The Impact of power plant location decisions on the long term development of the electricity sector

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***Abstract*—Location aspects are important in the investment decision for new power plants in liberalized energy markets. The precise impacts of the these locations aspects on the long term development of an electricity sector are still largely unknown. The permit procedure is considered very important by power producers and they try to avoid permit related risks. This paper presents a way to model the permit procedure and location selection for new power plants in an already existing electricity market simulation model. The results show that the way power producer select location significantly chances the geographical representation of power plants, but also changes the fuel mix of the power plants. Additionally the amount of activism (permit risk) also proved to significantly impact the investment behavior of power producers. This research could help to better understand power plant investments in liberalized markets and offers a new model addition to do so. Additionally possible new policy directions could be identified and researched using the resulting model.**

***Index Terms*—Electricity market modelling, Location Aspects, Permit procedure, Nucleolus, long term development**

I. Introduction

THIS paper will investigate the effects location decisions and permit procedures of new power plants have on an electricity market, using the agent-based modelling paradigm. [1] found that Italian gas power plant, since the liberalization, tended to be constructed in areas with the least amount of potential activism. These locations were not always located in the most optimal location for the technical requirement of that specific power plant. In empirical research based on interviews with executives of a large fraction of the Dutch power producer it became clear that permit risk plays a major role in the final investment decision for a new power plant [2]. Permit risk can be defined as the chance on delays (or worse) during preparation and construction of new power plants caused by e.g. court cases by local inhabitants or activists. So we know permit risk is taken in to account by power producer when investing in new power plants and we have reason to believe that it also impacts the final location decision, but the exact impact on the total electricity sector is unknown and what the consequences are of this risk averse behavior is also still unknown. The markets in Europe have not been liberalized for a long time yet and thus reflecting on previous investments is insufficient, an approach using modelling could help to give insights. The research question is: *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 paper will present a way to use the agent-based modelling paradigm to simulate an electricity market with location decisions and analyze the effects these decisions have on the long term development of the power sector. Specific location selection methods for power producer will be compared and the effect of the amount of activism (permit risk) analyzed. The main parameters of interest are the spatial distribution of power plants and the fuel mix of the generation capacity. EMLab-generation will be used as a base model, this is an already functioning electricity market agent-based model [3]. The data used in this paper will be based on the Dutch electricity sector.

First, in section II, we will briefly discuss the way activism is simplified and what other location aspects are considered. Secondly the base EMlab-generation model is discussed and the extension to the model to research location decisions is presented. This is done in section III. The experimental design is presented in section IV. The results will be discussed in section V and analyzed in section VI. This paper concludes with the answer to the research question and a discussion of the results in section VII.

II. Location Aspects

Some regions show a higher level of activism than others and power plant investors prefer the regions with lower levels of activism [1]. But the question is what determines the amount activism at a location? Wealth and education levels have shown to influence the amount of activism [4]. Other research suggest that the lack of understanding of other parties' views is a reason as well [5]. Furthermore the visibility of a plant also has an effect and closely related the value of open space for the local people [6]. In this model we have simplified the amount of activism factors to wealth & population density, with the addition of the public perception towards different types of generation technologies as a final component. Wealth has been chosen as it also incorporates for a large part education (very correlated). Population density is a simplification of the value of open space. Although other choices could have been made, for simplicity we believe these factors capture the important determinants in the amount of activism that a new power plant could generate. For technology specific location aspects data for the quality of water [7] and wind power data from the national weather institute have been used [8]. The activism and local opposition is a real part of the location decision as all parties can reflect their views in the permit application of a new power plants and have the opportunity to appeal

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against the issuing of the permit at court (based on the Dutch situation). So in the permit negotiations activism can play an important role, so it also plays a major role in the location decision of a new power plant by a power producer, as it permit risk was considered to be very important.

