Analyzing the market value of wind and solar power for different electricity markets

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1. Introduction

Power generation from renewable energy is on the rise. By 2018, the installed capacity of wind and solar was approximately 1043 GW worldwide [1]. In 2017 renewable energy represented 17.5 % of energy consumed in the EU [2]. The European Union's target is to obtain 20% of energy in gross final consumption of energy from renewable sources by 2020 and at least 32% by 2030. To reach these targets much of the growth will need to come from wind and solar power because hydro power had been developed in many countries and biomass has supply constraints limiting its growth.

The challenge that renewable energy poses is its variability due to its dependence in weather conditions, that is problematic for power systems integration, this affects the economics of the renewable generation. Market value represents this loss in economic value, it is affected by three intrinsic technological properties. First, its variability, that determines when the electricity is produced. Second, the uncertainty of output leads to forecast errors that have to be balanced and this cost money. Third, dependence on location, generally the windy sites are far from load centers, and this reduces the value of wind power. Another way to see the market value is as the revenue that generators earn on markets regardless the income from subsidies.[3]

The relative market value is the so-called value factor, that is the market value compared to the base price. A decreasing value factor of wind implies that wind power becomes less valuable as a generation technology compared to a constant source of electricity.

The problem that we will address in this project is that the revenue of renewable generators on electricity markets reduces with the increasing share of renewable capacities in the market. i.e., the market value and value factor decrease. This price drop varies for different electricity markets that are based on different generation technologies. Then we are going to create a model that calculate the market value and value factor for the time period of 2016 to 2018 for Germany, Sweden and France, we will compare how the decrease in market value and value factor changes from different countries, and we will explain why there are countries that have more flexibility in their power systems than others.

2. Method and Model description

2.1 Modeling Methodology

Our model takes as input the generation of technologies such as wind or solar, the price of electricity, the total generation of electricity and then it calculates the shares of wind and solar in each year and also calculates de market value and value factor of wind and solar.

The "market value" is defined as:

$$\bar{P} = \frac{\sum_{t=1}^{T} W_t P_t}{\sum_{t=1}^{T} W_t}$$

Where:

$\bar{P}$: Market value of solar or wind power

$t \in T$: Time period of a year

W_t: Generation of solar or wind power

P_t: The equilibrium electricity price

The "value factor" is defined as:

$$VF = \frac{\bar{P}}{\frac{1}{T}\sum_{t=1}^{T} P_t}$$

After the calculation of market value and value factor, we proceed with a linear regression to model the relationship between the market value with share, and value factor with share of solar and wind generation, then the graphs of market value and value factor of wind and solar were generated. Besides, a regression report is generated as a csv file which contains all the relevant information of the linear regression as regression function, R^2, RMSE (Root Mean Square Error). This can be seen in annex B.

In addition to the data calculated of market value and value factor for the three countries in this study in the time period of 2016-2018, a research was carried out to find data already calculated for past years. Data was found for the market value and value factor of solar and wind for Germany in the time period of 2001 to 2015, and data for the value factor of wind in the time period of 2007 to 2010. Taking the additional data and combining them with the data calculated by our team a better linear regression was generated since more points were available.

In Figure. 1. can be seen the flowchart of the methodology used, it can be observed the overview of the process we carried out for this study.

