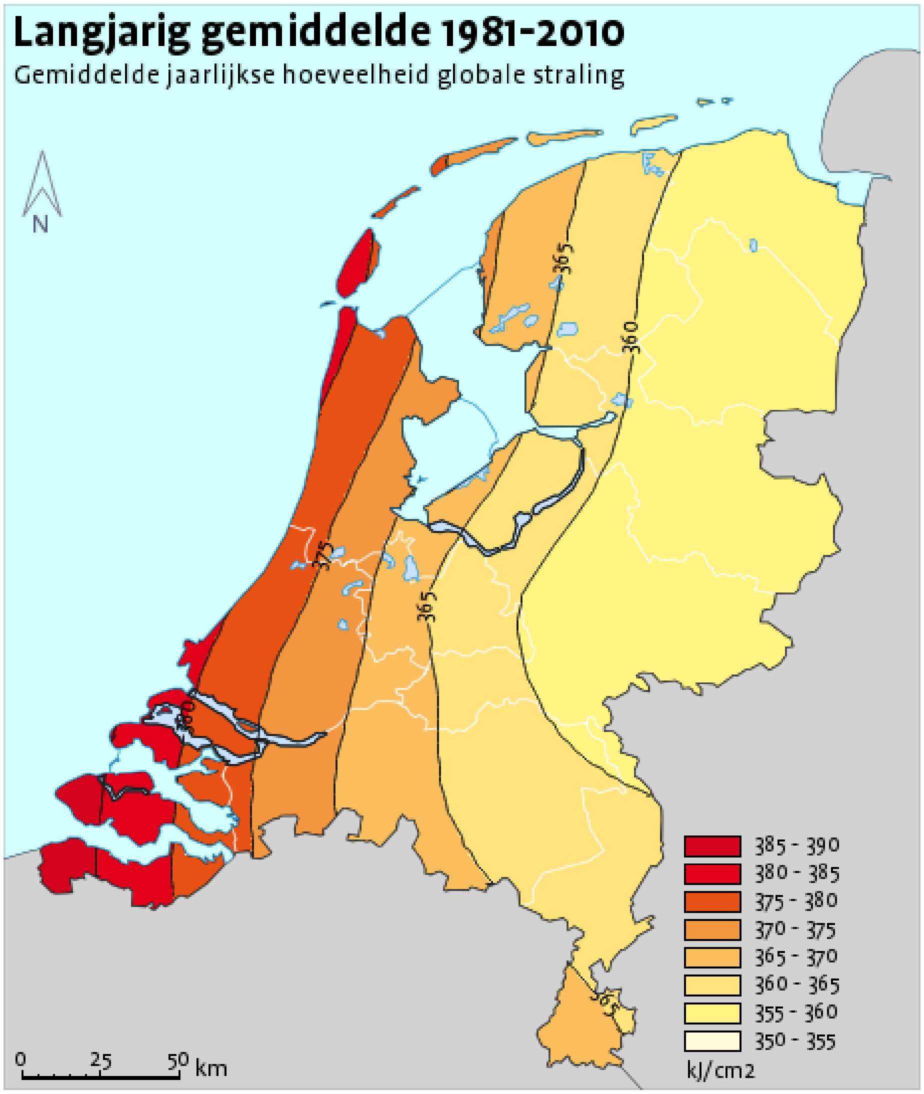


Figure F.2: Solar radiation average over 30 years

(KNMI, 2013b)

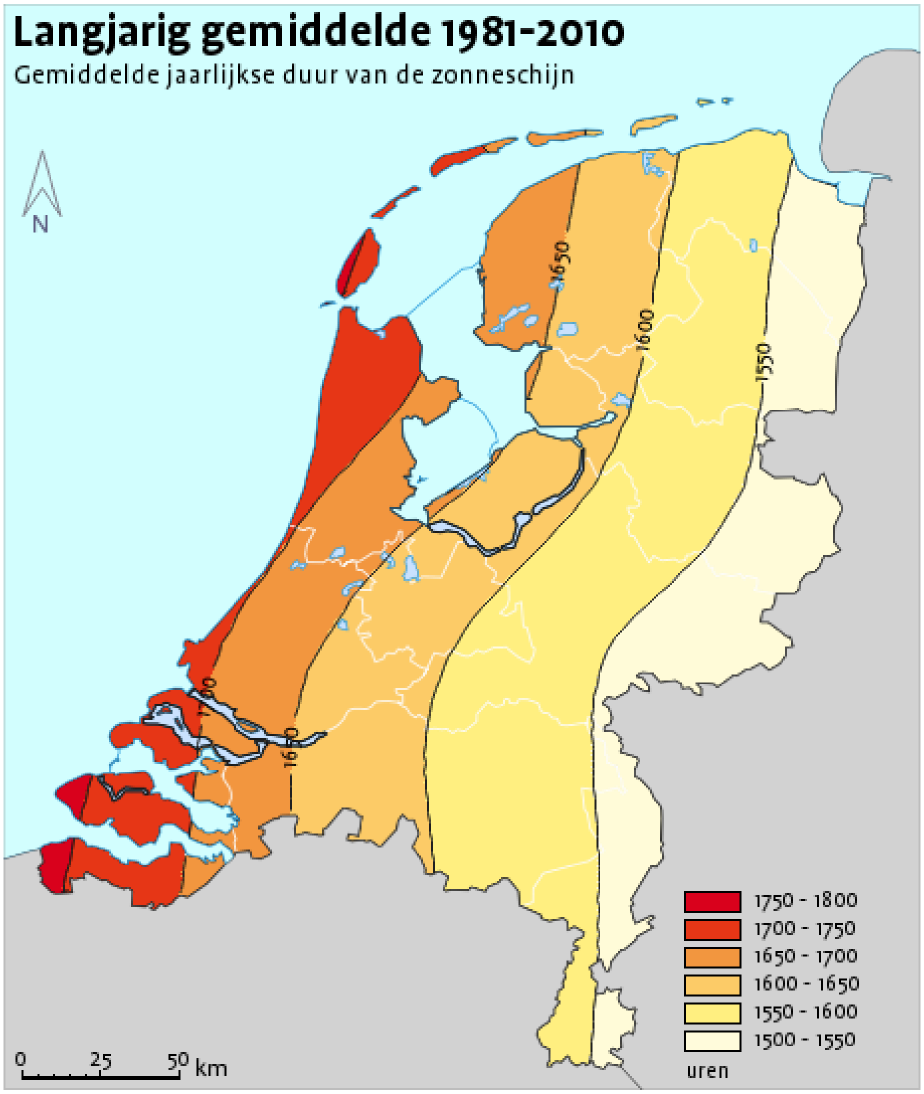


Figure F.3: Solar hours average over 30 years

(KNMI, 2013a)

