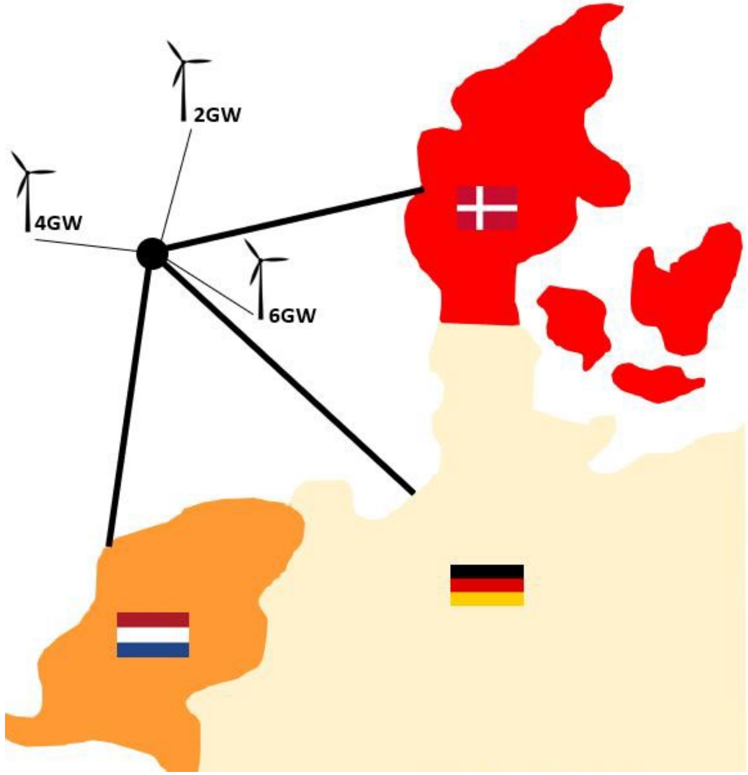
International Auctions for the Support of Renewable Energy in Offshore Hubs with cross-border interconnection

Authors: Mario Garzón González, Lena Kitzing



AUctions for Renewable Energy Support II

Wind offshore hub in the North Sea:
How could international cooperation on a joint auction look like?

Fictive case, based on NSWPH hub example
Reference: radially connected wind development without hub

Aim of the analysis:

To explore different options for international auctions, with focus on cost/benefit allocation and its impact on financing shares in a joint pool

Starting point of the analysis:

To create common grounds for the discussion, we assume:

- Creation of an offshore bidding zone
  -> we would like to investigate the potential of mitigating low offshore prices through auction design
- Creation of a joint auction
  -> we would like to investigate the opportunities and obstacles in the negotiation towards the establishment of international joint offshore development

Scenarios analysed*:

1. Rapid decarbonisation = low energy prices = subsidies required
2. Limited decarbonisation = high energy prices = no subsidies required

** Scenario results are obtained through energy systems optimisation in BALMOREL model*

Auctions for the Support of Renewable Energy

Support Scheme considered:
Contract for Difference (CfD)
Two-sided

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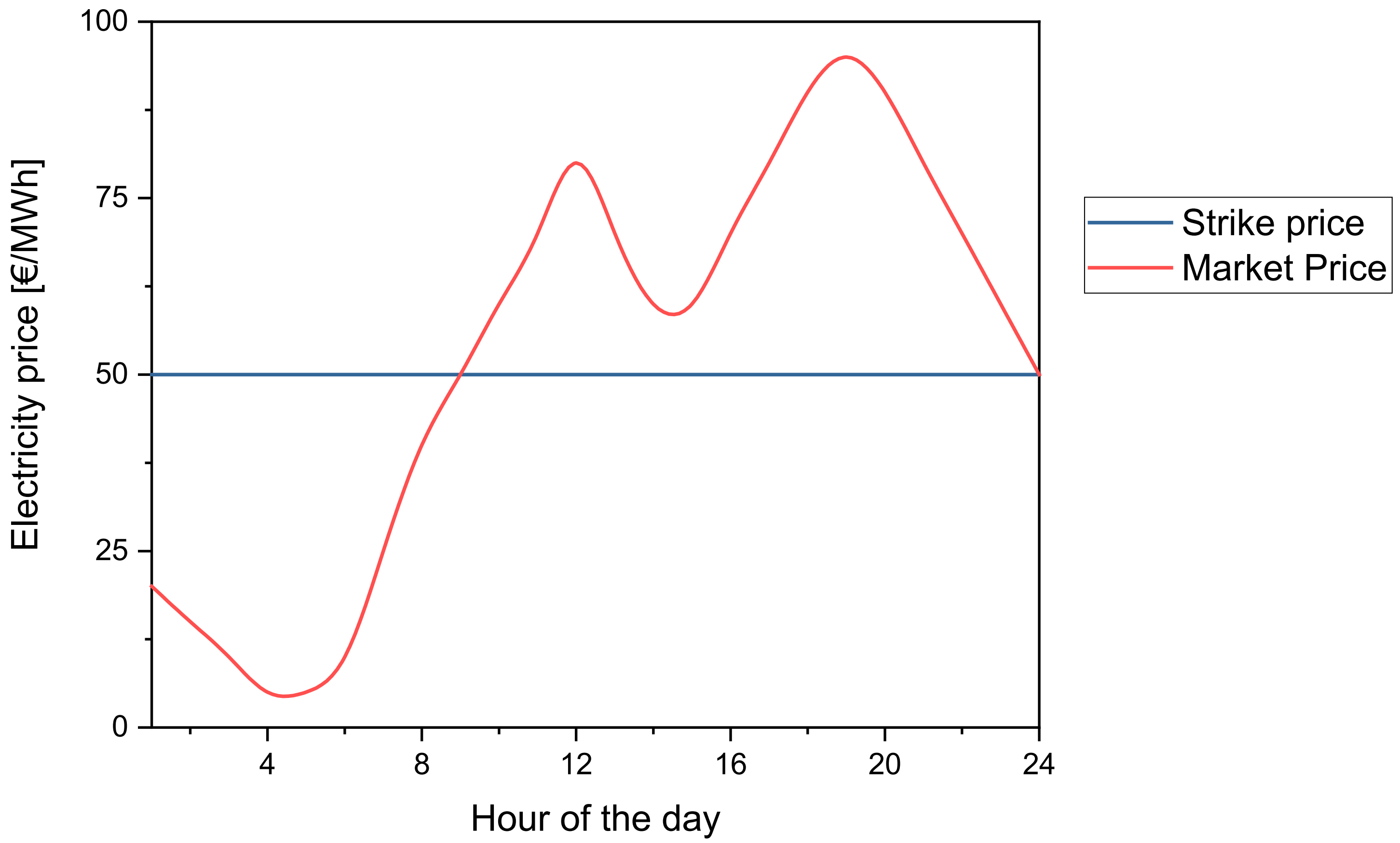

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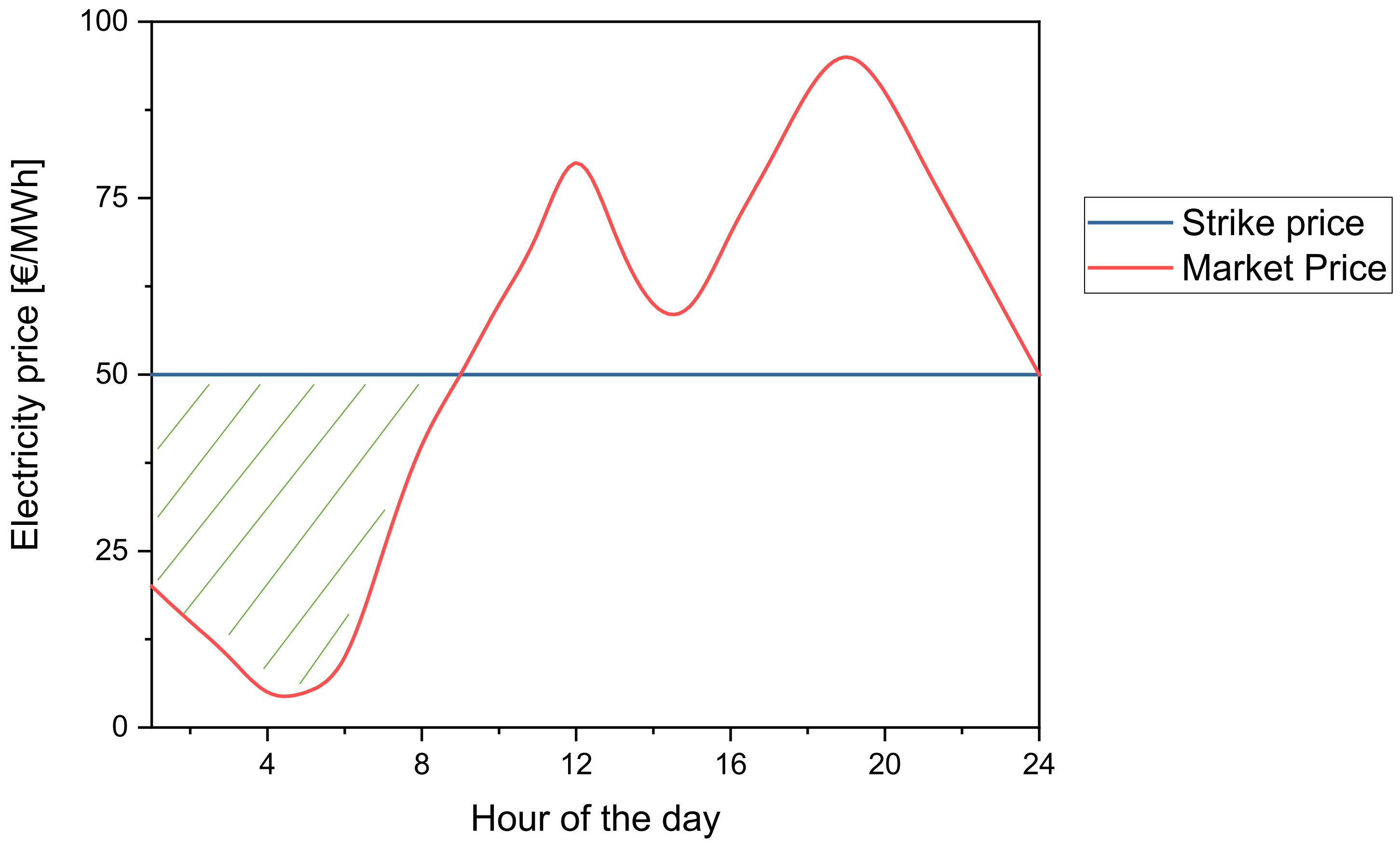

