Project - Modelling and Analysis of Sustainable Energy Systems using Operations Research

Investments in the future energy system

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1 Introduction

More and more energy is coming from renewable sources, but the energy is not dispatchable and it has to be stored or used immediately. This problem has not yet been solved perfectly and it can lead to difficult situations - such as negative prices on the spot power market. But the energy might be stored in a new way. Electric vehicles with good storage possibilities become more common. Their battery storage can be used, while the car is not used, and this leads to a new perspective on storing energy from renewable sources.

The project is based on electric grid in Denmark, focusing on electricity generated from coal plants and windmills over a year. In this project electric vehicles is added to the Danish electricity grid. They will be used as a storage, which means that they can both charge and discharge electricity from and to the grid, but they will still be used for driving, and thereby consume energy. It will be investigated if the possibility of storing energy will lead to investment in more renewables. The project does not consider import and export of energy, as the main goal is to see the effect of the electric vehicles.

The project will be divided into two main parts: "The Basic Model" and "The Extended Model". The basic model is an investment model aiming for minimizing cost, which will provide the optimal solution for investment in either coal or wind. A sensitivity analysis on the emission penalty will be performed on the basic model. In the extended model, the electric vehicles will then be added, seeing if they affect the solution. A sensitivity analysis will also be done for the extended model, by changing the efficiency of the charging and discharging, adding multiple car types and changing the driving pattern for the cars.

Through the report the following abbreviations will be used:

Abbreviation	**Meaning**
EV	Electric vehicle
CHP	Combined heat and power
O&M	Operation and maintenance

Table 1: Abbreviations used in the report

2 Basic Model

2.1 Introduction

In this study, only electricity is considered. The basic model consists of 2 technologies: wind turbines and coal CHP plants. The goal of the study is not to model the danish electricity grid as realistically as possible, but to measure the extent to which **electric vehicles can help foster investment in intermittent renewable energy.** Therefore, only these 2 technologies were chosen, with wind accounting for the variable renewable source and coal for the non-variable fossil fuel.

This section will introduce the basic model, without the implementation of EVs. Results will be tested through a sensitivity analysis on coal emission price, which increase is expected to result in more investment in wind energy and less use of existing coal power capacity.

2.2 Methodology

The model developed in this study is an investment model, with an objective of minimizing the total cost of the system. The resulting LP problem will be optimized using a dedicated software called *GAMS*.

Below is a table showing the elements of the model. There are 2 different indexes:

- **i** indexes the different technologies
- **t** indexes the time

Type	Abbreviation	Meaning
Objective	C	Cost
Parameters	v(i) e(i) om_v(i) om_f(i) inv(i) p_var_ini(i,t) max_cap_ini(i) cap_var(i,t) d(t)	Variable cost (€/MWh) Emission cost (€/MWh) Variable operation & maintenance cost (€/MWh) Fixed operation & maintenance cost (€/MW) Investment cost (€/MW) Production of variable renewable sources before investment (MWh) Capacity installed before investment (MW) Capacity factor of variable renewable sources Electricity demand (MWh)
Decision variables	p(i,t) new_cap(i)	Production (MWh) New capacity invested in (MW)

Table 2: Elements of the basic mathematical model

The LP problem can be formulated as follows:

$$\textbf{Minimize} \quad \mathbf{C} = \sum_{t=1}^{T}\sum_{i=1}^{I}[(v_i + e_i + om\_v_i) * p_{i,t}] + \sum_{i=1}^{I}[(inv_i + om\_f_i) * new\_cap_i + om\_f_i * max\_cap\_ini_i] \tag{1}$$

With the following constraints:

$$\begin{cases} \textbf{For i in base(i):} \; p_{i,t} \leq max\_cap\_ini_i + new\_cap_i \\ \textbf{For i in var(i):} \; p_{i,t} \leq p\_var\_ini_i + new\_cap_i * cap\_var_{i,t} \\ \sum_i^I p_{i,t} = d_t \end{cases} \tag{2}$$

- Equation 1 is the objective function. It states that the total cost over the whole period considered should be maximized. It takes into account all the technologies (indexed with i) and both variable and fixed costs. Although not mandatory to give the expected optimization results, fixed costs of already existing capacity have been included.

- The first two lines in equation 2 set the maximum levels of production for each technologies at each hour. It should be noted that subsets were used, as this equation is not formulated in the same way depending on the technologies. Although it would have been possible to formulate this in a single constraint, choice has been made to use two constraints for the sake of clarity.

  - For non-variable technologies (subset *base(i)*), the level of production during 1 hour is bounded by the installed capacity. No capacity factor has been taken into account, which means that 1 MW of installed capacity of coal power plant is able to produce 1 MWh of electricity during 1h.
  - For variable technologies (subset *var(i)*), the maximum level of production is bounded by the sum of the production of already installed capacity and the production of the new capacity installed. For each hour, a capacity factor was calculated by dividing the energy produced by wind turbines by the wind capacity installed. As new capacity installed will face the same conditions (e.g. wind speed) as already installed capacity, their production is calculated using the same capacity factor.

- The last line in equation 2 states that the total production should be equal to the demand for each hour. It should be noted that other ways of formulating this constraint can be found, and particularly by giving priority to variable renewables by directly subtracting their production to the demand. This has not been done here in order to avoid facing negative values for the demand. In any event, variable renewables will still be used in priority in this model, as they have the lowest variable cost.

2.3 Data and assumptions

To run the model some technological inputs is needed. The necessary constants for the production can be seen in table 3 below. The data is given for a year and the prices is in euro. The column index is used in GAMS.

	Variable cost (euro/MWh)	**O&M fixed (euro/MW/year)**	**O&M variable (euro/MWh)**	**Invest cost (euro/MW/year)**	**Initial capacity (MW)**	**Emission cost (euro/MWh)**
Column index	*1*	*2*	*3*	*4*	*5*	*6*
Coal	52	65000	2.3	104448	2521	20.4
Wind	0	33040	3.3	103963	5522	0

Table 3: The technological data input

The found data and the reference for these are: the fuel cost[1], the O&M fixed cost, the O&M variable cost[2], the investment cost (coal[3], wind[4]), the maximum initial capacity (calculated from wind energy data for 2018) and the emission cost (CO_2[5], NOx[6], sulfur[7]).

For the windmills the fixed and variable O&M cost is found by making an average based on the ratio of offshore and onshore windmills, respectively on their capacity and on their production.

