CO2 SAVINGS COMBINING OFFSHORE WIND FARM WITH A REDOX FLOW BATTERY

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CONTENT

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- Key take aways
- Used background information / description of the system analysed
- Setup of the analysis
  - “Base load” power station replacing a coal powered power station
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- Results
- Conclusion / Discussion

INTRODUCTION

Motivation: to enable making the electricity system carbon free by 2030 it will be required to replace base load as well as peaker power plants by renewable energy power plants

- Scoping analysis performed to request funding for a project showing applicability of redox flow battery
- Funding selection criteria are based on:
  a) LCoE reduction or
  b) CO2 savings

Adding storage to the RE plant will not lower the LCoE, although it will (probably) improve the revenue by time shifting the production to times with low RE availability but that is not a criteria to obtain financial support.

So we focus on the CO_2 savings.

The proposed system can be used to replace fossil fuel power stations in two different options:

1. Create a baseload power station which is capable to generate 90-95% of the time the nominal power where the power is coming directly from a wind farm and indirectly from the redox flow battery that is charged at times when the wind farm is producing more power than the nominal power of the “base load” power station has.
2. Create a power station that replaces a (gas) power station that provides services in the ancillary services, frequency containment reserve market and the automatic Frequency Restoration Reserve (aFRR) market.

SUMMARY
KEY TAKEAWAYS

Scoping analysis do show that it is possible to replace existing base load and ancillary services power station by renewable energy power station in combination with a (H2Br) redox flow battery.

- Renewables energy power plants (wind combined with e.g. solar ..) can provide base load power generation when combined with a redox flow battery

- Renewable energy power plants (wind energy combined with e.g. solar ..) can provide and ancillary services when combined with a redox flow battery system

- Other options to improve the economics of the system is to
  - provide time shift between production and delivering power to the grid

BACK GROUND DATA USED

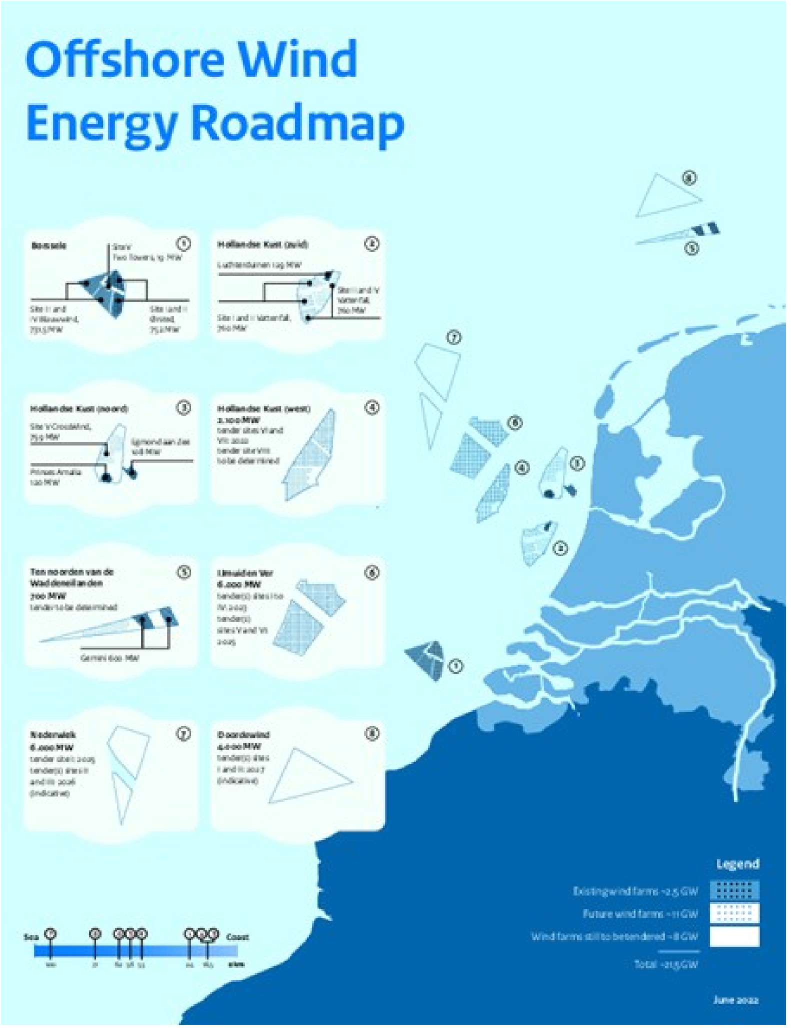
Wind Farm:

- Virtual wind farm 2 GW, located North Sea, 30- 40 km of the coast North of the Netherlands
  - 15 MW (virtual) wind turbines, with rotor diameter of 250 m, hub height of 155m. Rotor power density of 305 W/m^2.
  - Wind farm power density 5 MW/km2, regular lay-out
  - Wind power matrix determined taking into account wake losses
- 10 year 1 hourly hind cast data for the wind at hub height from Dutch Offshore Wind Atlas (DOWA)[1]

Battery:

- Redox Flow battery with high efficiency compared to Electrolysers / Fuel cell system
- Nominal power and storage capacity is outcome of the study

[1]Royal Netherlands Meteorological Institute KNMI

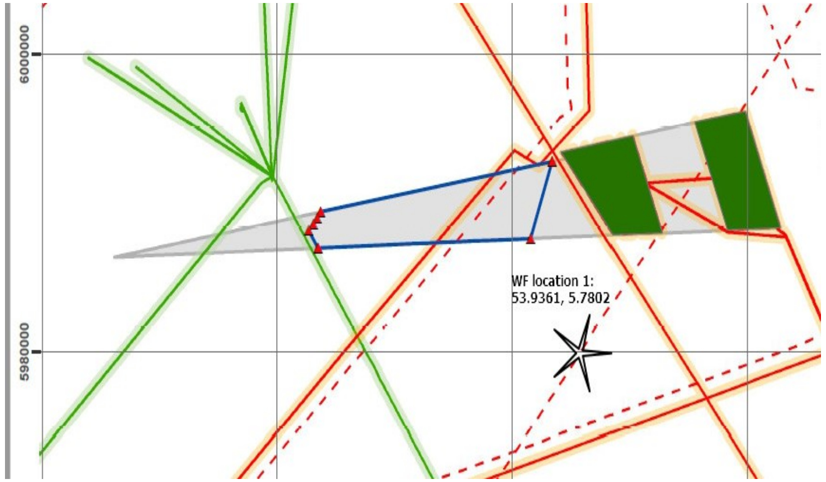


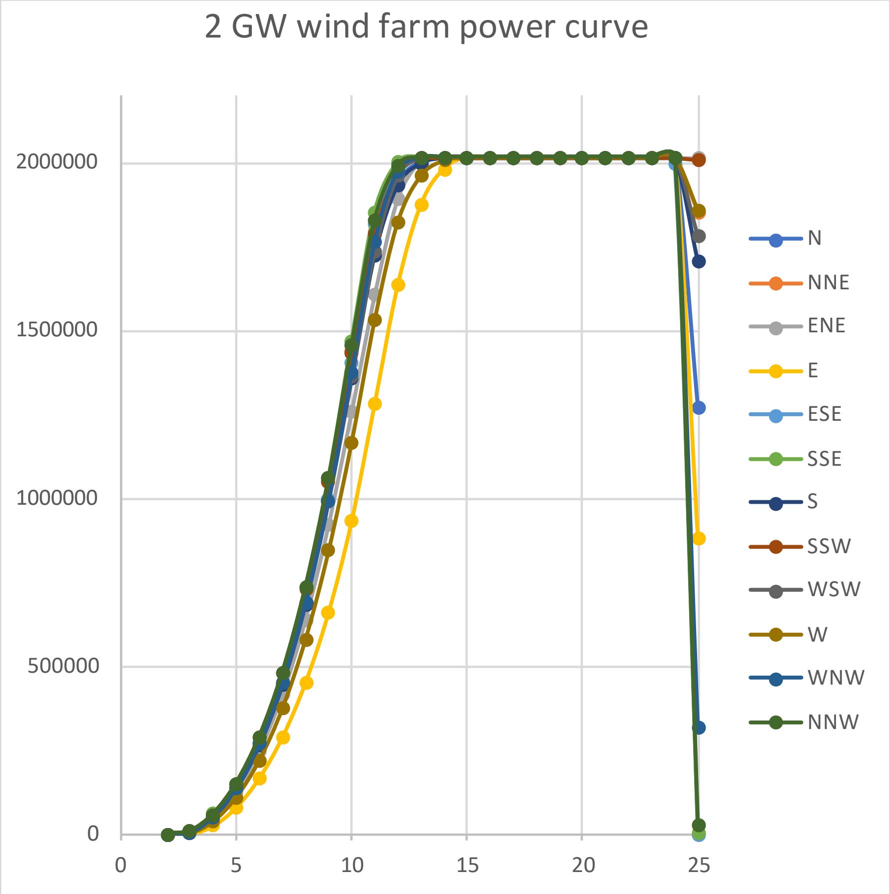
1. OFFSHORE GENERATION WIND POWER PROFILES

LOCATION

The location selected considers a hypothetical offshore wind farm of a size of 2 GW and an export cable connection of 2 GW tot the **onshore** redox flow battery.
This location is selected due to its proximity to the upcoming TNvdW wind farm, being representative for the expected conditions for existing and future wind farms in the Dutch Exclusive Economic Zone.

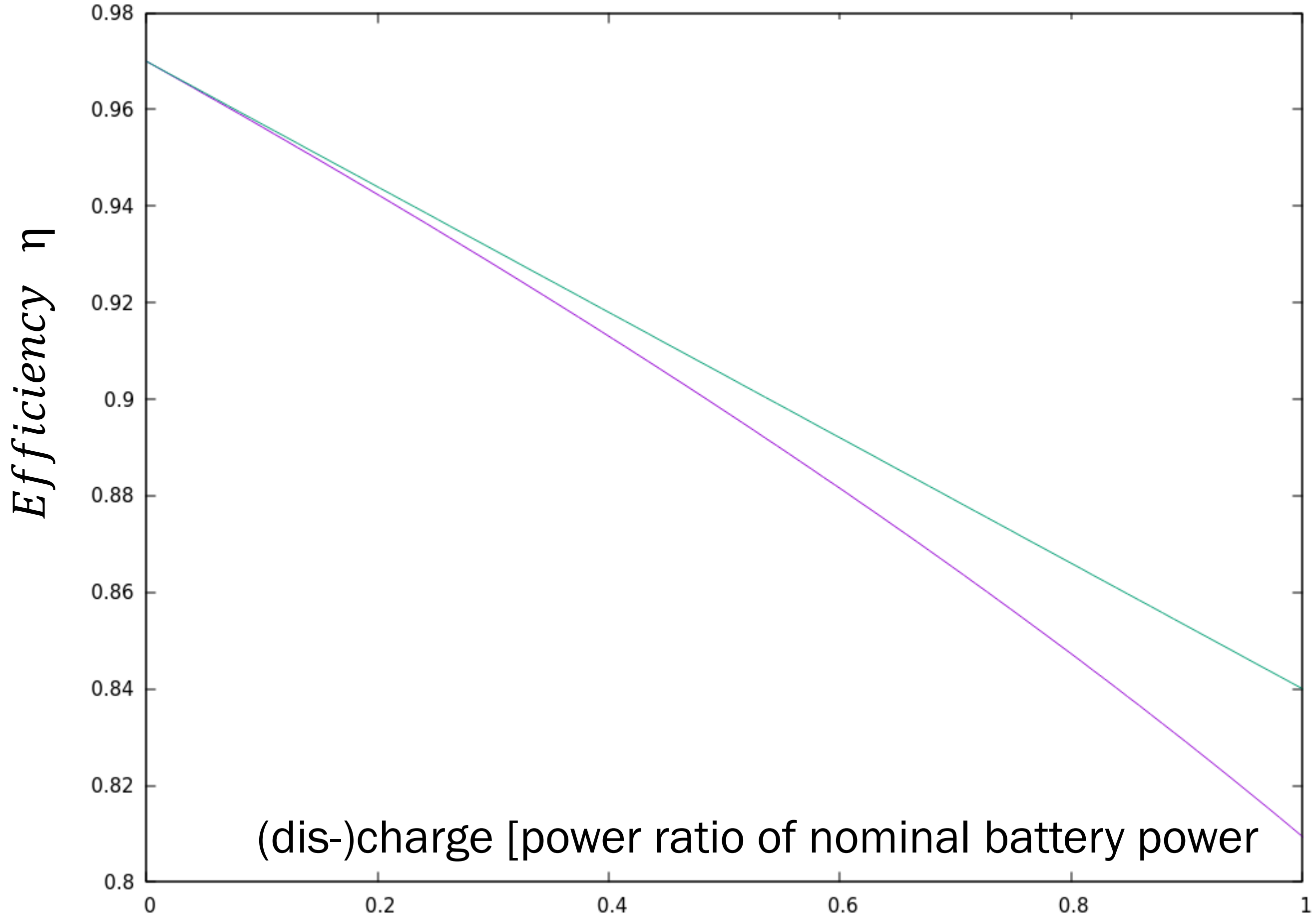
The grid connection, between battery system and electricity grid is up to 1 GW.





