Baltic InteGrid

Integrated Baltic Offshore Wind Electricity Grid Development

Weighing Costs and Benefits of a meshed grid in the Baltic Sea.

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DEUTSCHE WINDGUARD

IKEM

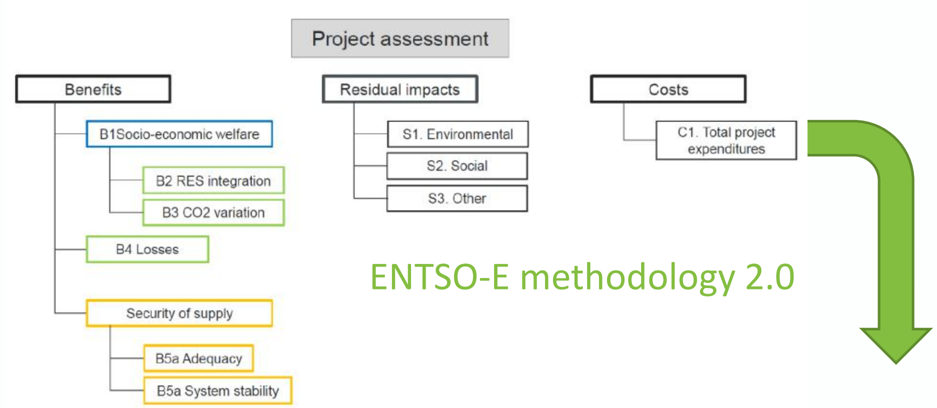
EU STRATEGY FOR THE BALTIC SEA REGION FLAGSHIP

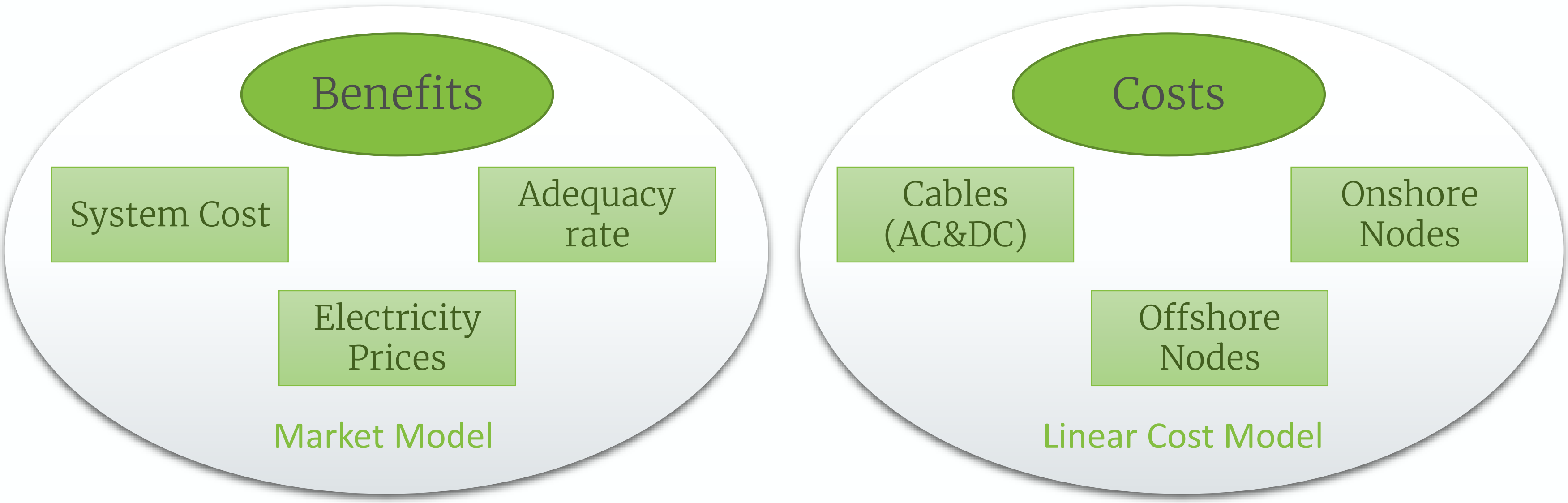
Interreg Baltic Sea Region

EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

1. Methodology and Case Studies
2. Benefits: Design and Result of the Regional Market Model
3. Costs: Design and Result of the Linear Cost Model
4. Balance and Conclusion

CBA Methodology





Two Pre-Feasibility Analyses

Pre-Feasibility Analysis 1:

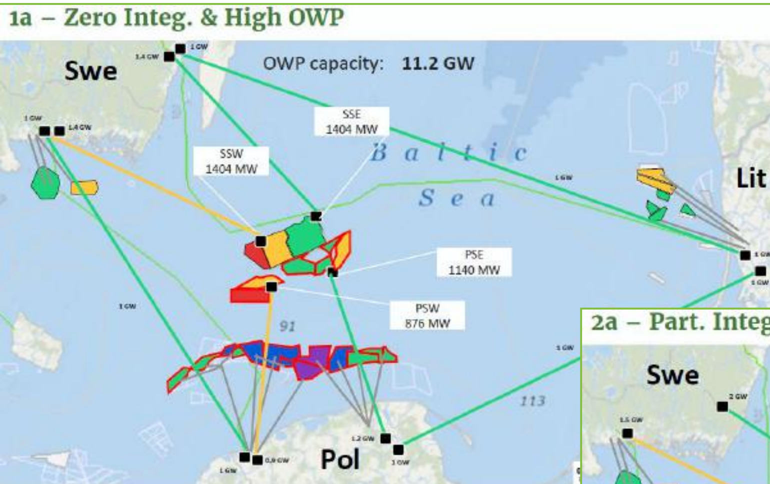
Sweden – Poland – Lithuania

Pre-Feasibility Analysis 2:

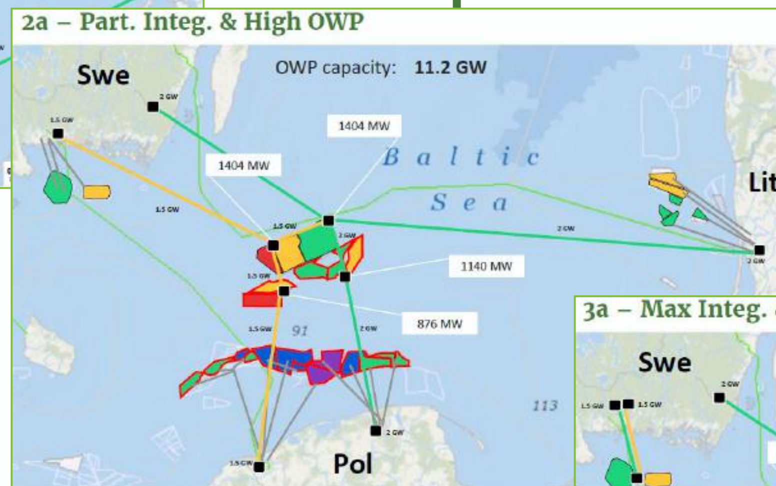
Germany – Sweden – Denmark

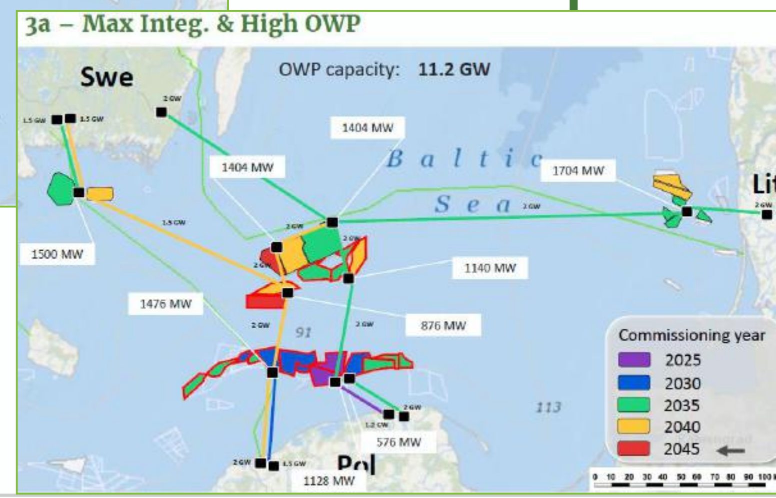
CS1 (SE/PO/LT) with High Offshore Wind Power