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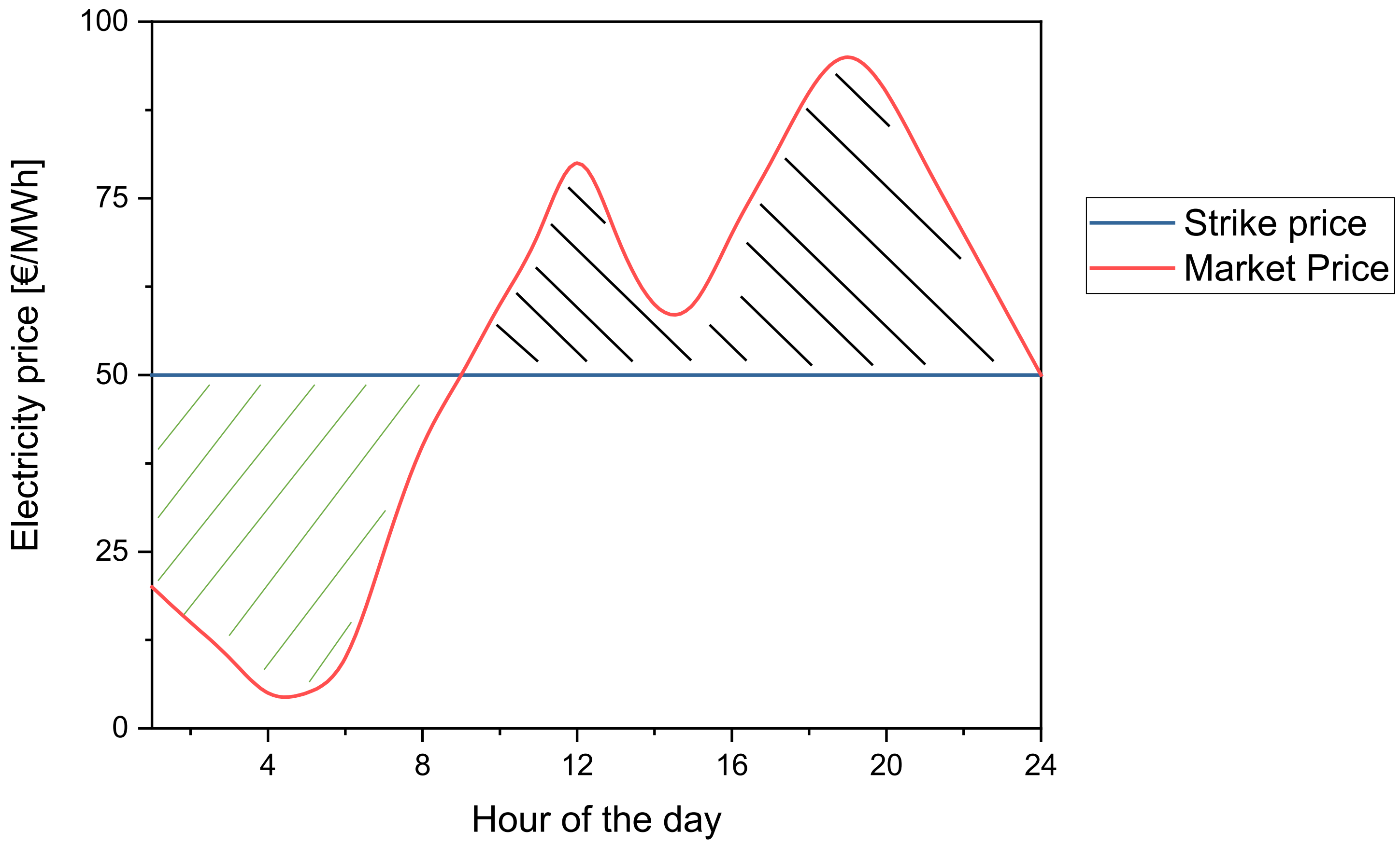
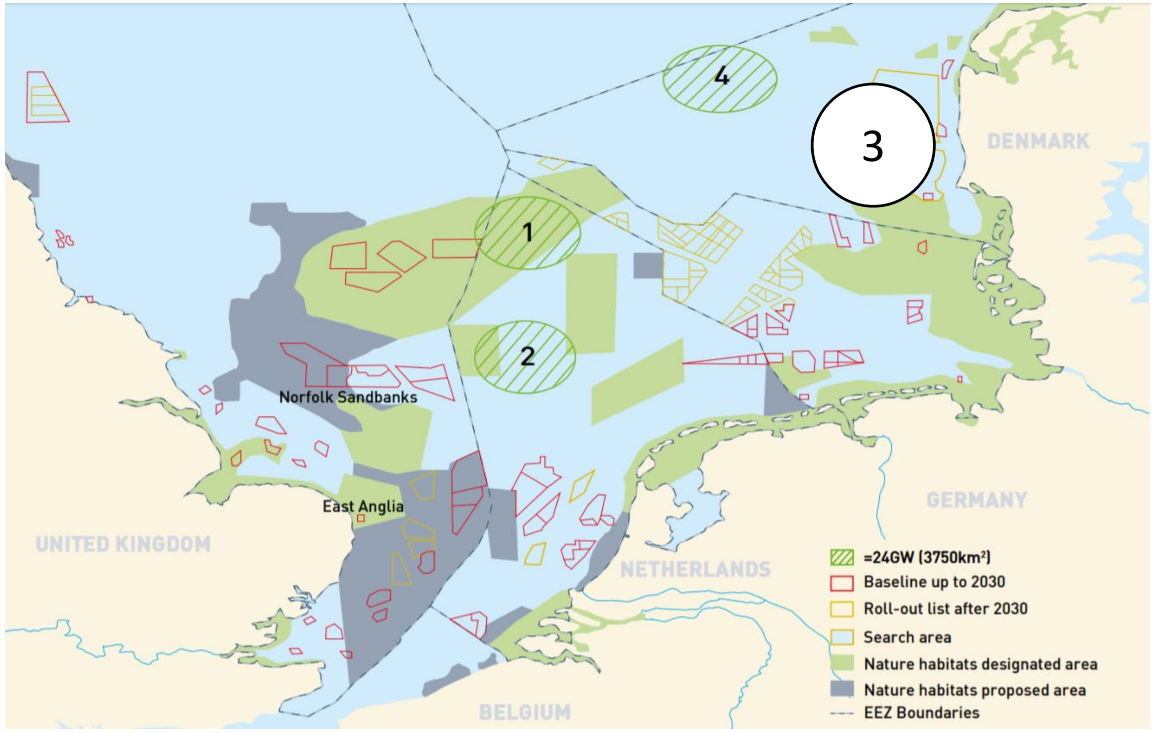
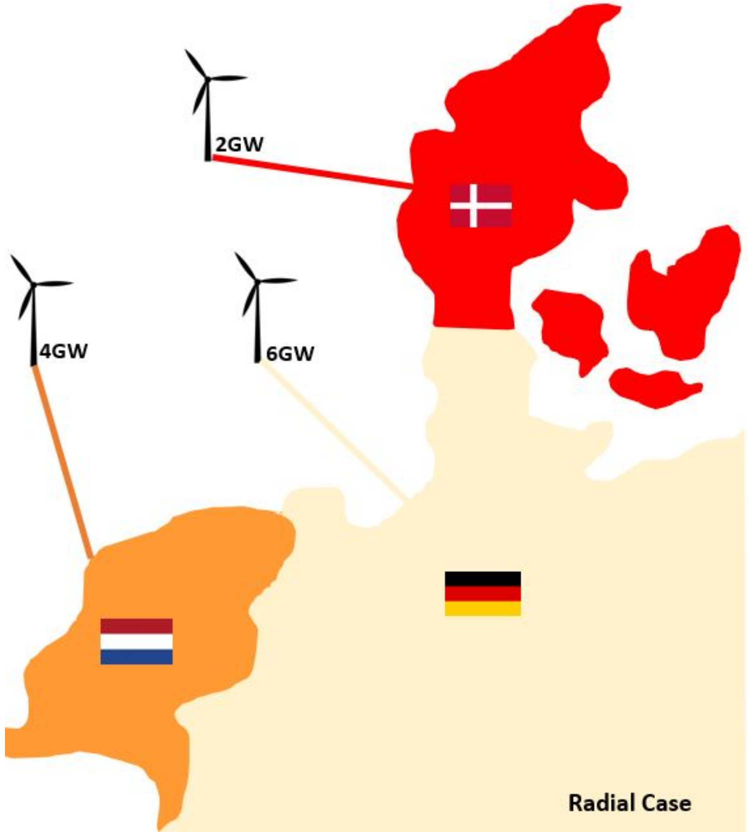