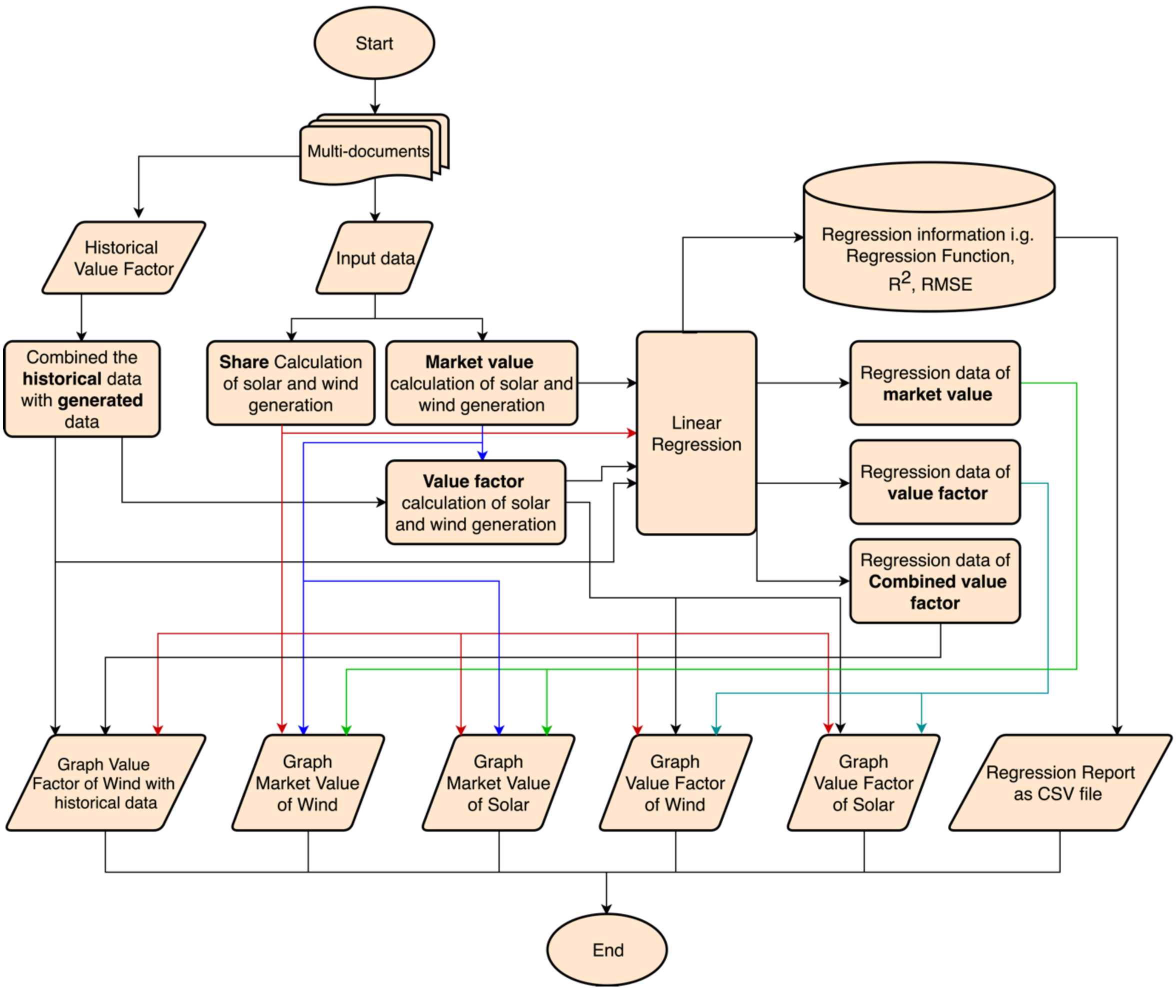

Figure 1. Flowchart of the methodology used to analyze the market value and value factor of wind and solar.

2.2 Input Data

Our model takes as inputs the generation of technologies such as wind or solar in MW , the price of electricity in EUR/MWh, the total generation of electricity in MW and then it calculates the shares of wind and solar in each year and also calculates de market value and value factor of wind and solar.

The input data was taken from different sources, the data for Germany comes from the database Open Power System Data [4], the data for the electricity price for Sweden comes from Nordpool [5], the data for the electricity price for France comes from EPEX website [6].

Since it was difficult to find the raw data, we did the model to calculate for three years, that was the data we could found for the three different countries mentioned before. It is important to highlight that our code is done in a way that if more data is available then it is easy to include it in the model. Besides, we wanted to make a linear regression but with just three points calculated for each country it is not enough to make a good regression, for this reason we decided to look in the literature for values already calculated to allow us to do a better regression and analyze the historical behavior of the market value and value factor with increasing share. We were looking for all the data we could get for the three countries and we found the value factor of wind for Germany from 2001 to 2015 and for Sweden we found the value factor of wind from 2007 to 2010.

2.3 Assumptions

- Data of electricity generation from solar and wind was used to calculate the market value and value factor respectively, and imports and exports were not considered.
- There were 18 data missing for the price of France in 2016 and 17 for 2017, the data missing was assumed to be the same as the last 18 data in the file.
- In the files of equilibrium electricity price for France were missing 6 values for years 2016 and 2017, it was assumed that these values were the average of the values immediately before and after.
- Solar generation from Sweden was so small that it was omitted for the calculations of market value and value factor.
- The price of Sweden was calculated as the average of the price of the four bidding zones.

3. Results

In Figure 2 can be observed the behavior of the Value Factor of Wind for Germany and Sweden, the figure shows that the value factor decreases for both countries but the decrease for Germany is faster than the decrease for Sweden. The R squared of Germany was 0.768, and the R squared of Sweden was 0.637, these values are considered to be not the best result of fitting, however they are higher than 0.6 that can be consider as a reliable fitting. The slope for Germany is 2.75 times steeper than the slope for Sweden. The slope for Germany is -0.011 and the slope for Sweden is -0.004, meaning that for every increase of 1% in share of wind the value factor for Germany will decrease 0.011 and the value factor for Sweden will decrease 0.004. Besides it is shown that the wind value factor for Sweden during the period of time studied was higher than the wind value factor of Germany. Further regression information for value factor of wind please check the Annex B, Table 6.