Appendix G

Verification Errors

- iterator for object list
- utility functions , correcting directions (Many different utility function, some really similar with each other: recipe for problems)
- wrong bracket use
- set initial size arraylist local parties (over 10 possible so)
- =! Instead of == in checking if there is space at a location for more power plants.
- Problem with calculation amount of plants, forgot to adapt that value with investment in powerplant.
- Smaller than instead of bigger than riskcacceptance vs average utility
- Implement conventions. Capital for classes etc. lower case variables etc.
- Smaller or equal too instaed of equal to in the test of number of plants at location
- Delete capacity from utility function site selection and put all utility functions in methods.
- Windloction instead of windlocation
- Spelling errors in names of locations, westwoud vs westwout referring to nothing
- Incorrect name of parameter in scenario file and getters / setters in class (provinces and sunlocation vs solarlocation), not using at all so deleted all
- Technologie ids used not names , this gave errors
- While = false instead of while == false

- Wrong query , checking for operational plants , I should check powerplants not dismantled at locations so also power plants that are under construction
- Couldn't access agent class so made local government in normal class
- Offshore? != false, must be offshore? != true
- Agent risk perception ¡ average utility in while, this should be riskperception ¿ average utility
- Utility function local method *-1 while not needed with tech pref.
- Compensation effectiveness curve () to little did not calculate correctly because of that (in utility function local parties)
- Variable double averageUtility = 0d; wrong place not in the loop but before so it counted up and didn't reset after each payment to local parties
- Tech failure did not work -¿ crash so now if no tech found set agent not willing to invest
- Initial value of averageutility made while loop stop
- Error with negative postponed utility with utility calculation of energy producer
- Compensationelectricity producer is negative, used to subtract from npv , so needs to be +
- Problem random factor utility locals , only ones with updating it was gone, implement is as variable of each local party and save it. Does not multiply the compensation .
- Some location in scenario file had the same name - ¿ not used in model than
- Energyproducer utility function to little

Appendix H

Validation

Table H.1: Initial spread statistics table

variable	value	ActualMean	PValue	TValue	ConfInt
MaasvlakteII	0	0	NA	NA	NA
Eemshaven	4000	4211.64659	0.002999704	2.99737895	4072.57376
Moerdijk	1200	1527.71084	9.93700e-11	6.75779341	1432.19871
Borgum	664	577.309237	0.005608824	-2.7942259	516.203219
Harculo	350	311.044177	0.065972151	-1.8467675	269.497831
Nijmegen	600	520.080321	0.009604886	-2.6100058	459.770932
Utrechtstad	850	931.927711	0.028210252	2.20728666	858.823103
Lelystad	1000	1174.8996	7.11796e-05	4.04051845	1089.64371
Velsen	1250	1484.73896	3.795780e-06	4.72856134	1386.96373
Hemweg	1430	1826.10442	1.85977e-11	7.04161965	1715.31206
Diemen	250	312.650602	0.009092579	2.62922888	265.718552
Maas-vlakteI	2822	2831.72691	0.874216097	0.15846914	2710.83346
Galilei-straat	350	318.273092	0.16794748	-1.3828735	273.085631
Borselle	1792	2035.74297	7.03492e-06	4.59039058	1931.16141
Amer	1285	1313.25301	0.552145995	0.59535962	1219.78607
Buggenum	250	305.220884	0.018172179	2.37785736	259.481509
Maasbracht	650	610.843373	0.186373557	-1.3250516	552.640404
Westland	0	0	NA	NA	NA
Geleen	150	0	0	-Inf	NA
Delfzijl	600	626.907631	0.427110184	0.7954539	560.283262
Rijnmond	1800	1724.29719	0.113397743	-1.5887196	1630.44651
Terneuzen	525	580.722892	0.054074428	1.93542937	524.016895