III. Model description

A. EMLab-Generation

EMlab-Generation is a model based on the agent-based modelling paradigm. Agent-based models are constructed to discover possible emergent properties from a bottom-up perspective [9]. It focusses on the the interactions and decision of individual agents and how that influences the entire system. EMlab-generation uses this to simulate the behavior of power producers in liberalized EU member states. The model is based on the AgentSpring framework [10], [11]. The main goal of the EMlab-generation project is to be able to assess the effect of different policy instruments upon an electricity market [3].

The agents in this model are power producers that own power plants and bid in their capacity in different market segments. These market segments represent the different load levels during a year. Each simulation tick represents a year. The bidding in of capacities is mainly based on marginal costs and this results in an electricity price. The EU-ECTS mechanism can also be included and the emission rights are than also traded by the power producer in a market which will result in a CO2 price. The power producer will buy (depending on their accepted capacity bids) the required fuels [3], [12]. These fuel price developments are based on IEA data [13] and the biomass price development on [14].

Besides the bidding of electricity capacity the power producer can also invest in new generation capacity. The investment is based on the net present value (NPV) of a power generation technology. The highest NPV is chosen by the power producer that wants to invest. The different technologies are defined in the input scenarios. The order of investment by power producers is random, to mitigate potential advantages for a single power producer. When an investment is made loans will be created and a powerplant will be constructed and it will be operational after a predefined number of years of construction time and permitting time (different for each technology) [3], [12].

B. Location decision extension

The location decision has to be included in the EMlab-model after the choice for a power generation technology has been made. Technologies have specific requirements for locations, as mentioned in section II. The next step is to identify several suitable locations. These locations need to be ranked and the best location is picked for the permit negotiations. When these negotiations fail, the second best location will be used for permit negotiations etc. .

This sounds rather simple and the ranking and selection of locations is simple, but the permit negotiations are more complicated. How do you model complex actor negotiations based on the permit regulations in the Netherlands? To do this several game theory concepts have been used. The most important one is the Nucleolus. Originally proposed by Schmeidler [15] , it assumes that a grand coalition will form and that it has a characteristics function which determines the 'payout' for the individual members of the coalition. The total excess is than calculated using equation 1. The excess is the difference between the value all the individual party could get on their own and together in the coalition, it would not make sense to join a coalition if the party is worse of in the coalition, this is called individual rationality (equation 2). The excess is minimized until an equilibrium is reached (equations are from [16]).

$$e_s(X) = v(S) - \sum_{i \in S} X_i \tag{1}$$

$$x_i \geq v(i) \tag{2}$$

$$s(L) = \begin{cases} \text{Accept offer} \\ \text{Opt - out for outside option} \\ \text{Counter - Offer at}(t+1) \end{cases} \tag{3}$$

A combination of the nucleolus and multiple player bargaining games [17], as shown in equation 3, will be used to conceptualize and model the permit negotiations for a new power plant at a specific location.

Power producers will pay off the government (attitude government is based on equation 7) until the government is compensated, so that the perceived environmental damages caused by the power plant have been covered (legal obligation in the Netherlands and the EU). Next the power producers get to deal with a number of local activists and compensates them until a satisfactory permit risk level is reached, or the investment is not profitable anymore and the power producer either cancels its plans or tries to get a permit at another location. The local party that is the most unhappy (highest negative utility) is payed first, this can be seen as the agent with the largest excess in terms of the nucleolus. The precise number of activists that emerge is determined using equation 4 and equation 5. A random draw from a normal distribution will be done which will be the number of activists. The standard deviationσ is based on environmental factors of the location. These environmental factors were found to influence the amount of local activism (see section II).

$$\sigma = (Density)w_{density} + (Wealth)w_{wealth} + (Technology)w_{technology} \tag{4}$$

$$amountOfLocalParties = \lfloor |\mathcal{N}(0, \sigma)| \rfloor \tag{5}$$

The permit risk will be defined as the average negative attitude of all the local parties or activists. The model thus assumes that we can express their attitude in a quantitative matter and that they will change their attitude when being compensated. The attitudes of the government and local parties will be calculated using utility functions that are based on environmental factors and can be influenced by monetary compensation payments by the power producer. The power producer has an incentive to pay local parties, because local parties can go to court and ultimately delay a project, which severely impacts the NPV of a power plant construction project. A local party can at most delay a project in this model, so they have two choices, accept money and a power plant or only a power plant. With this assumption the individual rationality equation of 2 holds and it is worthwhile to join the power producers coalition and accept payments.