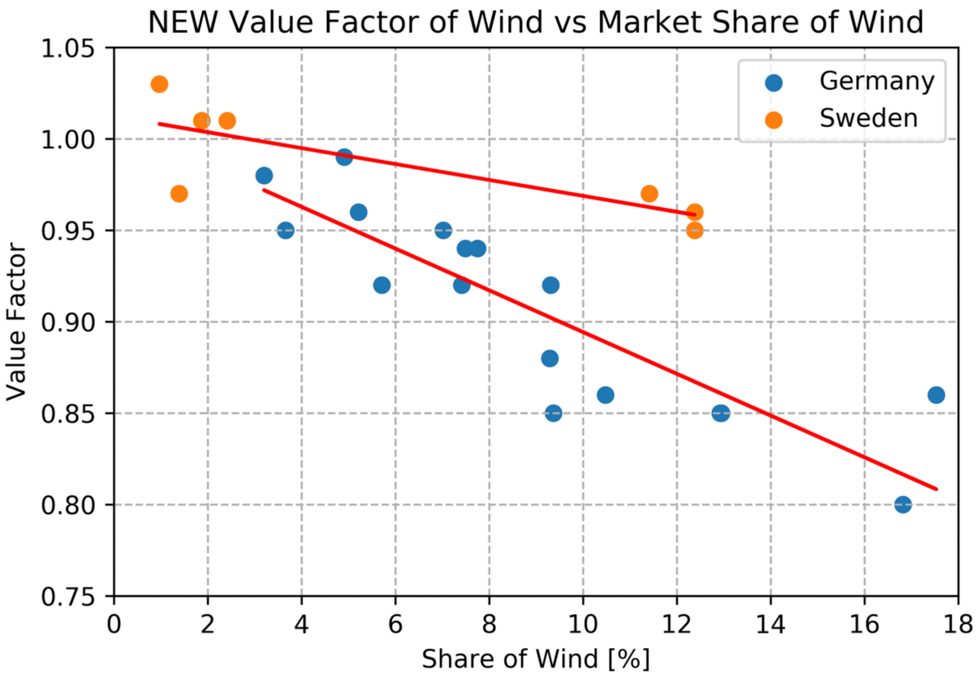

Figure 2. Value factor of wind vs market share of wind for Germany and Sweden from 2001 to 2018.

In Figure 3 is compared the value factor for solar and wind in Germany. The R squared of wind was 0.768, and the R squared of Sweden was 0.833, these values are considered to be not the best result of fitting, however they are higher than 0.6 that can be consider as a reliable fitting. It can be seen that the slope for solar is steeper than the slope for Germany for 3.54, meaning that the solar value factor decreases faster than the wind value factor for Germany . For every increase in share of 1% the value factor of solar decreases 0.039 while wind will decrease 0.011. Besides, it is observed that in the range of market share from 0 to 7.5% the solar value factor was higher than the wind value factor. However, if the tendency continues at shares higher than 7.5% the solar value factor would be lower than the wind value factor. Further information please check the Annex B, Table 6.

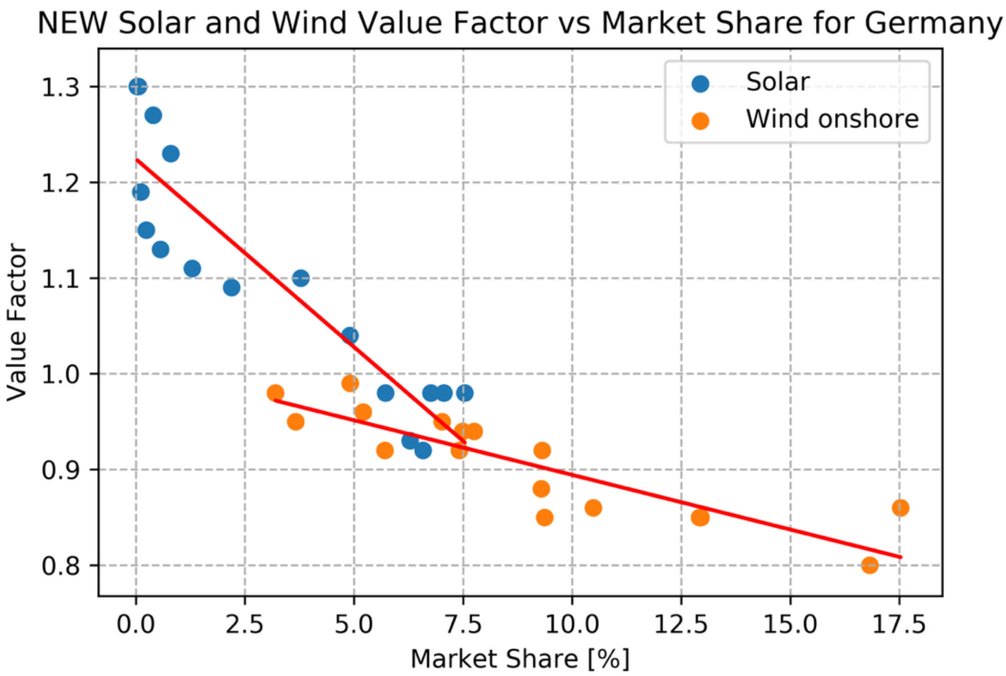

Figure 3. Solar and wind value factors for Germany from 2001 to 2018.

In Figure 4 can be observed the behavior of the market value of solar for Germany and France, the figure shows that increasing the share of solar, the market value will increase at the same time for both countries but the increased speed for France is faster than the increased speed for Germany. The R squared of Germany was 0.998, and the R squared of France was 0.999, these values are considered to be the excellent results of fitting, thus these two fitting can be consider as a reliable fitting. The slope for France is 2.52 times steeper than the slope for Germany. The slope for France is 33.862 and the slope for Germany is 13.406, meaning that for every increase of 1% in share of solar the market value for France will increase 33.862 EUR/MWh and the market value for Germany will increase 13.406 EUR/MWh. Furthermore, it is shown that the solar market value for France during the period of time studied was higher than the solar market value of Germany. Further regression information for market value of solar, please check the Annex B, Table 4.

