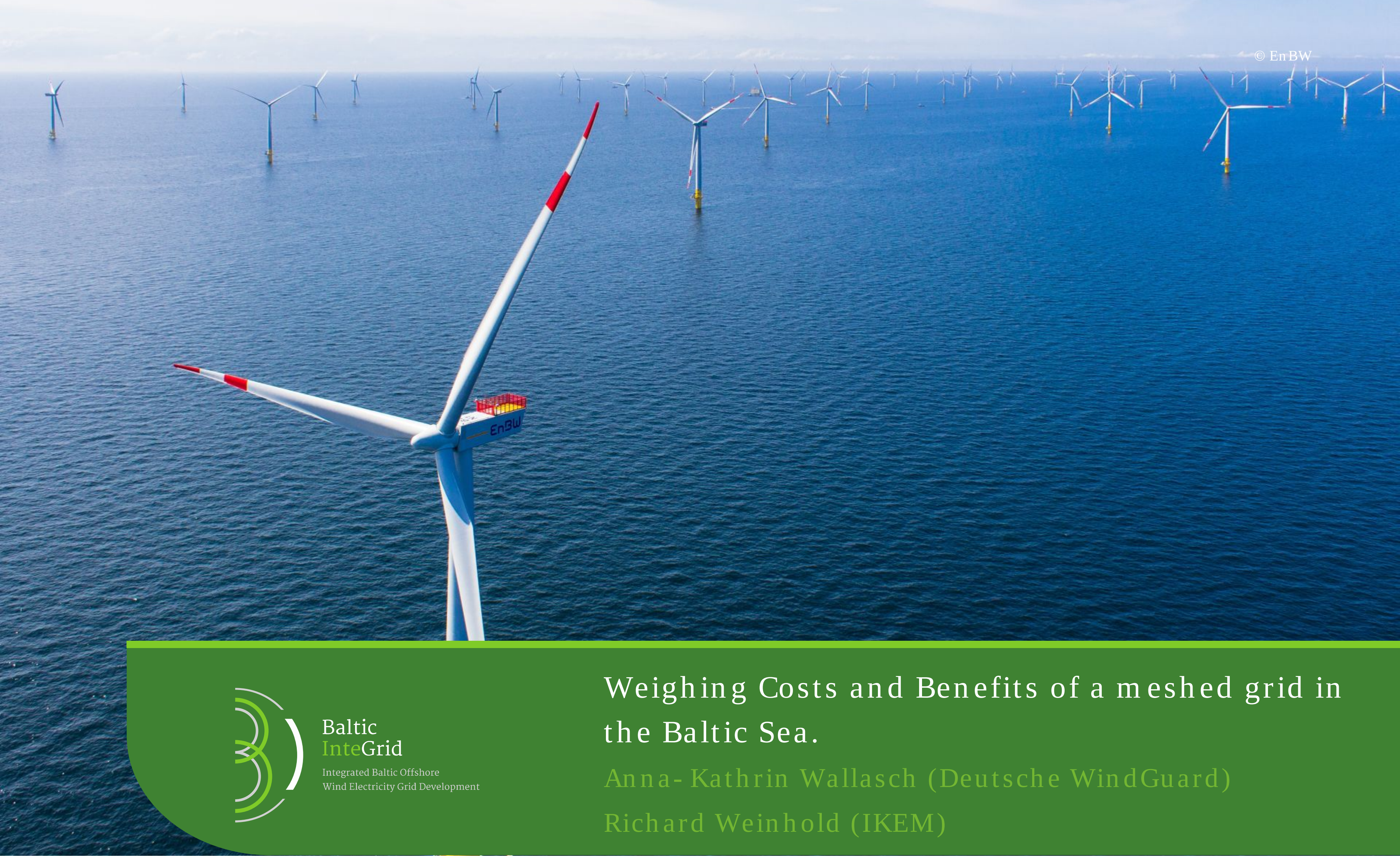

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Baltic InteGrid
Integrated Baltic Offshore Wind Electricity Grid Development

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

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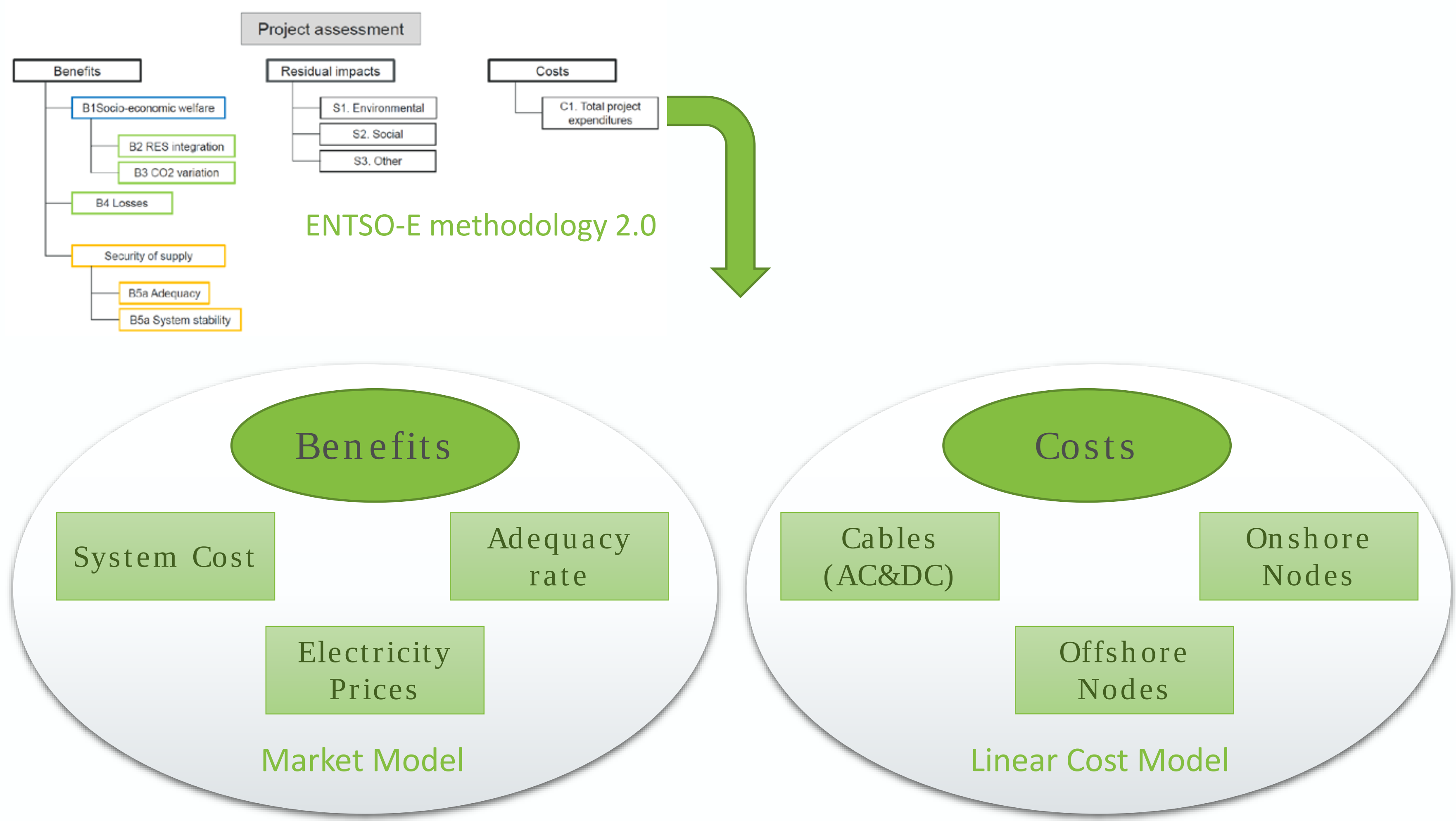
Richard Weinhold (IKEM)

DEUTSCHE WINDGUARD
IKEM
EU STRATEGY FOR THE BALTIC SEA REGION FLAGSHIP
Interreg Baltic Sea Region
EUROPEAN REGIONAL DEVELOPMENT FUND
EUROPEAN UNION

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

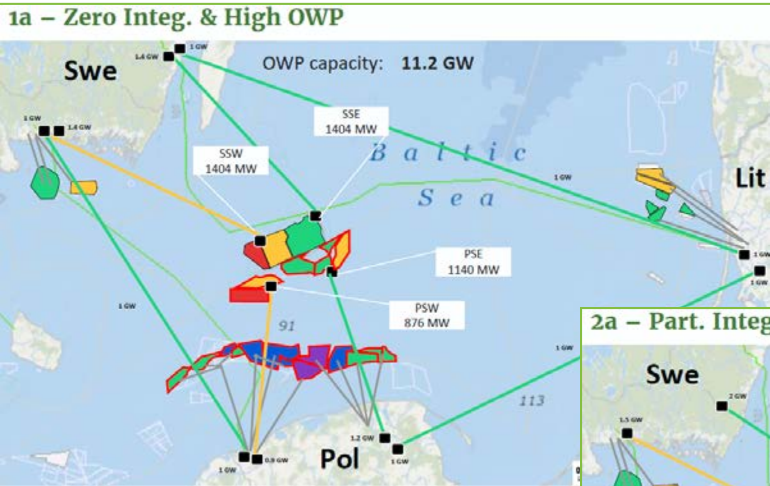
Pre-Feasibility Analysis 1:

Sweden – Poland – Lithuania

Pre-Feasibility Analysis 2:

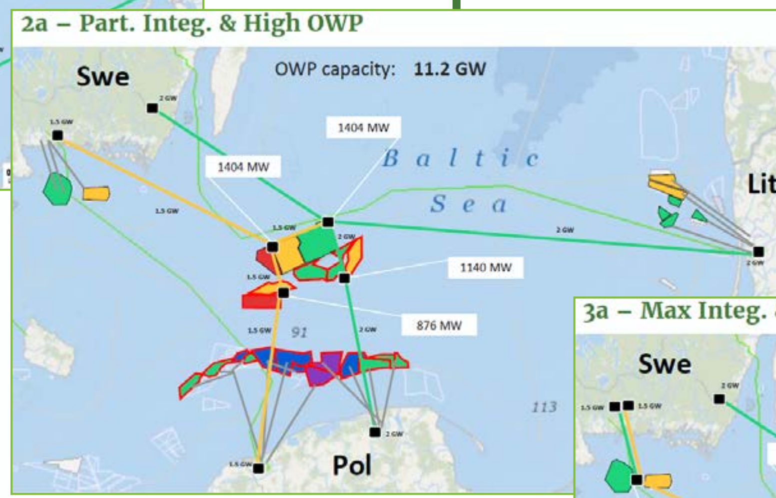
Germany – Sweden – Denmark

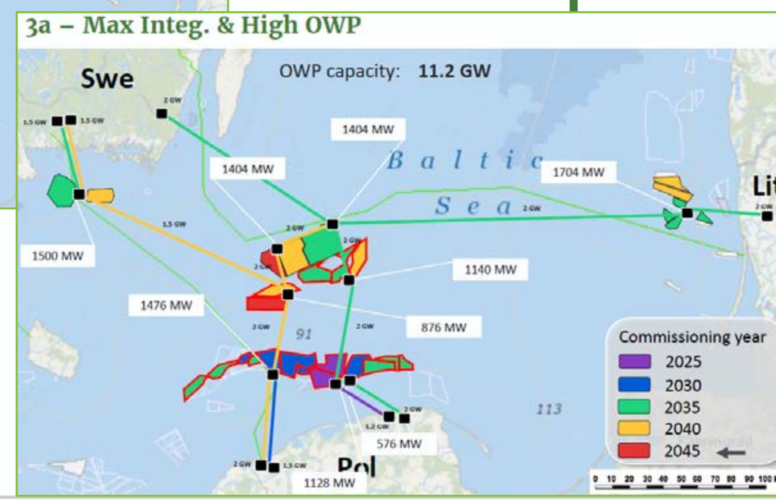
CS1 (SE/PO/LT) with High Offshore Wind Power

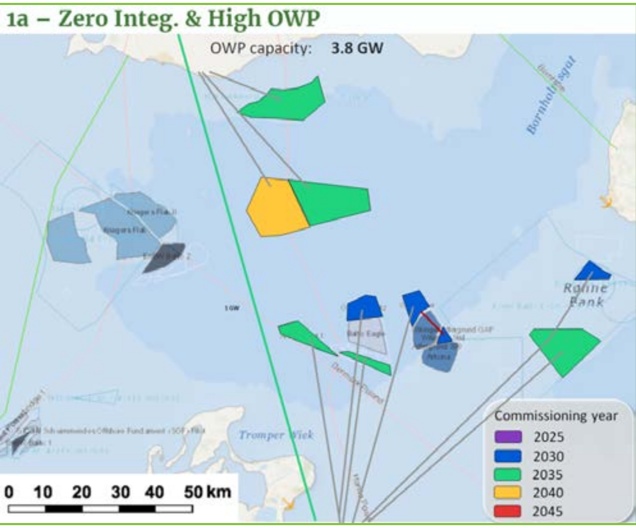


Baseline Scenario

Cost and Benefit Differences

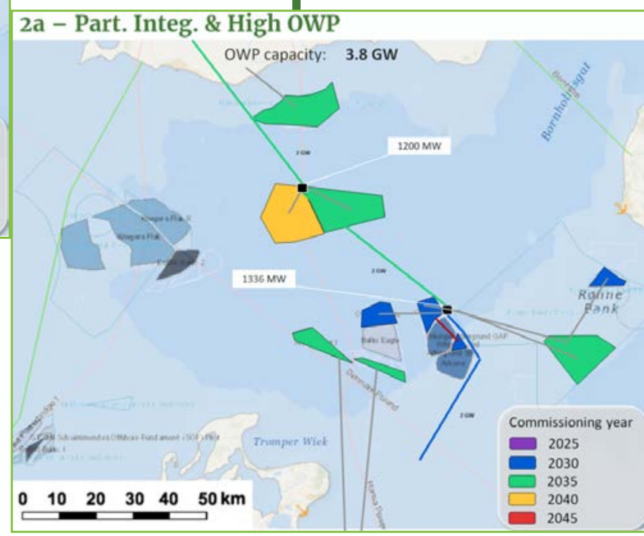


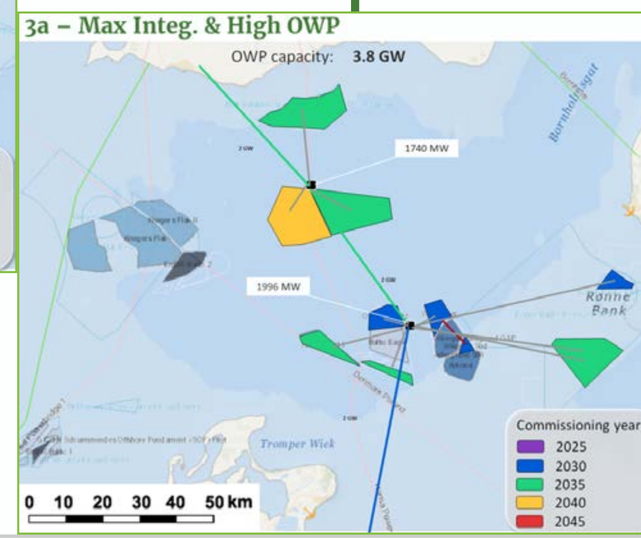




Baseline Scenario

Cost and Benefit Differences





Benefits: Design and Result of the Regional Market Model

Model dynELMOD:

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

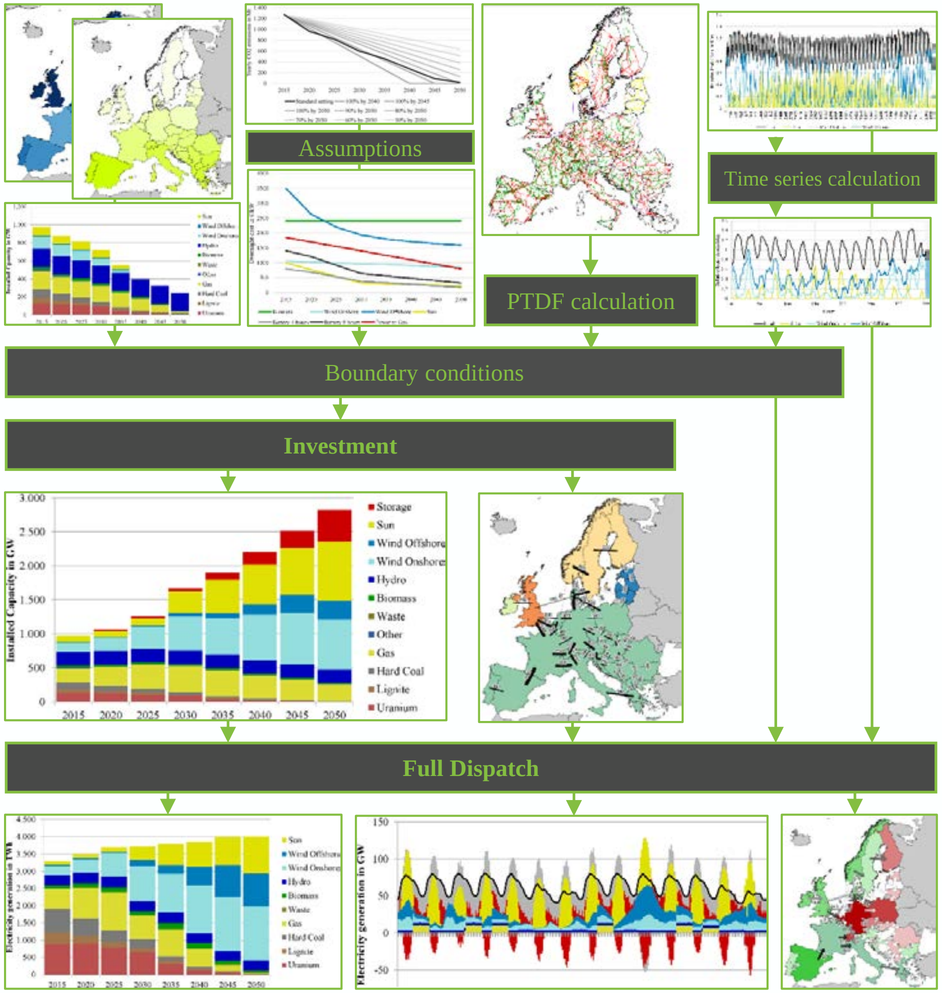
Calculation Steps

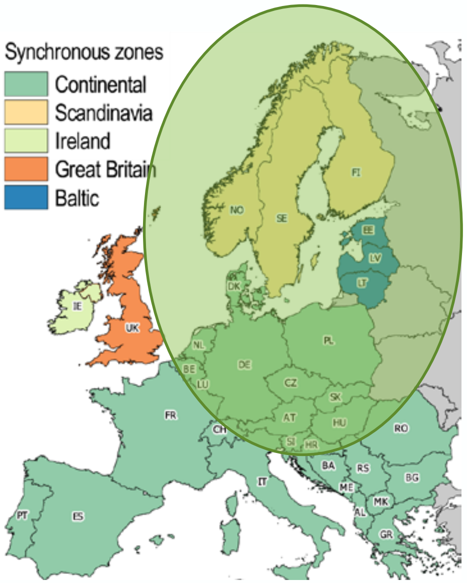
1. **Investment**
   - Investment into Conventional and renewable generation, cross-border capacities
   - Reduced time series used
2. **Dispatch**
   - Investment result from step 1 fixed
   - Time series with 8760 hours