REDOX FLOW BATTERY
CONVERSION EFFICIENCY IN CHARGING AND DISCHARGING

- Conversion efficiency of H2-Br redox flow battery
  based on previous project the efficiency as a function of the conversion power



BASELOAD POWER STATION

REQUIREMENTS

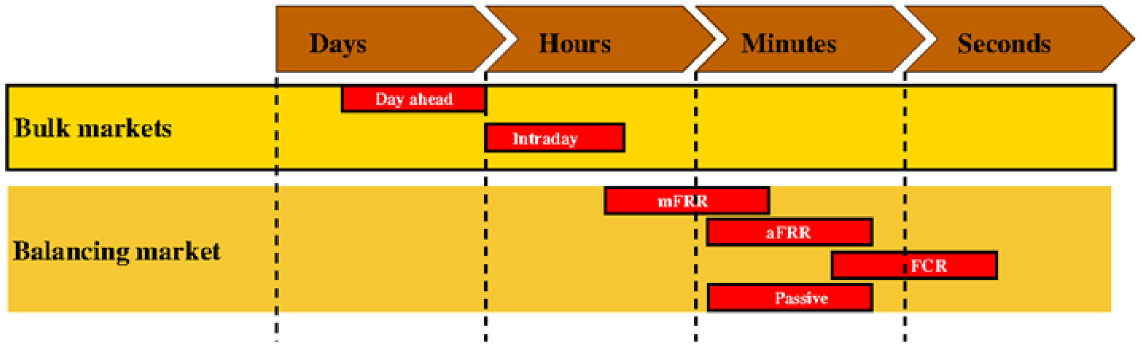
Simple requirements

- Being able to provide predictable power for at least 90% of the time
- Provide power at low cost

ANCILLARY SERVICE MARKET

The power market is divide in 3 main segments (EU?):

- The bulk market where the day ahead and intra day trade takes place and the
- Balancing market
- On top, the the PPA market where power purchase agreements are made for much longer periods, month/years or project lifetime.



Power market for different time scales (TenneT.org)

In this scoping analysis we investigated whether the RE plant combined with a redox flow battery system would be able to provide services in the balancing market with the focus on the aFRR service.

The FCR or primary reserve market is a locally designed fully automatic system ensuring a constant ratio between frequency change and installed power with a maximum ramp time of 30 seconds to contracted power level.

IMBALANCE MARKET IN THE NETHERLANDS

ANALYSIS OF YEAR 2021 DATA

	IGCC Contribution Up	IGCC Contribution Down	regulating up	regulating down	reserve up	reserve down
	MW	MW	MW	MW	MW	MW
Min	0	0	0	0	0	0
Mean	51	63	43	57	1	0
Max	823	999	643	1081	155	60
std. Dev.	101	117	84	91	7	2