Cost and Benefit Differences



Baseline Scenario

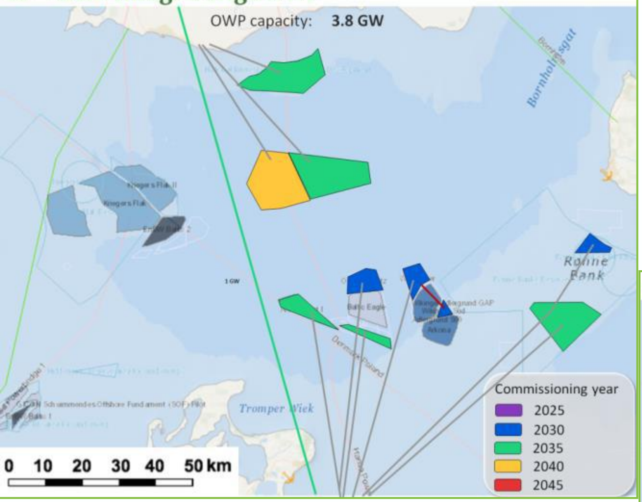




CS2 (DE/SE/DK) with High Offshore Wind Power

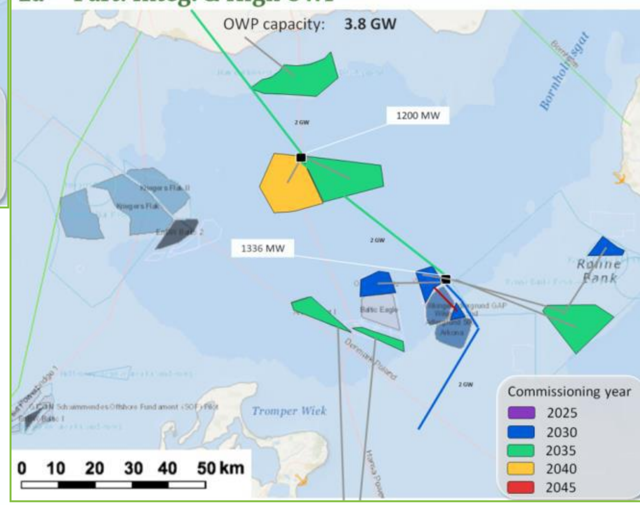
Cost and Benefit Differences

1a – Zero Integ. & High OWP

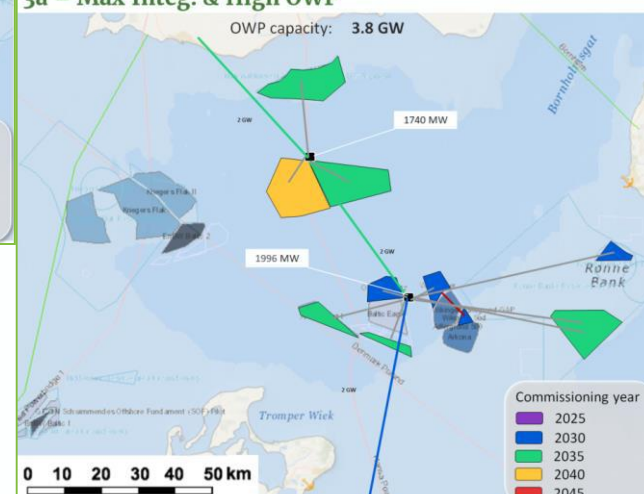


Baseline Scenario

2a – Part. Integ. & High OWP



3a – Max Integ. & High OWP



Baltic InteGrid

Benefits: Design and Result of the Regional Market Model

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CBA Application Model Overview

Model dynELMOD:

Linear program to determine cost-effective development pathways in the European electricity sector

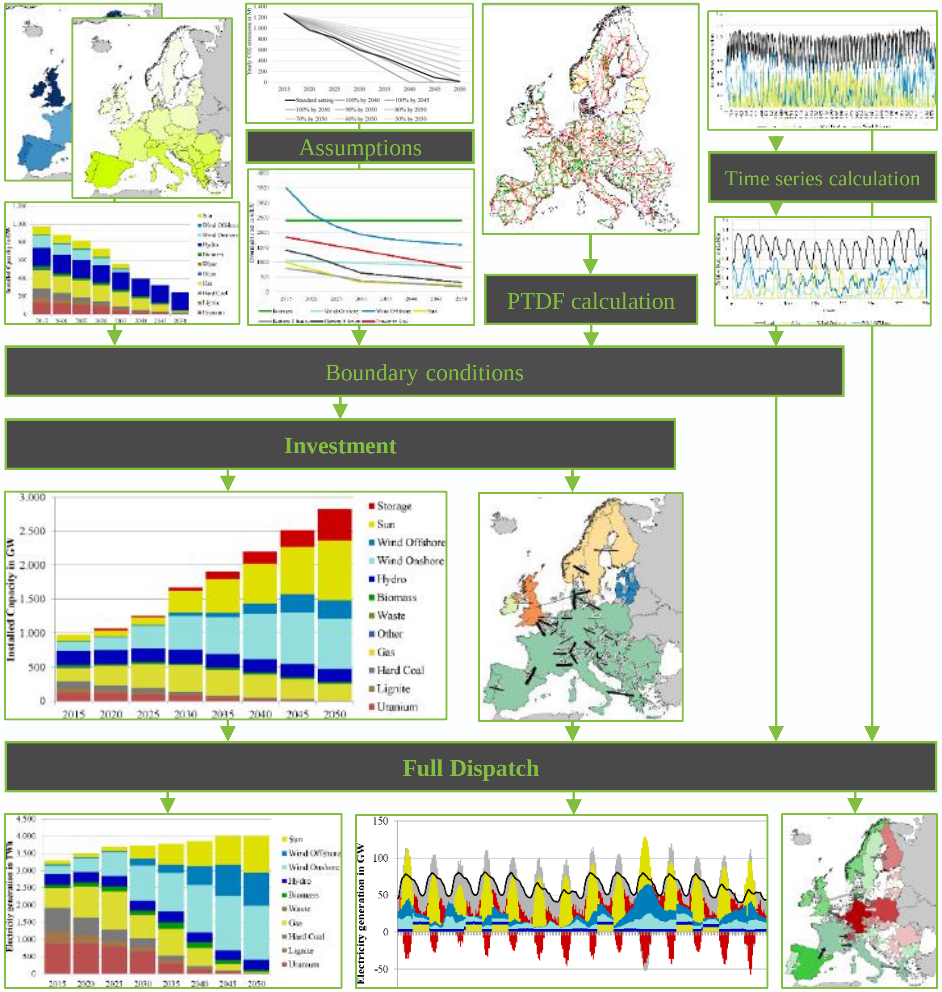
Calculation Steps

1. **Investment**
   - Investment into Conventional and renewable generation, cross-border capacities
   - Reduced time series used
2. **Dispatch**
   - Investment result from step 1 fixed
   - Time series with 8760 hours

Model:
33 European countries
31 conventional or renewable generation and storage technologies
9 investment periods, five-year steps 2020 – 2050

Outputs

- Investment into generation capacities, storage, transmission capacities
- Generation and storage dispatch
- Emissions by fuel
- Flows, imports, exports



CBA Application Model Overview

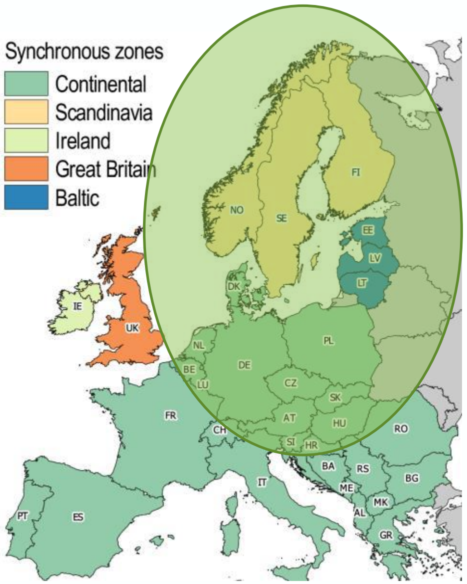
Application in BIG Model Context

Cost benefit analysis: Focus on Baltic countries (but calculate full dispatch for all countries)

Relevant Inputs

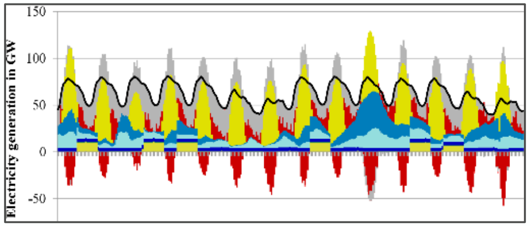
Installed Capacities, Fuel Costs, Emission limits/prices
Scenario-specific data:

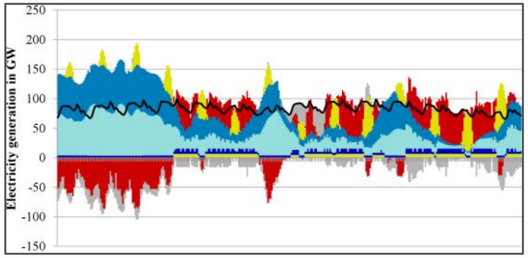
- Connections between countries
- Wind farm integrations