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





Application in BIG Model Context

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

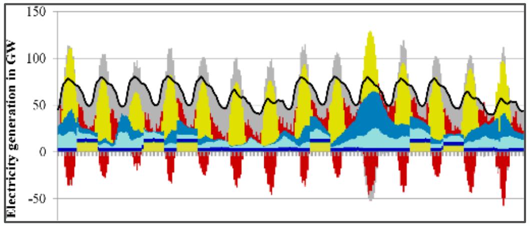
Relevant Inputs

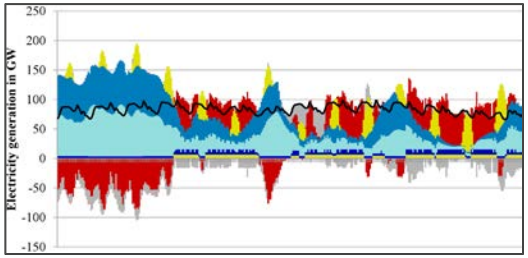
Installed Capacities, Fuel Costs, Emission limits/prices
Scenario-specific data:

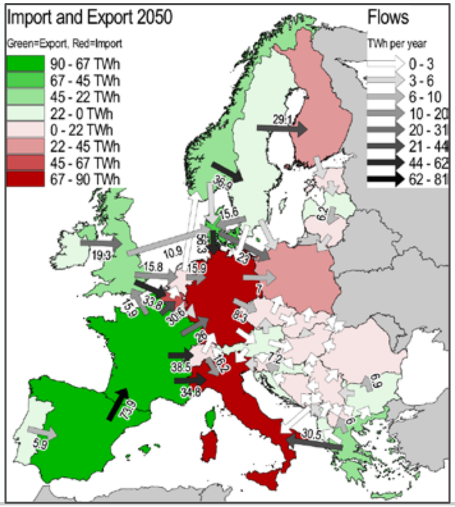
- Connections between countries
- Wind farm integrations

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





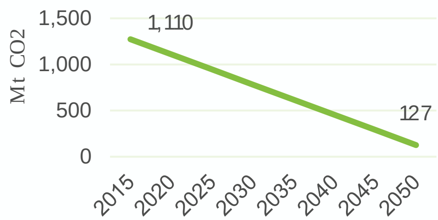


Electricity generation capacities

- 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

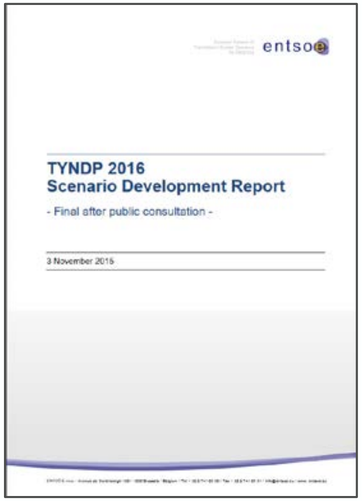
CO_2 decarbonization target:

- 90% CO_2 emission reduction until 2050



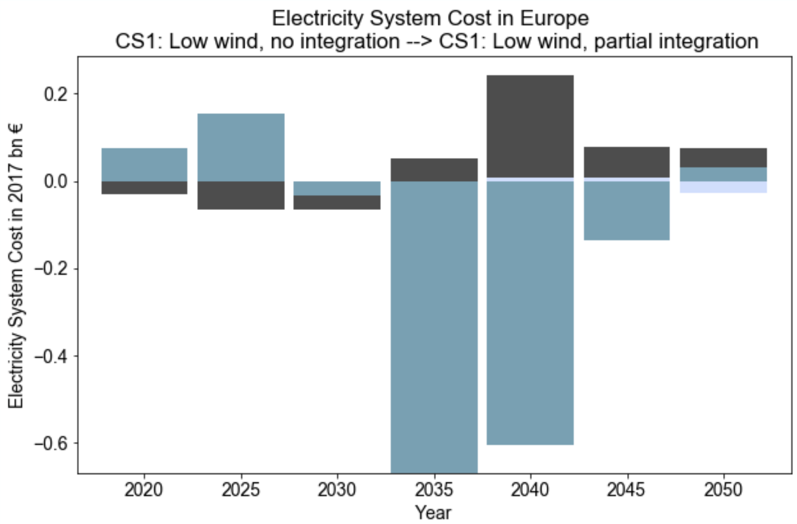
Other assumptions

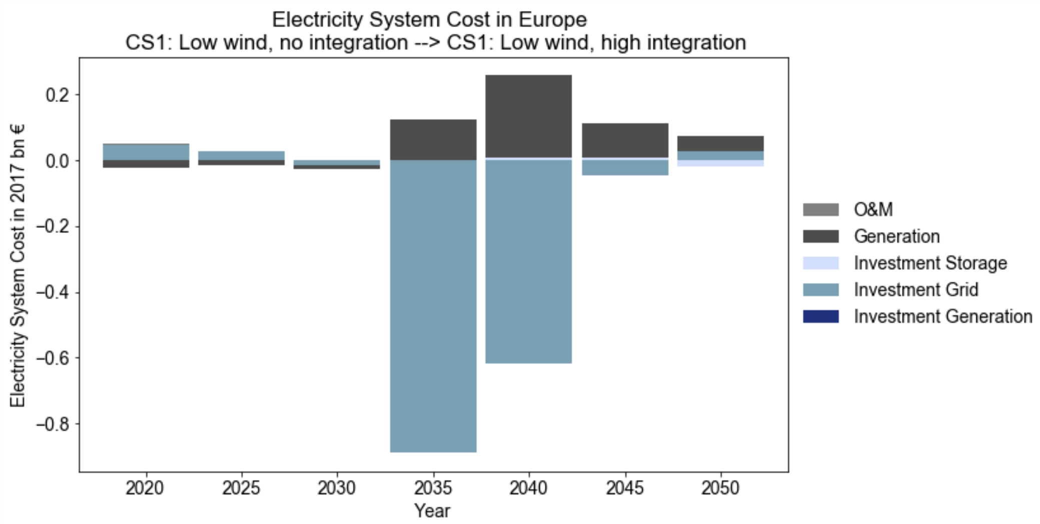
- Prices for fuels etc. are based on the European Commission's Reference Scenario 2016
- Time series: structure based on year 2013, full load hours are scaled to meet projections



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**



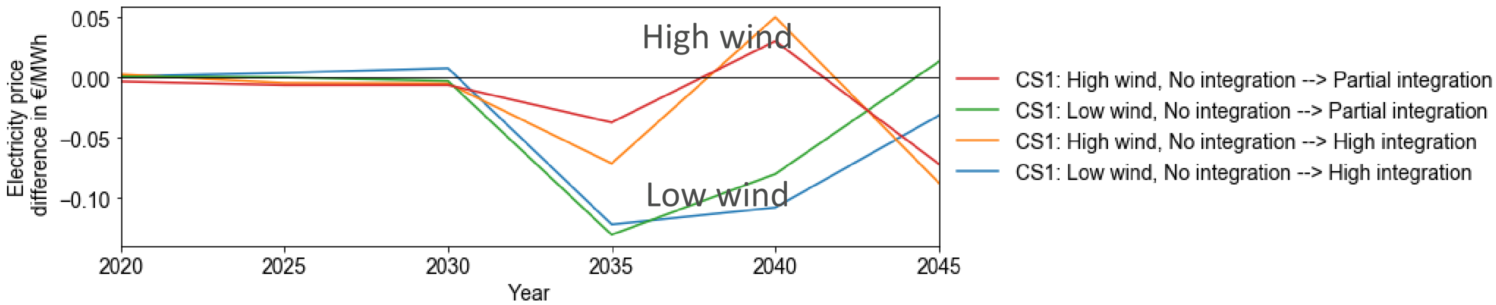


- In the high wind scenarios, the difference is relatively small
- Cost changes occur due to reduced grid expansion need in case of higher offshore interconnection
- Mainly in Sweden, Poland, and Lithuania. Other Countries less affected

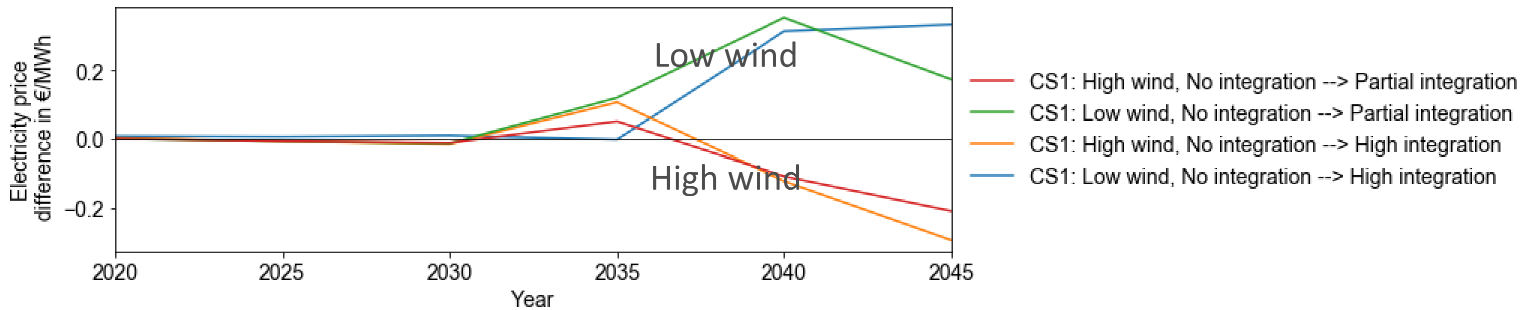
GoA 3.6, Case Study SE – PL – LT Price development