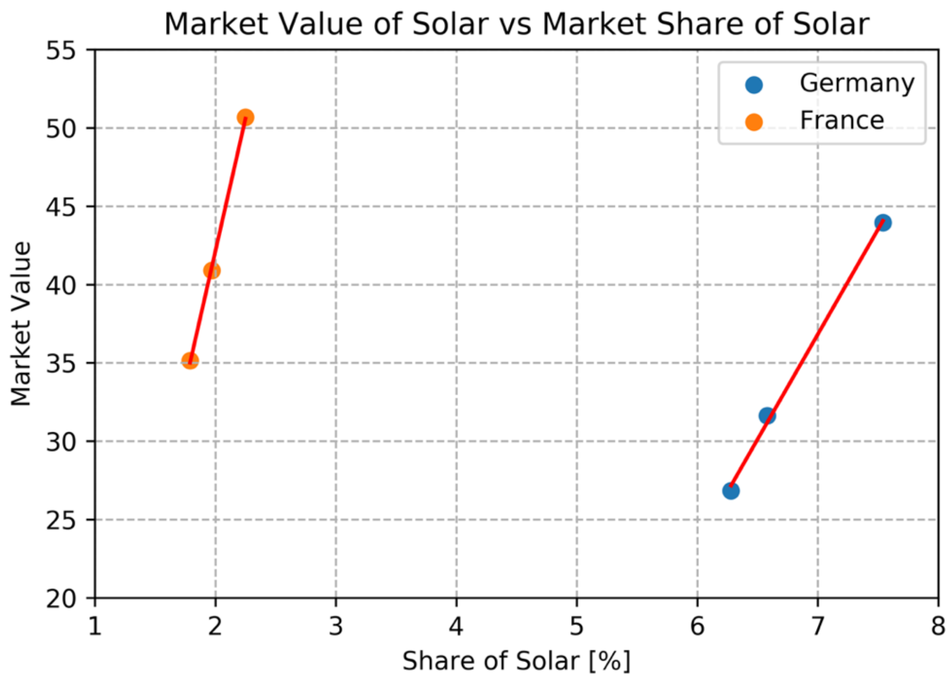

Figure 4. Market value of solar vs market share of solar for Germany and France 2016-2018.

In Figure 5 can be observed the behavior of the market value of wind for Germany, Sweden and France, the figure shows that increasing the share of wind, the market value will increase at the same time for all countries but the increased speed for France is faster than the increased speed for Germany and Sweden. The R squared of regression for Germany, Sweden and France are 0.579, 0.33 and 0.942 respectively. The value for France is a totally reliable fitting. Although the value for Germany is a little bit less than 0.6, it still can be trusted in this studied. Unfortunately, the R squared for Sweden cannot be a reliable regression result. The slope for France is 4.3 times sharper than the slope for Germany. The slope for France is 9.71, the slope for Germany is 2.25 and for Sweden is 8.19 meaning that for every increase of 1% in share of wind the market value for France will increase 9.71 EUR/MWh, the market value for Germany will increase 2.25 EUR/MWh and for the Sweden is 8.19 EUR/MWh. Additionally, it is shown that the wind market value for France during the period of time studied was higher than the wind market value of Germany and Sweden. Further regression information for market value of wind, please check the Annex B, Table 4.

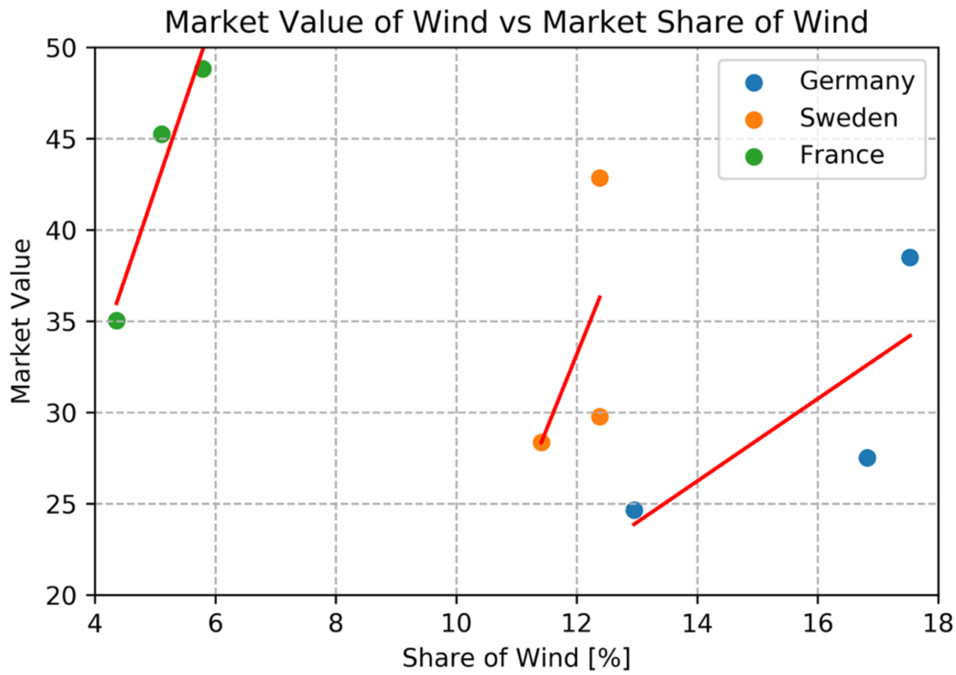

Figure 5. Market value of wind vs market share of wind for Germany, Sweden, and France 2016-2018.

