Technical rate of substitution between photovoltaics and wind power

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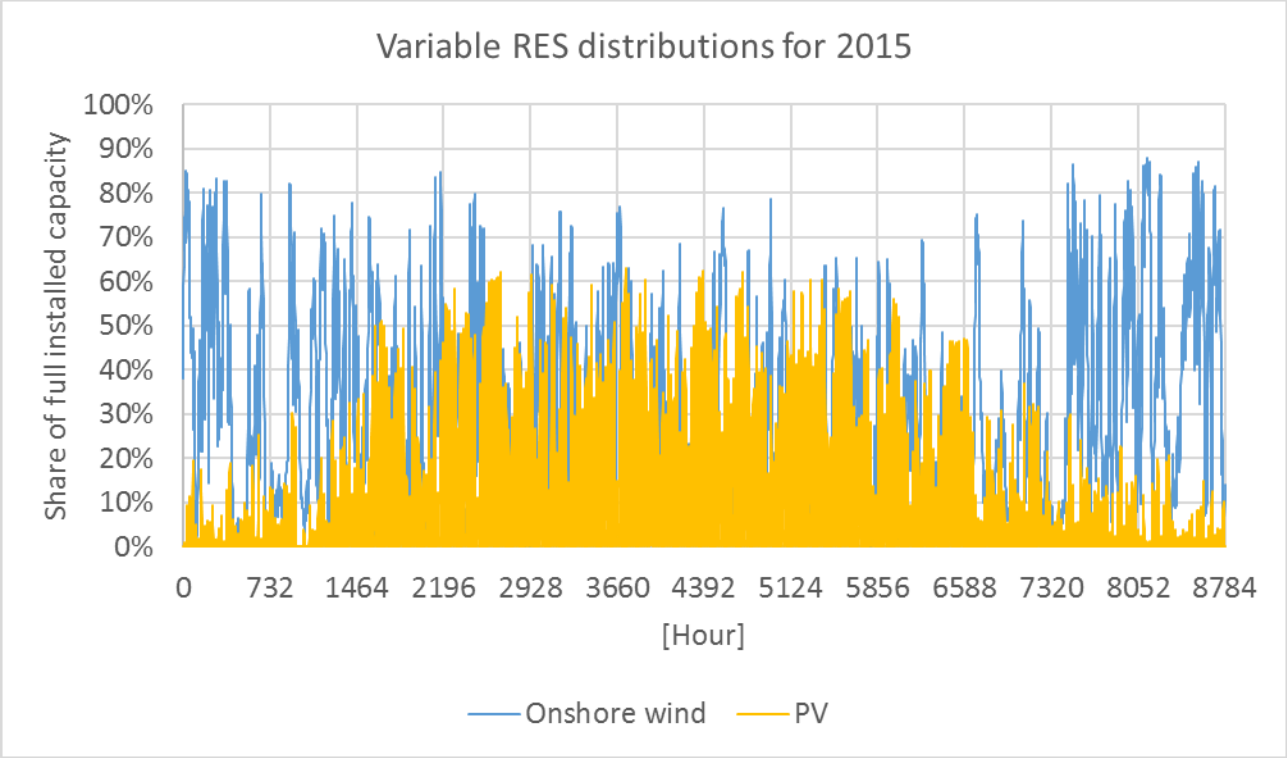
Political context & motivation of the study

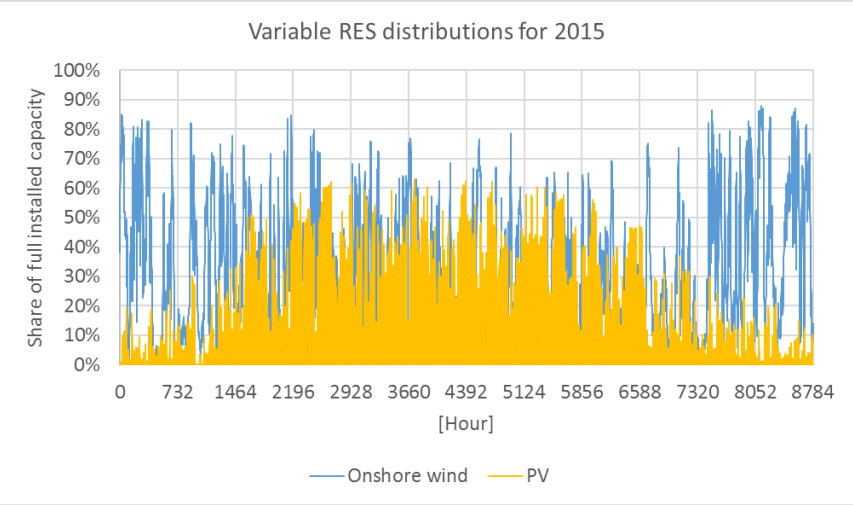
- Introduction of auction based systems where e.g. onshore wind power and photovoltaics compete
- This market design basically assumes homogeneity; that the technologies are perfect substitutes