Average electricity price difference for scenario variations

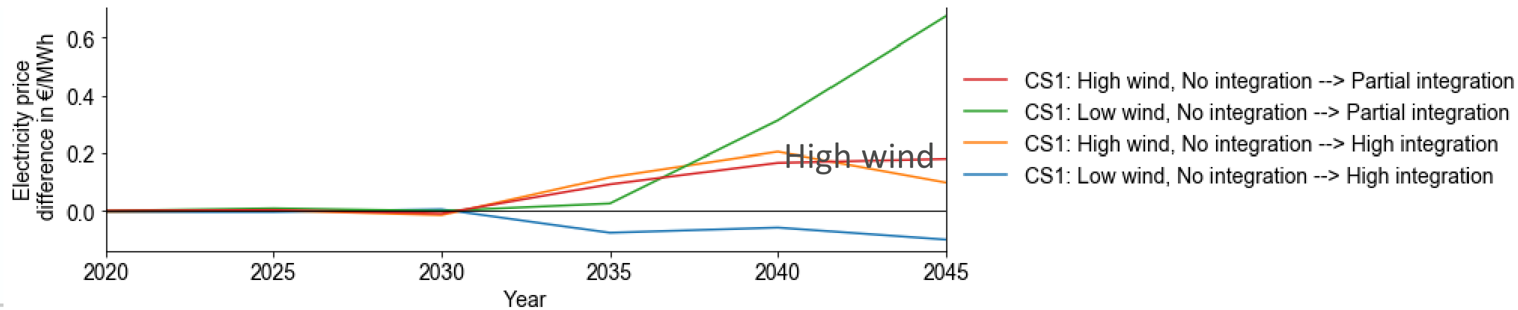
PL

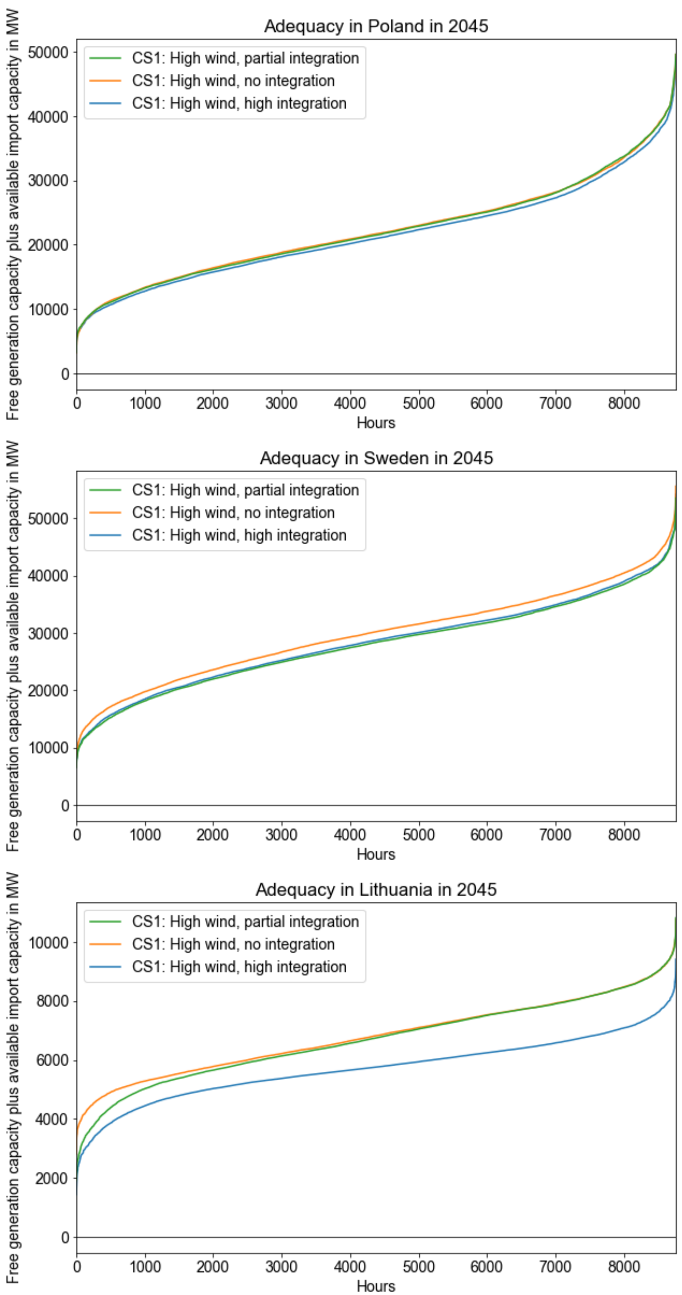


SE



LT





System Adequacy 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

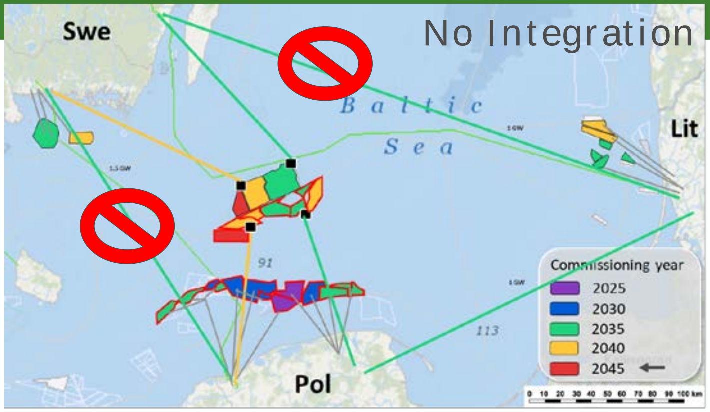
➢ In all scenarios the system configuration is adequate
➢ Adequacy is similar in all scenarios
➢ For Lithuania the system adequacy is lower in the High Integration scenarios

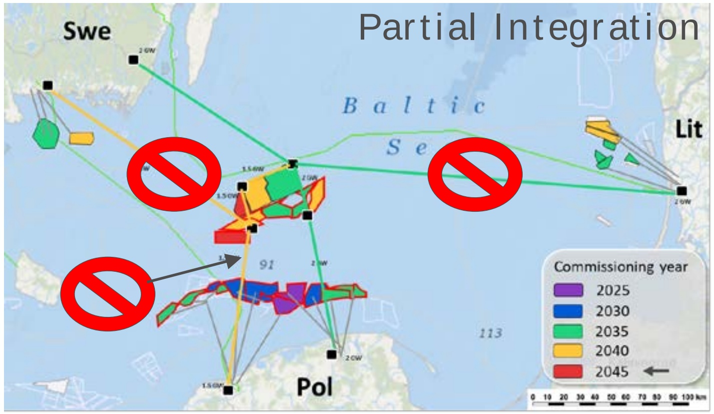
Adequacy in case of line outages

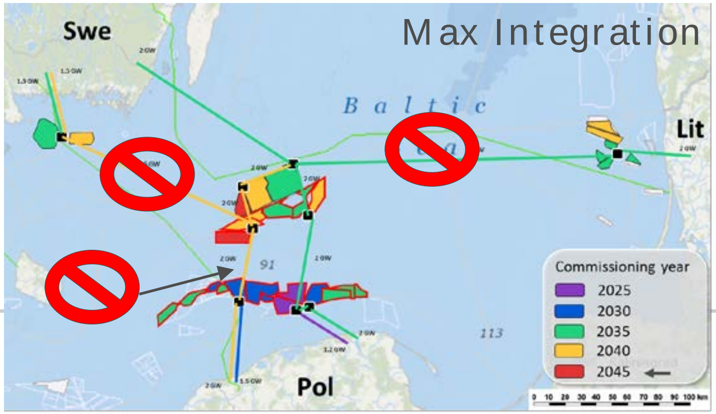
Question:

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

Comparison: Hourly Adequacy with and without lines.