For the local parties the utility function is shown in equation 6. The values in the utility function are based on a literature review that established the intervals for the parameters and the data of the specific locations in the model will determine the final values that are used to calculate the attitude of the local party. Power producers in return select locations based on utility functions of which the weight factors determine the importance of a factor. The impact of the compensation and the NPV are the basis for the power producers utility function (see equation 8 and equation 9). The utility function for the selection of a location for a thermal power plant can be found in equation 10. The weight factors can be used to investigate different ways of location selection, when creating scenarios for the simulation.

$$\begin{aligned}U_{Locals} = (RandomFactor * ((Density)w_{density} + \\ (Wealth)w_{wealth} + \\ (Technology)w_{technology} + \\ (compensation)w_{compensation}))\end{aligned} \tag{6}$$

$$\begin{aligned}U_{Government} = (EnvironImp)w_{environImp} + \\ (Employment)w_{Employment} + \\ (PreviousExp)w_{PreviousExp}\end{aligned} \tag{7}$$

$$U_{ElecGen} = (NPV)w_{NPV} \tag{8}$$

$$\begin{aligned}&NPV = (NPV_{current} - compensation) - \\ &(NPV_{current} - UtilityP * (\frac{1}{2} * NPV^{start(t+2)})) \\ \\ &UtilityP = \text{Chance on disruption} \\ &\text{action based on other parties utility} \\ &NPV^{startt+2} = \text{NPV if a delay} \\ &\text{ in construction happens} \\ &\frac{1}{2} = \text{chance of success in court based on [4]}\end{aligned} \tag{9}$$

$$\begin{aligned}&Utility(location)_{Thermal} = Utility(Density) \\ &+ Utility(Wealth) \\ &+ Utility(DistanceGrid) + Utility(QualityWater)\end{aligned} \tag{10}$$

This resulted in a model that can be used to study the impact of different ways of location selection and the impact of the permit procedure and local activism. There are a few weaknesses and possibilities for improvement. These will be presented in section VII

IV. Experimental Design

The experiments have been constructed to observe the effects of different ways of selecting locations by power producers and to analyze the effects of the permit procedure. Twenty different scenarios have been created and each one has been repeated fifty times to mitigate the effects of randomness, to which an agent-based model is very sensitive.

The following Hypothesis are tested:

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 locations based on technical aspects.

Hypothesis 2: Scenarios that have power producers incorporate activism criteria in the location selection have a different geographical distribution in generation capacity than scenarios with only technical requirements.

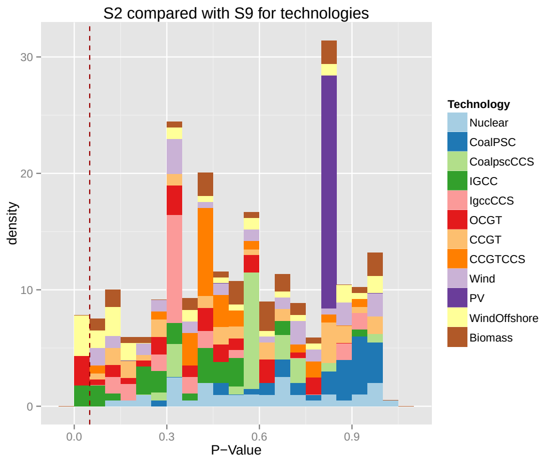
Hypothesis 3: The permit procedure causes a significant difference in the spatial and technological distribution of power plants.