Heterogeneity

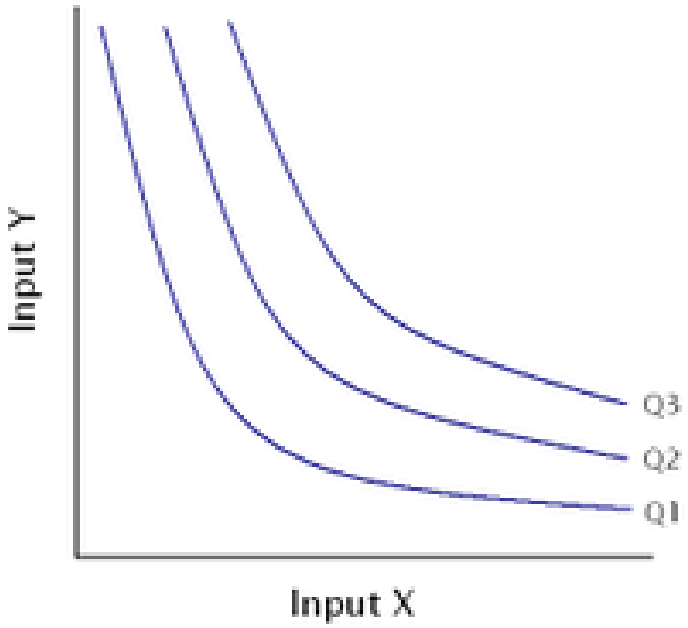


Research questions

What is the technical rate of substitution between onshore wind power and photovoltaics in a system perspective?



What is the Technical rate of substitution?



Source;Wikipedia, URL:
https://en.wikipedia.org/wiki/Marginal_rate_of_technical_substitution

Method

Parameter: CO2 emissions

Base scenarios:

1) Danish energy system 2015
2) IDA Energy vision 2050

Simulation strategy:

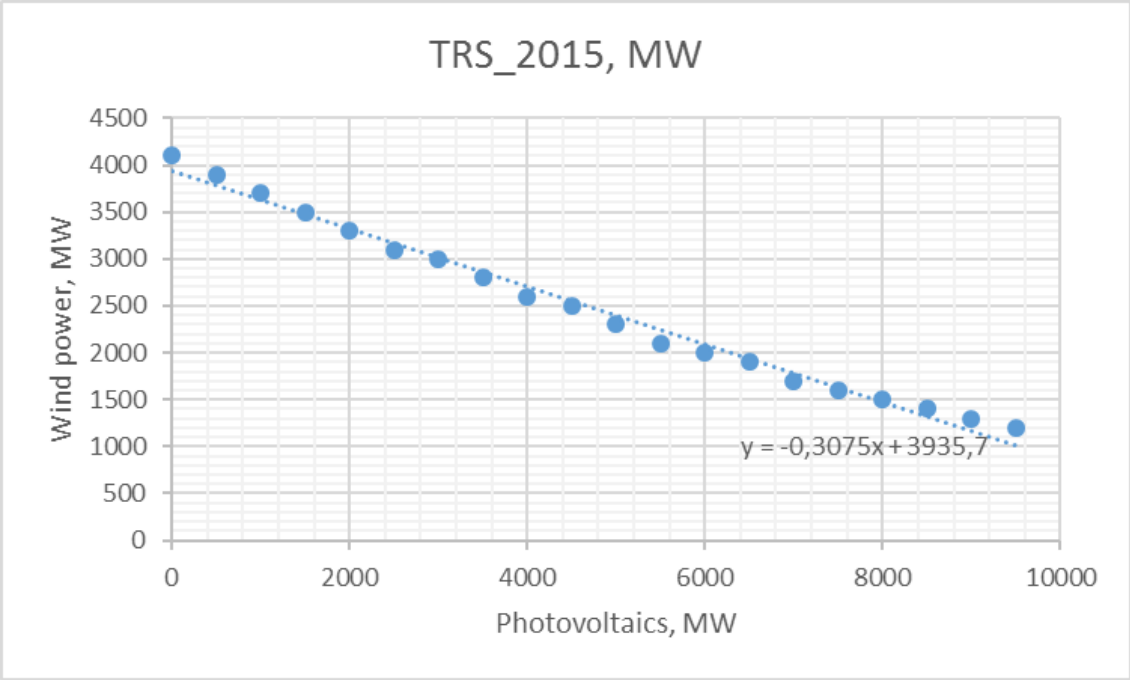
Technical simulation

Method

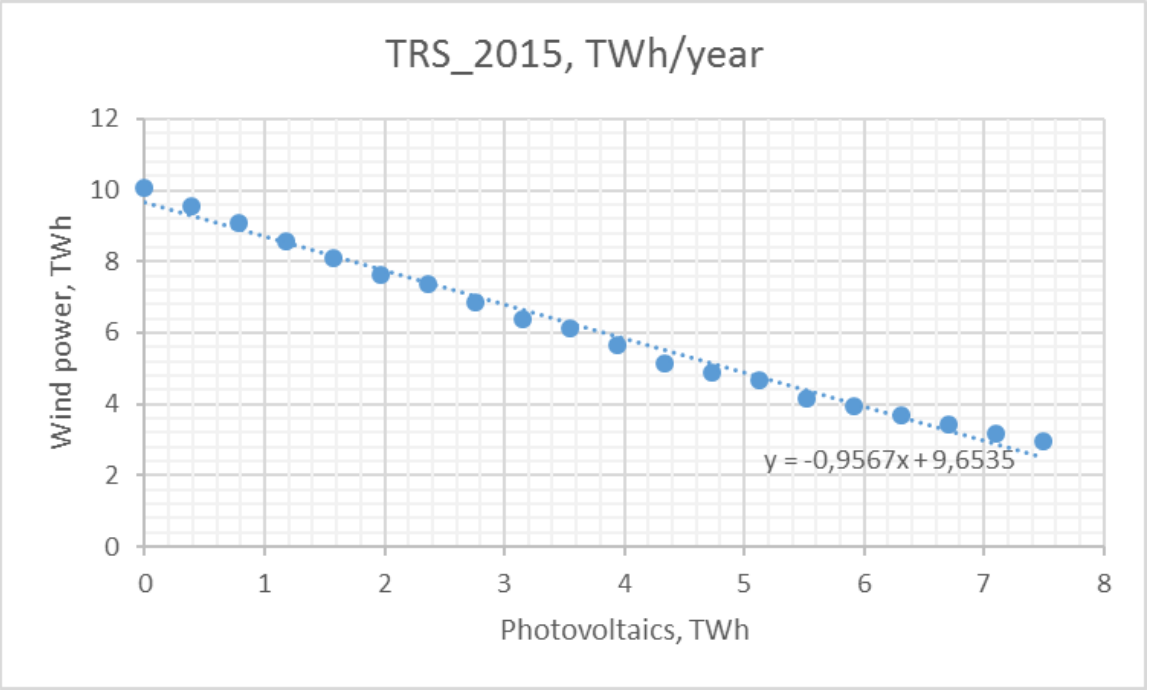
- Incrementally increasing photovoltaic capacity
- EnergyPLAN identifies the capacity of onshore wind that is needed to keep emissions constant, given the level of PV capacity