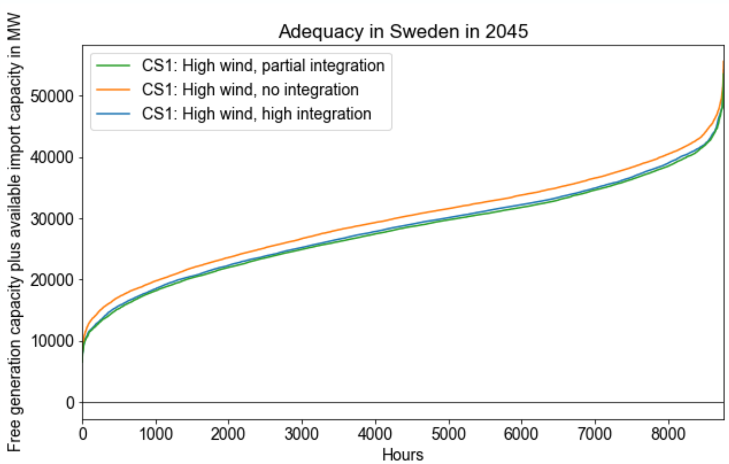


Lines excluded for system adequacy comparison:

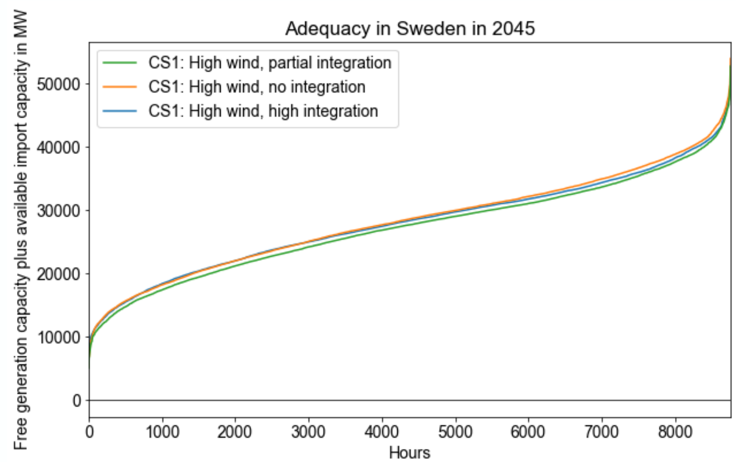
- No Integration: Main Interconnectors
- Partial Integration: Lines to Central Point
- Max Integration: Lines between Wind farms

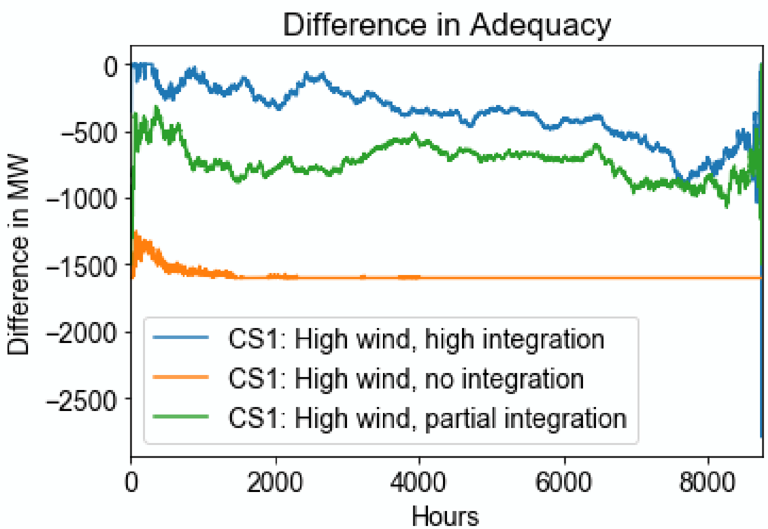
Adequacy in case of line outages – Sweden

Before



After line outage



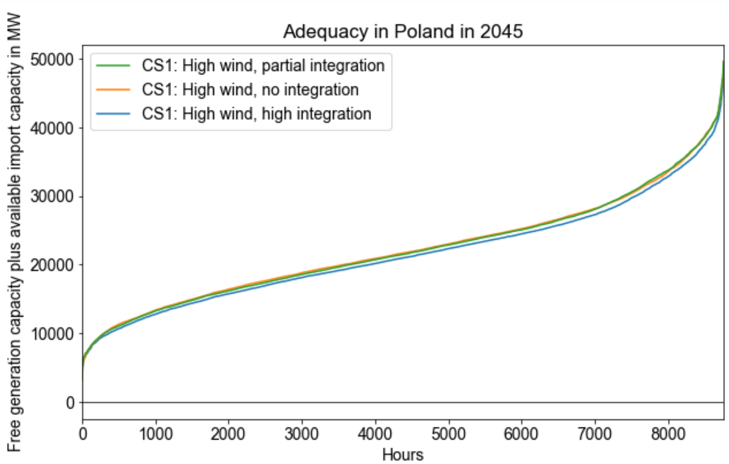


Adequacy after line outage

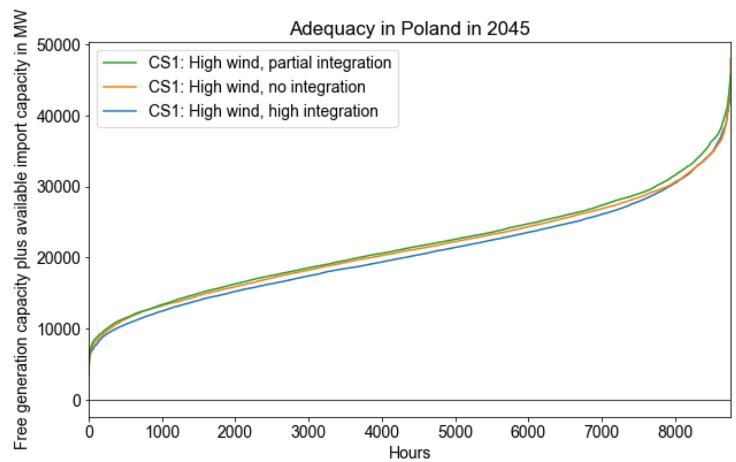
- Adequacy is reduced as expected, but no threat to system adequacy overall
- No Integration scenario mostly affected
- Similar adequacy reduction in partial and high integration scenarios.

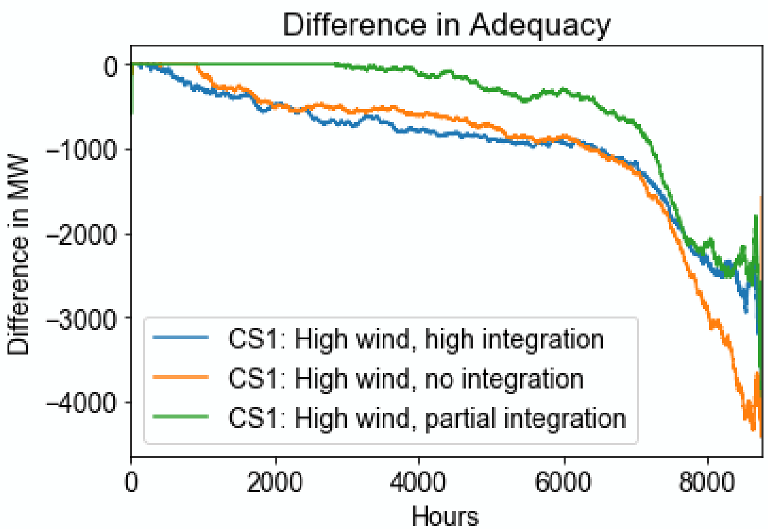
Adequacy in case of line outages – Poland

Before



After Line outage



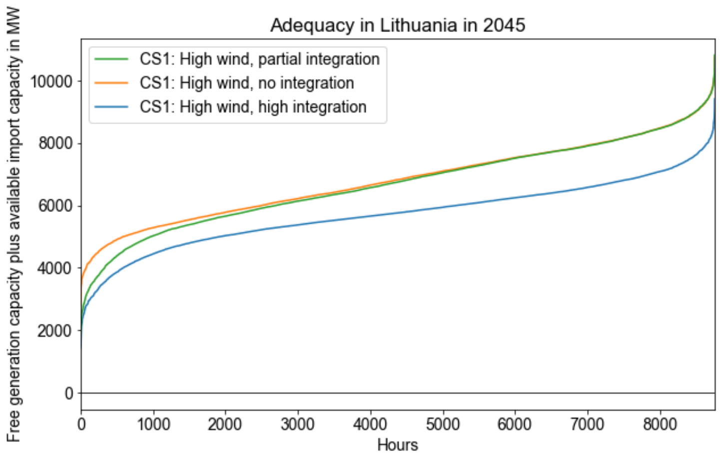


Adequacy after line outage

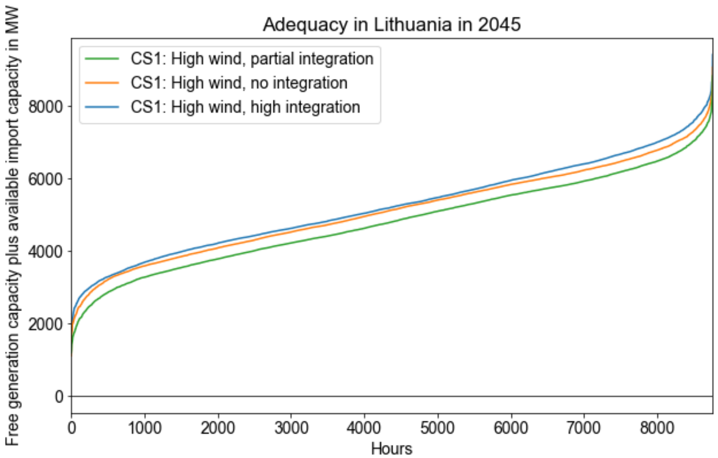
- Differences between scenarios are smaller
- In case of lowest adequacy the decrease due to line outage is smallest
- Partial Integration is most resilient against the modeled line outage

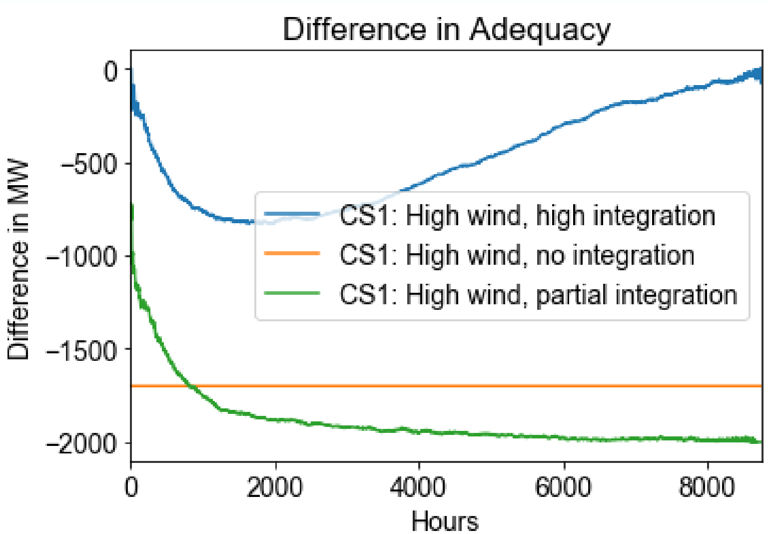
Adequacy in case of line outages – Lithuania