In Figure 6 can be observed the behavior of the value factor of solar for Germany and France, the figure shows that increasing the share of solar, the market value will increase at the same time for these two countries but the increased speed for France is faster than the increased speed for Germany. The R squared of regression for Germany and France are 0.858 and 0.478 respectively. The value for Germany is a totally reliable fitting. Unfortunately, the R squared for France cannot be trust as a reliable regression result. The slope for France is 3 times sharper than the slope for Germany. The slope for France is 0.15 and the slope for Germany is 0.045 meaning that for every increase of 1% in share of solar the value factor for France will increase 0.15 and the value factor for Germany will increase 0.045. Additionally, it is shown that the solar value factor for France during the period of time studied was higher than the wind market value of Germany. Further regression information for value factor of solar, please check the Annex B, Table 5.

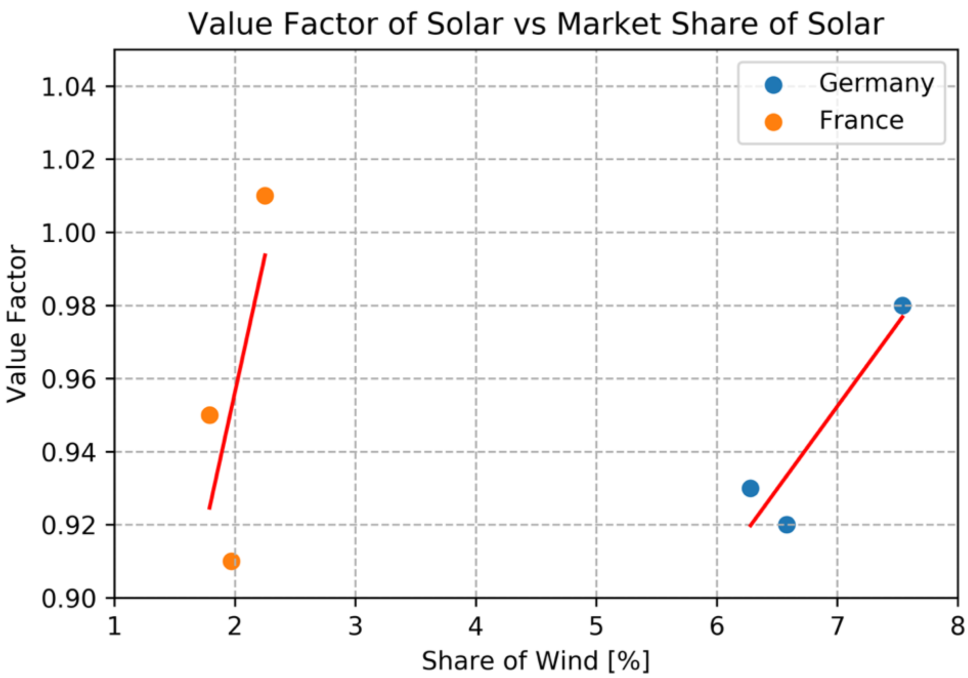

Figure 6. Value factor of solar vs market share of solar for Germany and France 2016-2018.

In Figure 7 can be observed the behavior of the value factor of wind for Germany, Sweden and France, the figure shows that increasing the share of solar, the market value for Germany and Sweden will decrease at the same time but for the France is increased instead. The R squared of regression for Germany, Sweden and France are 0.049, 0.75 and 0.125 respectively. Only the value for Sweden is a reliable fitting. Unfortunately, the R squared for Germany and France cannot be trust as a reliable regression result. The slope for Germany is -0.003, the slope for Sweden is -0.015 and the slope for France is 0.015, this meaning that for every increase of 1% in share of wind the value factor for Germany will decrease 0.003, for Sweden will decrease 0.015 and for France will increase 0.015. Additionally, it is shown that the wind value factor for France during the period of time studied was higher than the wind market value of Germany and Sweden. Further regression information for value factor of solar, please check the Annex B, Table 4.

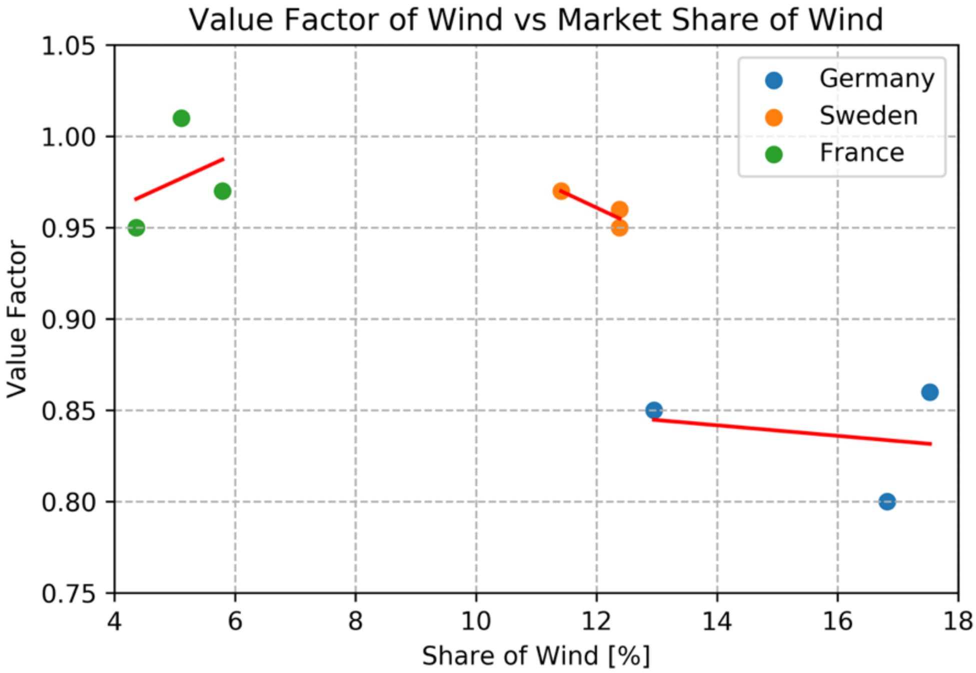

Figure 7. Value factor of wind vs market share of wind for Germany, Sweden, and France 2016-2018.