Appendix I

Batch run additional results

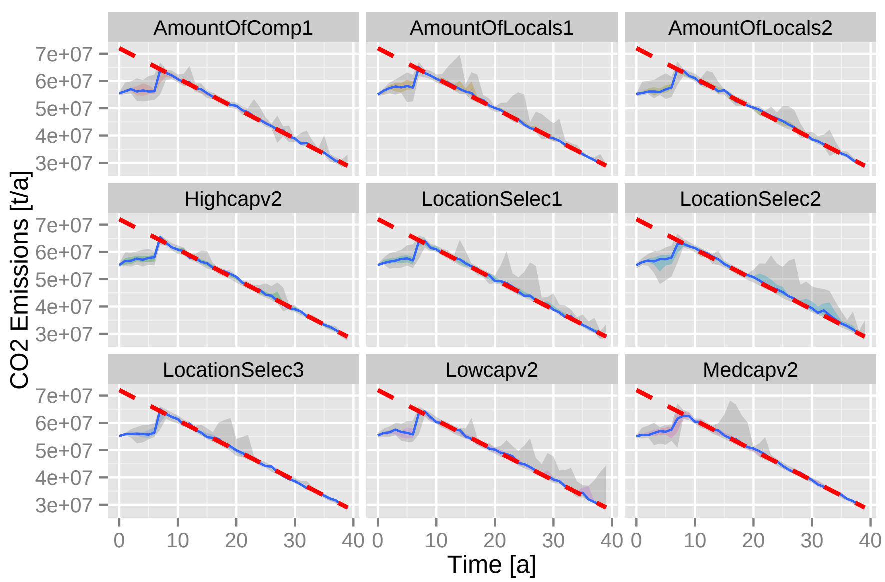


Figure I.1: CO2 emissions and price per scenario

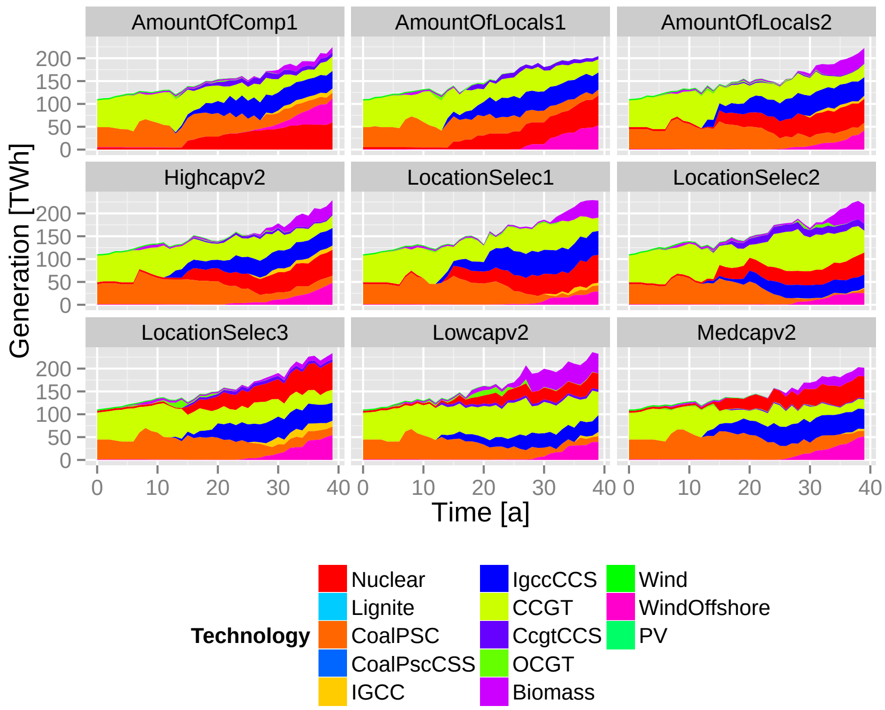


Figure I.2: Generated electricity per scenario

Cash position An interesting graph is the aggregated cash position plot of all power producer is the model's electricity market. The figure can be seen in figure I.3. What is especially visible is the effect of the amount of power plants that can be build at each location. Just before tick 20 we see the cash position of electricity producer improve dramatically in scenario Lowcapv2. This can be explained that at that point the locations are full and there will be shortages in electricity and thus the prices rise. In medcapv2 we see this point a lot later, around tick 25-30 and rises not as fast as in the low case, in highcapv2 we see this point at around tick 30. The effects are less dramatic, a possible explanation could be that at that point the importance of renewables is a lot higher, thus leading to less need for the extra locations. The effect of higher compensation is also visible and leads to the worst cash position from all scenarios. Location selection variables also seem to have different effects on the cash position, completely explaining this behavior with just this graph is hard, but choosing location fully considering activism seems to lead to a higher cash position, but the same goes for only looking at cooling water.