The investment costs have been annualized by using the formula 3 below, with an annual discount rate[8] of 0.04 and lifetimes of 40 years for coal plants and 25 years[9] for windmills[10].

$$\text{Investment}_{\text{Annualized}} = \frac{\text{Investment} \cdot \text{Annual discount rate}}{(1 + \text{Annual discount rate}) \cdot (1 - (1 + \text{Annual discount rate})^{-\text{Lifetime}})} \tag{3}$$

Regarding coal, an efficiency of 0.5 between the energy content of coal and the plant electricity output has been taken in order to calculate the variable cost of coal power plants. In table 3, this value is indeed given for a MWh of electricity, and not a MWh of coal. In addition, data from CHP have been used, whereas this project does not take into account

[1] https://skat.dk/skat.aspx?oid=2049004fbclid=IwAR16wSjlAUk2ZjKkWvjGH-1lQmLjc2o0dNovuy2jogXYC25OJHpfxcJboT4
[2] https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_el_and_dh.pdf
[3] https://ens.dk/sites/ens.dk/files/Analyser/update_of_financial_data_for_coal_fired_chp_plants_may17_july17.pdf
[4] Same reference as footnote 2.
[5] https://www.skm.dk/skattetal/satser/satser-og-beloebsgraenser/co2-afgiftsloven
[6] https://www.skm.dk/skattetal/satser/satser-og-beloebsgraenser/kvaelstofoxiderafgiftsloven-nox
[7] https://www.skm.dk/skattetal/satser/satser-og-beloebsgraenser/svovlafgiftsloven
[8] Same reference as footnote 2.
[9] Same reference as footnote 3.
[10] Same reference as footnote 2.

the production of heat. This is an approximation that might give a disadvantage to coal in the model compared to the reality.

Wind and coal can produce energy enough to supply 70% of Denmark's demand. Therefore the demand used in the model is scaled down, so it will give a realistic results. 70% of the energy demand in 2018[11] for Denmark is showed below in figure 1.

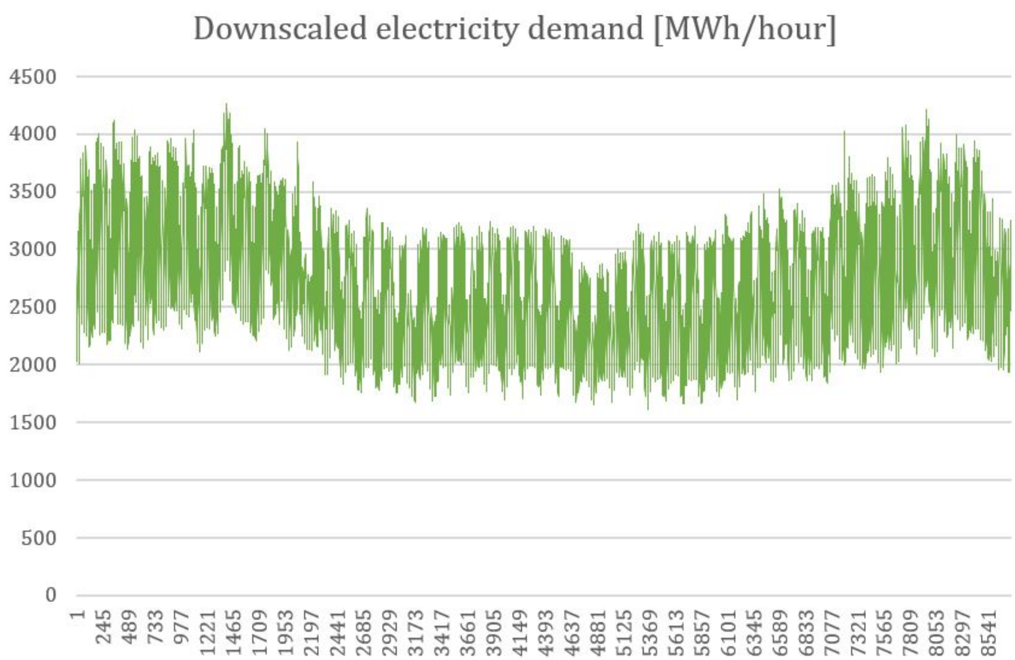

Figure 1: Down-scaled electricity data for 2018

The electricity production from windmills[12] in 2018 is shown below in figure 2. The hourly capacity factor for the wind energy is also calculated based on this data.

[11] https://www.energidataservice.dk/dataset/electricitybalancenonv/resource_extract/02356e88-7c4e-4ee9-b896-275d217cc1b9?fbclid=IwAR16BAecB7iwCrazF0cXrNqO-7ksTwyC2j3-UiwPgXhBMyjRhO7pDc5Rx34

[12] Same reference as footnote 11.

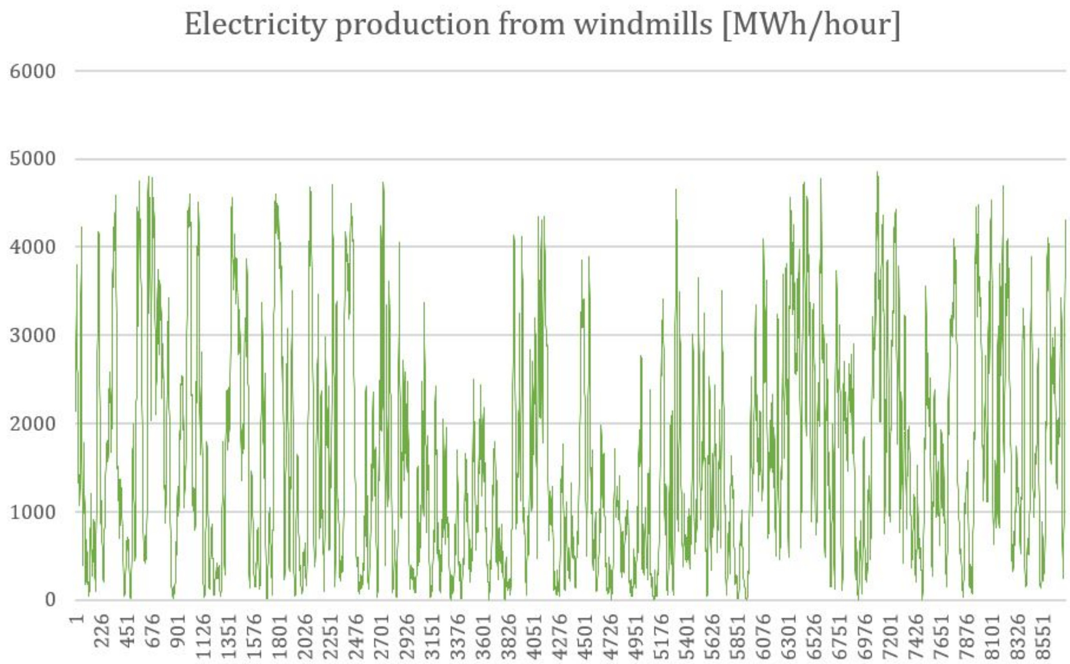

Figure 2: Electricity production from windmills in Denmark from 2018

2.4 Results

The results of the optimization process are given by the values of the total cost (objective function) and of the decision variables, i.e. the hourly production of each technology and the new capacity invested in.