IGCC = International Grid Control Cooperation

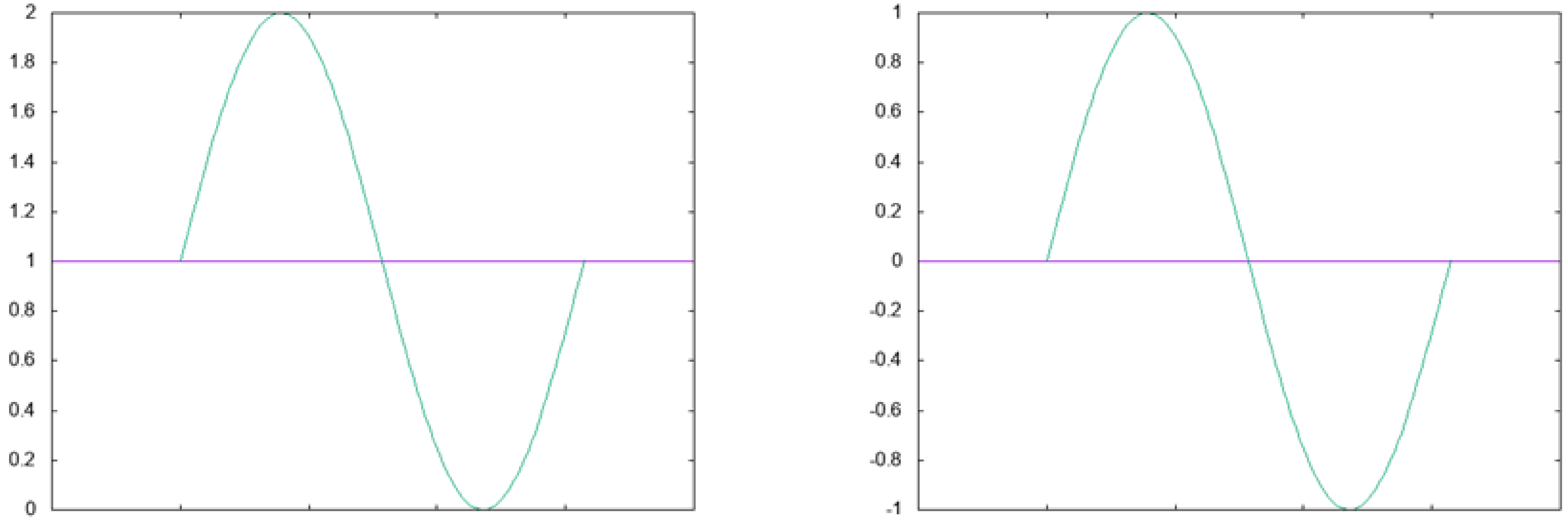
IGCC contribution: IGCC is based on "netting" of instantaneous imbalance values from the participants

		January	February	March	April	May	June	July	August	Septembe	October	November	December
Max Up	MW	430	531	487	604	643	0	484	445	590	594	545	533
Max Down	MW	589	30	24	28	30	37	26	28	28	39	43	35
Total Up	MWh	17282	20362	18081	20142	22032	26566	19018	21044	20513	29350	30796	26245
Total Dow	MWh	34909	28585	28755	40946	26304	19996	25601	21626	19296	24298	31347	32149

Compared to contracted power the max up/down power is relatively small

This might or will probably change when the majority or all of the power is from renewable sources

DIFFERENT SETUP BETWEEN CONVENTIONAL AND RE-POWER PLANT FOR THE IMBALANCE MARKET



max range up and down of gas peak plant(left) versus a battery system (right)

CO2 SAVING

- Replacing a gas power station
  At the moment the FCR and aFRR market are operated by gas turbine powered plants.

  CO2 production of a gas turbine powered system is ~

$$Specific\ Emmissions = \frac{0.0036\ kWh/GJ \cdot 56,100\ kgCO_2/TJ}{\eta_{des}}$$