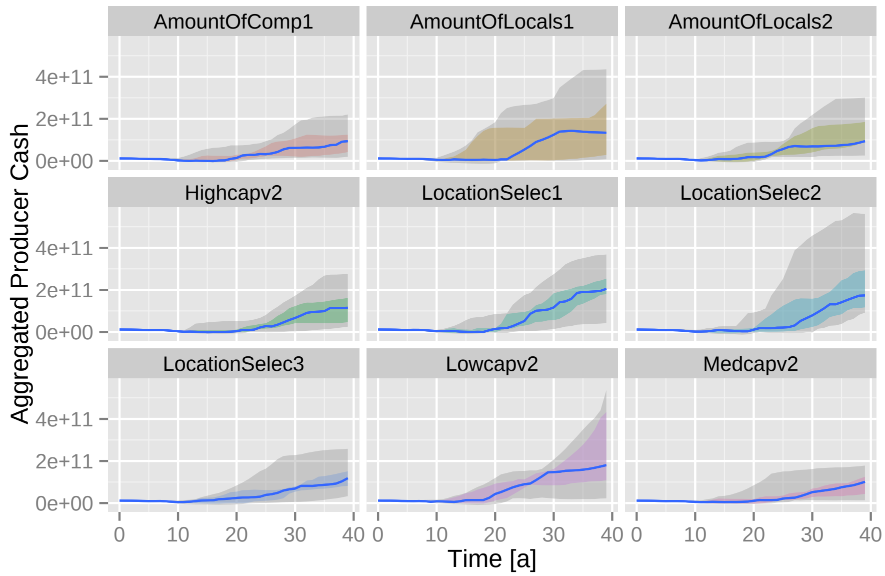


Figure I.3: Aggregated cash positions electricity producers

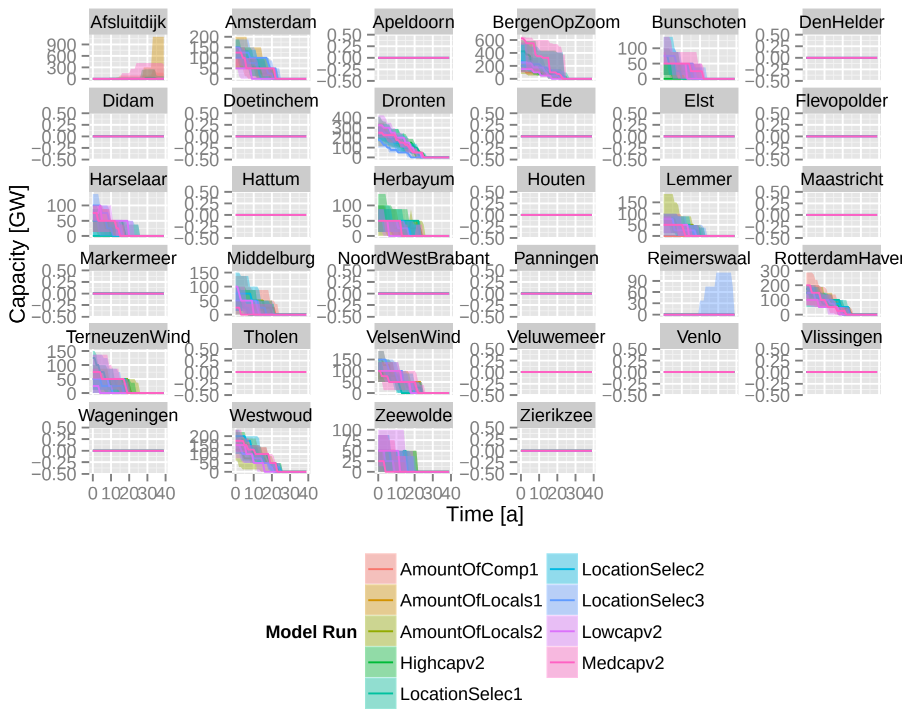


Figure I.4: Location wind onshore MW

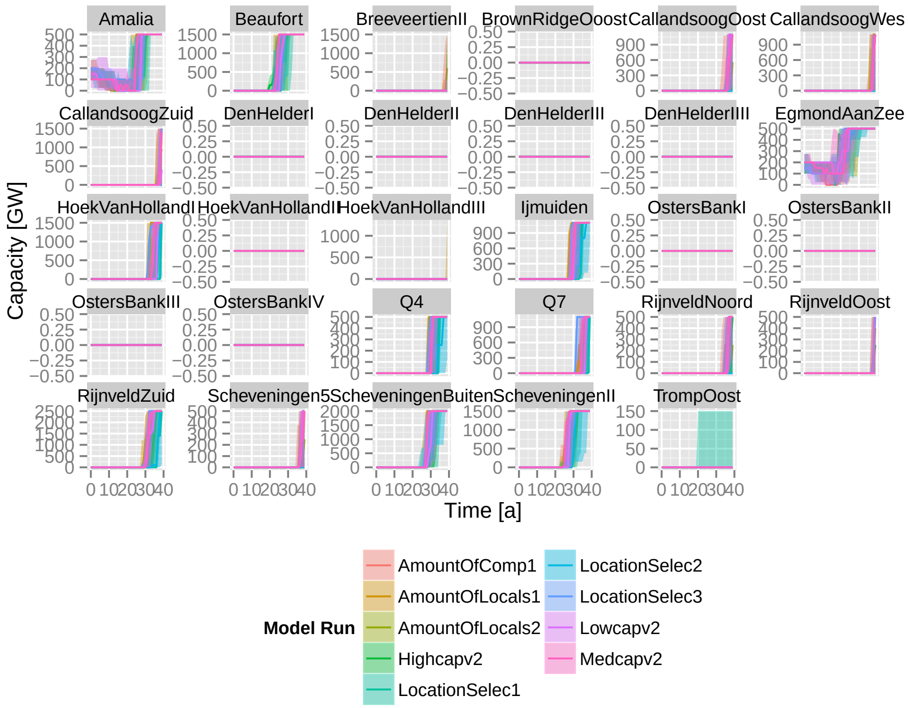


Figure I.5: Location wind offshore MW

Appendix J

Extra Results

This Appendix contains some extra figures for the results and analysis chapter. For each hypothesis all the technology and location capacity graphs (when applicable) for the scenario combination are given. Also all the statistical test histograms for all the hypotheses are given. All the other graphs and figures of location capacities, technology capacities, timing of investment can be found in the extra appendix. Also for each technology and location for each scenario combination a table for the amount of runs above a reference point at different time steps can be found in the extra appendix.

The extra appendix can be accessed at *https://github.com/jeroenpaling/emlab-generation/tree/LocationAspects/Report*

Hypothesis 1 complete generation capacities technologies figure

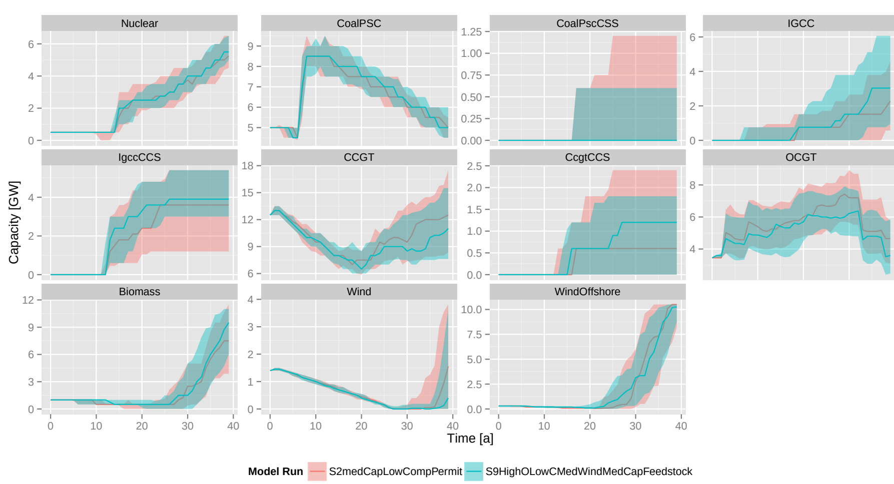


Figure J.1: Generation capacities for each technology, permit Medium cap low compensation scenario versus feedstock medium cap low compensation scenario