Cost (M€)	1458
Investment in wind capacity (MW)	0
Investment in coal capacity (MW)	1361

Table 4: Results of basic model

These results mean that, while wind energy is used in priority - because it has lower variable cost -, the model finds it cheaper to complete the rest of the electricity needed to meet the demand with coal power. Figures 4 and 5 show the use of the different technologies, respectively during the year and during the first week of the year.

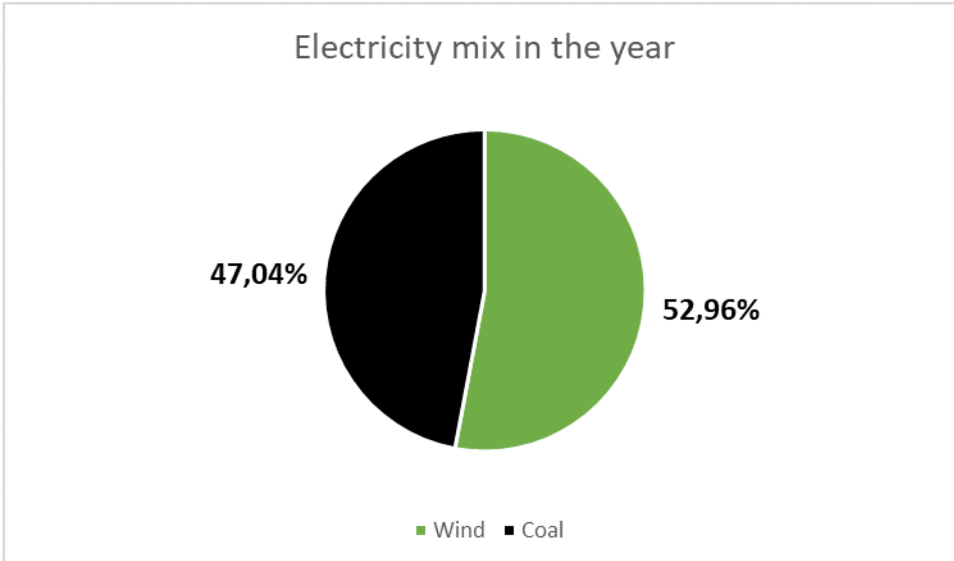

Figure 3: Electricity mix in the year

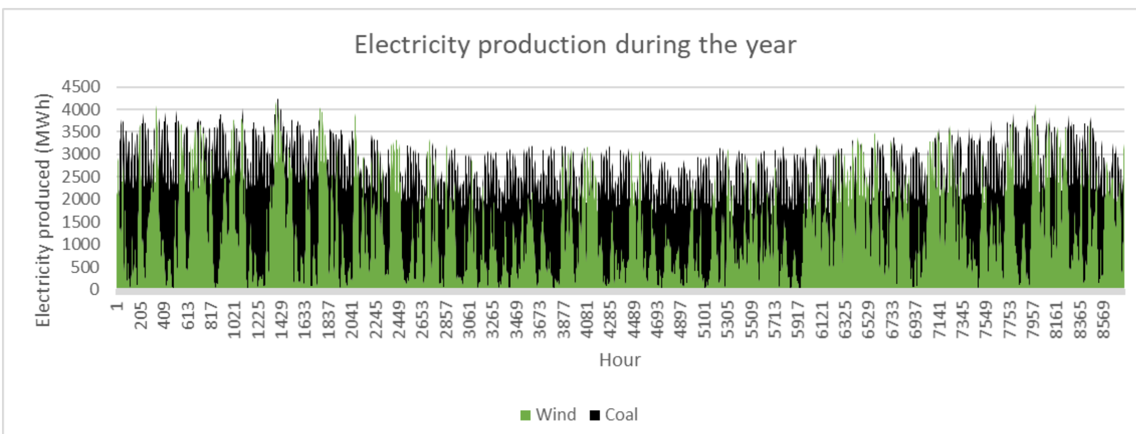

Figure 4: Electricity mix during the year

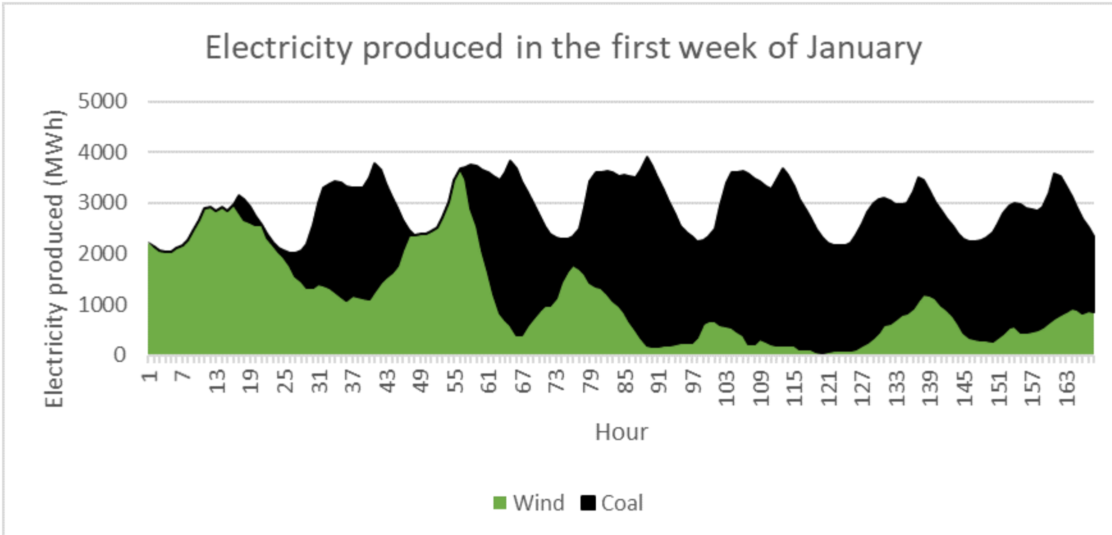

Figure 5: Electricity mix during the first week of the year

The initial power generation capacity is not enough to meet the demand at every hour. Thus, the model has to install new capacity, and it chooses to invest in coal. This could appear as surprising at first glance, since wind technology has lower variable and O&M costs than coal, as well as comparable investment cost. The reason is that wind is a variable resource, while coal is not. When existing wind and coal power is not enough to meet the demand, the model has to decide whether it should invest in wind or in coal. These two technologies are not equivalent in terms of energy output: 1 MW of coal is able to produce 1 MWh of electricity in an hour, while the electricity produced by 1 MW of wind turbines depends on the capacity factor. This gives an advantage to coal plants.

It is possible to highlight this issue by studying what would happen if we removed this variability effect. This can be done by using a constant capacity factor for wind production. Table 5 shows the optimization results when an average capacity factor of 0.29 is used to calculate the electricity produced in an hour by 1 MW of wind capacity invested in. This value of 0.29 was calculated by making an average of all the hourly capacity factors during the year.

This result is obtained by changing the last line in equation 2 in the constraints (see section 2.2.) to the following:

$$p_{i,t} \leq p\_var\_ini_i + new\_cap_i * 0.29 \tag{4}$$