4. Discussion & Conclusion

4.1 Discussion

In figures 2 and 3 it was evident that with increasing penetration of wind and solar the market value of this renewable energy decreases, meaning that wind and solar power becomes less valuable as a generation technology. This is called in the literature as the cannibalization effect that is the result of extra supply depressing the price and then decreasing the market value of solar and wind.

One important aspect to emphasize is that the decrease was faster in Germany than in Sweden. A reason for this behavior is because Germany is a power system that is dominated by thermal generation technologies (as can be seen in the historical data in Annex C. Figure 8.) contrary to Sweden that is a power system with a large quantity of hydropower (as it is shown in the historical data in Annex C. Figure X.) This hydroelectricity provides flexibility to the system because they have a water inflow during the year and choose when to generate electricity, leading to more stable prices and helping to reduce the decrease of market value of wind and solar.

In figures 4, 5, 6 and 7 the trend was that with increasing share of wind and solar the market value increased, however this is not totally right if we consider the historical behavior.

4.2 Conclusion

From the model output of the market value and value factor for wind and solar that was calculated for the last three years (2016-2018) it was observed that the behavior of market value and value factor for the majority of countries was increasing. However, taking into account the historical values for value factor of wind and solar in Germany, their behavior was that with increasing penetration of solar and wind, the value factor was decreasing. This is totally opposite to the results calculated with our model. But it is important to highlight that for our model just three years were considered and to make a linear regression and observe a trend it is more reliable to have more points.

4.3 Model enhancement

To enhance our model, it would be necessary to have more historical data that allows the calculation of the value factor and market value of different countries to have a better linear regression or if the tendency does not show a linear behavior, another way of fitting could be considered.

Another aspect that could improve the model is to do sensitivities, for example varying the price of CO_2 prices and see how this change affects the market value for solar and wind, also it could be considered the sensitivity for the storage capacity of the different countries and see how adding flexibility to the system helps to improve the market value.

4.4 Problems

At first, we wanted to model the historical behavior of the market value since 2000 for different countries but we faced a lot of problems finding the data we needed to calculate the market value and value factor, then we asked the tutors and they recommend to do it for the last three years.

Also, we wanted to calculate the levelized cost of electricity LCOE to plot it together with the market value and see the intersection of these two curves as represented in Figure 11. In order to find the optimal share of wind and solar for the countries that were studied. The problem was that we did not find the row data to calculate it and we also looked for the LCOE already calculated annually witout success.

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C. Division of tasks

Research of the topic, data research:
- Both

Implementation of the code
- Both

Report:
- Both

D. Tables

Table 1. Shares of solar and wind electricity generation for Germany (DE), France (FR) and Sweden (SE).

	Solar_DE (%)	Wind_DE (%)	Solar_FR (%)	Wind_FR (%)	Wind_SE (%)
2016	6.28	12.95	1.79	4.36	11.41
2017	6.58	16.82	1.97	5.11	12.38
2018	7.54	17.53	2.25	5.79	12.38

Table 2. Market Value of solar and wind for Germany (DE), France (FR) and Sweden (SE).

	Solar_DE (EUR/MWh)	Wind_DE (EUR/MWh)	Solar_FR (EUR/MWh)	Wind_FR (EUR/MWh)	Wind_SE (EUR/MWh)
2016	26.84	24.66	35.14	35.04	28.36
2017	31.63	27.52	40.89	45.25	29.77
2018	43.96	38.5	50.67	48.83	42.84

Table 3. Value Factor of solar and wind for Germany (DE), France (FR) and Sweden (SE).

	Solar_DE (-)	Wind_DE (-)	Solar_FR (-)	Wind_FR (-)	Wind_SE (-)
2016	0.93	0.85	0.95	0.95	0.97
2017	0.92	0.8	0.91	1.01	0.95
2018	0.98	0.86	1.01	0.97	0.96

Table 4. Report of the linear regression for the scatter points of market value against shares for wind and solar for Germany (DE), Sweden (SE) and France (FE).

	DE_wind_MV	SE_wind_MV	FR_wind_MV	DE_solar_MV	FR_solar_MV
Regression Function	y = 2.256x + (-5.344)	y = 8.191x + (-65.096)	y = 9.711x + (-6.358)	y = 13.406x + (-57.018)	y = 33.862x + (-25.604)
R^2	0.579	0.33	0.942	0.998	0.999
RMSE	14.96883	28.47082	1.96852	0.10374	0.02339
Slope	2.256	8.191	9.711	13.406	33.862
Intercept	-5.344	-65.096	-6.358	-57.018	-25.604

Table 5. Report of the linear regression for the scatter points of value factor against shares for wind and solar for Germany (DE), Sweden (SE) and France (FE).