Before



After Line outage



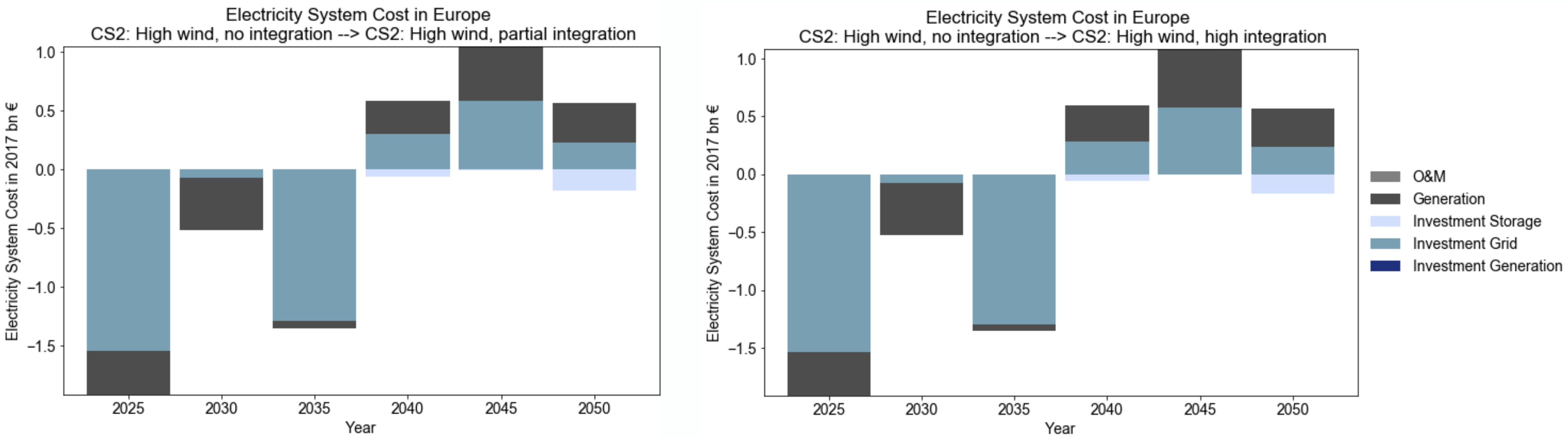


Adequacy after line outage

- 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

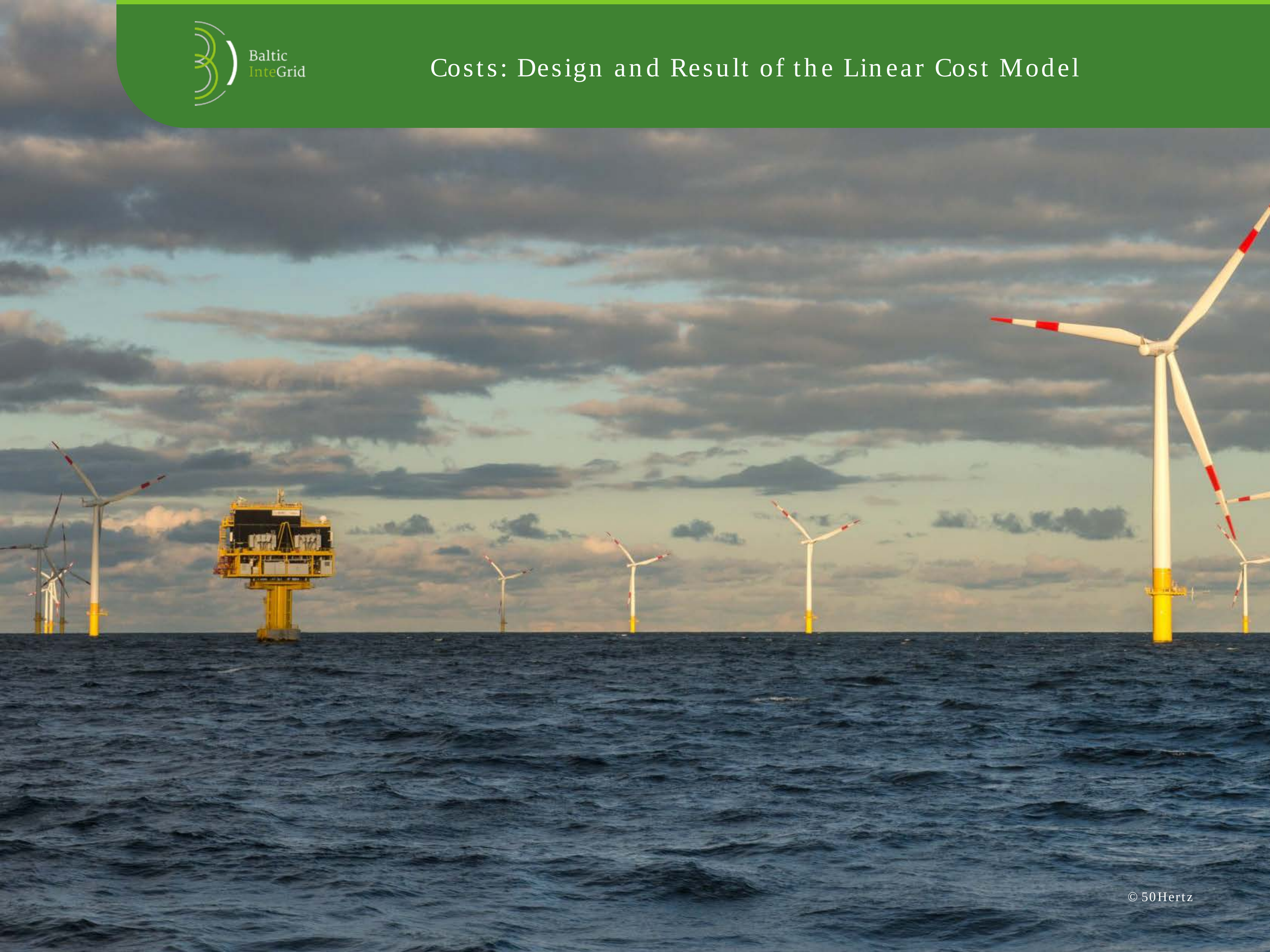
Conclusions Benefits Part

- 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

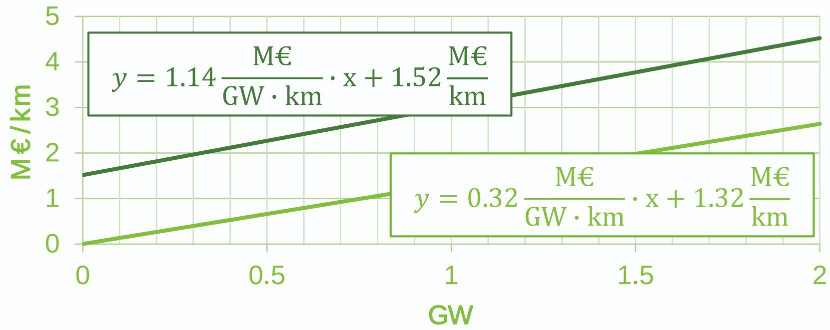
- Linear Cost Model (incl. expected future trends)
- Sensitivity Analysis
- All results dicsounted to 2017 with an interest rate of 4%

Evaluated as most suitable cost data sets

Linear Cost Model

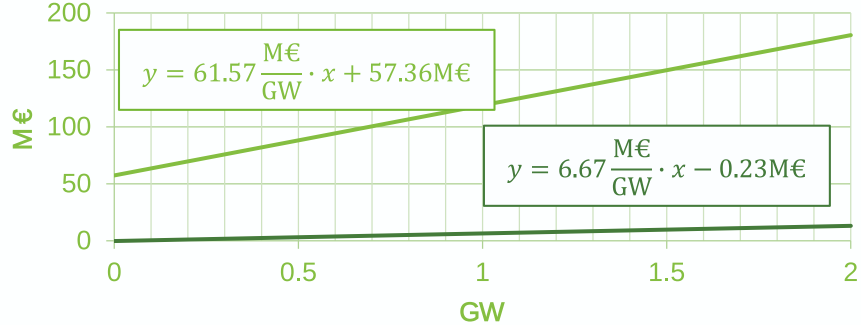
Cable Cost
(Cable + Installation)

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



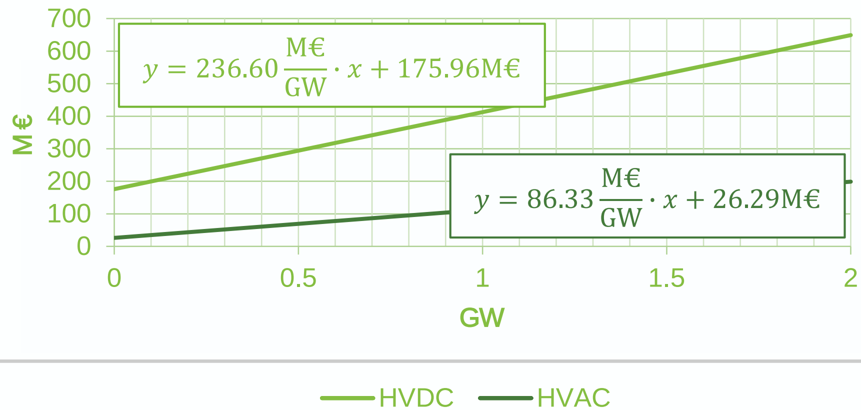
Onshore Node Cost
(Converter/Transformer + Installation)