Hypothesis 2 complete location capacities figure

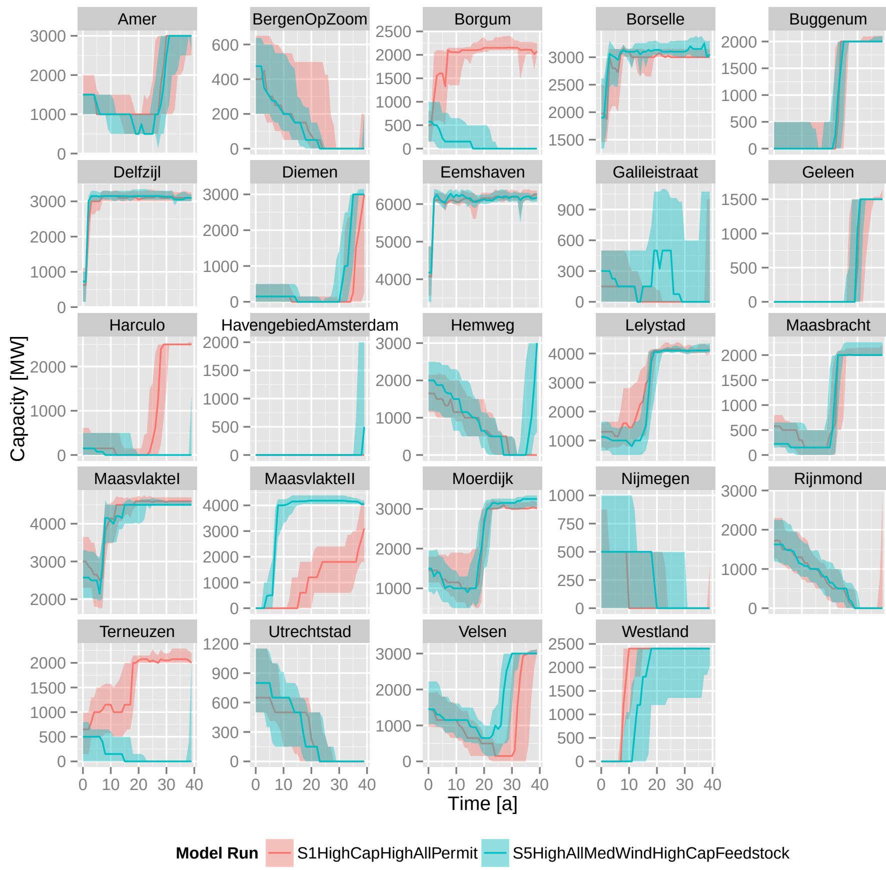


Figure J.2: Generation capacity at the different locations

Hypothesis 3 complete generation capacities technologies figure

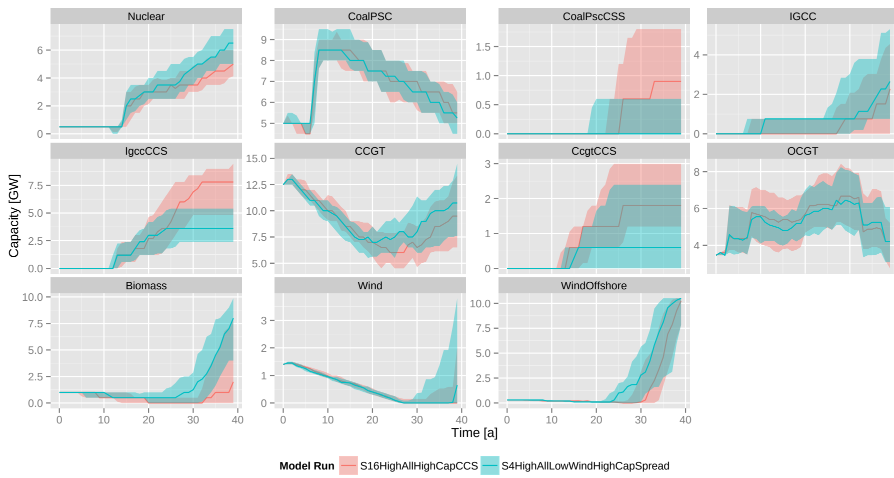


Figure J.3: Technology graphs for the two CCS scenarios with high location capacity caps

Hypothesis 4 complete location capacities figure

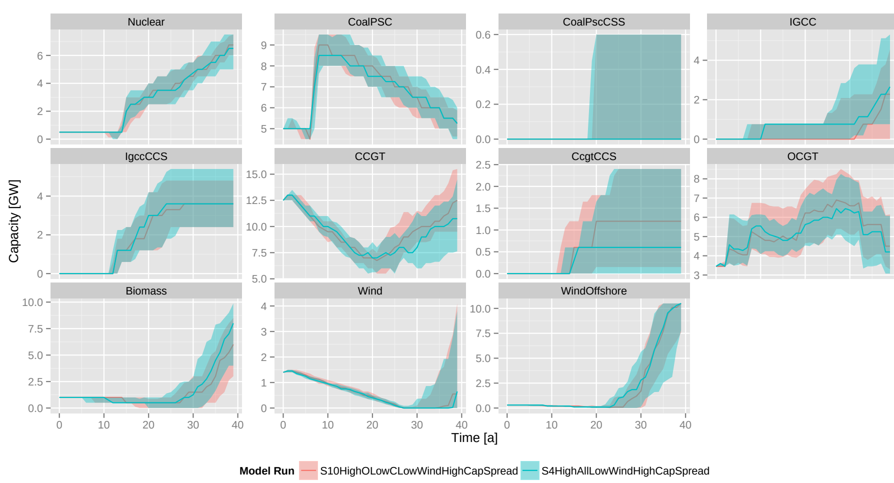


Figure J.4: Technology capacity chart of scenarios high cap spread selection method

Hypothesis 4 complete generation capacities technologies figure

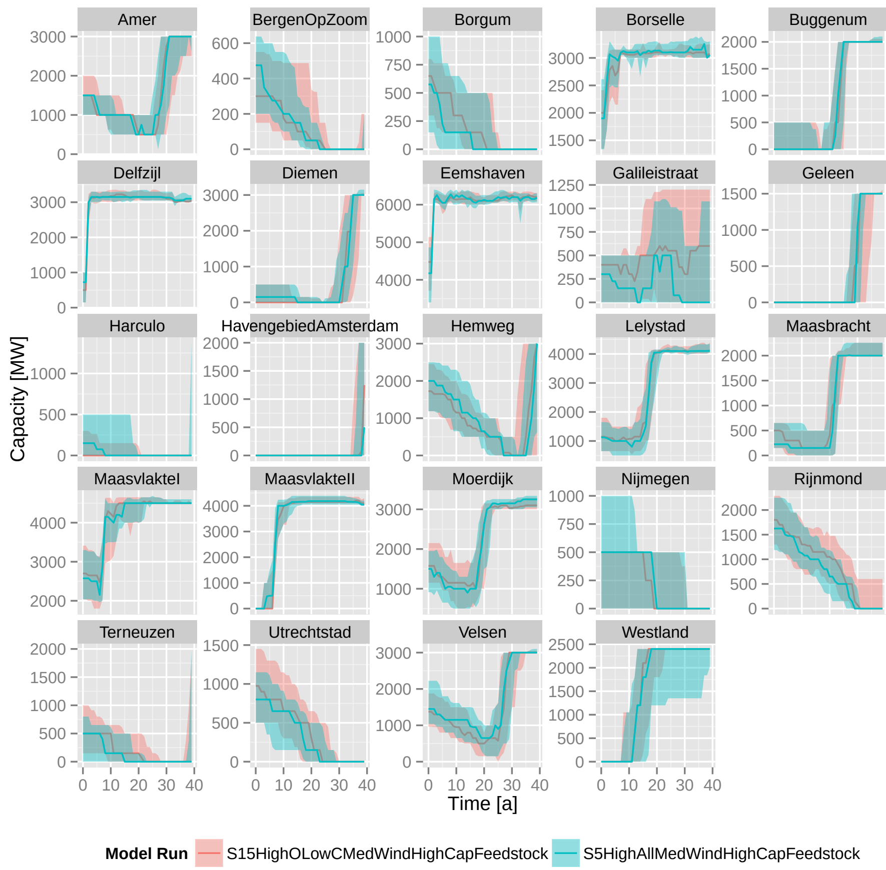


Figure J.5: Technology capacity chart of scenarios high cap spread selection method