	CO2-emis	input_RES3_capacity=	input_RES1_capacity=	CO2-emis
Scenario1	0,698	5000	5000	
Scenario2	1,818	0	8200	0,697
Scenario3	1,689	500	7800	0,708
Scenario4	1,559	1000	7500	0,691
Scenario5	1,44	1500	7100	0,707
Scenario6	1,325	2000	6800	0,696
Scenario7	1,211	2500	6500	0,688
Scenario8	1,104	3000	6200	0,682
Scenario9	1	3500	5800	0,714
Scenario1	0,894	4000	5600	0,682
Scenario1	0,793	4500	5300	0,687
Scenario1	0,698	5000	5000	0,698
Scenario1	0,61	5500	4700	0,713
Scenario1	0,524	6000	4500	0,695
Scenario1	0,443	6500	4300	0,681
Scenario1	0,36	7000	4000	0,705
Scenario1	0,277	7500	3800	0,695
Scenario1	0,195	8000	3600	0,685
Scenario1	0,116	8500	3300	0,715
Scenario2	0,033	9000	3100	0,712
Scenario2	-0,048	9500	2900	0,705

Technical rate of substitution of capacity at current emission level



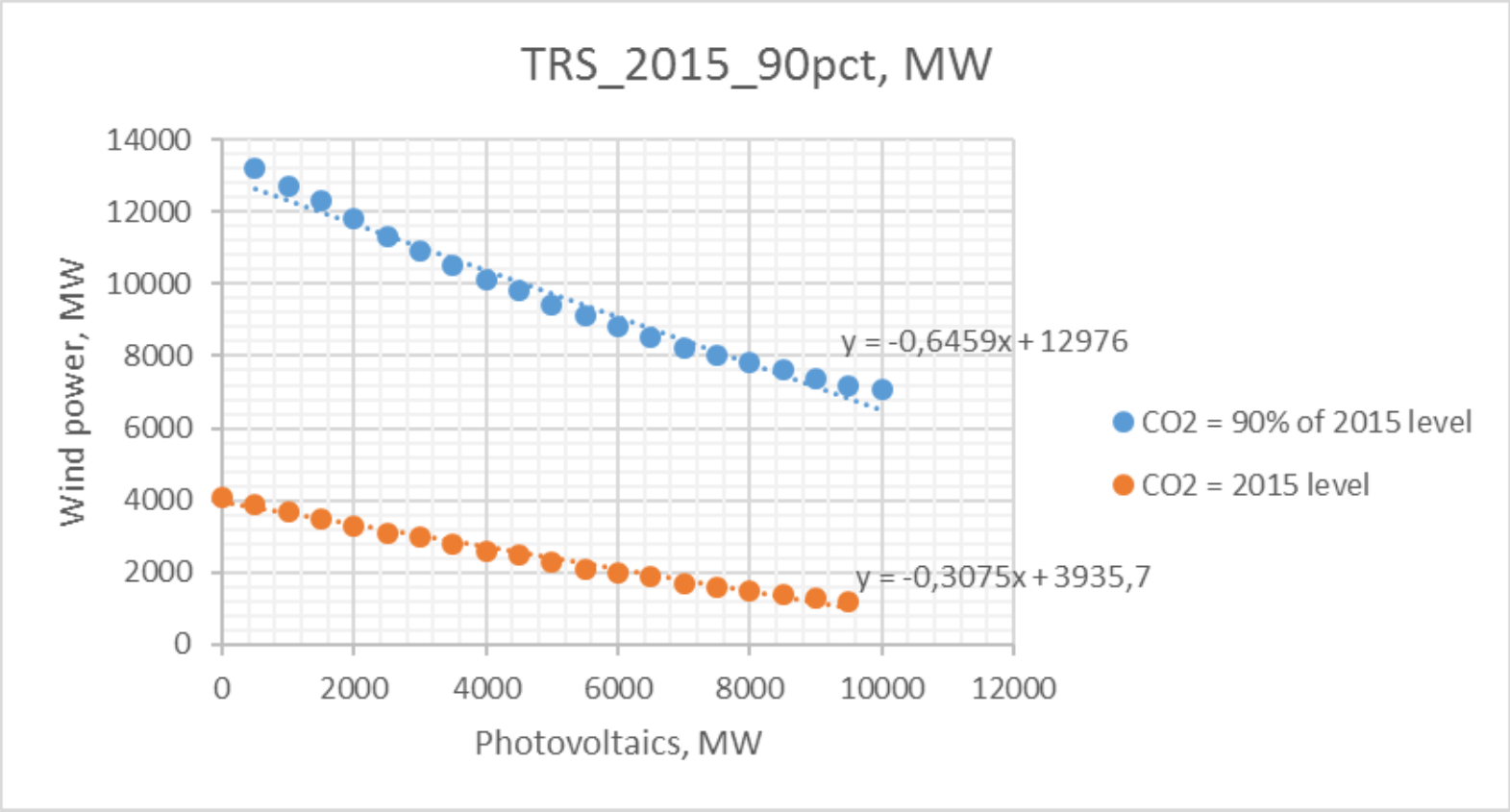
Technical rate of substitution of energy at current emission level