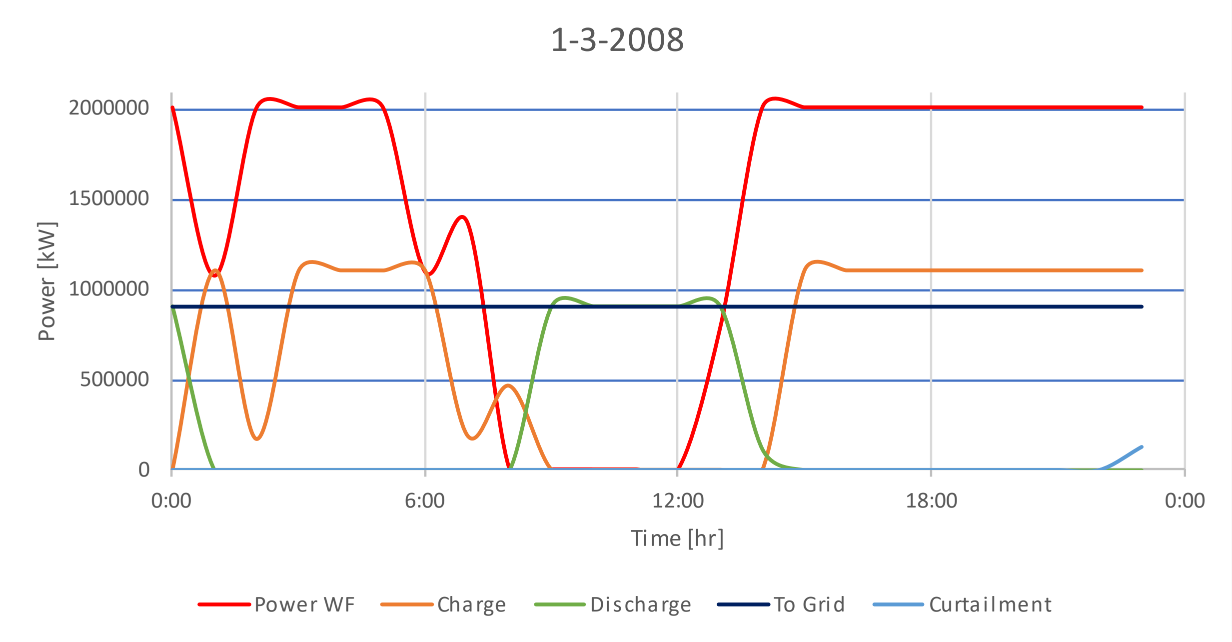
With present efficiencies reached of 55% resulting in 370 gCO_2/kWhe (0.37TON CO_2/MWh)

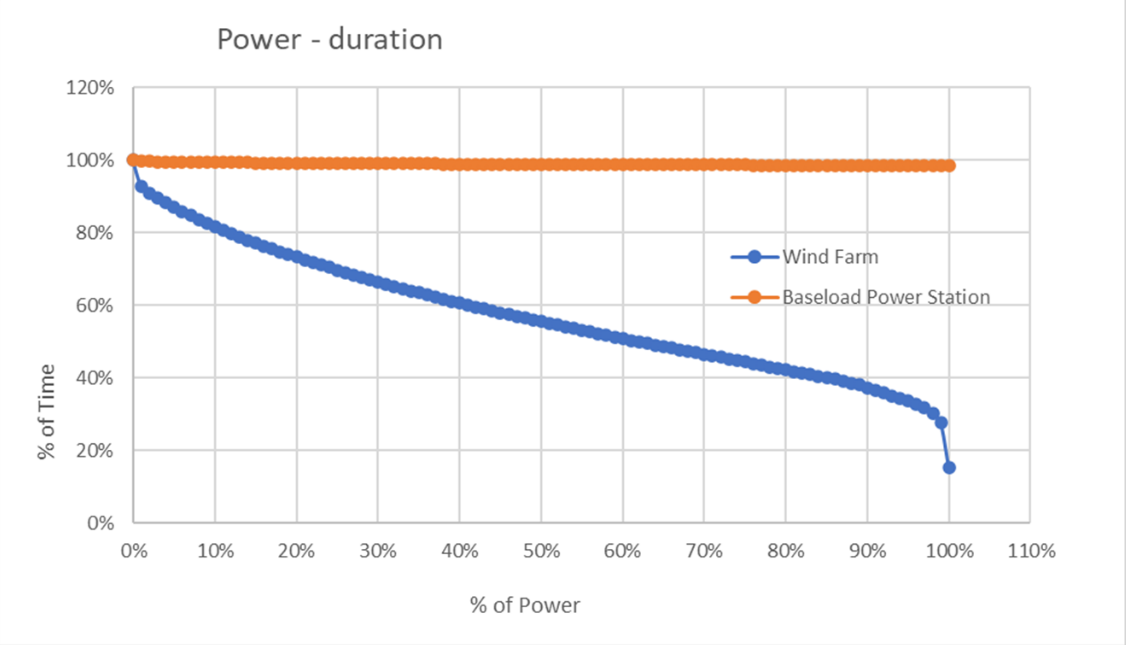
- Replacing a coal power station, and equal analysis of the coal power stations characteristics in the NL