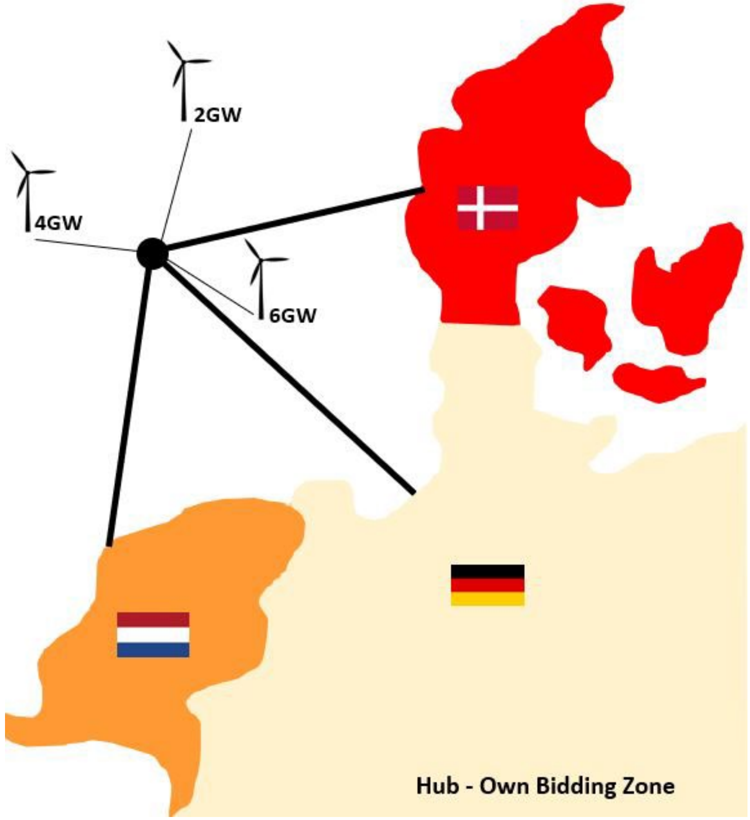
North Sea Wind Power Hub



Location	1	2	3	4
Cluster size: 2 GW	53.9%	53.2%	54.1%	Not studied in detail; expected to be similar to locations 1-3
Cluster size: 6 GW	52.1%	51.3%	52.5%	
Cluster size: 12 GW	50.7%	49.9%	51.0%	
Cluster size: 24 GW	49.7%	48.9%	50.0%	
Cluster size: 36 GW	49.2%	48.4%	49.4%	

NSWPH – Market Set Ups





Studies Related to the NSWPH

PROMOTioN (Progress on Meshed HVDC Offshore Transmission Networks), 2016-2020:

Final deliverables: Optimal scenario for the development of a future European offshore grid & deployment plan 2020-2050

Other reports: DC grid protection, regulation and financing, and grid topology converters

The study recommends the standardisation of a 2 GW. 525 kV. platform and converter design

Roland Berger for the European Commission, 2019:

Savings corresponding to 2,500 M.€ during the entire lifetime of the project (25 years) considering only CAPEX and OPEX

Barriers: Market arrangement, lack of a transnational support scheme for renewable energy, fair distribution of welfare

Market modelling was not carried out for this study

Navigant (PowerFys), 2020: Offshore hybrid assets provide cost advantages when compared with the traditional radial connection

Gea-Bermúdez et al (Balmorel), 2020: remarks the importance of a long planning horizon for developing the offshore North Sea grid, since it leads to a significant cost reduction for the entire energy system.

Methodology

Methodology - Balmorel

Characteristics: Open source, deterministic, bottom-up

Optimise simultaneously the generation, transmission, and consumption of both **heat** and **electricity**

Objective function: minimises the total costs of the system, constrained by technical, physical or regulatory aspects

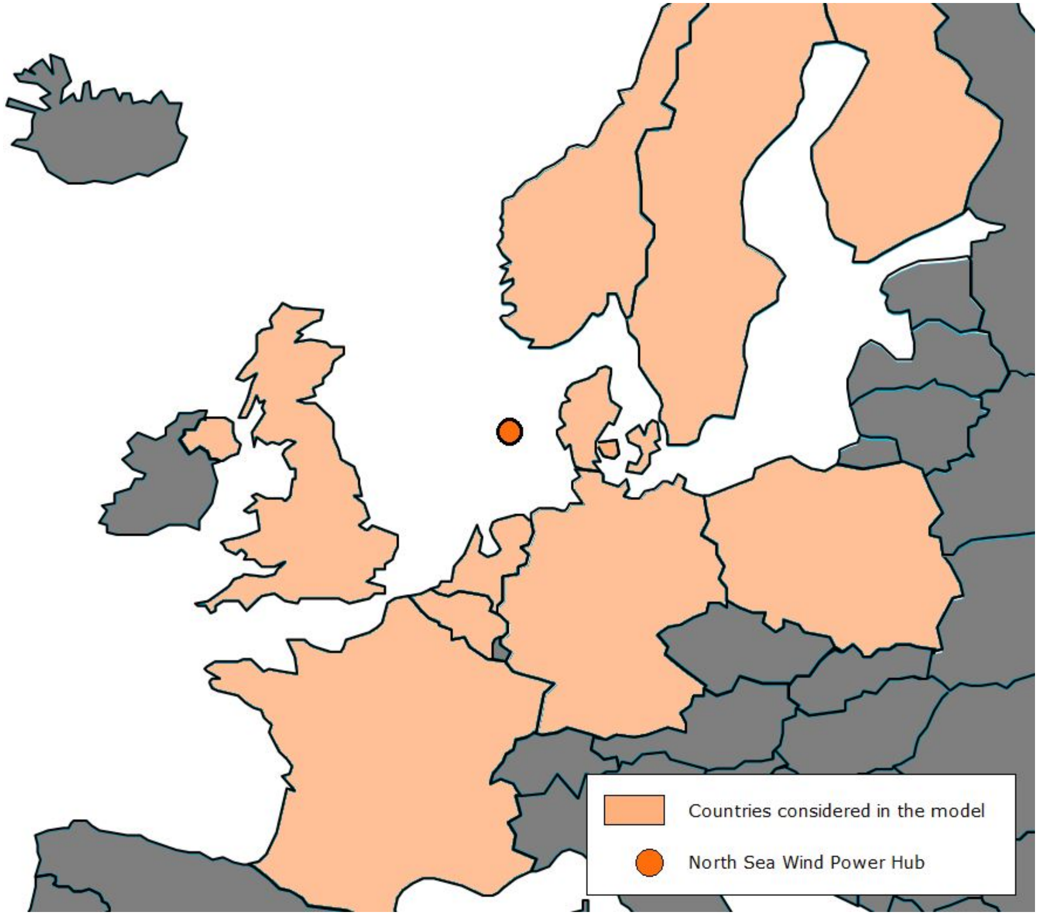
Assumes perfect competition between energy producers

Optimises the energy system from a socio-economic point of view

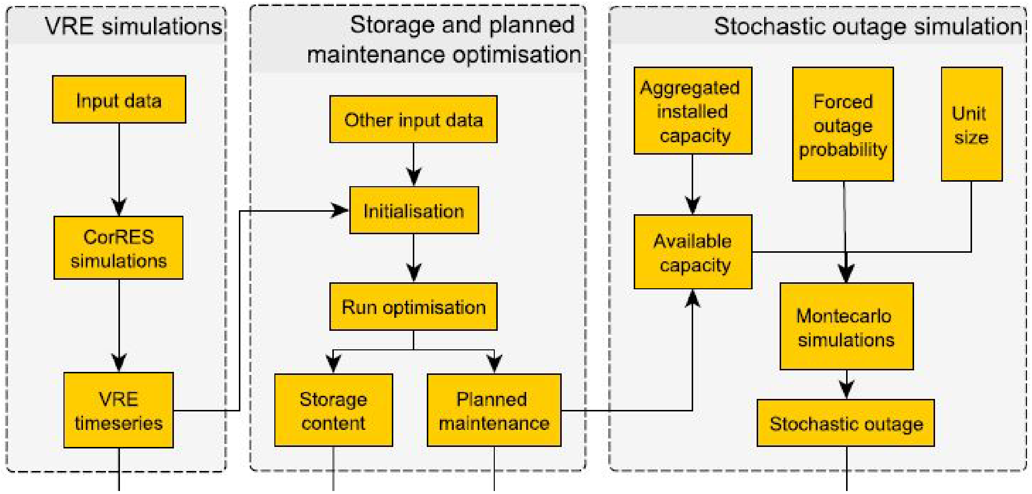
Add-ons: **Heat** demand from **Industry** & **Individual users**
Private **electric vehicles** (EVs)
Decarbonisation of the **rest of the transport** sector as additional **electricity demand** (2 constrains)