Input data for the model contains data about the Dutch electricity market portfolio (based on [18] and enipedia). Stochastic fuel price and demand scenarios are used and these are based on [13]. The locations of the power plants come from the Dutch government [19]–[21]. The location data is from the Dutch bureau of statistics [22], [23]. The chance a local party succeeds in court has been set to roughly 50% and is based on research to previous environmental permit lawsuits in the Netherlands [4]. A maximum amount of generation capacity is assigned to each location and this is based on cooling water availability and capacity of nearby grids. Finally for the statistical tests used to falsify the hypothesis the population is considered to be the EMLab-generation model.

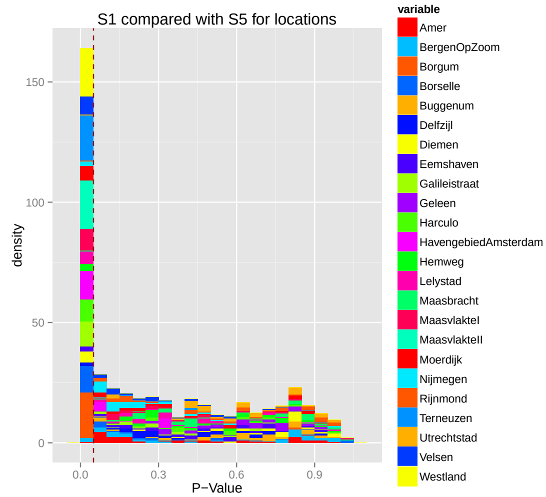
V. Results

In figure 1 four histograms are presented. These histograms contain the results of the statistical tests, to falsify the three hypotheses presented in section IV. The four histograms are for one scenario combination and there are many more combinations that have been analyzed and they all showed similar results (tested significant, but perhaps with other technologies or locations). For all the other test results please refer to https://github.com/jeroenpaling/emlab-generation/tree/LocationAspects/Report/Extra%20appendices/Graphs%20figures%20tables%20 , here all the results, data and figures are available.

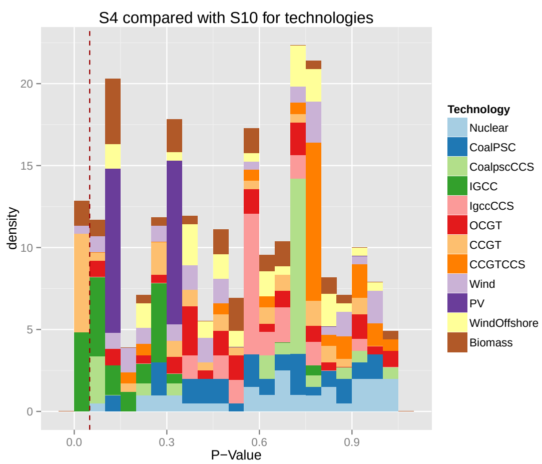
To compare the amount of generation capacity at a location, at a specific time, between two scenarios the parametric U tests has been used, as the capacity was not normally distributed. The technology capacities showed normal behavior and here t tests were used. The histograms have a dotted red line indicating the significancy level of 0.05. There are significant differences between the scenarios if there are observation in the bin left of the red dotted line. The colors either indicate the location or technology. These colors help analyze the data and



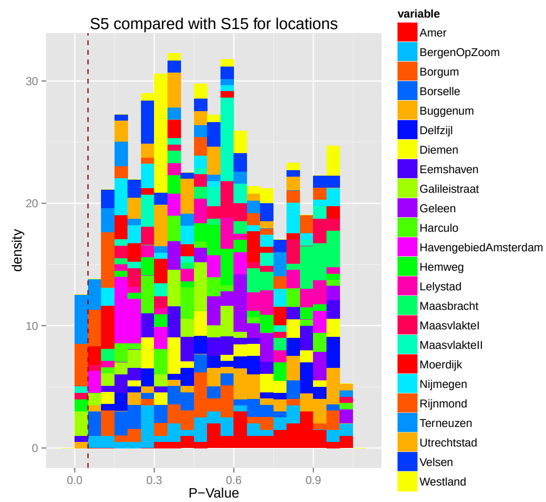
(a) Hypothesis 1 (1 scenario combination)



(b) Hypothesis 2 (1 scenario combination)



(c) Hypothesis 3 Technology (1 scenario combination)



(d) Hypothesis 3 Locations (1 scenario combination)

Fig. 1: The results of the statistical tests for all three hypothesis, for one scenario combination (as illustration). Other scenario combinations also tested significant

show which particular technology or location is significantly different.