- power-dependent cost
- fixed cost



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

- power-dependent cost
- fixed cost

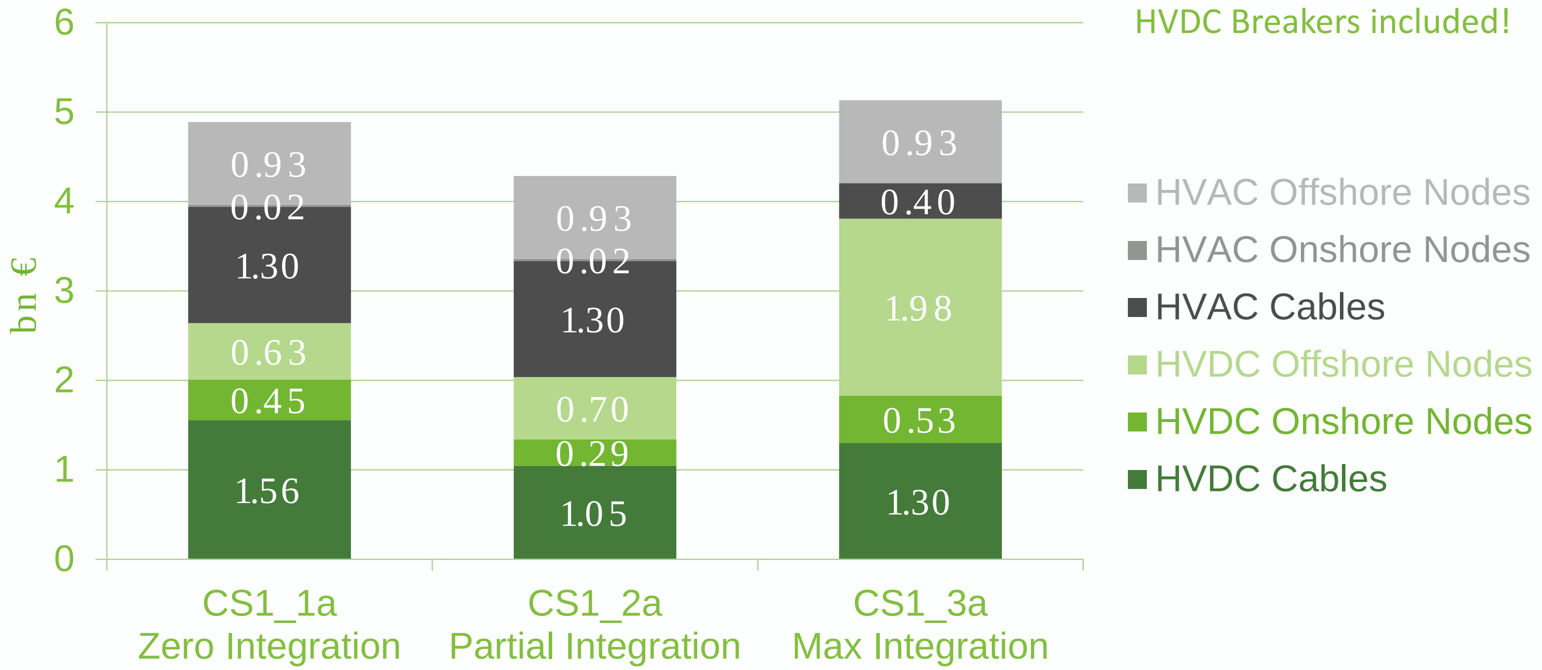


[Linear Cost Model, cf. Härtel et. al. 2017]

CS1 (SE/PO/LT)

High Offshore Wind power

HVDC Breakers included!



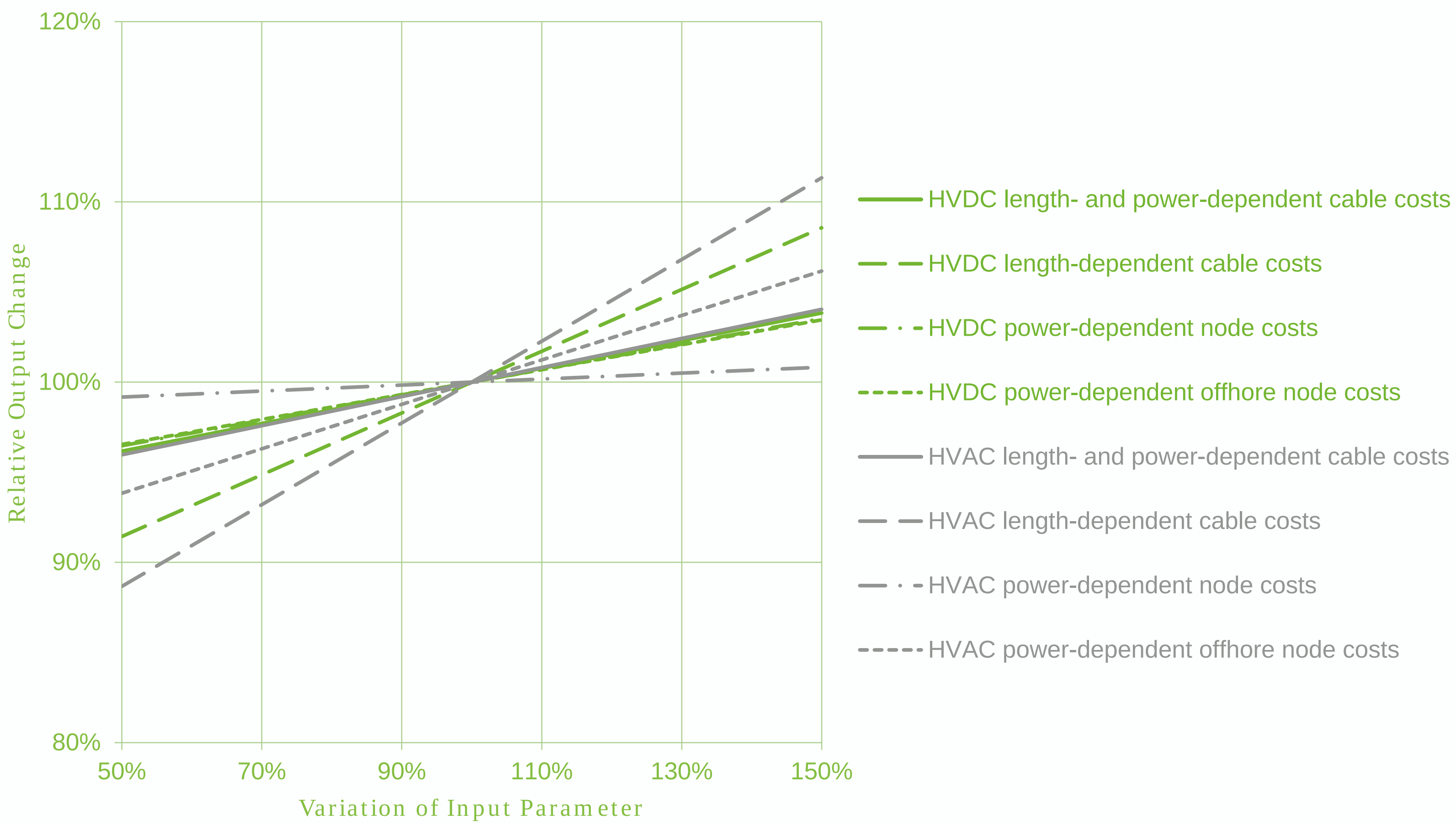
- 0.66 bn€	0.24 bn€

CS2 (DE/SE/DK)