Methodology – Model Set Up

Countries Considered



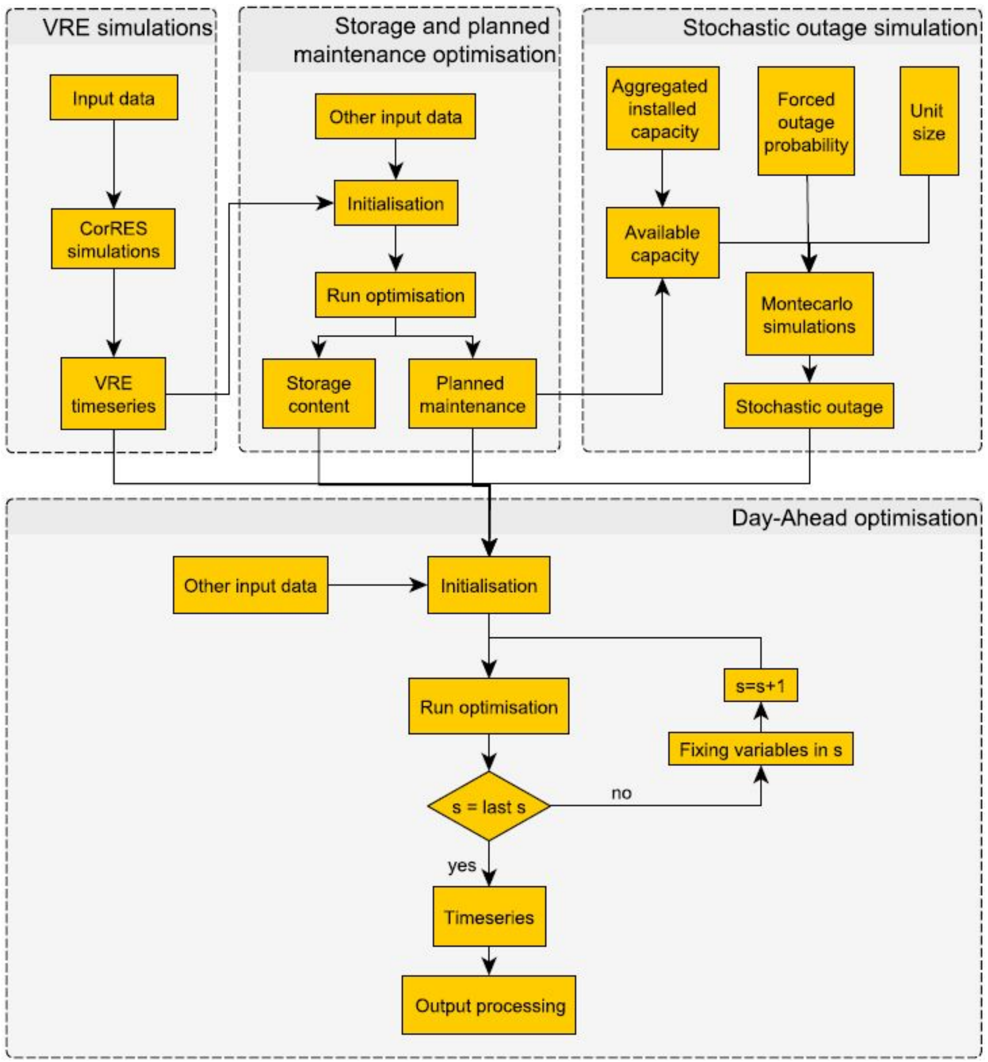
Methodology - Balmorel



1. Investment Run
2. Storage and planned maintenance optimisation
3. Stochastic outage simulation

Juan Gea-Bermúdez et al. “Operational planning of large-scale energy systems with high share of renewable generation” (2020)

Methodology - Balmorel



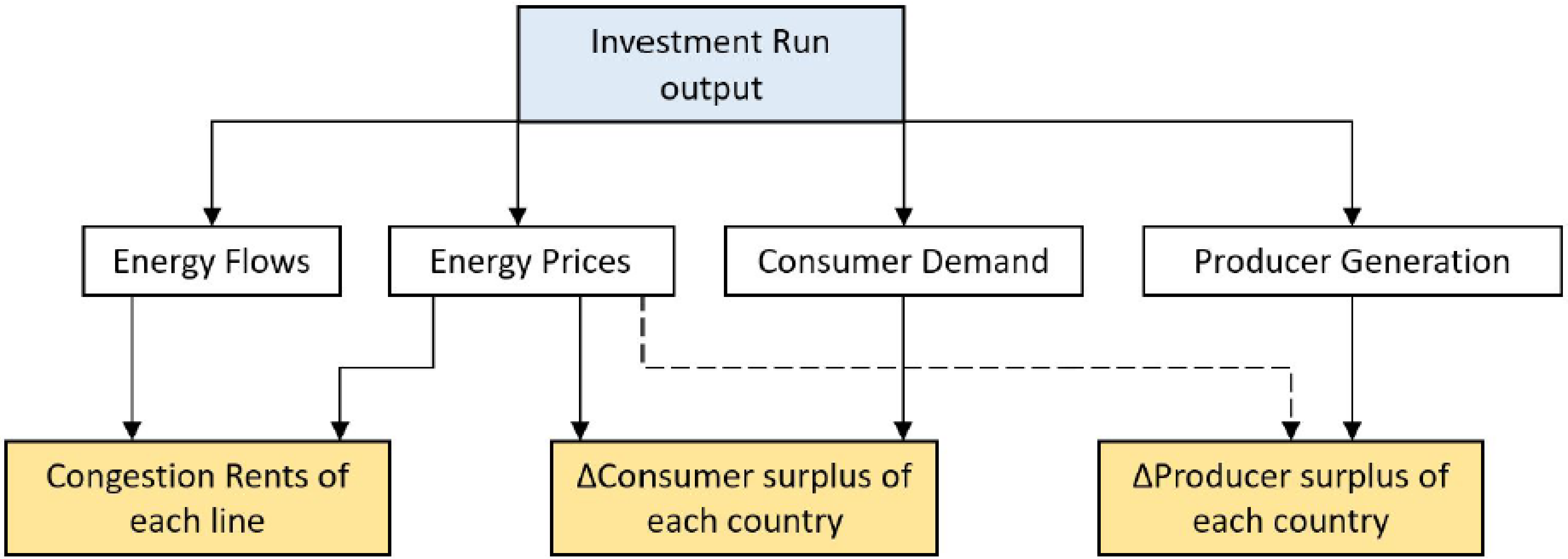
1. Investment Run
2. Storage and planned maintenance optimisation
3. Stochastic outage simulation
4. Day-Ahead

Output: Detailed hourly energy dispatch

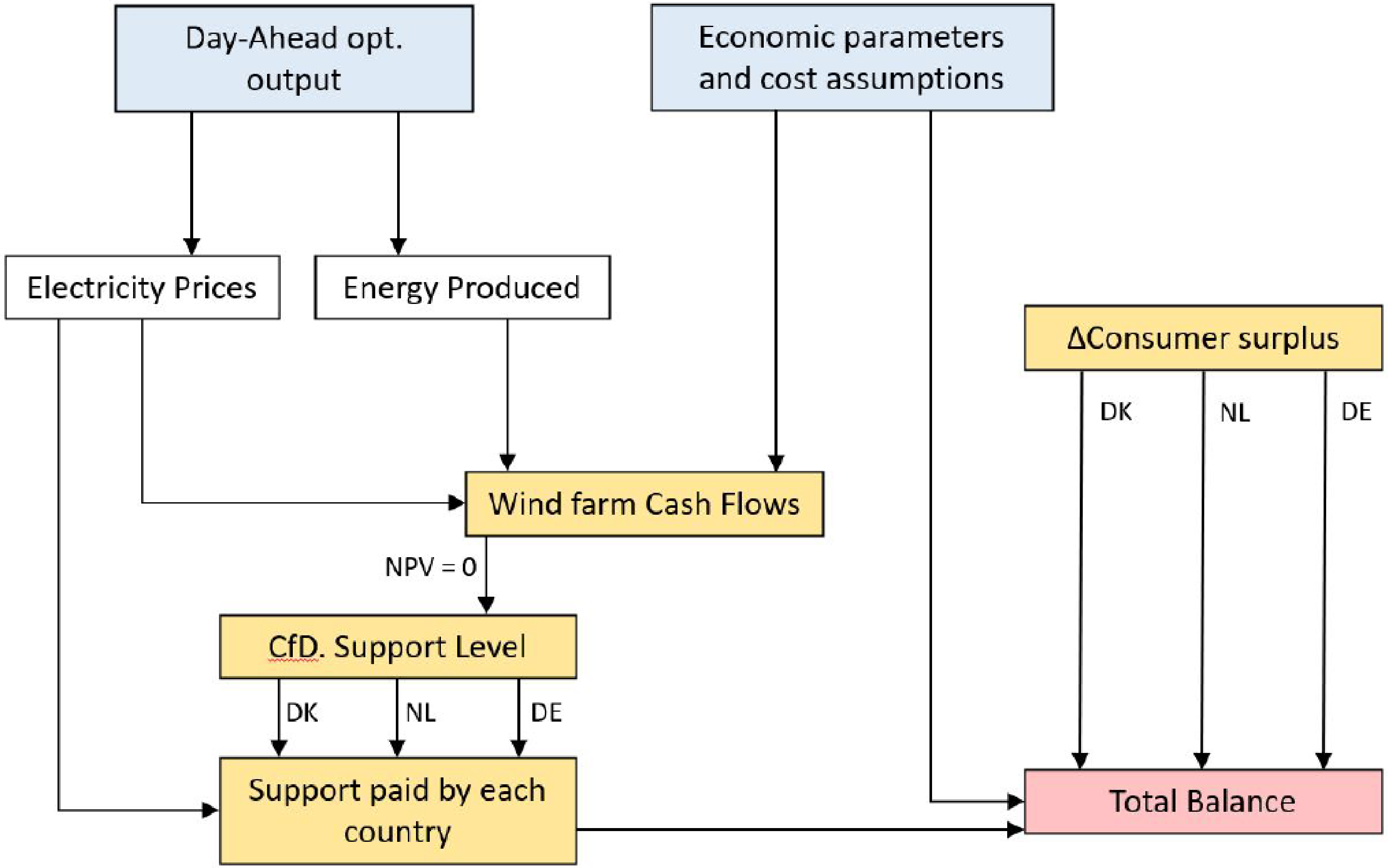
- Hourly energy generation mix
- Energy flow among regions
- Electricity and heat prices
- Curtailment of variable renewable energy