investment timing graphs

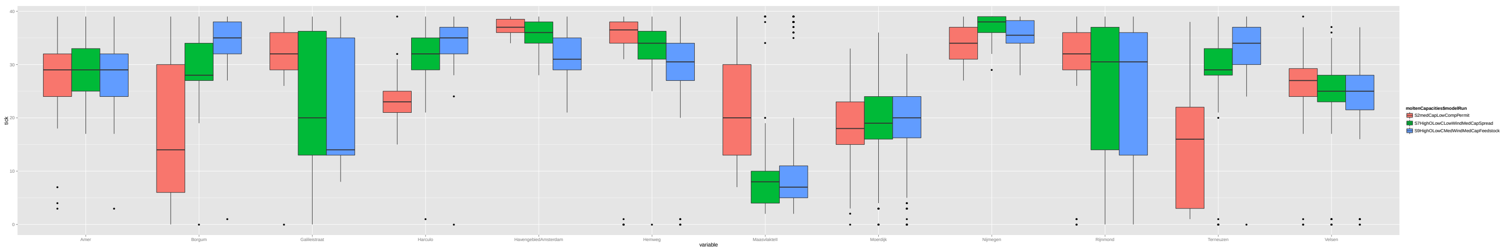


Figure J.6: Boxplot three different medium cap scenarios and investment times

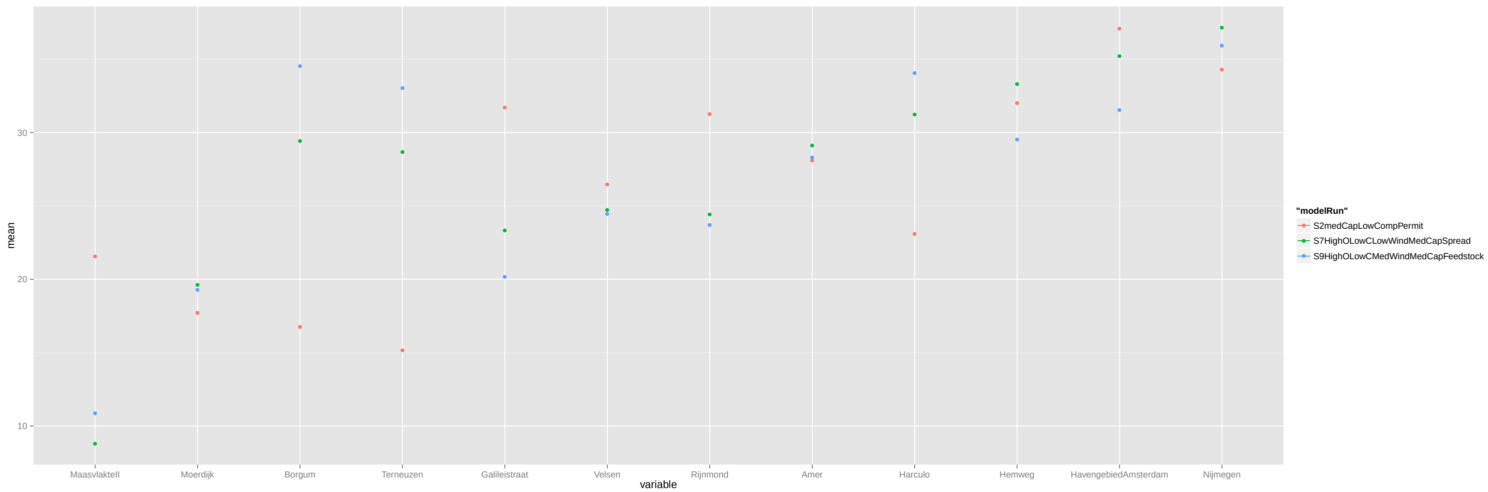
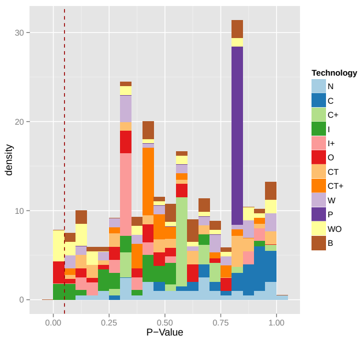


Figure J.7: Scatterplot different start point investments

Hypothesis 1 combinations



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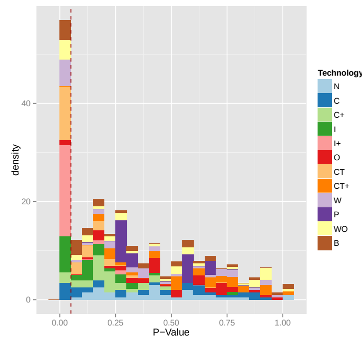

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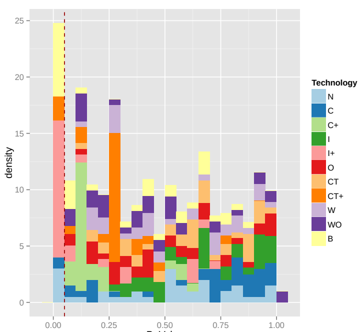

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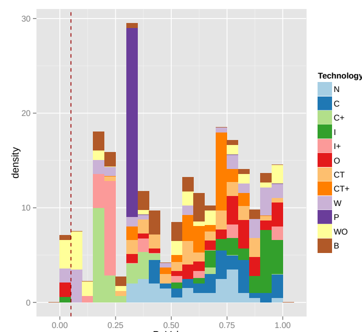

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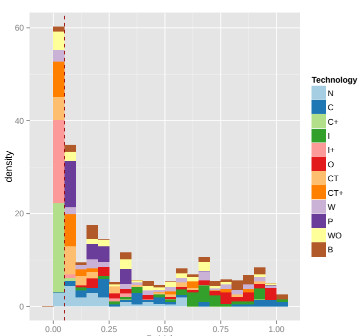

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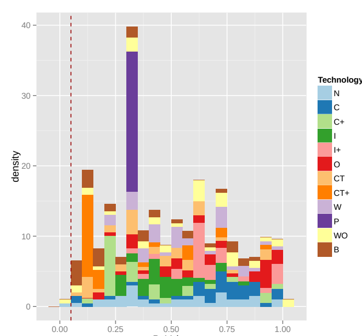
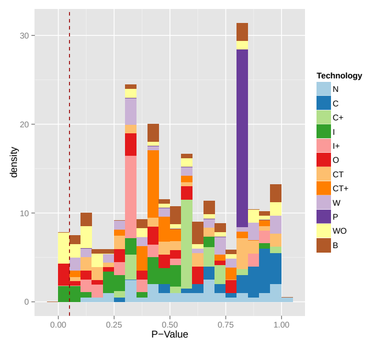