High Offshore Wind Power

0.46 bn€	0.04 bn€

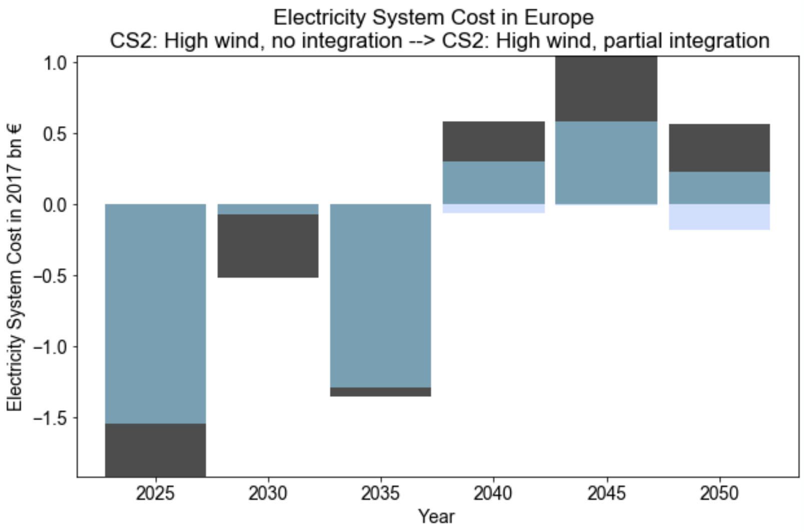
Sensitivity Analysis

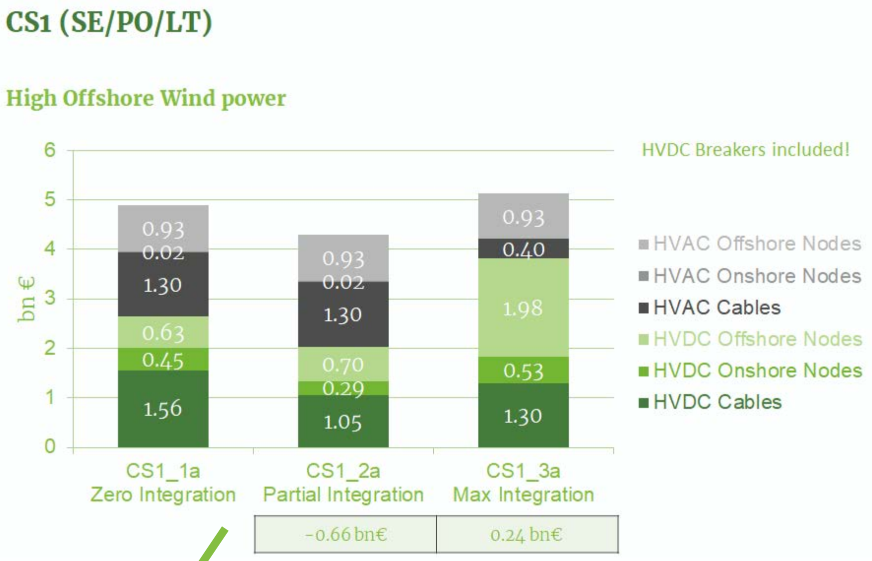


Exemplary Analysis for CS1_2a (Part. Integ., High OWP)

Baltic InteGrid

Balance

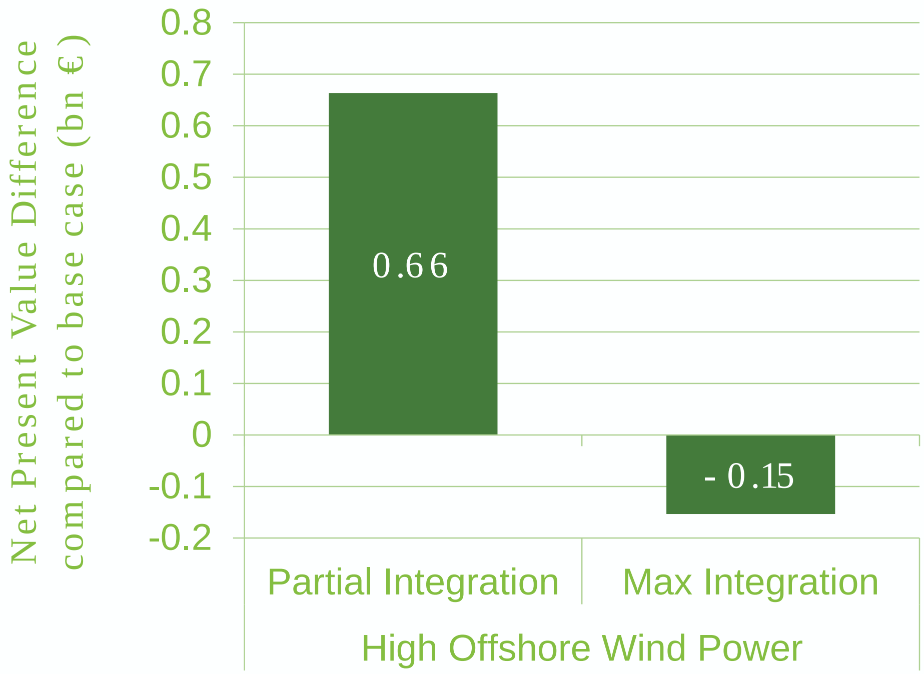


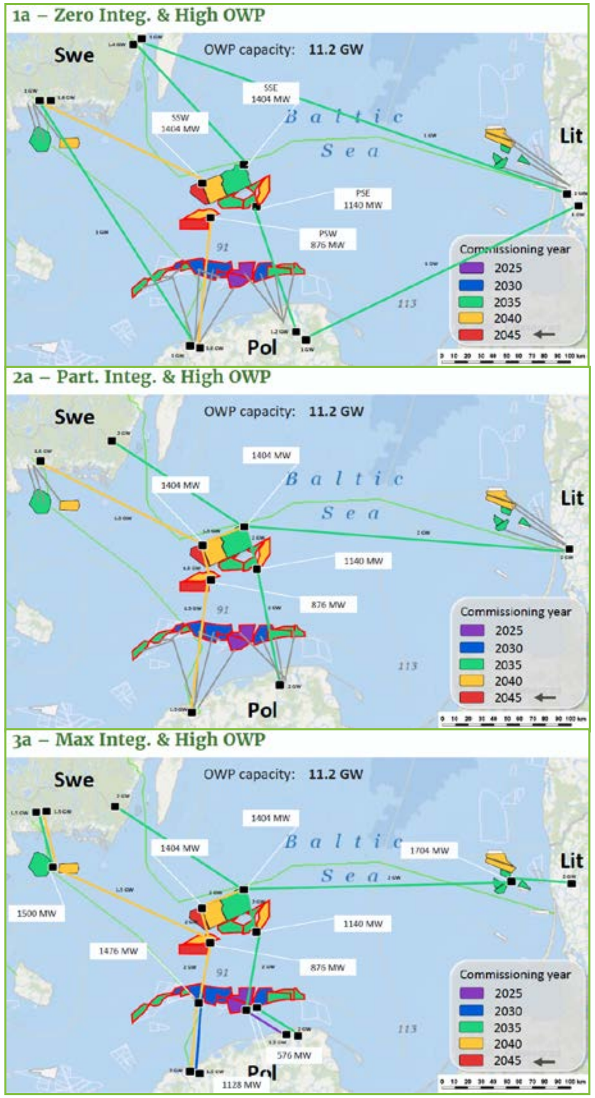


Net Present Value Difference compared to Base Case

CS1 (SE/PO/LT)

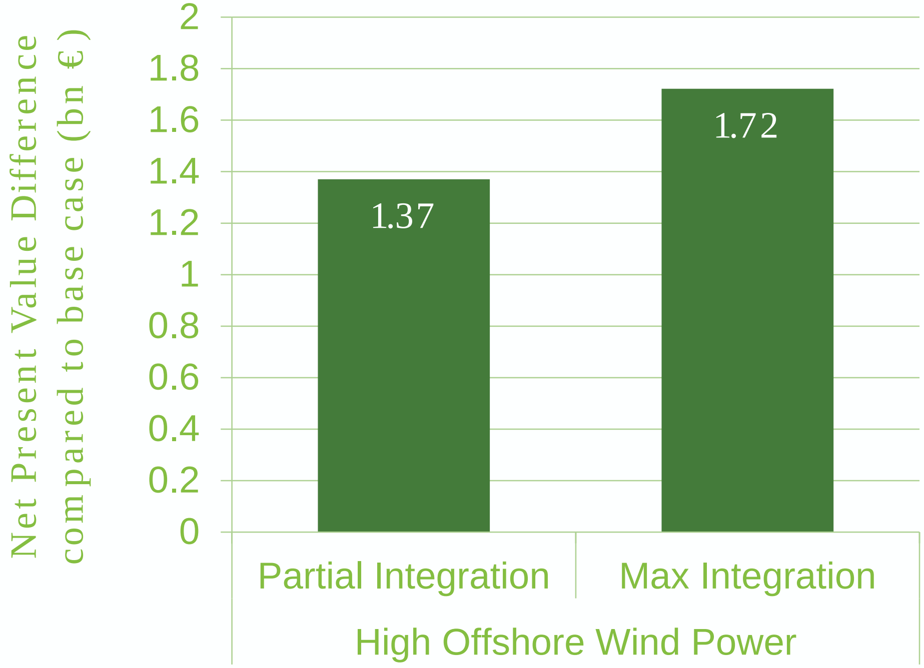
High Offshore Wind Power

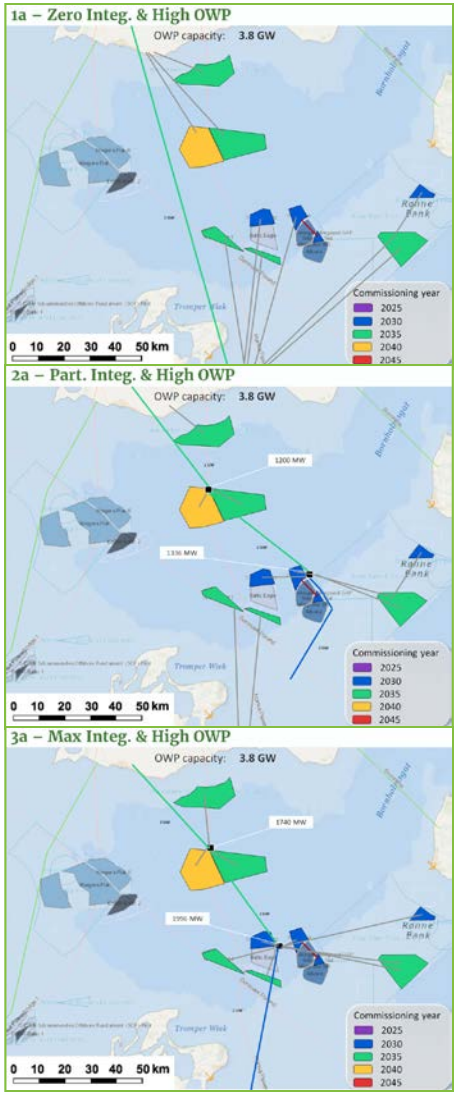




CS2 (DE/SE/DK)

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

Contact & Disclaimer

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