Juan Gea-Bermúdez et al. “Operational planning of large-scale energy systems with high share of renewable generation” (2020)

Methodology – Economic Analysis



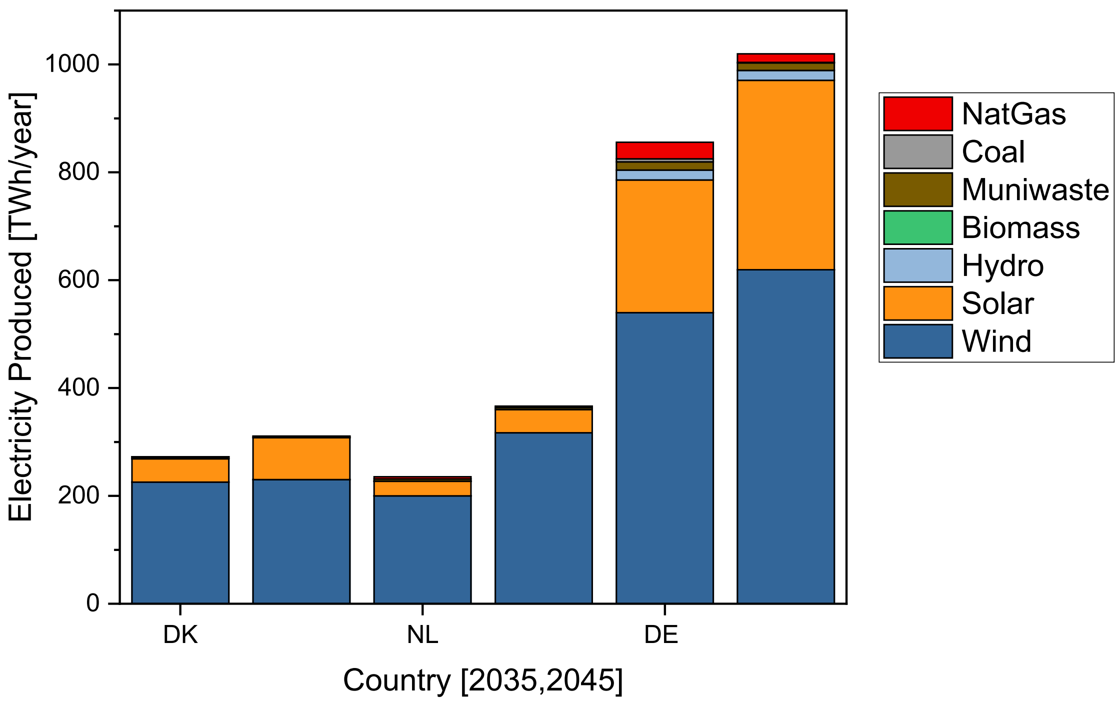
Methodology – Economic Analysis



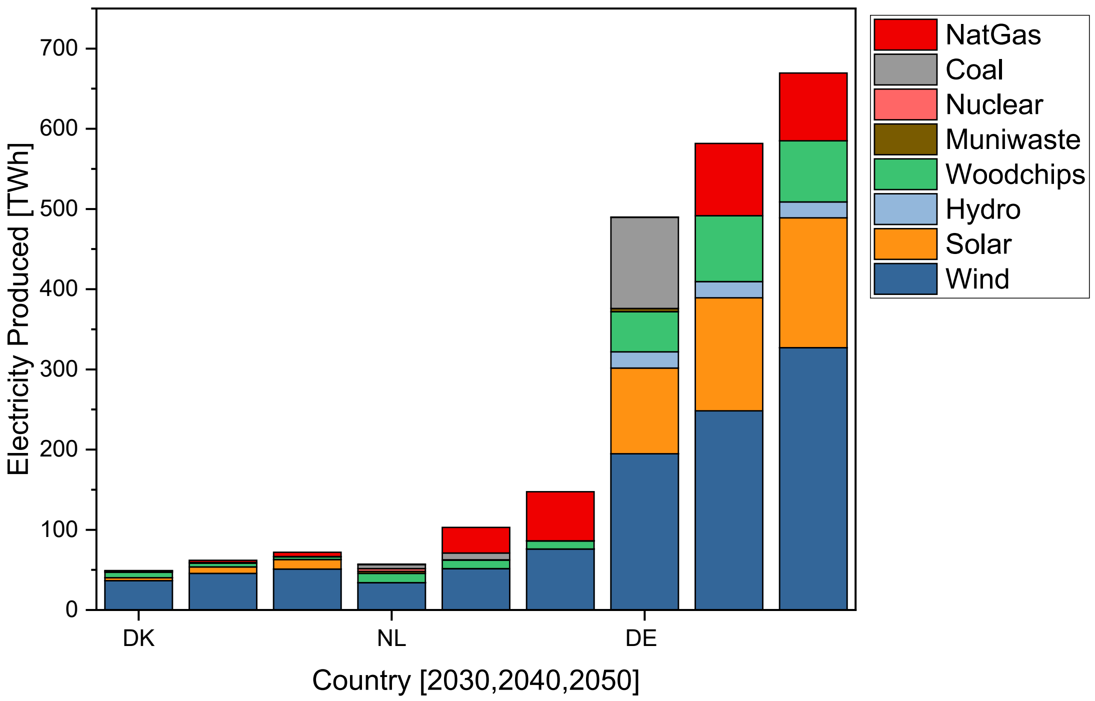
Results

Results – Electricity Production Scenario Comparison

Rapid Decarbonisation Scenario

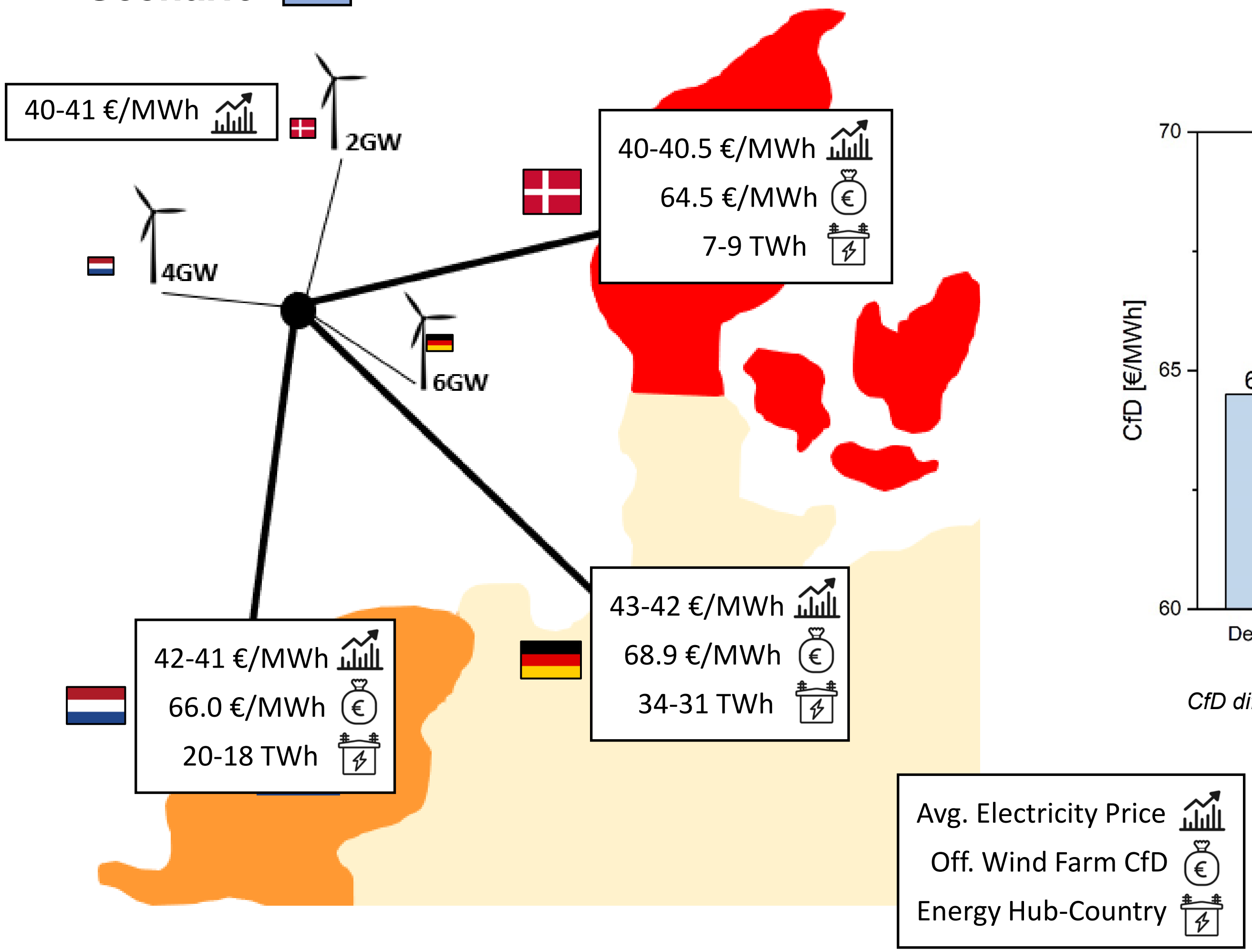


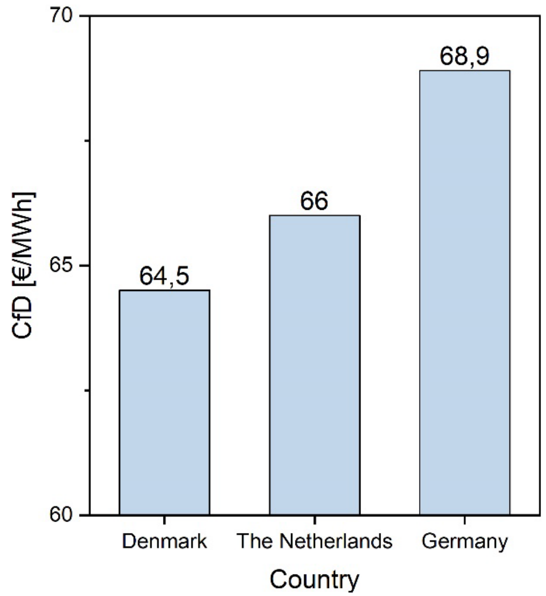
Slow Decarbonisation Scenario