Table 5 shows how fundamental variability is in the optimization results. If this aspect of wind resource were not taken into account, the model would find it less expensive to invest into wind energy, almost completely waiving investment in coal plants. This justifies the need to find a way to store the electricity produced by renewables.

	With variability	Without variability
Investment in wind capacity (MW)	0	4656
Investment in coal capacity (MW)	1361	11
Total cost (M€)	1458	1313

Table 5: Comparison of results with and without variability of wind

2.5 Sensitivity Analysis

The aim of the following section is to show how the model reacts to changes in the coal emission penalty. This type of analysis is essential when studying an energy system, as it can help quantify the efficiency of policies on emission tax.

To perform this sensitivity analysis, a loop was created in the *GAMS* code, allowing to store the results given by the model for emission costs varying between 0 and 100 €/MWh. The results are displayed below on

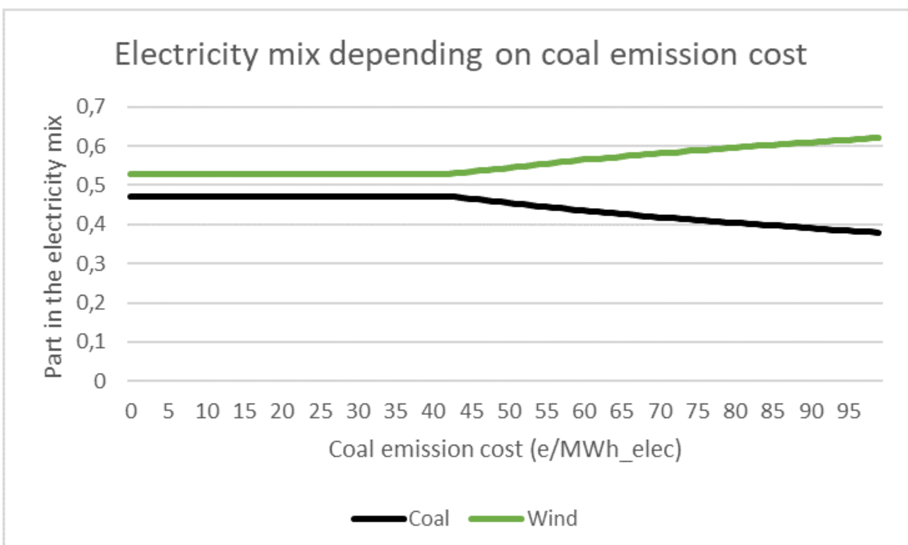

Figure 6: Evolution of the electricity mix with the emission cost

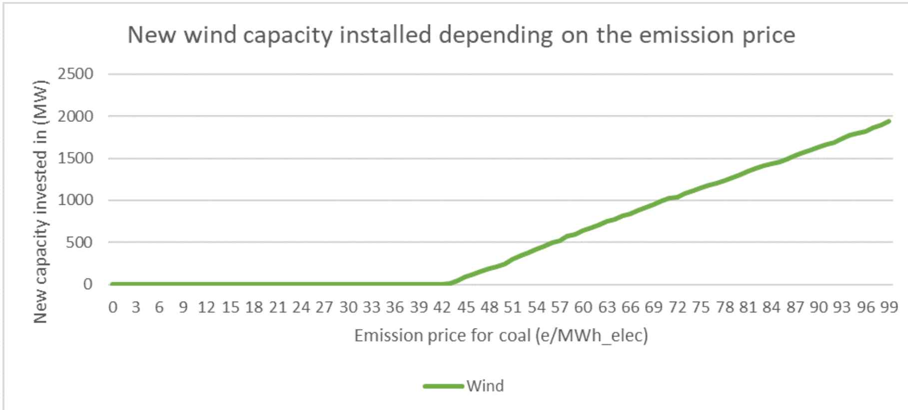

Figure 7: Evolution of the new capacity installed with the emission cost

As expected, increasing the emission penalty on coal encourages the model to invest in more wind capacity (and less coal capacity), increasing the use of wind power in the electricity mix.

An interesting aspect of figures 6 and 7 can be seen in the shape of the curves. They are both linear, but they are constant for costs ranging from 0 to 42 €/MWh. This is an crucial result, especially since the emission tax initially used in the basic model is around 20 €/MWh - exactly within this range -. Regulators should take into account this phenomenon, which can be described as a form of **inertia of the power production system**. A very small tax is likely to offer little to no incentive to switch from fossil fuels to variable renewable energy sources.

3 Extended model

3.1 EVs as storage system

As expected, the basic model is strongly limited because of the inflexible wind power generation. Since no other energy source is taking part in the model, a storage system is needed in order to give some degrees of freedom to the power system. This storage system is the extension of the assignment. For this purpose, electric vehicles (EVs) will play the role of the storage system[13].