(f) TechnologyHistogramHighAllHighCap.pdf

Figure J.8: Hypothesis 1 statistical test scenario combinations

Hypothesis 2 combinations



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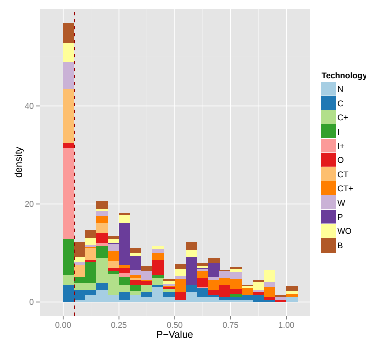

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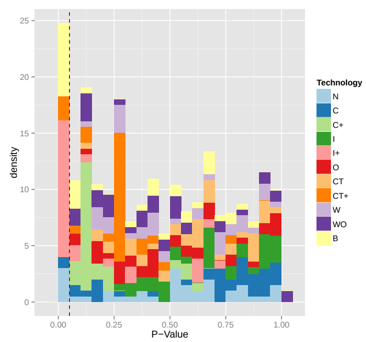

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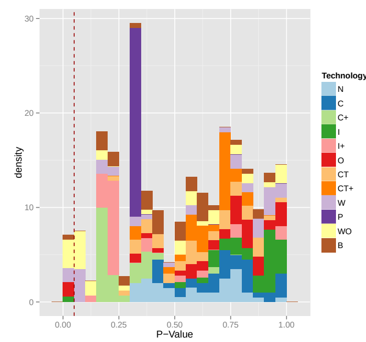

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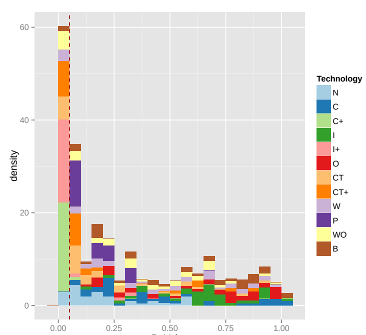

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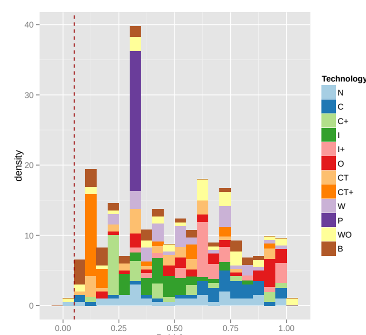

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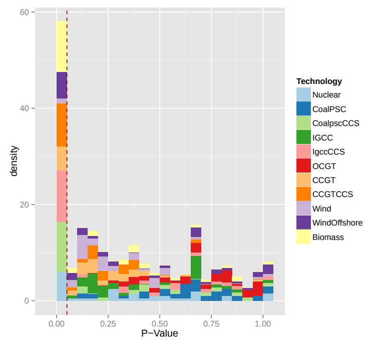
Figure J.9: Hypothesis 2 statistical test scenario combinations

Hypothesis 3 combinations



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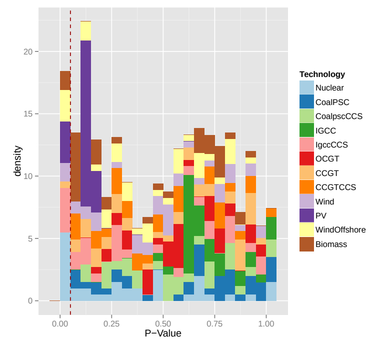

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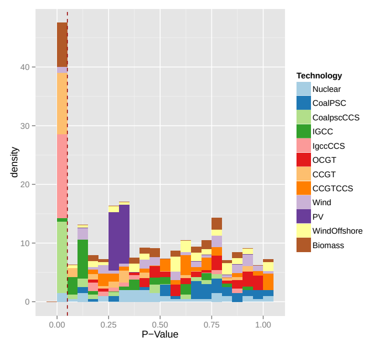
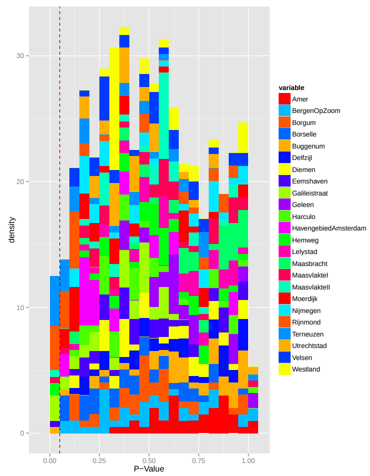


(c) TechnologyHistogramCCSM.pdf

Figure J.10: Hypothesis 3 statistical test scenario combinations

Hypothesis 4 combinations locations



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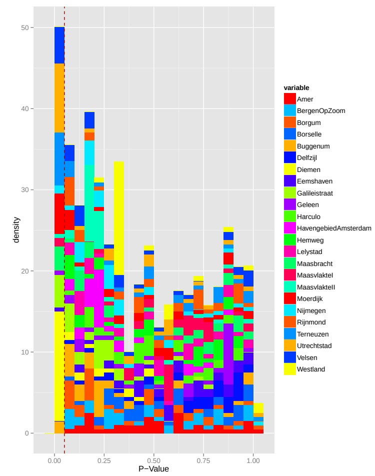

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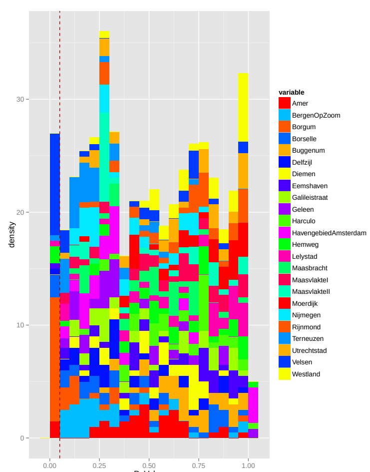

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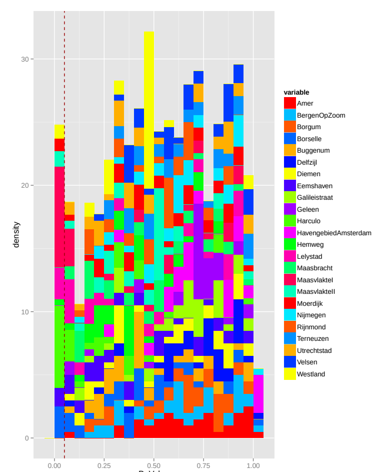
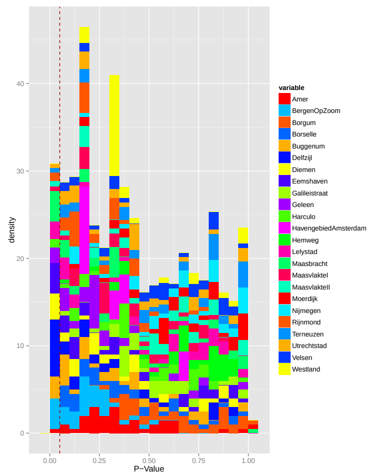