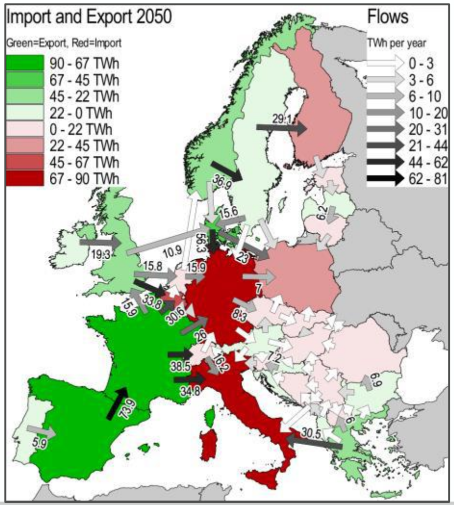


Outputs relevant for CBA

- Security of supply → hourly adequacy margin
- Electricity generation costs and prices.
  - Relevant stakeholders for welfare implications: Consumers, Producers (conventional and renewable), TSOs
- Hourly generation & storage dispatch
- Cross-border flows
- RES Integration factor (rate of curtailment)
- Generation and storage dispatch
- Emissions by country and fuel







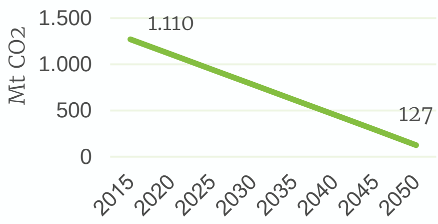
Cost-Benefit analysis Modeling Assumptions

Electricity generation capacities

- Entsoe TYNDP 2016 Market Modeling Data for 2020 and 2030 Scenario Vision 3
- **Offshore wind** capacities for the baltic sea region are set within consortium and differ by scenario

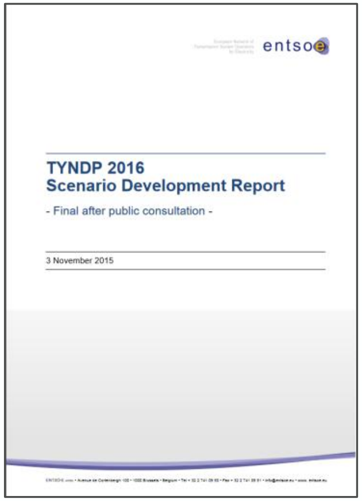
CO_2 decarbonization target:

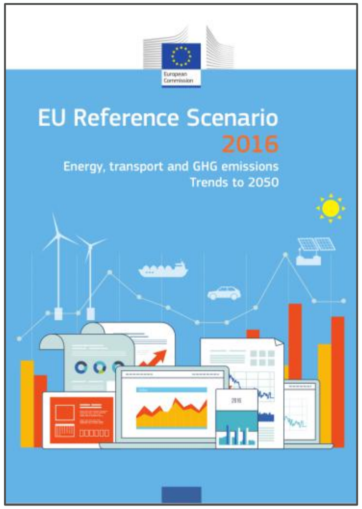
- 90% CO_2 emission reduction until 2050



Other assumptions

- Prices for fuels etc. are based on the European Commission's Reference Scenario 2016
- Time series: structure based on year 2013, full load hours are scaled to meet projections

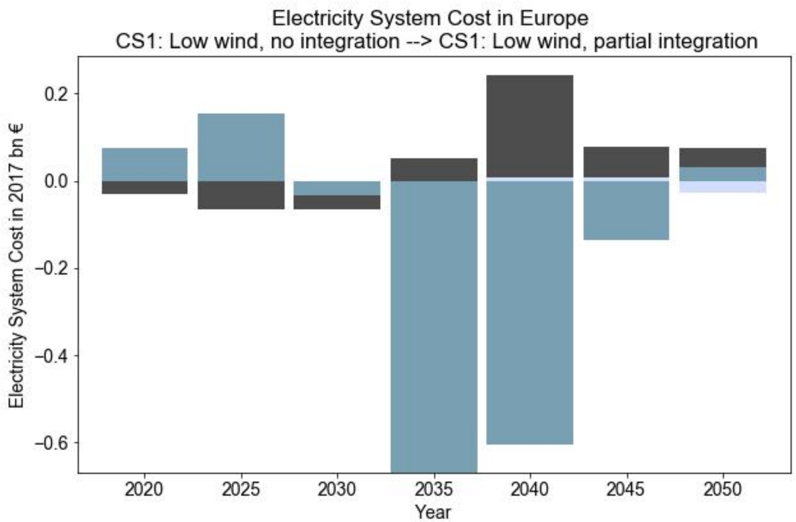


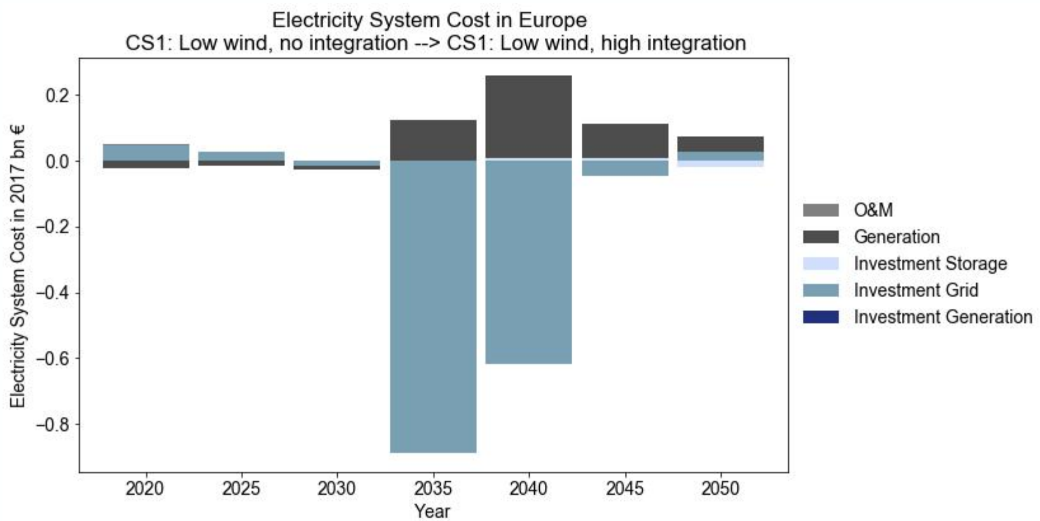


GoA 3.6, Case Study SE –PL – LT
System Cost differences (without scenario specific costs)

Overall system cost differences in 2017 bn €

Scenario	2020	2025	2030	2035	2040	2045	2050	*sum*
CS1: High wind, no integration --> high integration	0.00	0.00	-0.01	0.03	-0.07	-0.03	-0.02	**-0.09**
CS1: High wind, no integration --> partial integration	0.00	0.00	-0.01	0.03	-0.06	-0.01	-0.01	**-0.06**
CS1: Low wind, no integration --> high integration	0.03	0.01	-0.03	-0.76	-0.36	0.07	0.05	**-0.99**
CS1: Low wind, no integration --> partial integration	0.04	0.09	-0.07	-0.62	-0.36	-0.06	0.05	**-0.92**



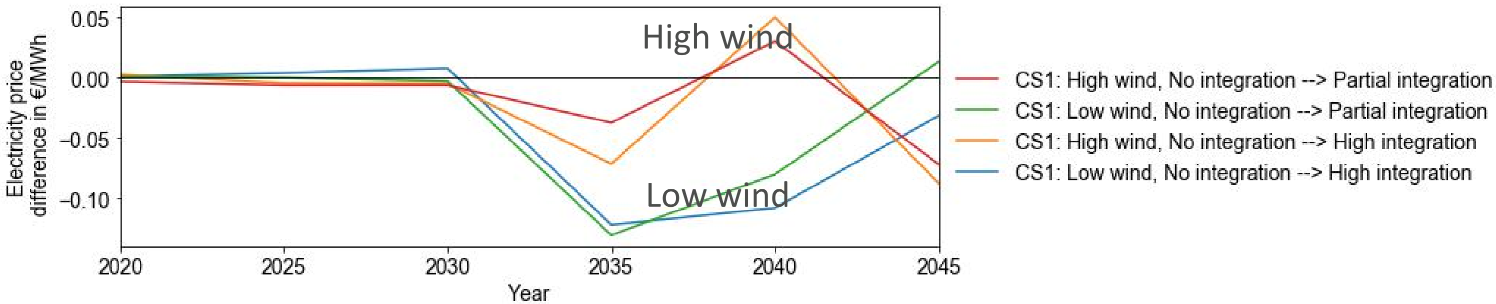


- In the high wind scenarios, the difference is relatively small
- Cost changes occur due to reduced grid expansion need in case of higher offshore interconnection
- Mainly in Sweden, Poland, and Lithuania. Other Countries less affected