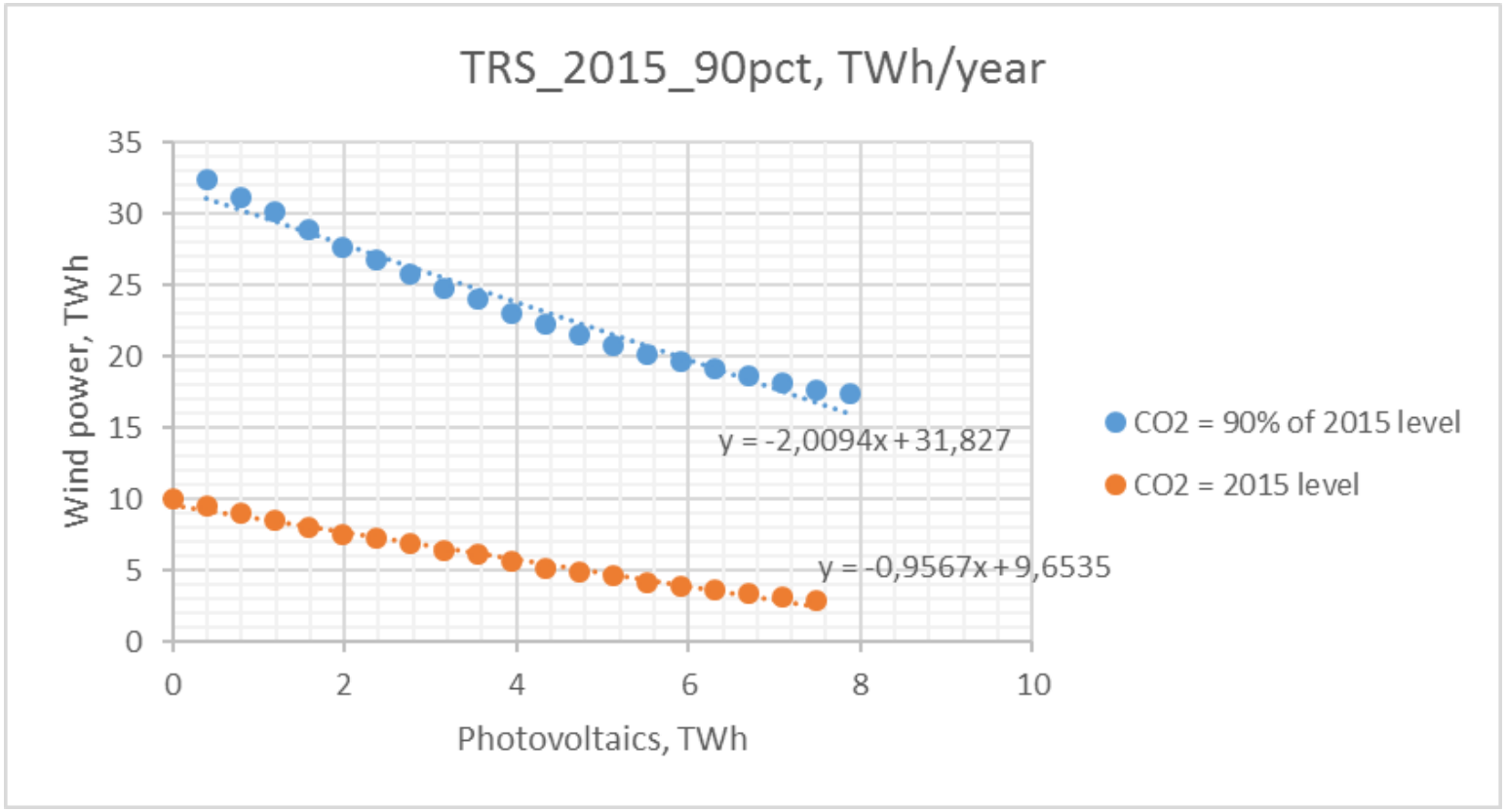
2015 results

- The isoquants are convex but has (surprisingly) almost a linear relation.
- For energy (MWh), photovoltaics and wind power are almost perfect substitutes (The slope of the curve is close to -1)