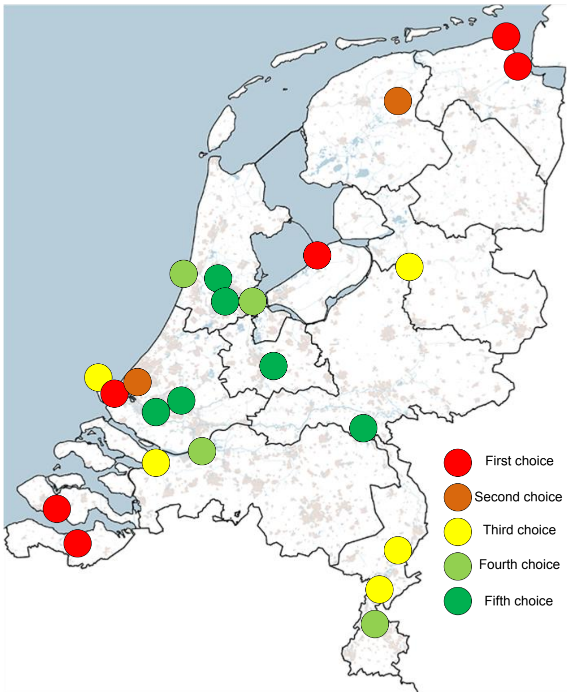
Using these figures and analyses of individual run results we can conclude that in all cases, there are significant differences between the scenarios tested. So there are differences and thus all the hypotheses have to be confirmed.

VI. Analysis

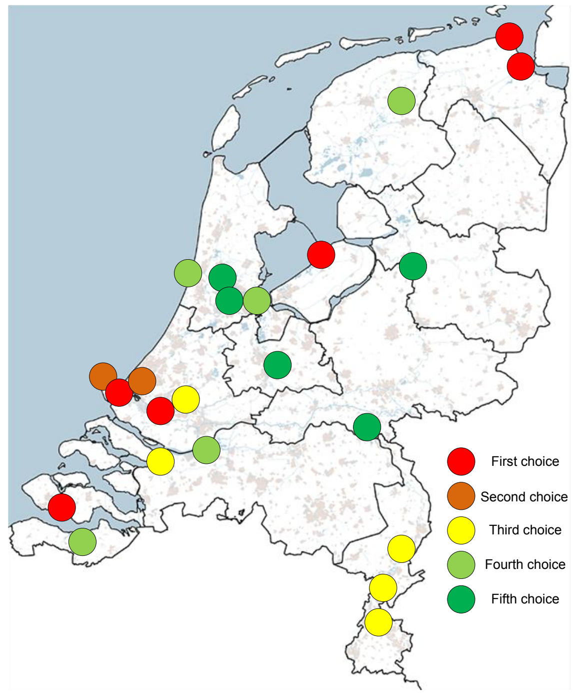
It is now interesting what we can do with these results. It suggests that the model creates a different spread of locations and technology based on the way power producers select locations. Furthermore it suggests that the model reacts significantly to different levels of activism in the permit procedure resulting in different technological and spatial distributions of power plants.

For the way power producers select locations interesting observations can be made. Some locations are always preferred over others. To illustrate this figure 2 is presented. Here the locations in the Netherlands are shown for the three different location selection methods. As you can see the red locations are mostly the same locations and they are always used first in every way of selecting locations. In the order after the first group big changes can be observed in the color pattern on the maps in figure 2. These results with perhaps more detailed scenarios can be used to assist TSOs and spatial planners to anticipate power plant investments better. It gives insight in the likelihood a new power plant will be build at a certain location.