For coal the specific CO_2 emission are estimated at 660 gCO_2/kWhe (0.66TON CO2/MWh)

A TYPICAL DAY OF OPERATION & POWER DURATION CURVES

For a power station rated at 43% of the Wind Farms power and max storage set at 20 days





VARYING THE POWER OF THE BASELOAD STATION - DAYS OF STORAGE

Without full economic analysis it's difficult to determine the optimal ratio of the baseload power station power / wind farm nominal power

Curtailment [% WF Yield]

Days of Storage <=	=> ratio P Grid/P Wind Farm 41%	42%	43%	44%	45%	46%	47%	48%	49%	50%
2	28.5%	27.2%	25.9%	24.6%	23.4%	22.2%	21.0%	19.9%	18.7%	17.7%
4	24.6%	23.2%	21.8%	20.4%	19.1%	17.9%	16.7%	15.6%	14.5%	13.4%
6	23.0%	21.5%	20.1%	18.7%	17.3%	16.0%	14.8%	13.6%	12.5%	11.5%
8	22.3%	20.7%	19.2%	17.8%	16.4%	15.0%	13.7%	12.6%	11.5%	10.4%
10	21.8%	20.2%	18.7%	17.2%	15.7%	14.3%	13.0%	11.8%	10.7%	9.8%
12	21.4%	19.9%	18.3%	16.8%	15.3%	13.8%	12.4%	11.2%	10.1%	9.1%
14	21.1%	19.6%	18.0%	16.4%	14.9%	13.4%	11.9%	10.6%	9.5%	8.5%
16	20.8%	19.3%	17.7%	16.1%	14.6%	13.1%	11.6%	10.1%	8.9%	7.9%
18	20.6%	19.0%	17.4%	15.8%	14.3%	12.7%	11.2%	9.7%	8.4%	7.3%
20	20.3%	18.7%	17.1%	15.5%	14.0%	12.4%	10.8%	9.4%	8.0%	6.7%

Numbers of hours in ten years that the nominal power of the plant can not be delivered

Days of Storage <=	=> ratio P Grid/P Wind Farm 41%	42%	43%	44%	45%	46%	47%	48%	49%	50%
2	9396	9840	10305	10784	11326	11845	12361	12884	13401	13997
4	5105	5494	5893	6331	6801	7352	7956	8540	9118	9781
6	3360	3730	4116	4525	4940	5460	6028	6657	7281	7964
8	2590	2932	3274	3611	3996	4477	5003	5601	6260	6967
10	2092	2409	2750	3109	3426	3821	4323	4921	5594	6370
12	1791	2076	2384	2699	3041	3404	3834	4415	5075	5841
14	1475	1763	2073	2367	2673	3027	3418	3944	4575	5317
16	1219	1503	1810	2103	2391	2677	3048	3460	4087	4808
18	941	1233	1523	1854	2104	2388	2731	3102	3567	4292
20	676	953	1252	1560	1846	2109	2387	2795	3199	3772

Reminder, the net capacity factor of the wind farm is 58%.

CONCLUSION / QUESTIONS
BASED ON SCOPING ANALYSIS

Conclusions

- Both options, i.e. providing base load power to the grid and balancing the grid in the ancillary services market seem an option.
- The overall efficiency of the battery in the ancillary services market is in the order of 80-85%
- The overall efficiency of the battery in the base load power station mode is ~ 85%

- CO_2 could be set equal to the CO_2 emissions of the gas peaker plant or the base load power station.

Questions

- Will base load power stations still be needed in a fully renewable electricity system or are they relics of the past?
- Are there other initiatives in EU or US or ? aiming at replacing peaker and base load power stations?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