Analogue to the power system, the current transport system seeks to achieve sustainability. Greenhouse gas emissions are bound to decrease as new clean energy sources emerge. In parallel, conventional fuel cars must give room to electric cars. The following plot obtained from International Energy Agency shows an exponential tendency of deployment of EVs. Thus, considering EVs as a storage system appears to be a relevant option for the problem in question.

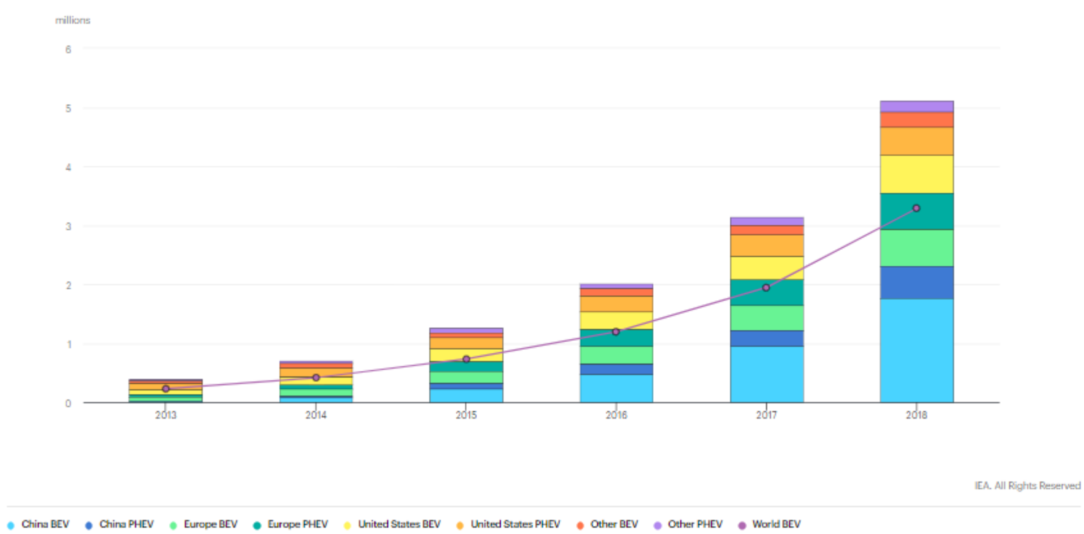

Figure 8: Electric cars deployment

The basic model results in an investment in coal plants set by the maximum difference between the demand and the wind production in the whole data set. Once the EVs are established, it is expected that the missing capacity of the worst hours of the data set is not going to be completely satisfied by new coal capacity but also with the EVs.

The expected new power balance is translated as saving costs in the total objective function with a lower investment in coal power .

[13]'Optimal configuration of an integrated power and transport system' Nina Juul *, Peter Meibom

3.2 Methodology

For the extended model, only purely electric cars are considered. Therefore, no emission or fuel costs are used.

The maximum capacity of the EVs is defined by the sum of the battery capacity of all the cars in the power system. The power taken or given to the grid by the EVs is constrained by the charge and discharge capacity. The following constraints are added to the model.

$$Storageunload_{k,t} \leq \text{Car unload capacity} \tag{5}$$

$$Storageload_{k,t} \leq \text{Car load capacity} \tag{6}$$

$$Storagelevel_{k,t} \leq \text{Maximun storage capacity} \tag{7}$$

$$Storagelevel_{k,t+1} = Storagelevel_{k,t} + Storageload_{k,t} - Storageunload_{k,t} \tag{8}$$

Where the storage load is the energy charging the EVs and the storage unload is the energy flowing to the grid. The capacities are parameter while the load and unload are positive variables. The "k" index represents the drive pattern (explained in next section).

The EVs power generation must be set in the demand constraint equation represented by the storage loaded and unloaded power variables.

$$... - \sum_{t=1}^{T}\sum_{k=1}^{K}(storageunload_{k,t} - storageload_{k,t}) * Ncars_k \tag{9}$$

Regarding to the EVs energy demand for driving, an additional demand for each driving pattern must be added to the total demand.

$$Newdemand_t = \sum_{t=1}^{T}(Demand_t + \sum_{k=1}^{K} CarDemand_{k,t}) \tag{10}$$

But a last constraint must be satisfied, that the car demand for a certain hour must be satisfied by the storage level of that cars, meaning that the car must have enough energy for the driving needs and the storage unload must be at least equal to the car demand in order to have a realistic scenario.

$$Storageunload_{k,t} \geq CarDemand_{k,t}; \tag{11}$$

$$Storagelevel_{k,t} \geq CarDemand_{k,t} \tag{12}$$

Putting this new constraints, parameters and variable to the model, the GAMS code is ready to provide new results.

3.3 Input data assumptions

New parameters and assumptions are taken for the new extended model. Technical data related to the electric car has been taken from the last model Porsche Taycan Turbo[14]. The car's consumption is calculated with the relation between the total battery capacity and the car's autonomy in miles.

Charge capacity (kW)	270
Discharge capacity (kW)	270
Battery capacity (kWh)	93.4
Range (miles)	239-279

Table 6: Technical EVs data assumed

The car's demand has to be defined but since we can not include all driving behaviors, some driving patterns must be assumed.

- For this project 20 hourly driving pattern are provide by the course files.
- The patterns are achieved by studies and they are weighted by the number of cars following a specific pattern.
- The 24 hours patterns change from a week day to a weekend day, so the annual car demand must be built in order to match with the total demand.
- The units are provide in kilometers so they must be transform in consumption (kWh) units.
- All EVs are considered connected to the grid if there is not car consumption in a certain hour.

3.4 Results

Already established the new GAMS code, some results can be analyzed. In the following table it is found an updated cost and investment model.

Cost (M€)	1406.51
Investment in wind capacity (MW)	0
Investment in coal capacity (MW)	1079.477

Table 7: Results of extended model

Comparing with the results of the basic model. It can be observed in the next figure the flexibility acquired in the first week of January, as there is overproduction of wind energy

[14]https://techcrunch.com/2019/09/04/porsche-taycan-vs-tesla-model-s-spec-for-spec-price-for-price/

in the first hours, the EVs are able to store that energy and unload it on low wind energy production hours.