(d) HistogramLocationsPL.pdf

Figure J.11: Hypothesis 4 statistical test scenario combinations locations part 1



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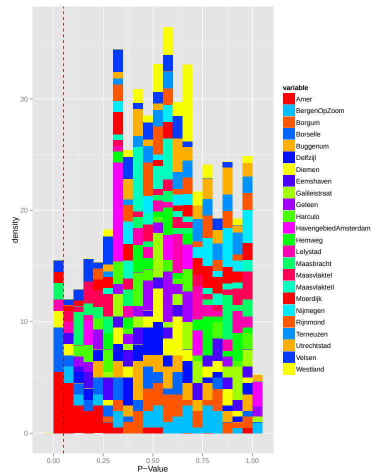

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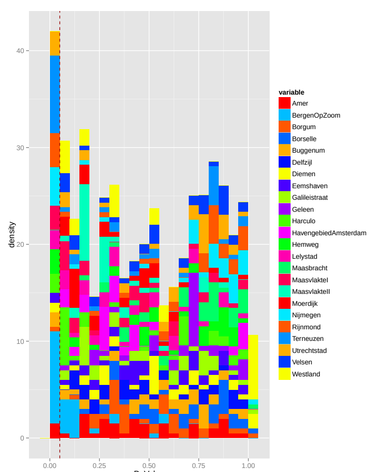

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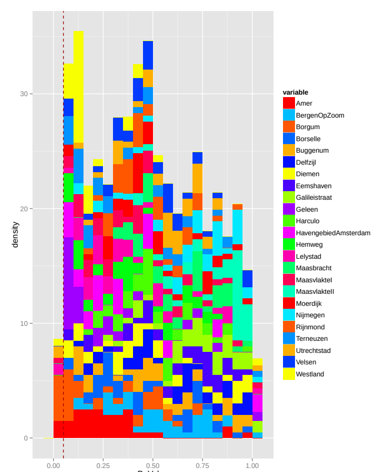

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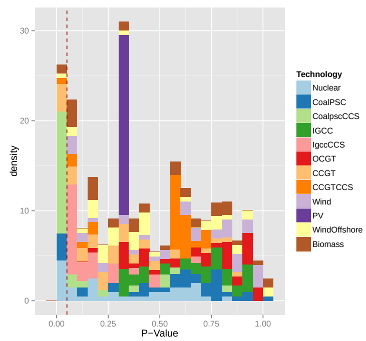
Figure J.12: Hypothesis 4 statistical test scenario combinations locations part 2

Hypothesis 4 technology part 1



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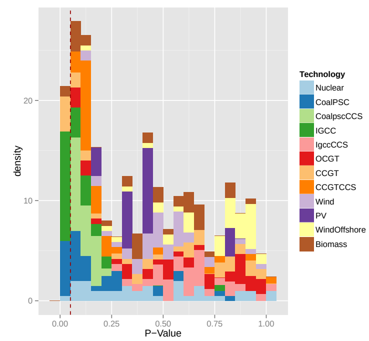

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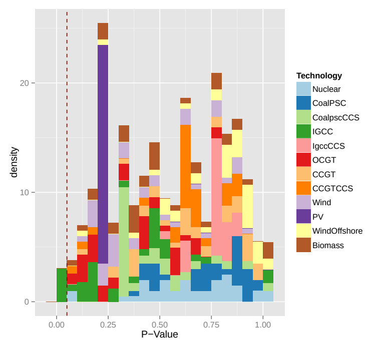

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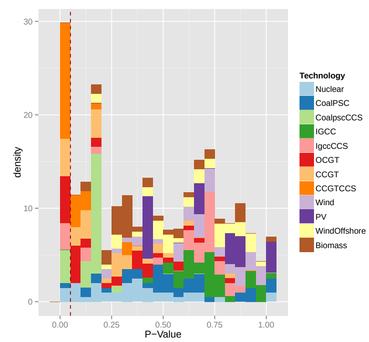

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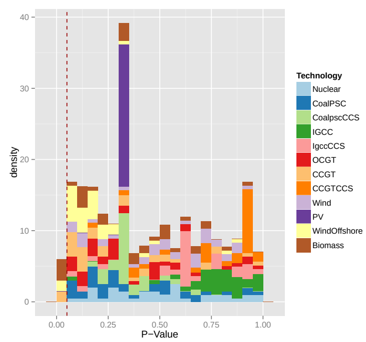
Figure J.13: Hypothesis 4 statistical test scenario combinations technology part 1



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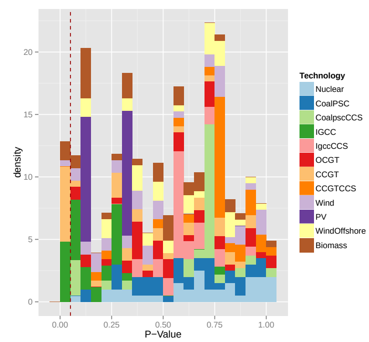

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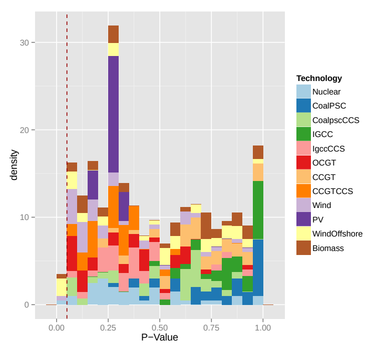

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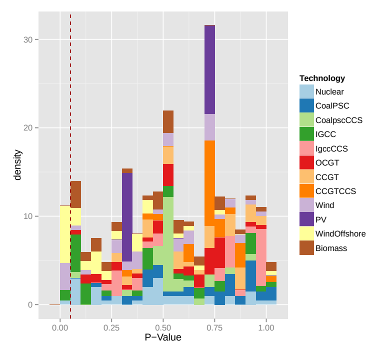

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Figure J.14: Hypothesis 4 statistical test scenario combinations technology part 2