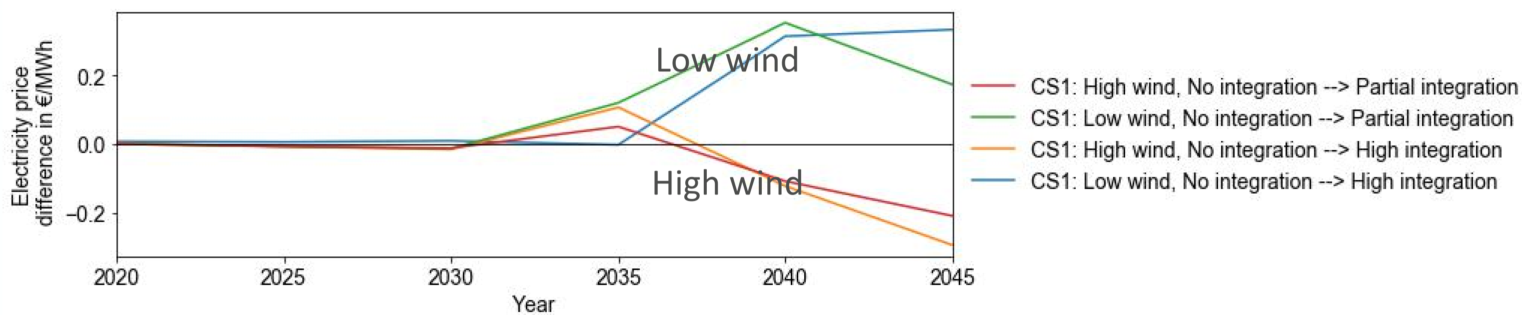
GoA 3.6, Case Study SE –PL – LT
Price development

Average electricity price difference for scenario variations

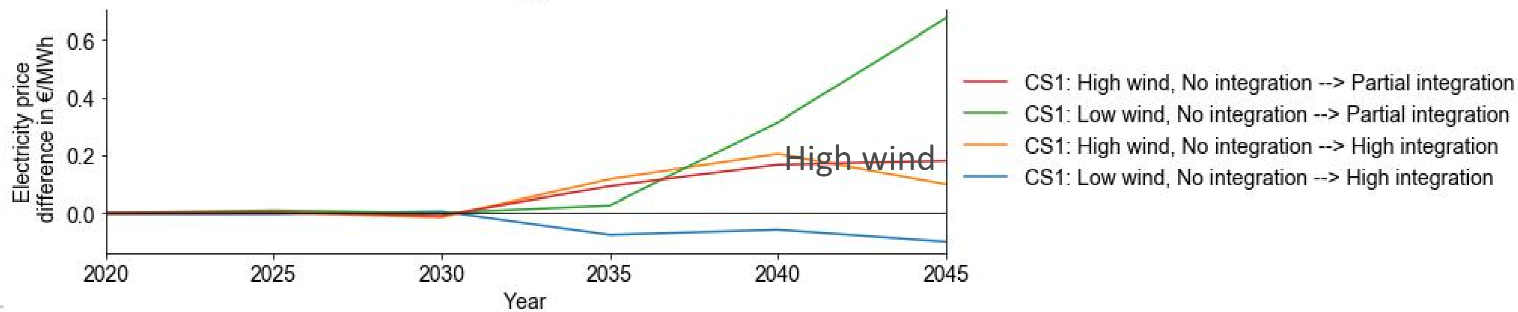
PL



SE



LT



System Adequacy / Security of Supply

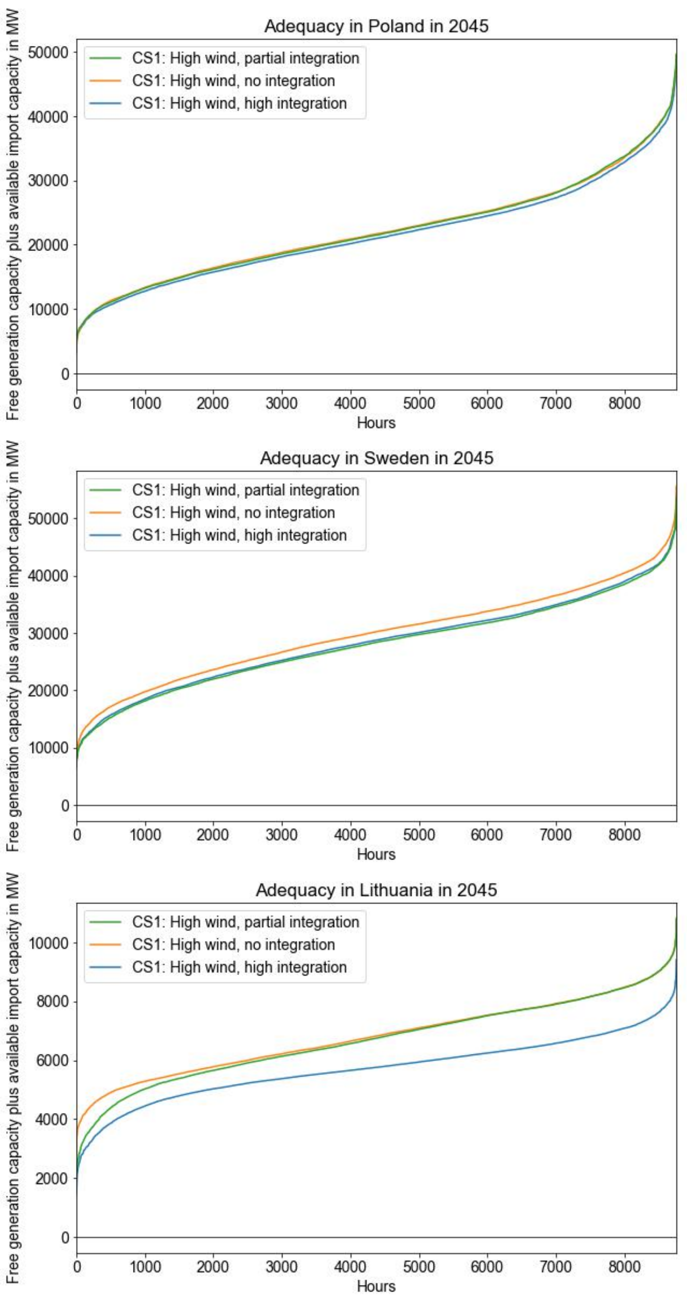
System Adequacy depends on:

- Unused generation and available capacity in each country
- State of network: flows and flow directions, which determines the available import capacity

➢ Derive System Adequacy Margin for each hour in each country

System Adequacy

- ➢ In all scenarios the system configuration is adequate
- ➢ Adequacy is similar in all scenarios
- ➢ For Lithuania the system adequacy is lower in the High Integration scenarios



Adequacy in case of line outages

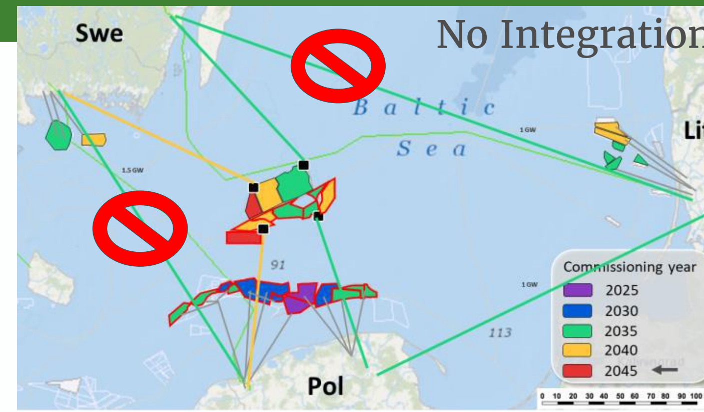
Question:

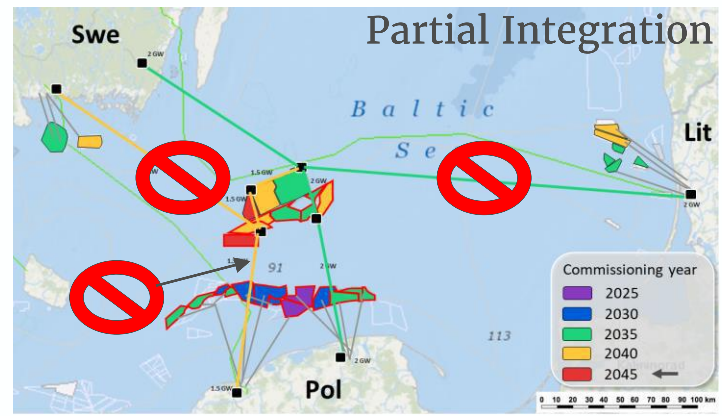
Do scenarios with higher connectivity provide higher adequacy in case of a line outage?

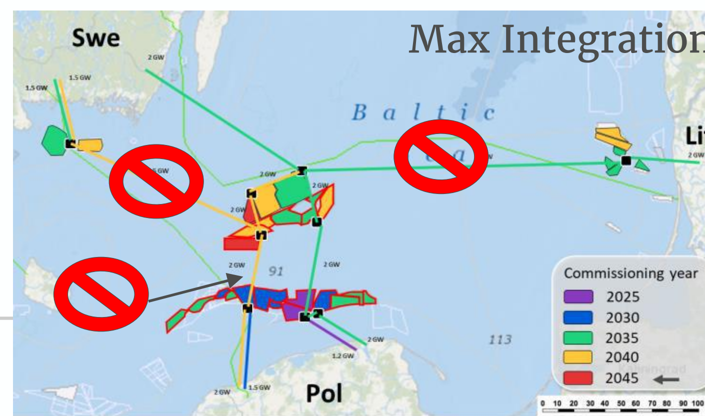
Comparison: Hourly Adequacy with and without lines.