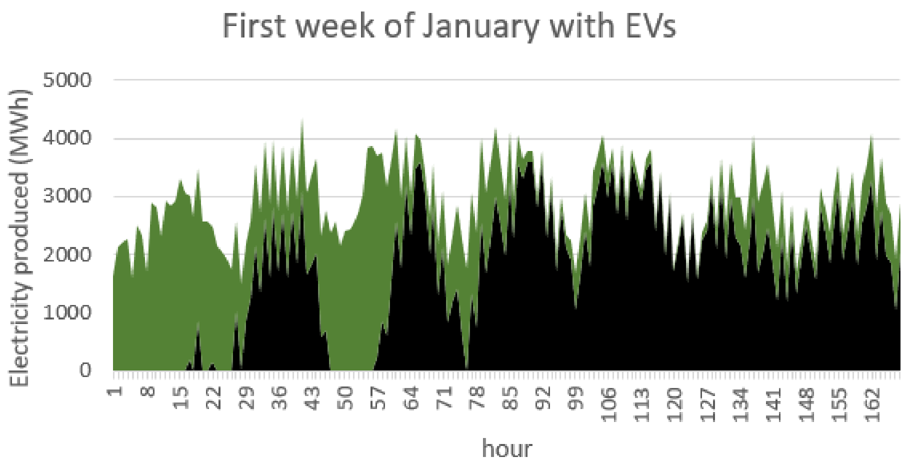

Figure 9: Electicity production in the first week of January

As expected, a lower coal consumption is obtained. From the basic model to the extension, a total of 281.5 MW of new capacity has been saved, and more than 50 millions euros. Considering that this model has been ran with 6 thousands EVs and Denmark has more than 2 millions cars registered, the model shows promising results about using EVs as storage system.

The following figure shows the light decrease of coal capacity, it is translated in a 0.3 percent difference in comparison with the basic model,

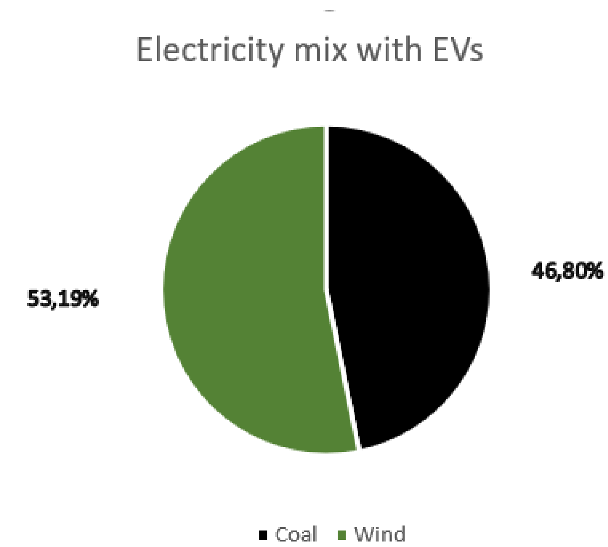

Figure 10: Electricity mix with EVs

A deeper look to the storage level in EVs can give a better evidence of the limits of the EVs in the power system. The next plot describes the behavior of the battery level in the EV pattern 20.

With a huge charging and discharging capacity, the total available storage is short compared to the potential flexibility that the batteries could provide to the grid.

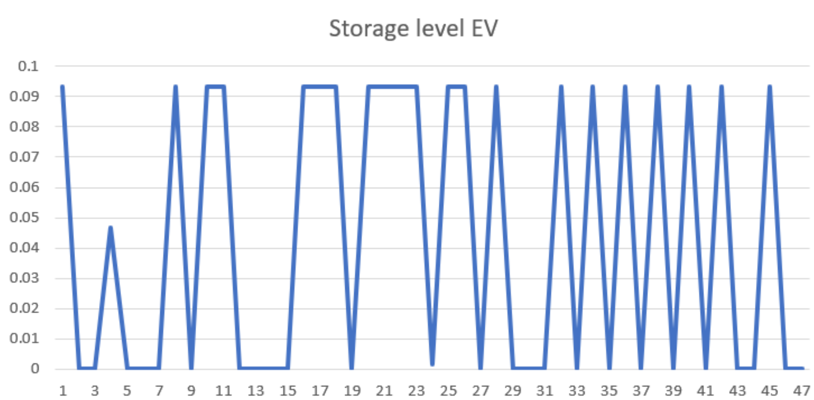

Figure 11: Storage level in EV20 (kW)

In the graph can be observed how the batteries are totally charged or discharged in just one time step, meaning that the flexibility obtained in this models just represent a little part of the potential that EVs would have in a future by increasing the number of cars.

3.5 Sensitivity Analysis

To get a better understanding for the input parameters for the electric vehicles three analysis is made: A sensitivity analysis for changing the charging and discharging efficiency, adding different types of cars to the model and changing the driving pattern for the cars.

3.5.1 Charging and discharging efficiency

In the original extended model, the efficiency for charging and discharging is 100%. To see what effect the efficiency, have on the results a sensitivity analysis is made based on changing the charging and discharging efficiency from 1% to 20%. Why the maximum efficiency used in this analysis is 20% will be described later. The aim of the analysis is to see of the investment will change and to locate the sensitivity parameter.

The sensitivity analysis is done in GAMS using a loop. The code can be seen in the file ”Power investment_extension_v4_sensitivityanalysis_efficiency.gms”. The efficiency will affect the loading and unloading for the cars, so in the loop a factor of 0.01 will be added to the parameters “car_unload_cap” and “car_load_cap” every time it runs. This will increase the efficiency by 1% starting from an efficiency of 1%. The charging and discharging efficiency are changed at the same time and with the same efficiency. A new set for the loop is defined and also new parameters for the efficiency dependent solutions.

Below in figure 12 the new investment in coal related to the efficiency can be seen. There is no new investment in wind.