	DE_wind_VF	SE_wind_VF	FR_wind_VF	DE_solar_VF	FR_solar_VF
Regression Function	y = -0.003x + (0.882)	y = -0.015x + (1.146)	y = 0.015x + (0.9)	y = 0.045x + (0.636)	y = 0.15x + (0.656)
R^2	0.049	0.75	0.125	0.858	0.478
RMSE	0.00066	2E-05	0.00054	0.0001	0.00088
Slope	-0.003	-0.015	0.015	0.045	0.15
Intercept	0.882	1.146	0.9	0.636	0.656

Table 6. Regression report for the combined data (calculated and the data found in literature)

	NEW_DE_Wind_VF	NEW_SE_Wind_VF	NEW_DE_Solar_VF
Regression Function	y = -0.011x + (1.008)	y = -0.004x + (1.012)	y = -0.039x + (1.224)
R^2	0.768	0.637	0.833
RMSE	0.00065	0.00029	0.00256
Slope	-0.011	-0.004	-0.039
Intercept	1.008	1.012	1.224

E. Additional Figures

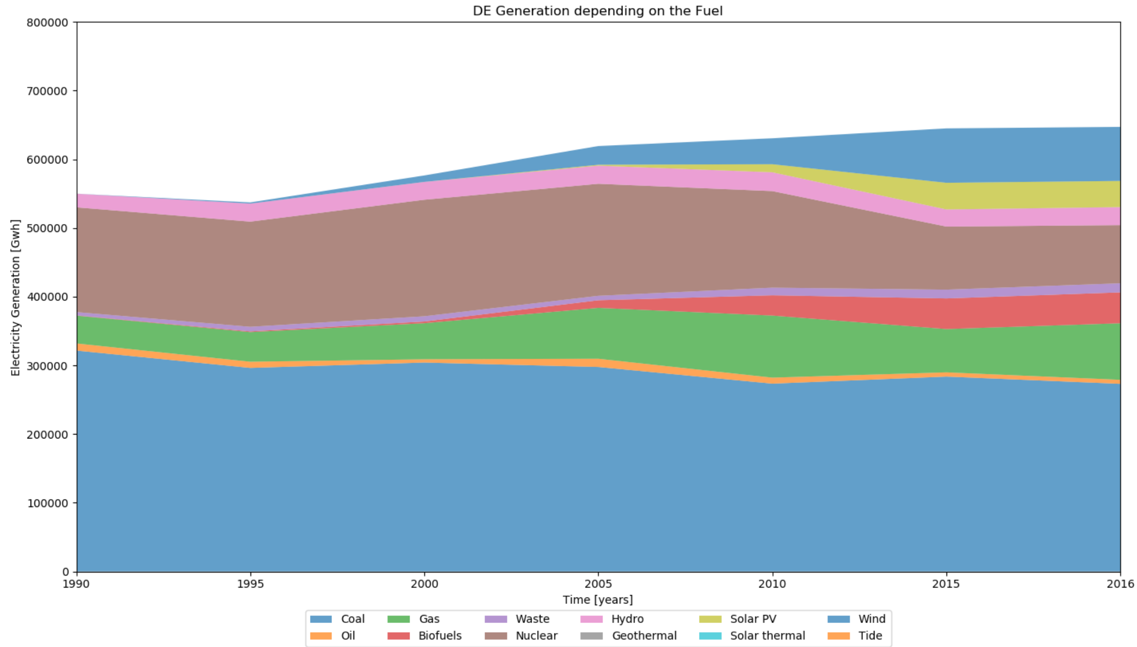

Figure 8. Historical data of generation of electricity in Germany depending on the fuel.

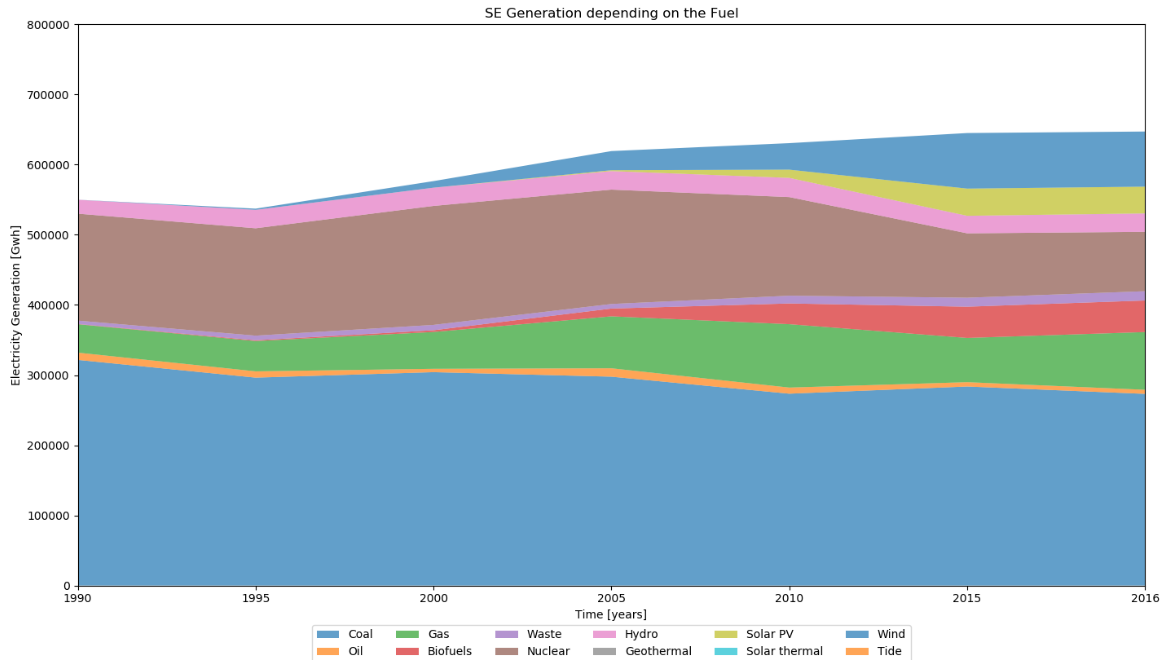

Figure 9. Historical data of generation of electricity in Sweden depending on the fuel.