Lines excluded for system adequacy comparison:

- No Integration: Main Interconnectors
- Partial Integration: Lines to Central Point
- Max Integration: Lines between Wind farms

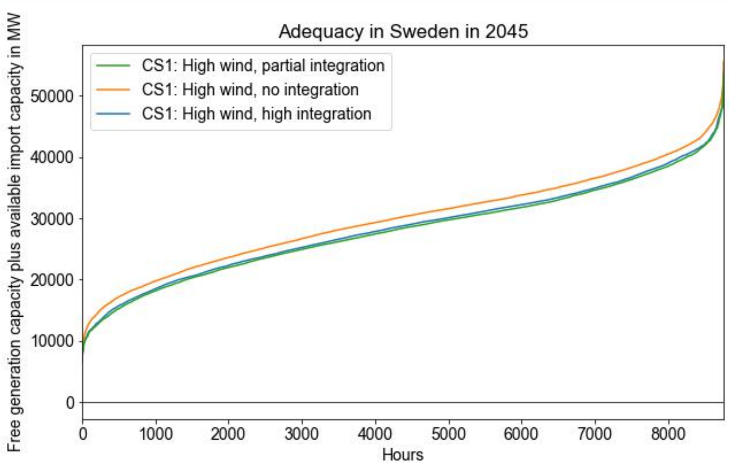




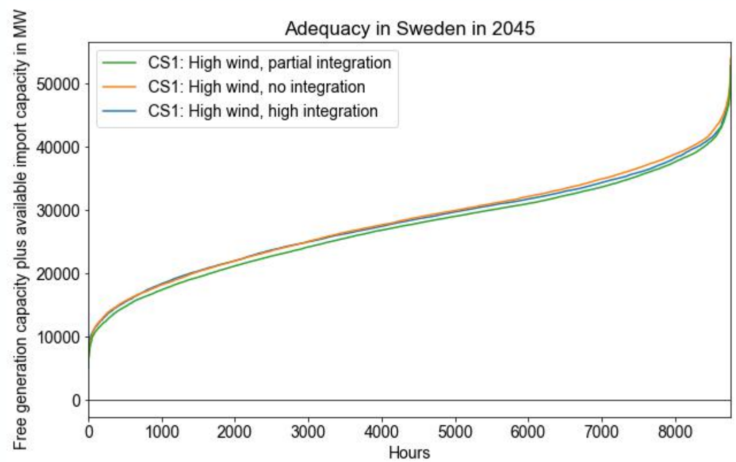


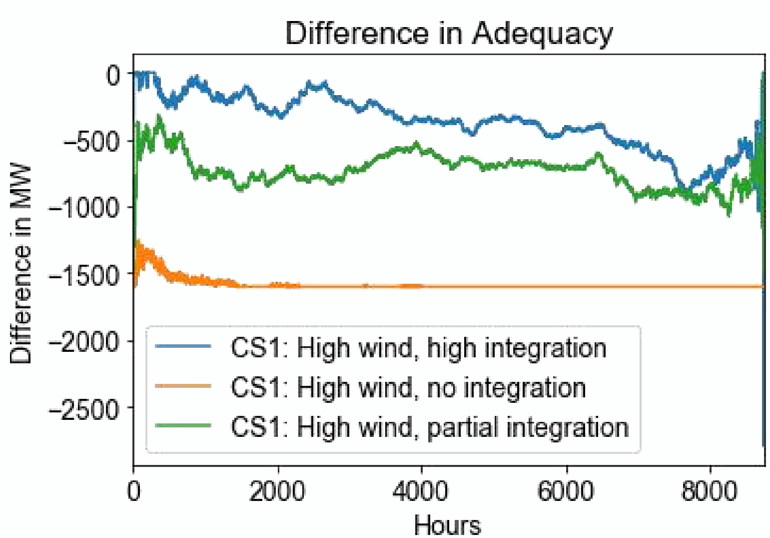
Adequacy in case of line outages – Sweden

Before



After line outage



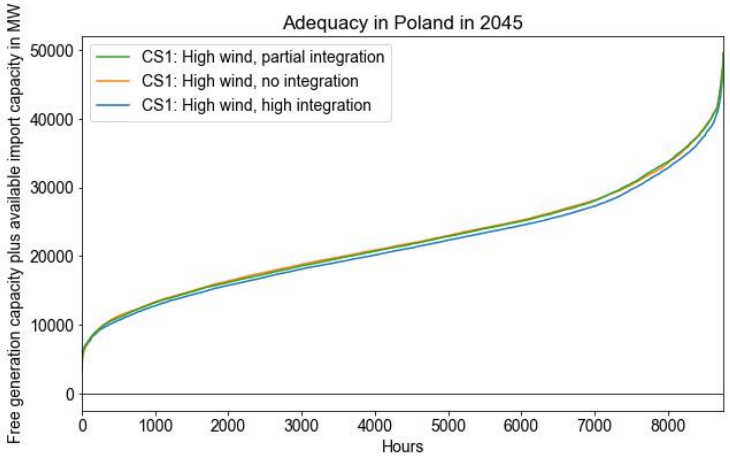


Adequacy after line outage

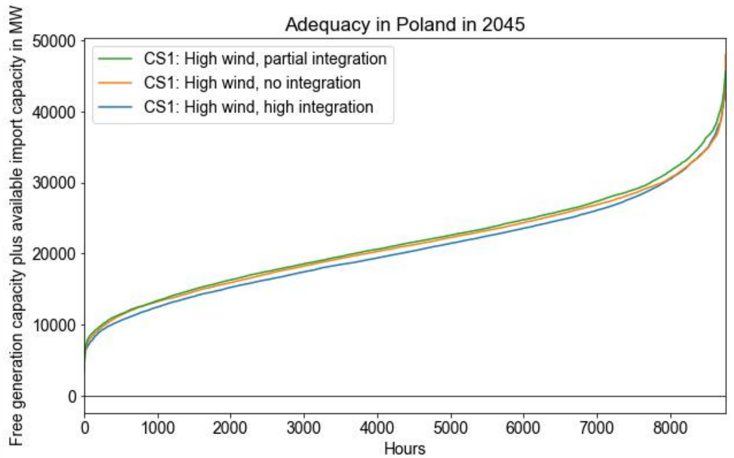
- Adequacy is reduced as expected, but no threat to system adequacy overall
- No Integration scenario mostly affected
- Similar adequacy reduction in partial and high integration scenarios.

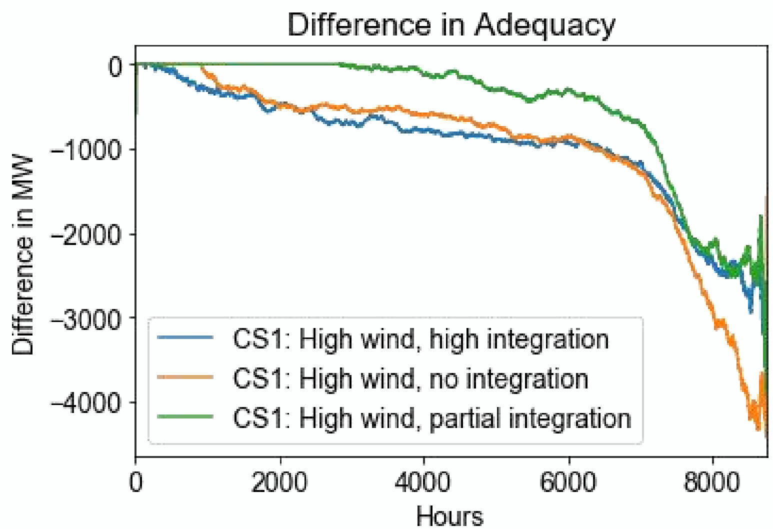
Adequacy in case of line outages – Poland