Isoquant for 10% reduction in carbon dioxide emission



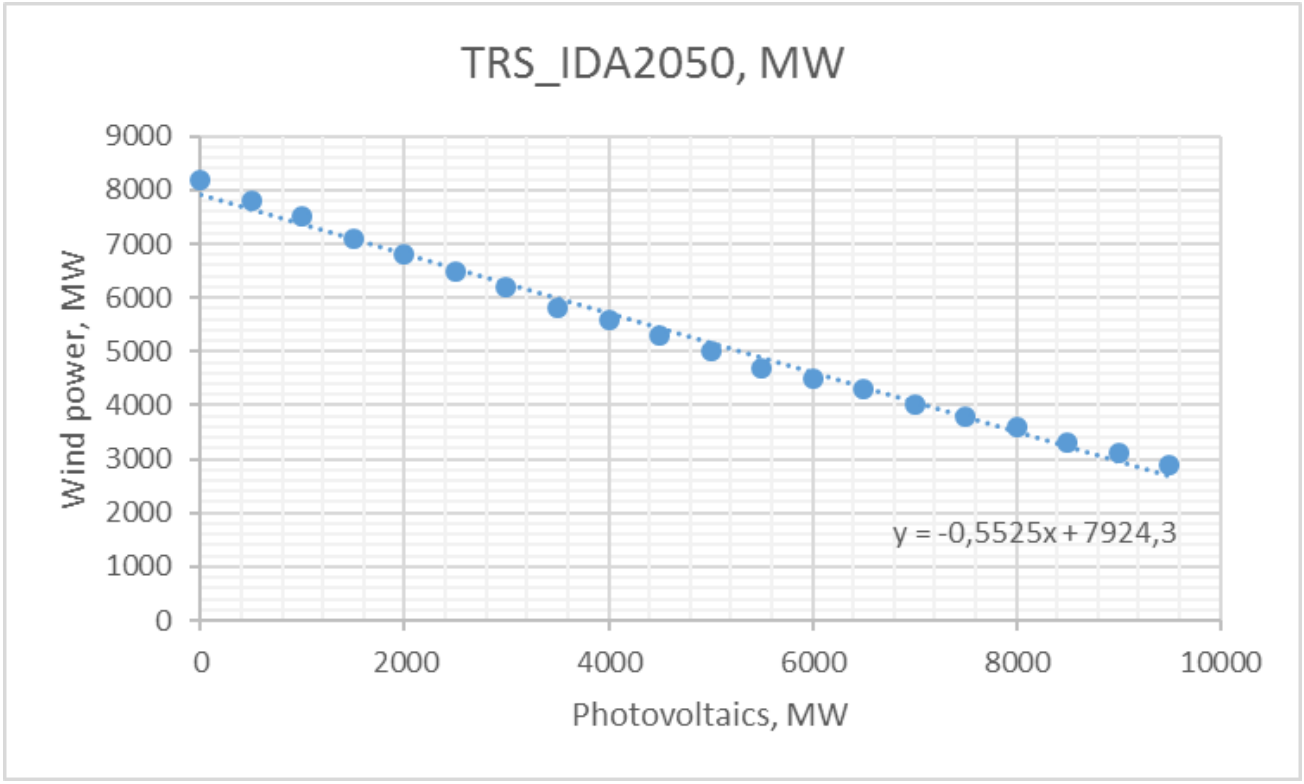
Isoquant for 10% reduction in carbon dioxide emission