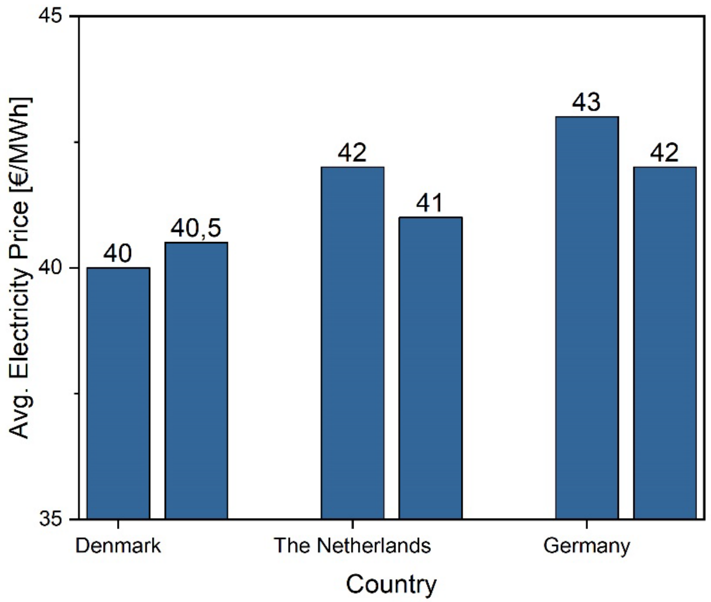
Results of scenario 1 (Rapid decarbonisation)

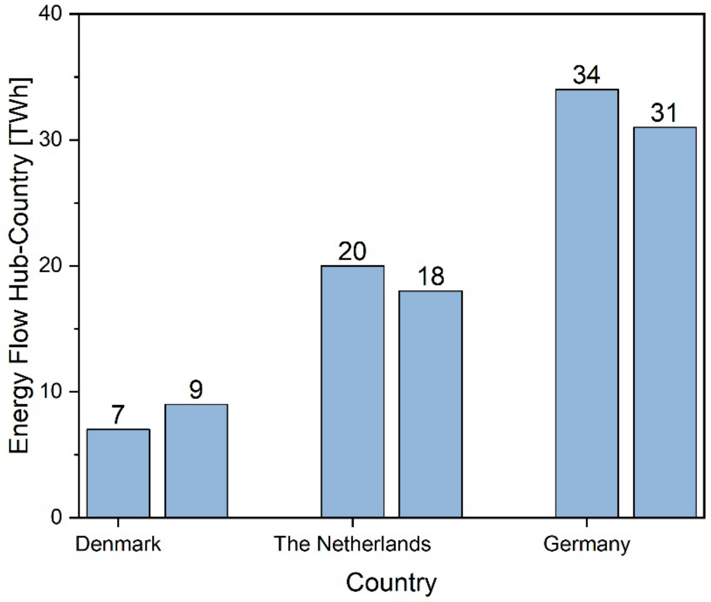
Scenario





CfD differences due to different tax levels





Note: The two bars represent the trend over the years (2035/45)

Results of scenario 1 (Rapid decarbonisation): Shares across countries

Countries

Received RES volumes*

13%

32%

55%

Electricity price impact

2035/2045

+1.4 %

-2.2 %

-3.5 %

Asset owners

CfD premium (paid to OWF)