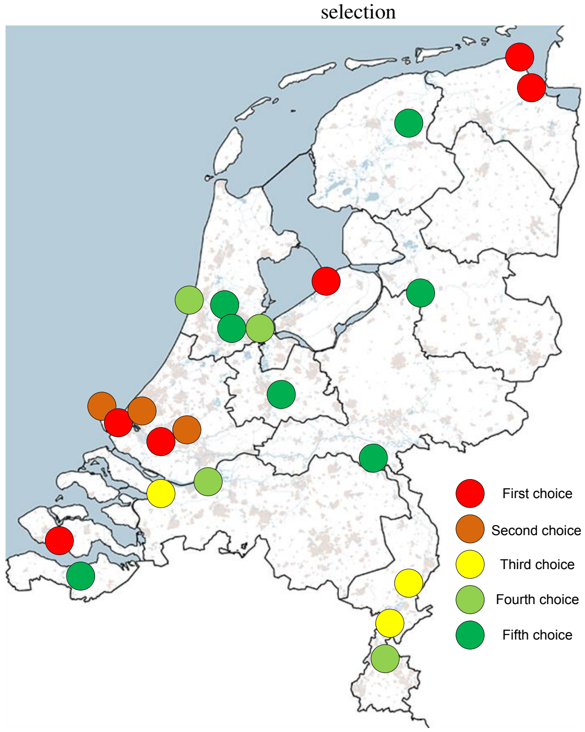
Another interesting observation has been made while testing the different scenarios. Each location has a predefined number of power plants that can be constructed. The precise amount is rather arbitrarily, but is based on the nearby grid capacity and the quality of the cooling water. It could be that all the locations are full and that there is no more room for new power plants. You would assume that lowering the amount of power plant sites will cause electricity prices to rise when all location are full and the market continues to grow. However this growth seems to be limited as the power producers started



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



(b) Order of investment for location selection based on balanced selection



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

Fig. 2: 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

to invest in off-shore wind turbines in the model. In figure 3 the different technologies and their capacities on a time scale are shown. In figure 4 the electricity price in the model is shown. We can clearly see earlier investments in renewable generation capacity in case of the low cap and a fairly limited increase in electricity price compared to the high cap scenario. We see that renewable investments take place earlier in low cap scenarios. Also we see big differences in the number of CCS plants and nuclear energy. These are interesting findings which could be used to evaluate policies and design new ones, more research with other scenarios and fuel prices is needed to say more about the effects observed here.

VII. Conclusion & Discussion

Other research suggested that the permit procedure and local activism possibilities were very important factors in the investment decision and location decision of power plants [1], [2]. The results generated by this paper were able to generate results that seem to match with the observation of these authors. It enables us to model investment decisions in more detail and also research spatial patterns of power plant siting. Additionally the way the permit negotiations are modelled is a new approach that could be used in other fields as well.

The research question was: *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?*

We have shown that the way power generators select locations, based on permit risk or based on only technological requirements can significantly change the geographical distribution of generation capacity. Additionally it showed to impact the powerplant technology portfolio. More detailed scenarios and research to real world development of the siting of power plants is needed to really conclude that the model matches with reality, but this paper presents a first step in assessing the impacts of locations decisions of power plants.

By assessing the possible effects that the permitting procedure has on the electricity market, we found that a hard cap on the amount conventional capacity at a location did not lead to a dramatic increase in electricity price compared to scenarios with location caps that were a lot higher. Power producer switched to renewable generation options like off-shore wind turbines. This is certainly worthy of extra research as it was not in the initial scope of this research and could perhaps lead to new policy directions.

We showed the possibilities to investigate patterns in investment behavior of power producers. This could help transmission system operators with grid extension and market scenarios, but also policy makers to anticipate investments better. However more detailed scenarios are required and of course the model can only help give insights, but it is a new to help validate and improve long term scenarios for the power sector.