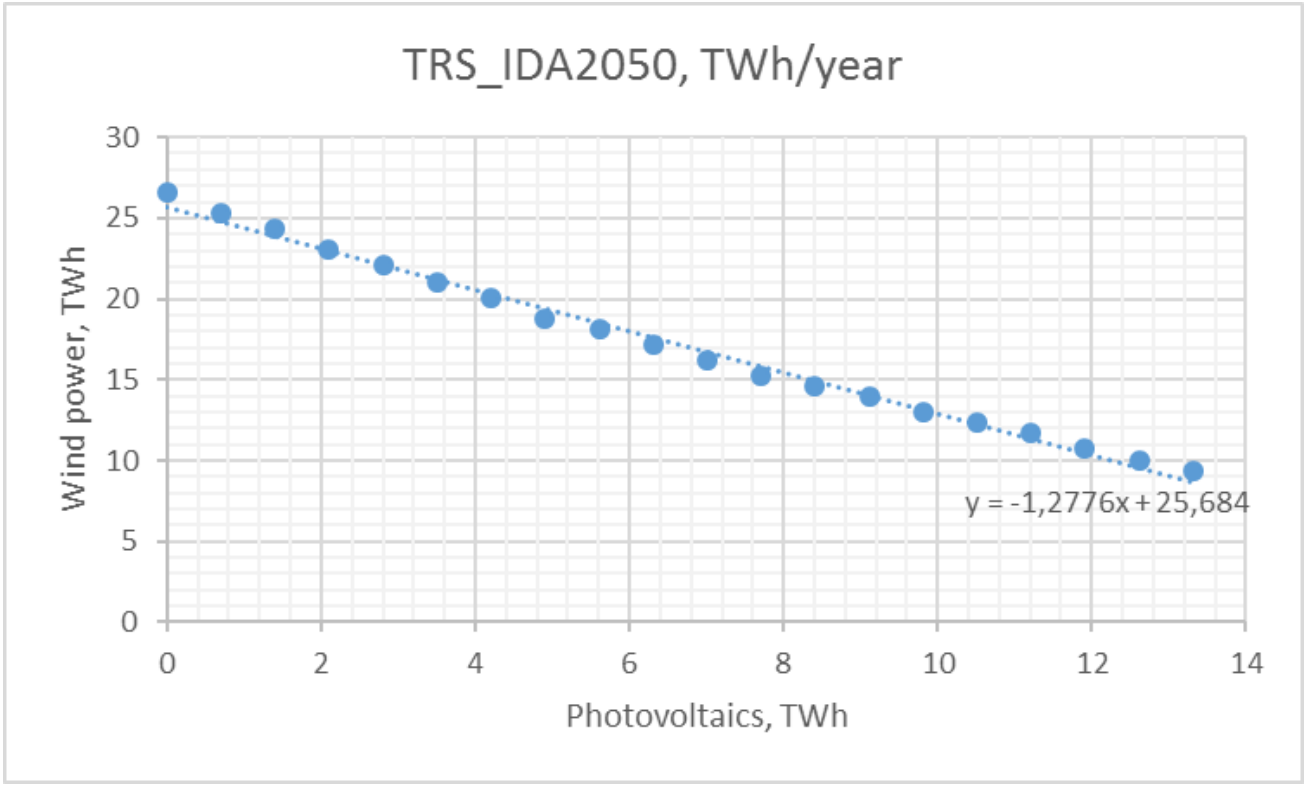
Results for 10 percent reduction in emissions in a 2015-system

- The isoquants are convex but has (surprisingly) almost a linear relation.
- Energy from photovoltaics contributes twice as much as onshore wind power to reduction in emissions (The slope is -2)
    - However, this result should be tested with higher levels of PV production as the curve shows a stronger convexity.

Technical rate of substitution of capacity in IDA2050



Technical rate of substitution of energy in IDA2050



2050 results

- The isoquants are convex but has (surprisingly) almost a linear relation.
- Energy from photovoltaics contributes with a higher reduction in emissions than onshore wind energy (slope of -1.28).

Conclusions

- The isoquants are generally convex but has in most cases an almost linear relation.
- When looking at capacity, wind power gives a higher CO2 reduction per MW installed than PV capacity.
- When looking at energy produced, the contribution from photovoltaics generally seems to give a higher reduction in CO2 emissions, i.e. more than 1 MWh wind energy is required to replace 1 MWh of energy from photovoltaics.

Further research

There are several points we would like to explore further before concluding:

- Offshore sensitivity (Present capacity is 14 GW in IDA2050). Is likely to affect the gain from onshore wind energy.
- The CO2 levels are not import/export corrected (only relevant for 2015 scenarios)
- Explore 2015 scenario with higher levels of PV for 10% reduction in emissions.

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