Before



After Line outage



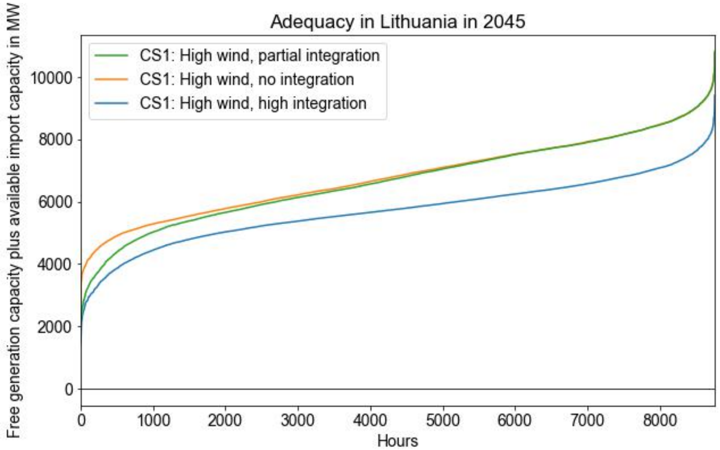


Adequacy after line outage

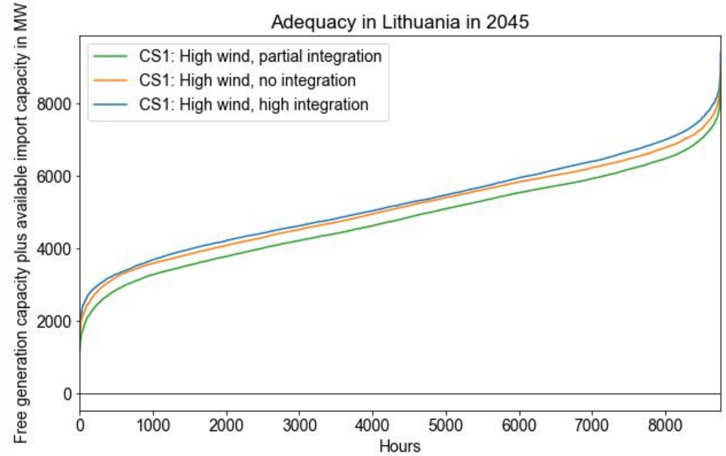
- Differences between scenarios are smaller
- In case of lowest adequacy the decrease due to line outage is smallest
- Partial Integration is most resilient against the modeled line outage

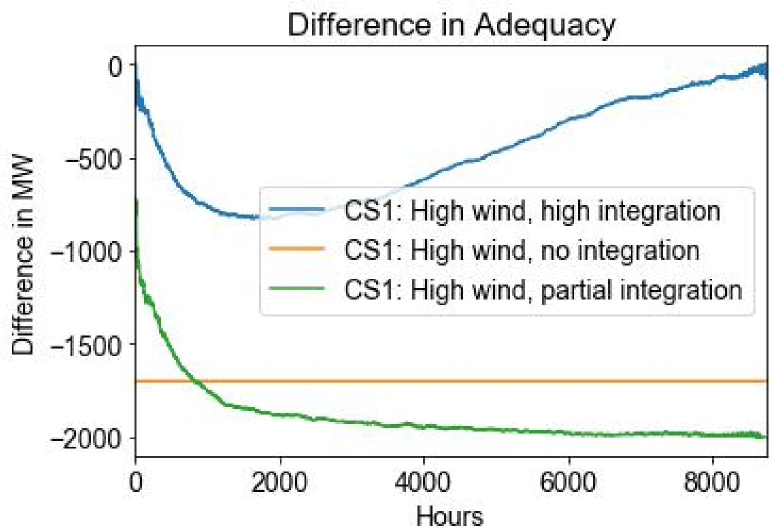
Adequacy in case of line outages – Lithuania

Before



After Line outage



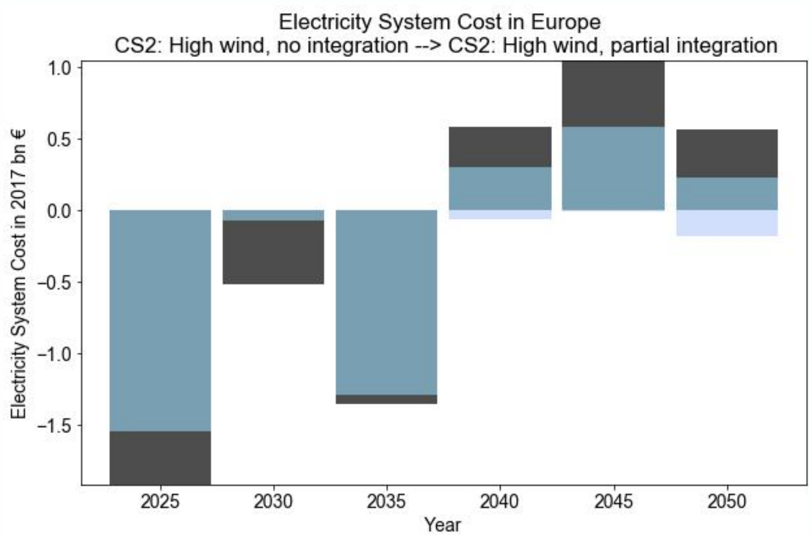


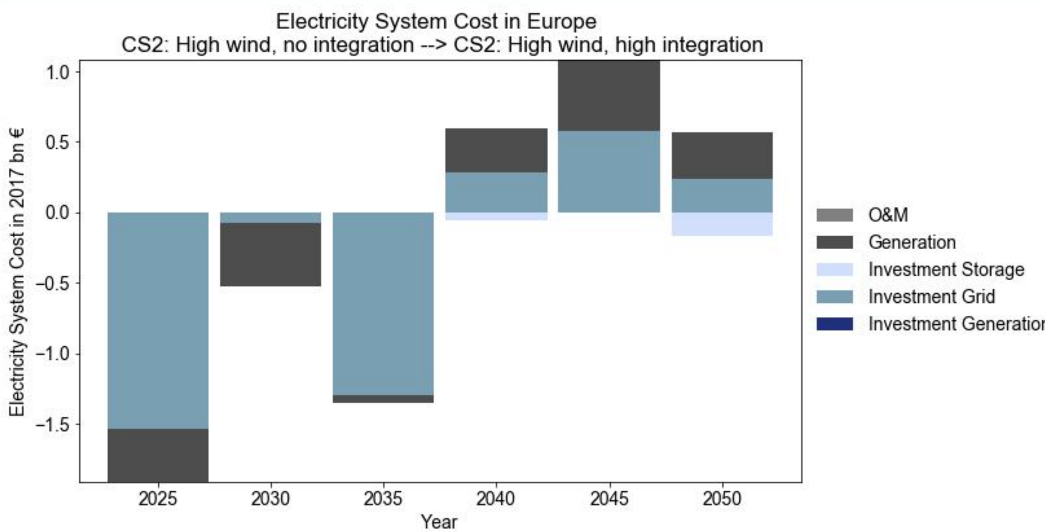
Adequacy after line outage

- Differences relative to total generation capacity largest in Lithuania
- High integration scenario is most robust against line outage
  - Especially in case of already low adequacy

Overall system cost differences

Scenario	2025	2030	2035	2040	2045	2050	sum
CS2: High wind, no integration --> high integration	-1.91	-0.52	-1.35	0.54	1.09	0.41	-1.76
CS2: High wind, no integration --> partial integration	-1.92	-0.52	-1.35	0.52	1.05	0.38	-1.83
CS2: Low wind, no integration --> high integration	0.00	0.00	0.00	-0.01	0.01	0.01	0.01
CS2: Low wind, no integration --> partial integration	0.01	-0.04	-0.02	0.03	0.03	0.03	0.03





- Cost decreases also here mostly in grid expansion.
- Mainly in the scenario-relevant countries Germany, Sweden, and Denmark

Conclusions Benefits Part

- Expectation previous to model runs: Small overall system cost differences between levels of integration in the baltic sea region
- Results: Depending on Wind installation, the need for grid expansion can be reduced by increased offshore integration across countries
- Increased integration also helps to improve system reliability

Next:

➢ Combination of Benefits results with the Costs part in the following presentation

Costs: Design and Result of the Linear Cost Model

Approach

- Linear Cost Model (incl. expected future trends)
- Sensitivity Analysis
- All results dicsounted to 2017 with an interest rate of 4%

Evaluated as most
suitable cost data sets

Linear Cost Model

Cable Cost
(Cable + Installation)