14%

31%

55%

Hub investment cost

17%

33%

50%

TSOs / Asset owners

Interconnection cost

7%

39%

54%

Congestion rents

21%

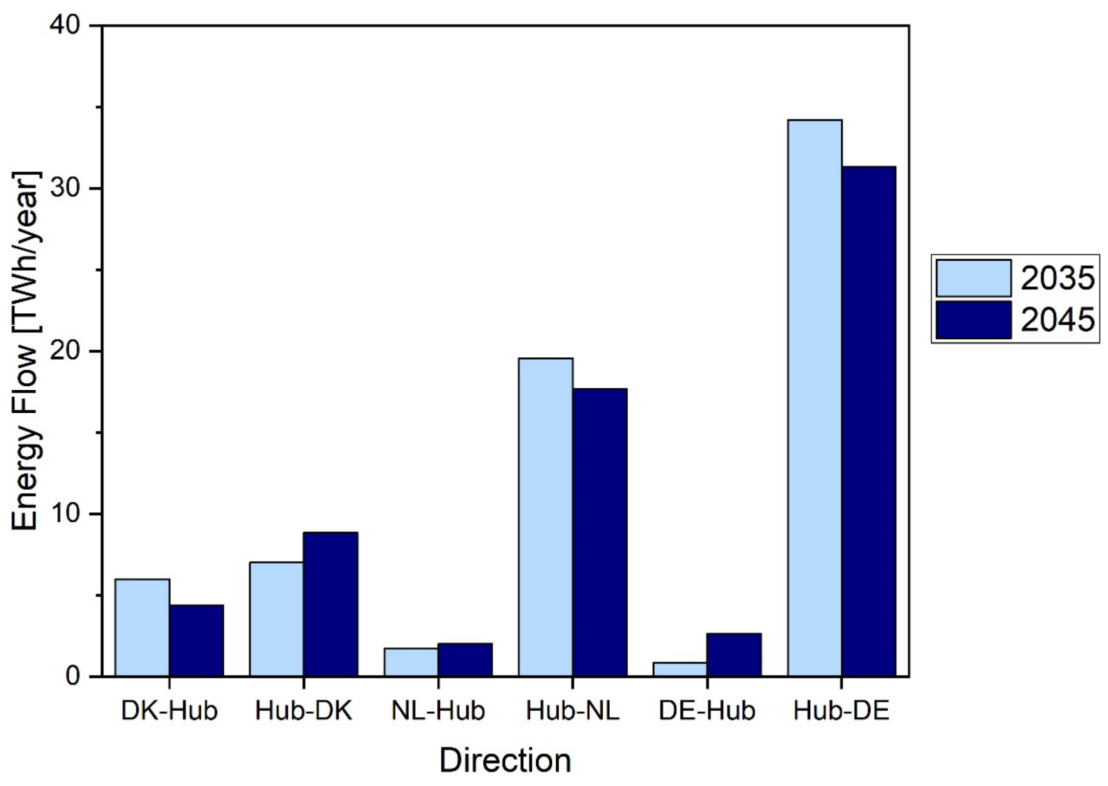
27%

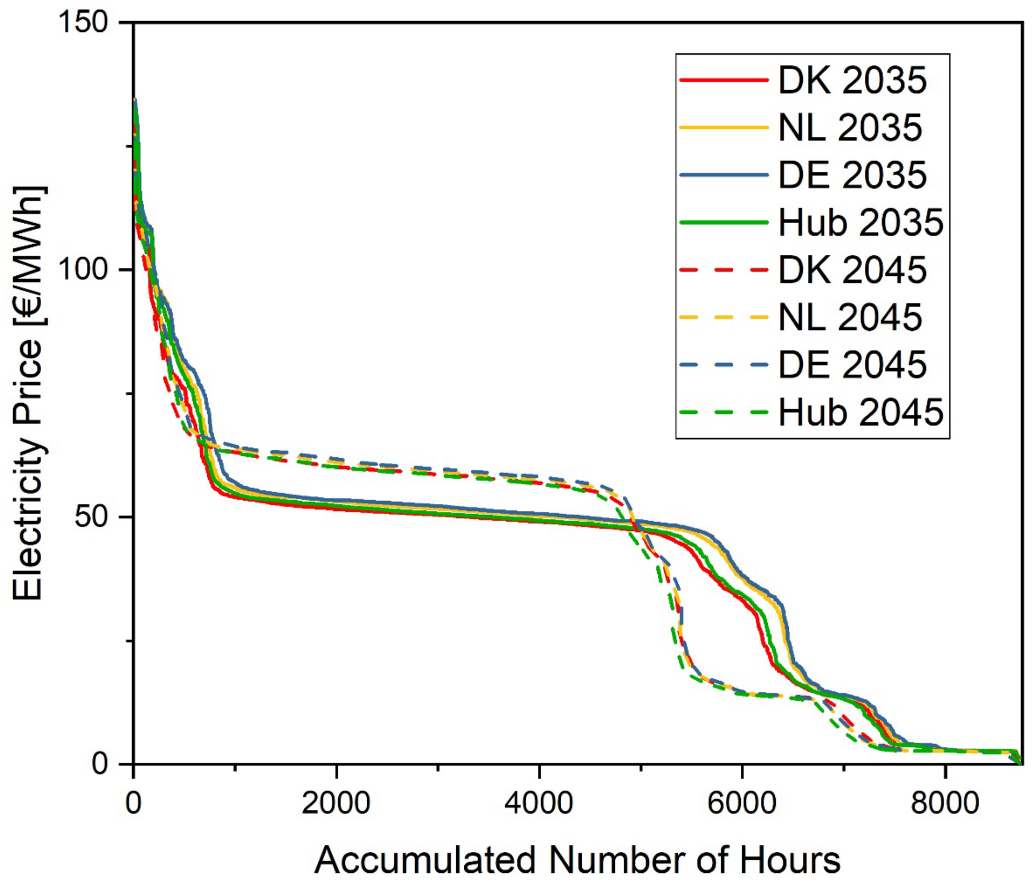
52%

- Germany receives more electricity than its installed share and has the strongest price reduction impact
- Denmark receives higher congestion rents as compared to its share of interconnection cost

** Physical electricity flows from hub to country, as optimised by system, average over project lifetime*

Price in the Hub: Scenario 1 – Subsidies required

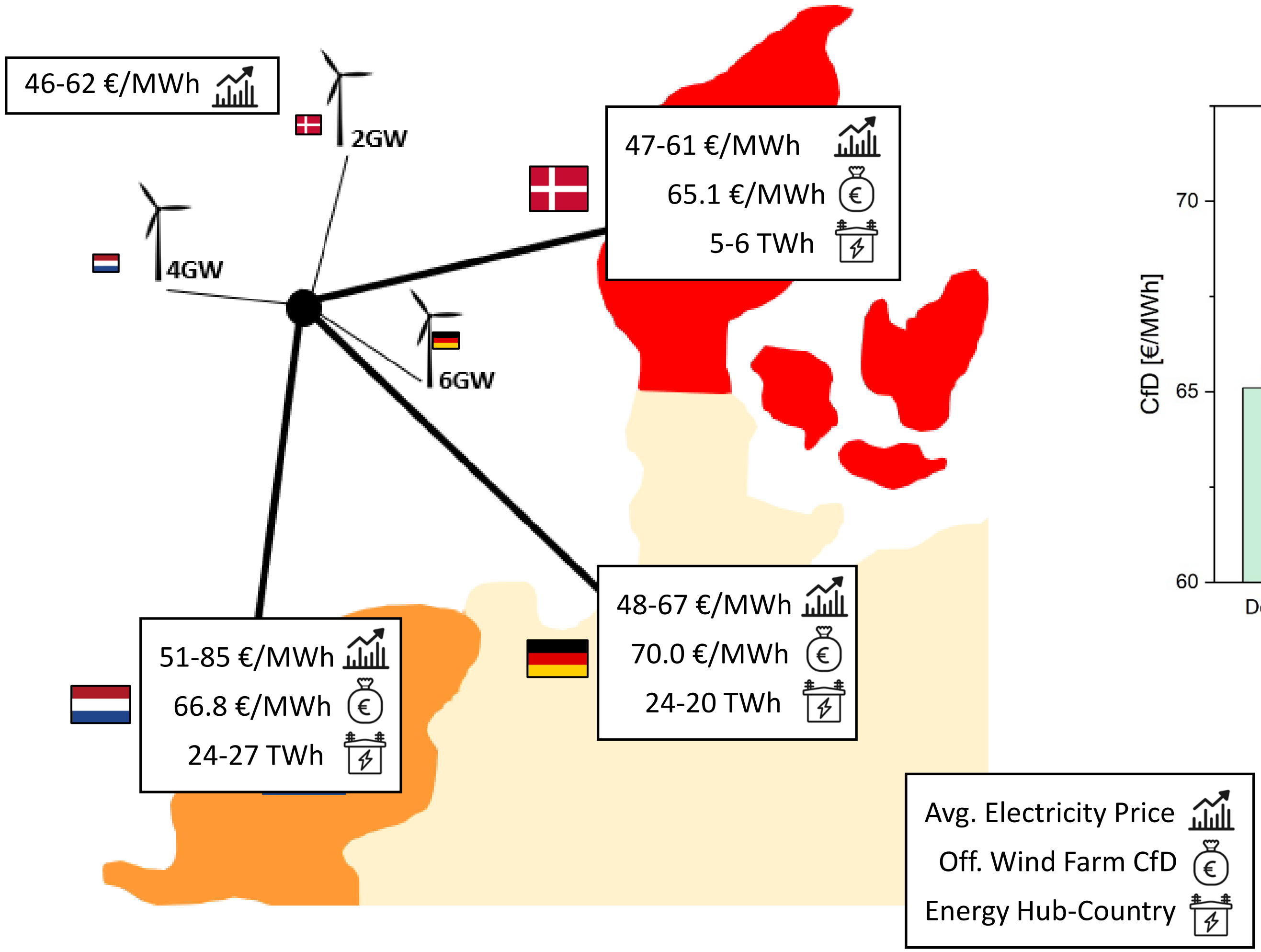


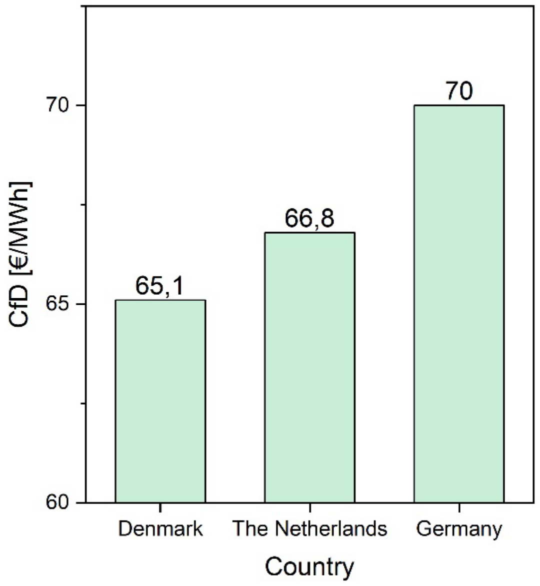


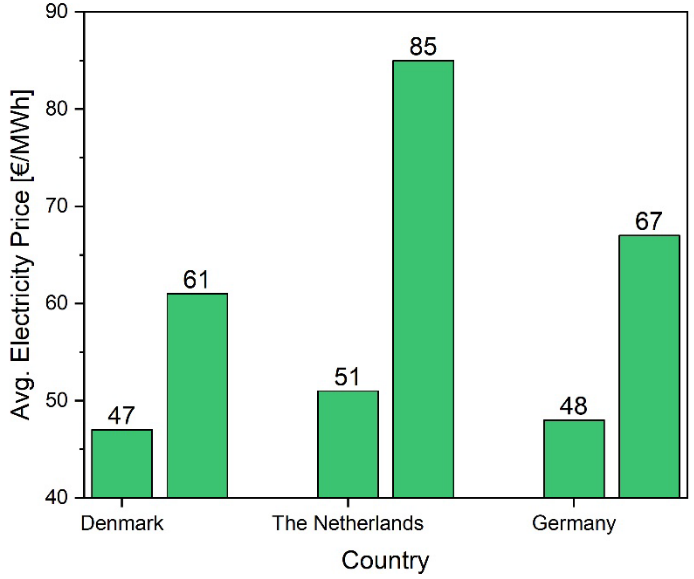
Hub Taking Price from	2035 [% of the year]	2045 [% of the year]
DK	45%	37%
NL	30%	35%
DE	25%	28%