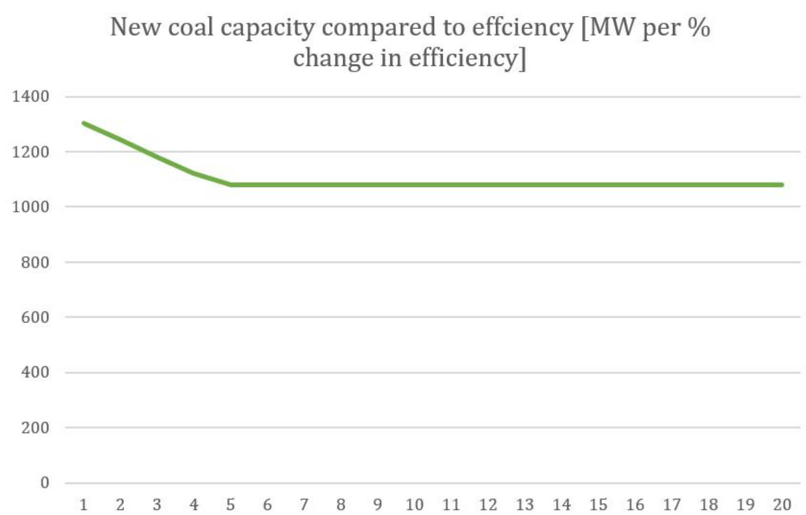

Figure 12: New investment in coal per percentage change in charging/discharging efficiency

In the figure a decrease in investment in coal can be seen when the efficiency increase. It is as expected since more energy from wind can be stored when the batteries from the vehicles is introduced. However, it is interesting, that the curve smooths out as quickly as it does. At an efficiency at 5% or more the investment is constant corresponding to the investment found for an efficiency of 100% used in the extended model. This will be due to the battery size of the car, which is the limiting factor. Even though the charging and discharging capacity for the car is large, it will not change the help in storing more energy from wind. The battery size is so limited that even if the charging and discharging efficiency was only 5% the maximum effect of implementing the electric cars would have been reached.

3.5.2 Car types

The car used in the extended model has a large battery size and high charging and discharging capacity, so it would be interesting to see how implementation of cars with smaller specification values would affect the system. To do this, two other electric vehicles is added to the system: BMW i3[15] and Hyundai Ioniq electric[16]. The specifications for these can be seen in the table 8 below. The car types are chosen because they should reflect more common bought electric cars. For example, is the BMW i3 often seen in the roads in Copenhagen.

	BMW i3	**Hyundai Ioniq electric**
Battery capacity [kWh]	42.2	38.3
Charging capacity [kW]	50	44
Discharging capacity [kW]	50	44
Range [km]	310	260

Table 8: Technological data for BMW i3 and Hyundai Ioniq electric

Three types of cars are now used in the extended model. The car types are added using the 20 different driving patterns in the existing data. Now the car “Porsche Taycan Turbo” represent the driving patterns for vehicle 1-7, “BMW i3” represents the driving patterns 8-14 and “Hyundai Ioniq electric” the driving pattern 15-20. All three cars is represented in the model at the same time.

The car types are represented in GAMS using subsets. These is represented in all affected parameters. The data for battery capacity and charging/discharging is added as well. In the model is “Porsche Taycan Turbo” type1, “BMW i3” type2 and “Hyundai Ioniq electric” type3. The code can be seen in the file ”Power investment_extension_v4_sensitivityanalysis _cartypes.gms”.

This leads to the electricity mix of coal and wind seen below in figure 13.

[15] https://www.bmw.dk/da/alle_modeller/bmw-i/i3/2017/tekniske-data.htmltab-0
[16] https://ev-database.org/car/1165/Hyundai-IONIQ-Electric

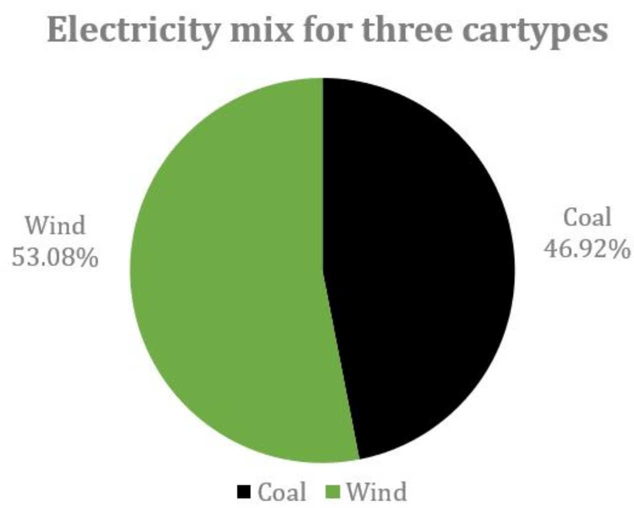

Figure 13: Electricity mix for the extended model with three car types

The data for the investment model is seen in table below.

Cost [M €]	1425.90
Investment in coal [MW]	1181.943
Investment in wind [MW]	0

Table 9: Solution for the extended model with three car types

The percentage of wind decreases 0.11% compared to the extended model only using the Porsche Taycan Turbo. This is due to the lower average battery storage. Even though the battery storage in the two new models is around 50% of the one in the Porsche, the decrease in the share of wind energy is relatively low. The model with the three different car types does still assume an efficiency of 100% for the charge and discharge of the car. In the sensitivity analysis above (section 3.5.1), the limiting factor was the battery size, so the car was charged and discharged quickly, but the full potential of this was limited due to the battery. Now the two new car types have a significant lower charge and discharge capacity and also battery size, but because their full potential might be more utilized, so the decrease in the energy production is less than expected. Still the implementation has changed the new investment resulting in a high investment in coal resulting in a larger investment cost.

3.5.3 Driving pattern

To see what effect the amount of electricity consumed for driving has on the model, the extended model is tested for a varying driving pattern. The driving pattern describes how much electricity is used every hour. The driving pattern will be decreased by 50% and then increased with steps of 10% until the driving pattern has been increased by 50% compared to the original pattern. In GAMS this is done by defining a new set, and making a loop with a loop. This is due to the dimensions of the parameter "dcars" the demand for driving. A new set "l" is going from 1 to 11, because a factor with the equation $0.1 \cdot l + 0.4$ then can be added to the demand. Thereby solutions is found for the desired variable driving pattern. The code can be seen in the file "Power investment_extension_v4_drivingpattern.gms".

Below in figure 14 is the new capacity for coal compared to the decrease and increase in the driving pattern showed. Two graphs for the percentage of wind and coal in the system is also showed in figure and figure .