It has to be acknowledged that there are some omissions and limitations in the current model. First of all the permit applications are handled individually and if the first succeeds a power plant will be constructed and other locations will not be assessed. It would perhaps be an improvement to let the power producer do several permit procedures at the same time and choose the best one. Furthermore the model is very data intensive, like most agent-based models. Choices for other parameters that e.g. represent permit risk could change the outcomes. This is something that always should be considered when evaluating the results. The model also lacks a representation of the transmission grid. It only considers the distance to the grid, while capacity of the grid is far more important. Power producer do consider grid connection risks according to [2]. There are also still improvements possible in the application of the game theory concepts. The possible forming of alternative coalitions that oppose the power plant would be a very interesting addition. However the model, as presented in this paper, is a step forward to further analyze and understand investments in liberalized electricity markets and could easily be adjusted for other countries, by changing the location data.

Appendix A
Scenarios

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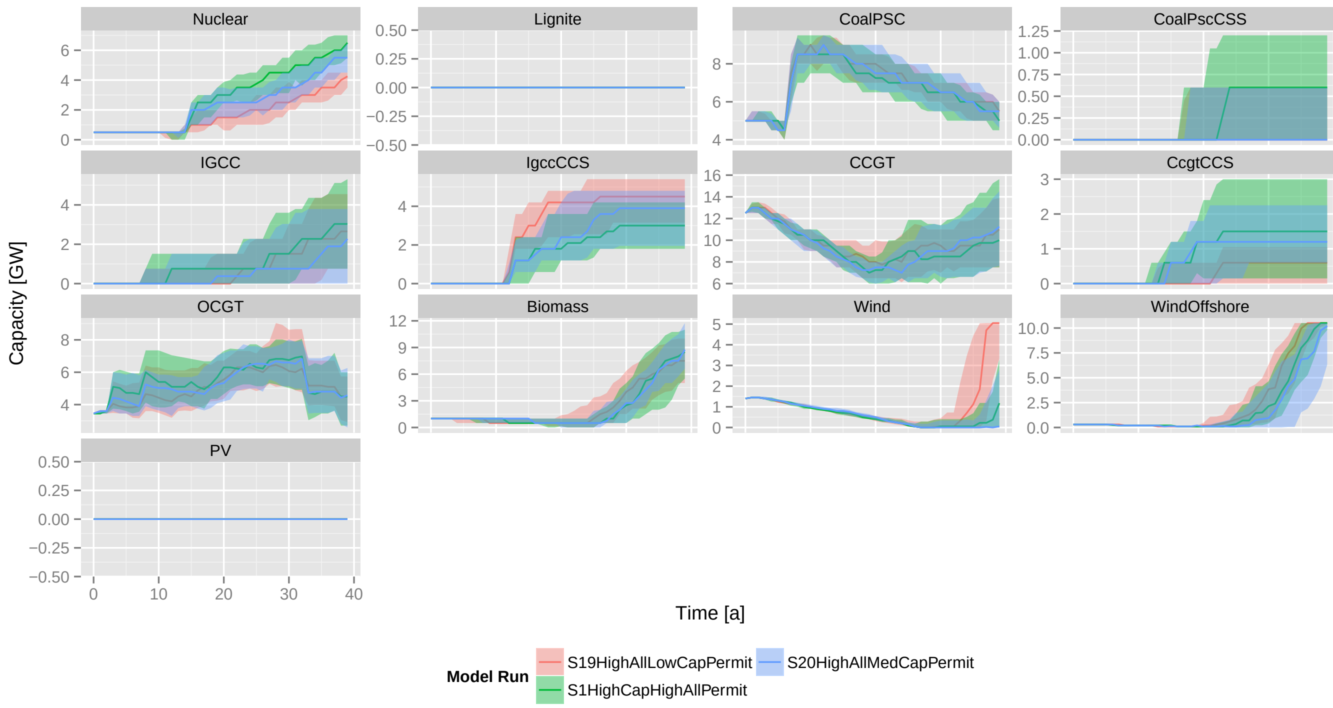