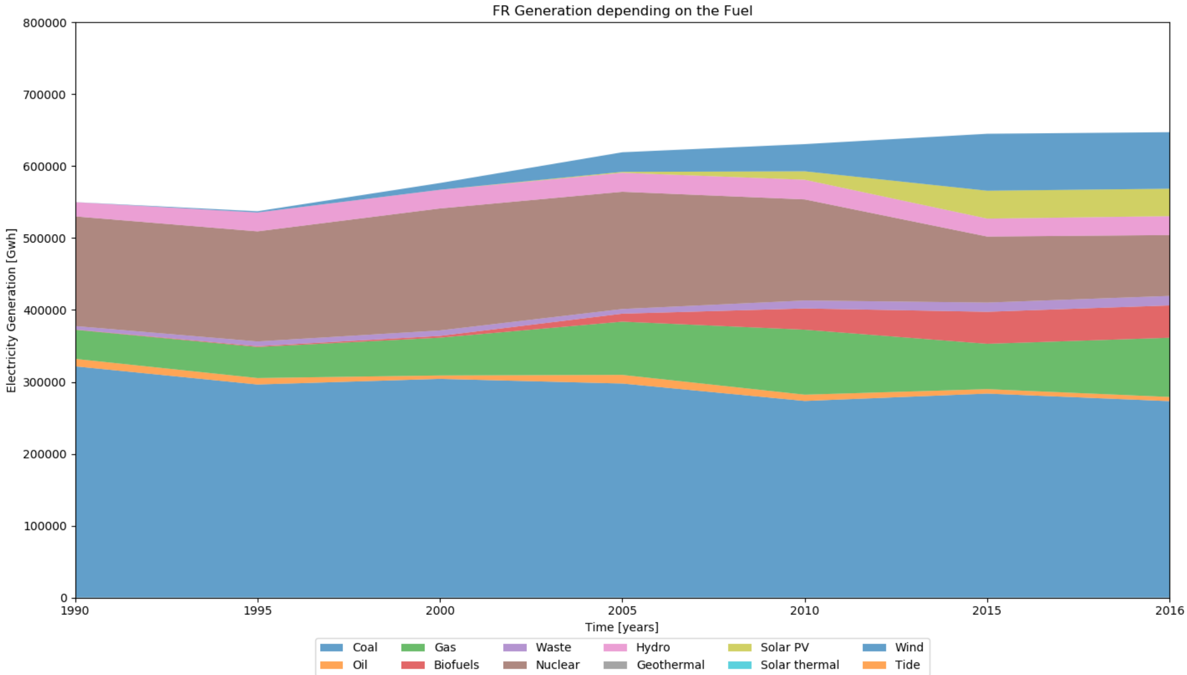

Figure 10. Historical data of generation of electricity in France depending on the fuel.

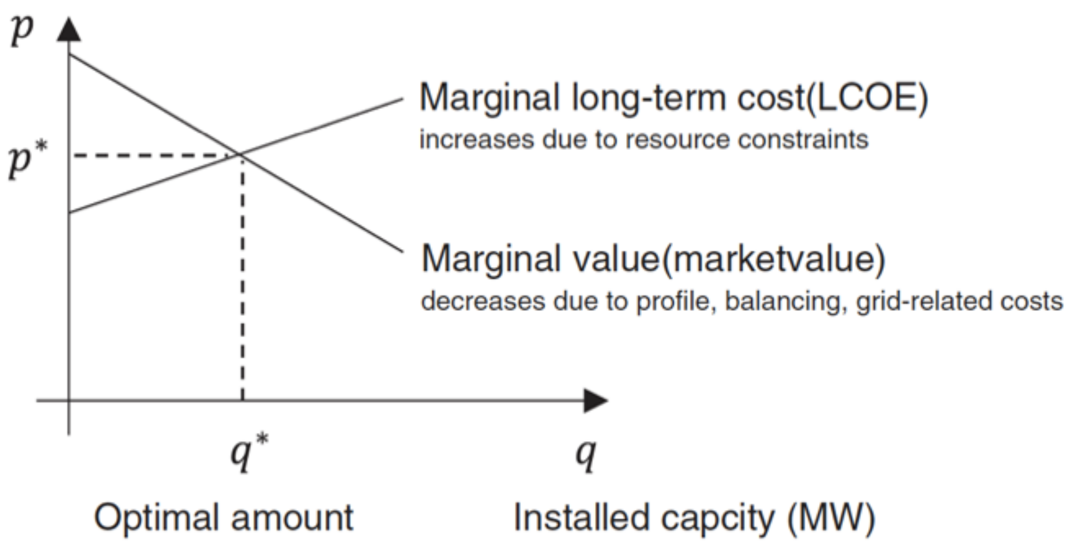

Figure 11. Optimal deployment.