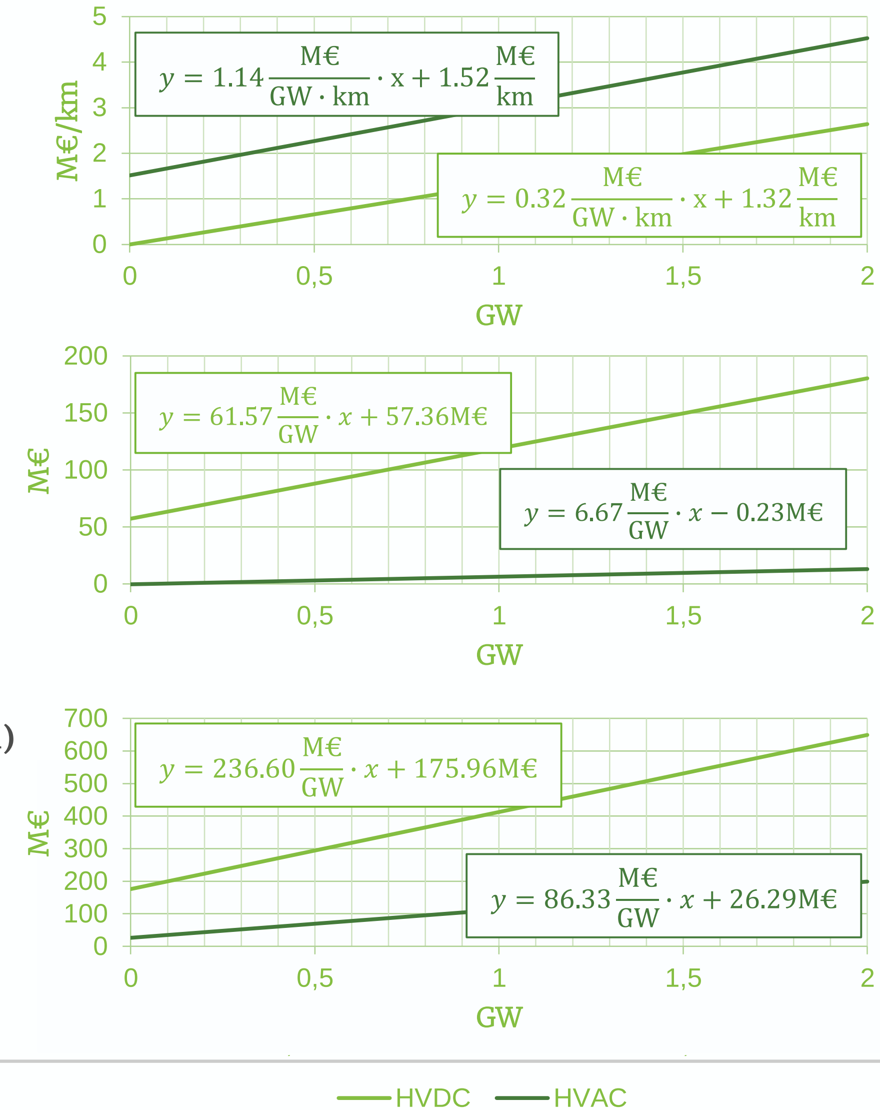
- length- and power dependent cost
- length-dependent cost

Onshore Node Cost
(Converter/Transformer + Installation)

- power-dependent cost
- fixed cost

Offshore Node Cost
(Converter/Transformer + Platform + Installation)

- power-dependent cost
- fixed cost



[Linear Cost Model, cf. Härtel et. al. 2017]

CS1 (SE/PO/LT)

High Offshore Wind power

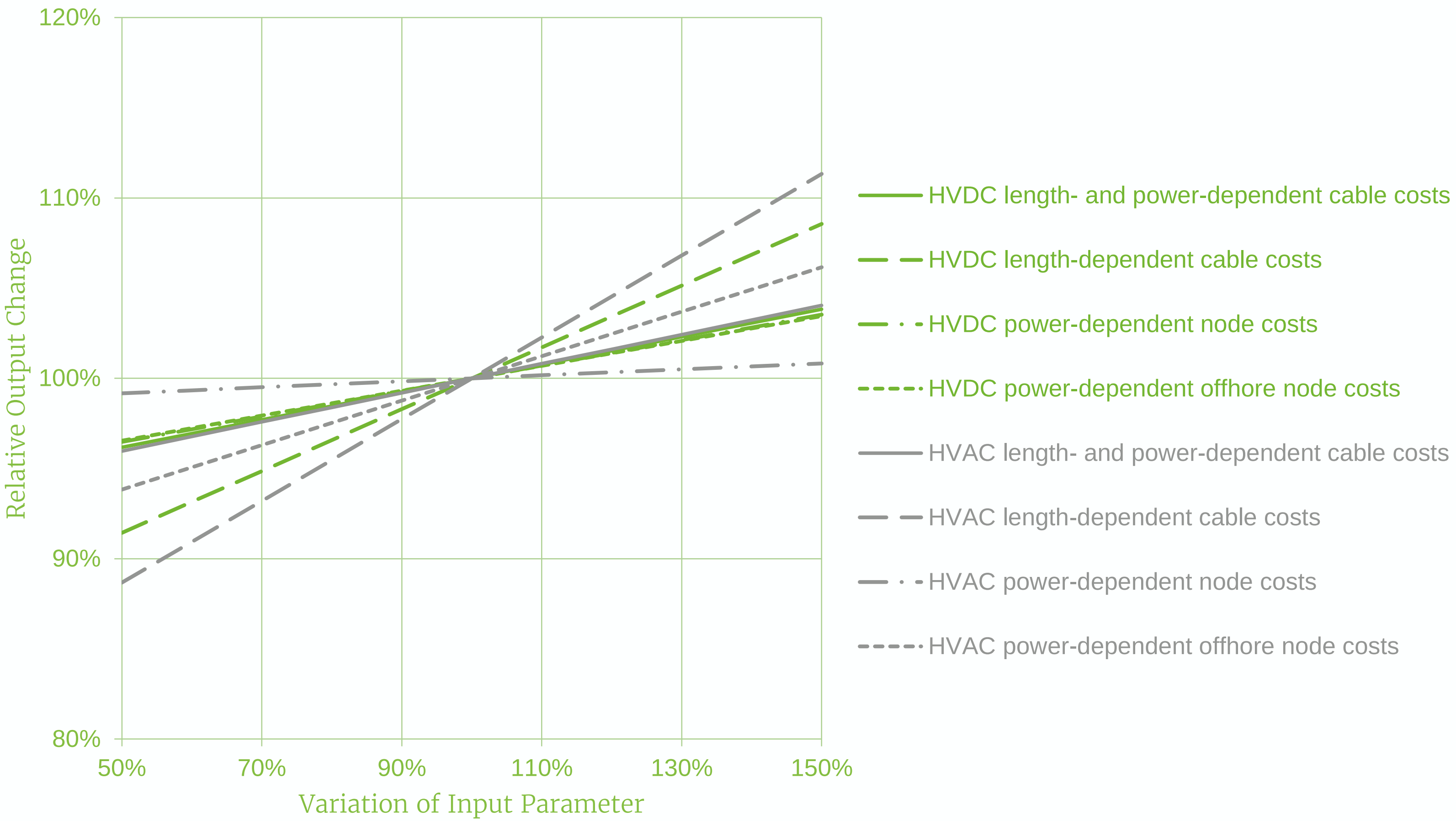
-0.66 bn€	0.24 bn€

CS2 (DE/SE/DK)

High Offshore Wind Power

0.46 bn€	0.04 bn€

Sensitivity Analysis



Exemplary Analysis for CS1_2a (Part. Integ., High OWP)

Balance

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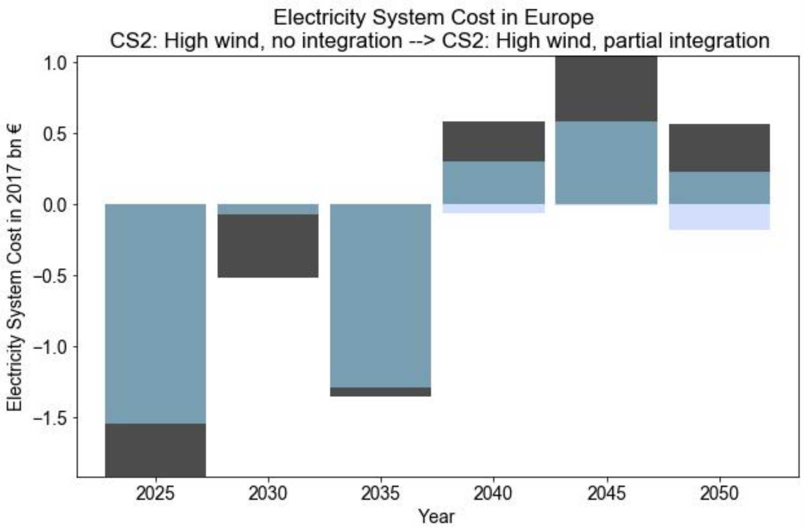
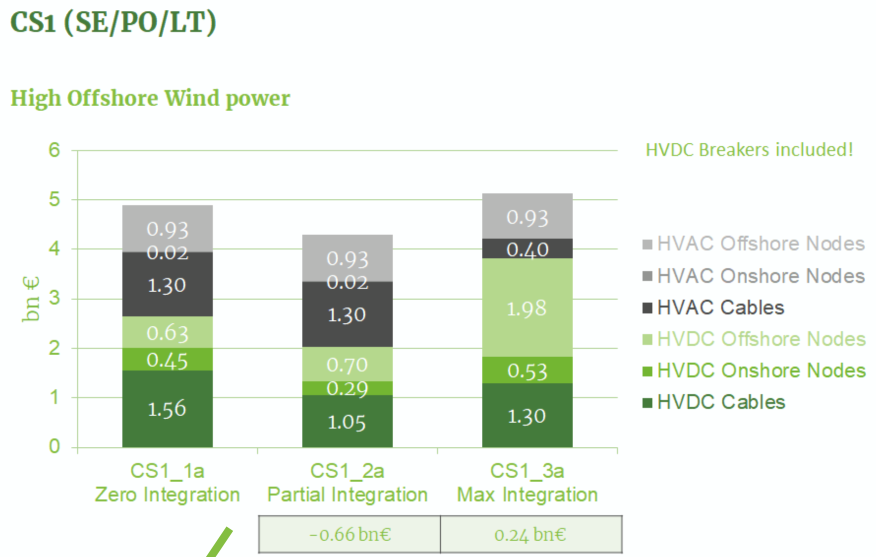
Approach