Fig. 3: Generation capacities technologies for low , medium and high Cap

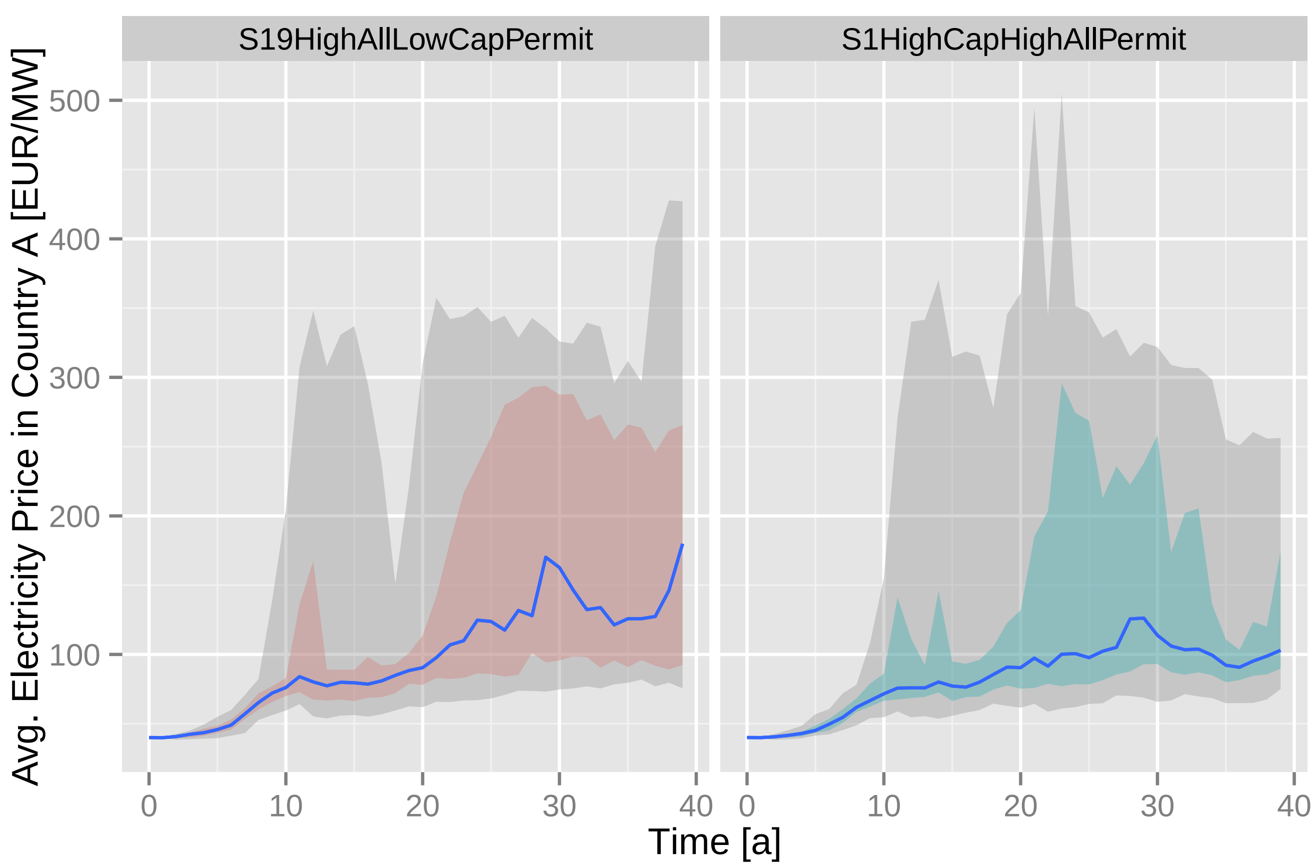

Fig. 4: Price Development High and Low cap

TABLE I: Scenarios experiments

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

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