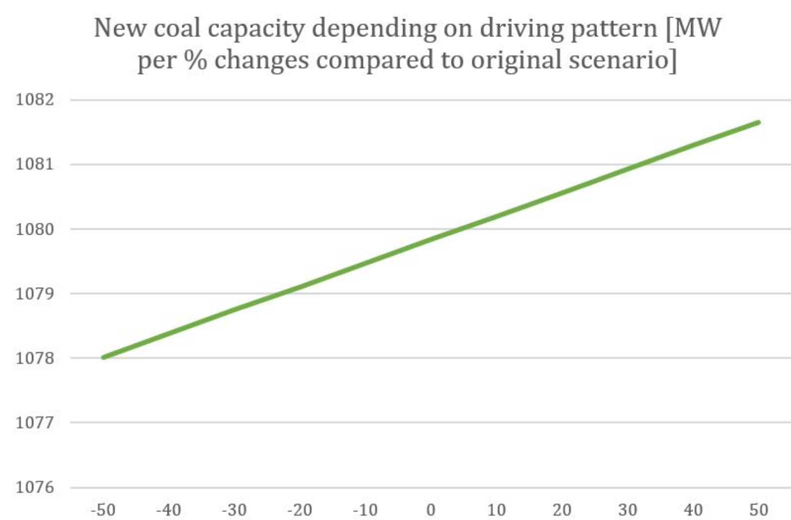

Figure 14: Coal capacity depending on driving pattern

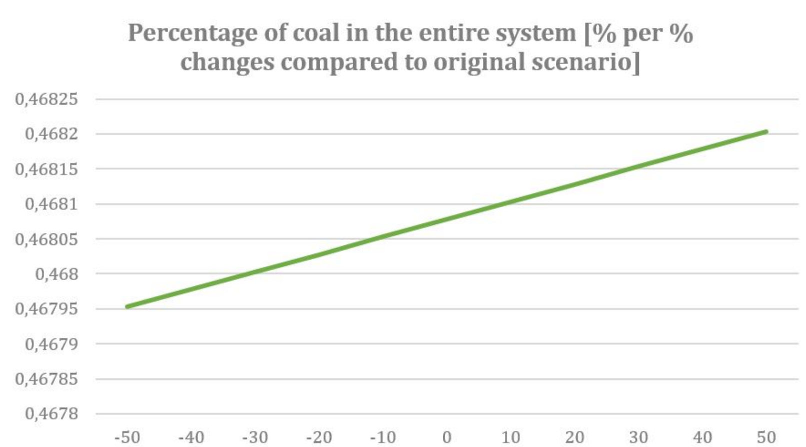

Figure 15: Percentage of coal compared to driving pattern

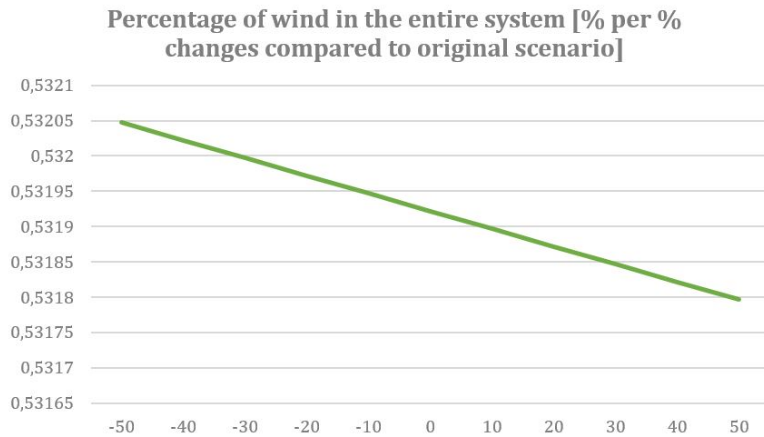

Figure 16: Percentage of wind compared to driving pattern

The new capacity for wind is zero. The figures show a linear correlation between the electricity used and electricity invested. This is due to a bigger request for energy. The percentage of wind is increasing as less electricity is used for driving. This makes sense since there is less electricity consumed and more capacity for storage.

It could also be interesting to see what would happen to the electricity mix if the electricity consumption for driving was zero and the cars was only used for storage. This is modeled in GAMS by setting the demand for driving to zero. The code can be found in the file "Power investment_extension_v4_no_driving.gms". Below in figure 17 the electricity mix can be seen.

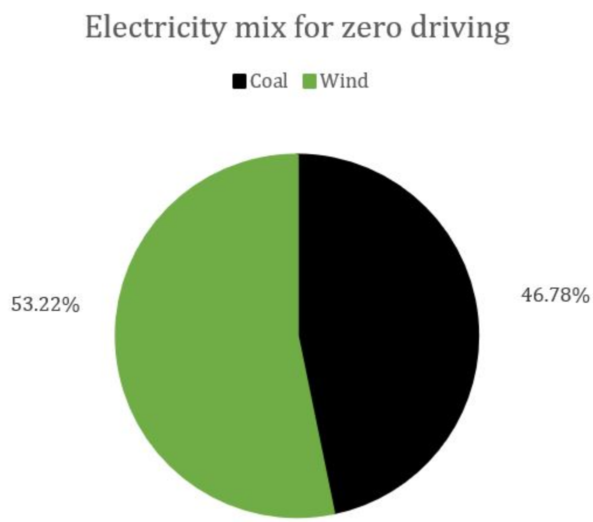

Figure 17: Electricity mix when using the electric vehicles only as storage

This shows a slightly increase of 0.03% in the electricity from wind energy compared to the original extended model. This is almost negligible, and it shows, that even though some electricity is used for driving, implementing of the electric vehicles to the system can make an impact in storage of energy from renewable sources.

4 Conclusion

Variability of renewable energy sources appears as a crucial challenge that needs to be addressed by efficient policy measures. Although renewables are in theory able to compete with fossil fuels, their potential intermittent aspect gives them a disadvantage compared to conventional sources.

Financial incentive - for example through emission tax - could be an appropriate answer, but it needs to take into account the ***inertia* of the system** (c.f. section 2.5.).

The possibility of storing the electricity produced by variable renewables is a promising prospect. It can be done by taking advantage of EVs which will surely develop at a large-scale in the years to come. The results of the project show that **they can indeed help foster investment in variable renewables by dispatching the electricity produced.** However, it must be noted that this technology is not primarily fitted for this purpose of storing energy. Its efficiency depends on external factors such as the driving behaviors of drivers. Other options should be considered, such as using stationary batteries that are designed for this very purpose.

Finally, it is important to keep in mind the limits of the model built for this project. It considers only two technologies, and all the decisions are based on a single constraint. The reality is more complex, as choosing to use one plant rather than another one depends on various other aspects - ramp-up and ramp-down, interaction between the different power markets, interconnections with other countries,... The central outcome of the project is not the exact numbers obtained, but rather the trends and phenomena brought to light.

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