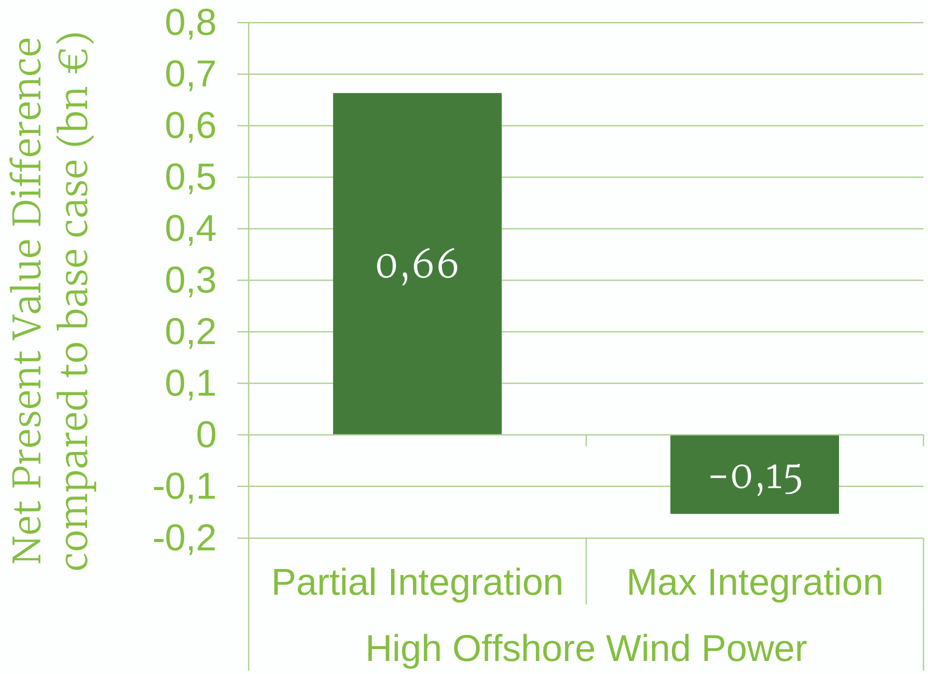


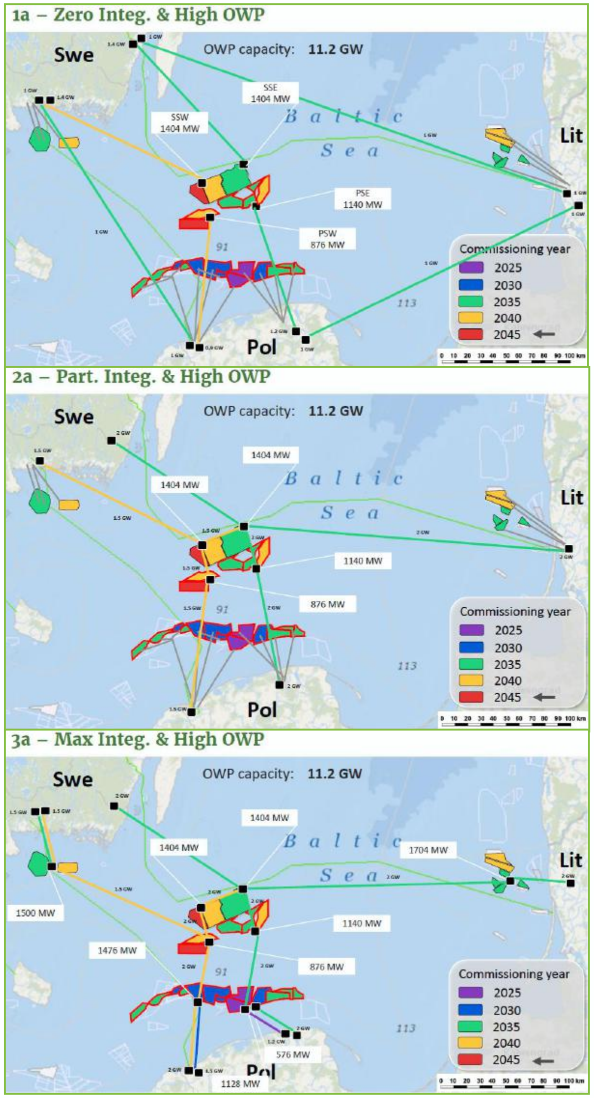


Net Present Value Difference compared to Base Case

CS1 (SE/PO/LT)

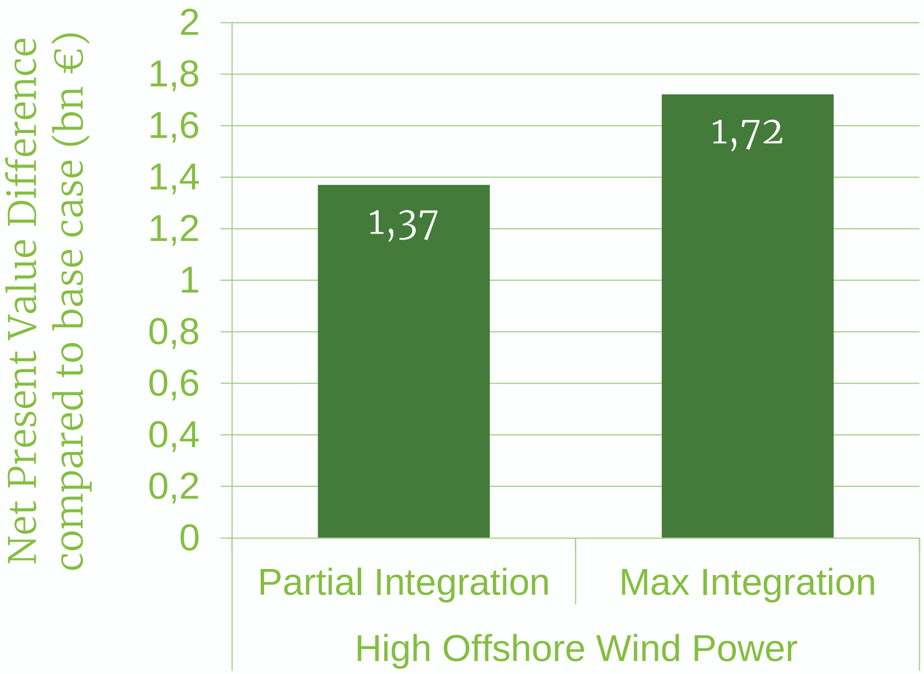
High Offshore Wind Power

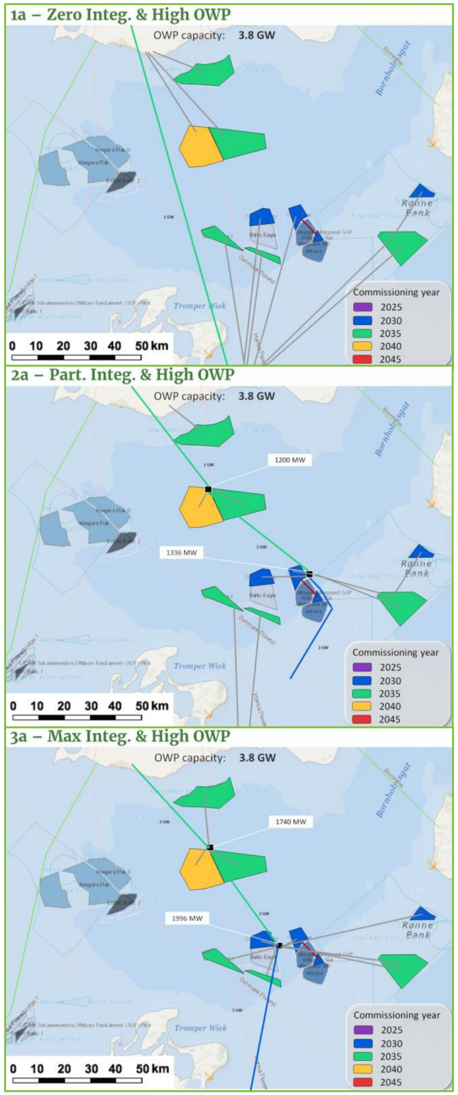




CS2 (DE/SE/DK)

High Offshore Wind Power





Conclusions

- The main benefit brings the interconnection, which is already part of the base case (zero integration)
- No general trend related to the evaluation of partial and maximum integration scenarios could be identified
- The cost structure is case specific
  - Cost reduction potential is higher when hub connections are also part of the zero integration case
  - Reduction of AC components could be positive but is often compensated by additional DC offshore node cost
- Benefits are almost equal for partial and max integration scenarios, costs can vary significantly

For further information:

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