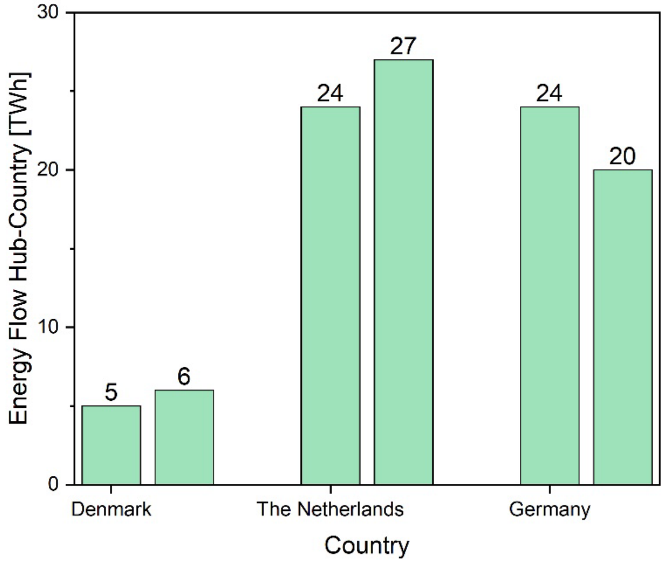
Results of scenario 2 (Limited decarbonisation)

Scenario









Note: Two numbers represent the trend over the years (2035/45)

Results of scenario 2 (Limited decarbonisation): Shares across countries

Countries

Received RES volumes

10% (DK)

48% (NL) 42% (DE)

Electricity price impact

+7% (DK)

-4% (NL) +1% (DE)

Asset owners

CfD premium (paid by OWF)

21% (DK)

38% (NL) 41% (DE)

Hub investment cost

17% (DK)

33% (NL) 50% (DE)

TSOs / Asset owners

Interconnection cost

7% (DK)

39% (NL) 54% (DE)

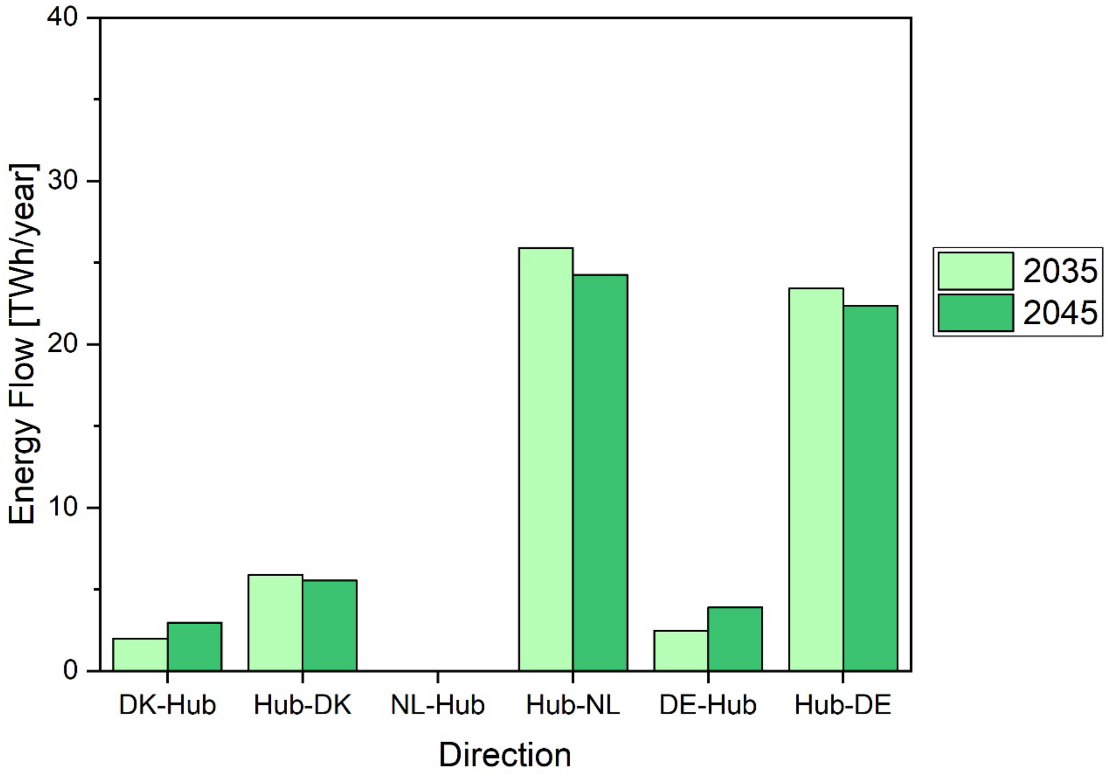
Congestion rents

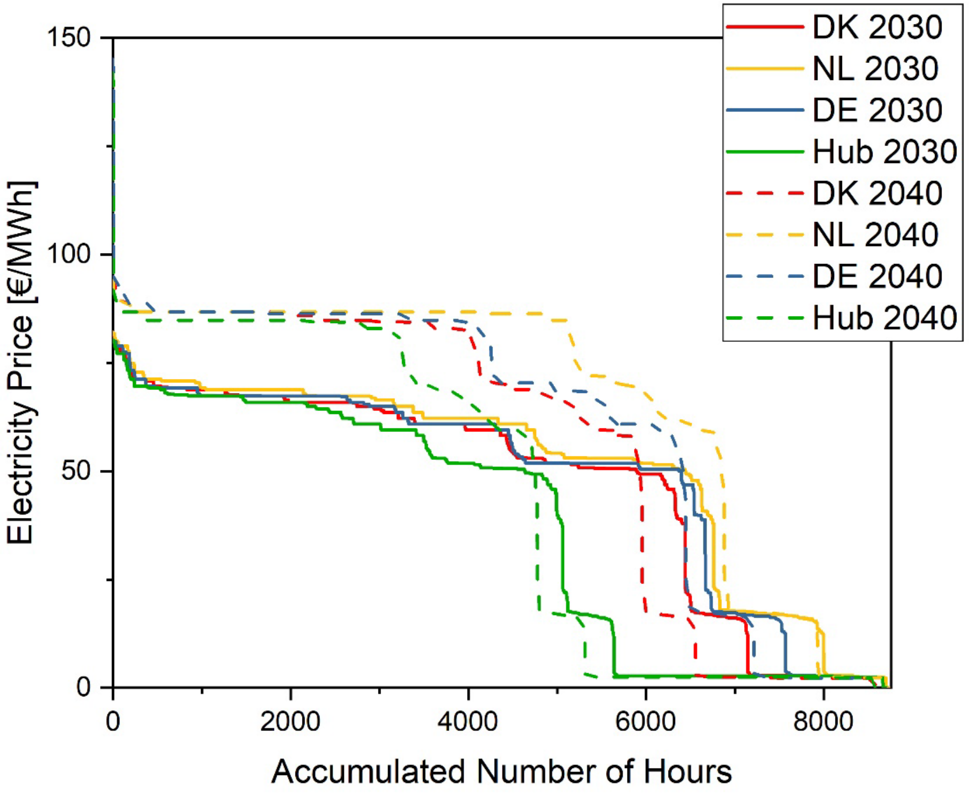
20% (DK)

41% (NL) 39% (DE)

- The Netherlands receive more electricity than their installed capacity and have the strongest price reducing impact
- The Netherlands receive the highest share of congestion rents

Price in the Hub: Scenario 2 – Subsidies required





Hub Taking Price from	2035 [% of the year]	2045 [% of the year]
DK	42%	40%
NL	32%	42%
DE	26%	18%

Scenario 1 Costs & Benefits (Country Perspective)

Scenario

Option 1: Net effects

Support to the OWF	-1,641
Interconnector cost	-255
Congestion rents	+1,445
Wholesale price impact**	-2,057
Tax Hub Income	+1,071
Net Effect (M€, 2029 PV)	- 1,437

Support to the OWF	- 3,641
Interconnector cost	-1,530
Congestion rents	+1,899
Wholesale price impact**	+2,497
Tax Hub Income	+2,525
Net Effect (M€, 2029 PV)	**+1,750**

Support to the OWF	-6,464
Interconnector cost	-2,104
Congestion rents	+3,673
Wholesale price impact**	+38,081
Tax Hub Income	+4,845
Net Effect (M€, 2029 PV)	**+38,031**

Option 2: Net effects w/o grid assets

Support to the OWF	-1,641
Wholesale price impact**	-2,057
Tax Hub Income	+1,071
Net Effect (M€, 2029 PV)	-2,627

Support to the OWF	- 3,641
Wholesale price impact**	+2,497
Tax Hub Income	+2,525
Net Effect (M€, 2029 PV)	**+1,381**

Support to the OWF	- 6,464
Wholesale price impact**	+38,081
Tax Hub Income	+4,845
Net Effect (M€, 2029 PV)	**+36,462**

***Demand weighted impact at country prices (mEUR, Present Values over lifetime)*

Scenario 2 Costs & Benefits (Country Perspective)

Scenario

Option 1: Net effects

Support to the OWF	+1,506
Interconnector cost	-255
Congestion rents	+1,445
Wholesale price impact**	-3,958
Tax Hub Income	+776
Net Effect (M€, 2029 PV)	- 486

Support to the OWF	+2,625
Interconnector cost	-1,530
Congestion rents	+2,889
Wholesale price impact**	+7,164
Tax Hub Income	+1,834
Net Effect (M€, 2029 PV)	**+12,982**

Support to the OWF	+2,862
Interconnector cost	-2,104
Congestion rents	+2,734
Wholesale price impact**	- 4,952
Tax Hub Income	+3,538
Net Effect (M€, 2029 PV)	**+2,078**

Option 2: Net effects w/o grid assets

Support to the OWF	+1,506
Wholesale price impact**	-3,958
Tax Hub Income	+776
Net Effect (M€, 2029 PV)	- 1,676

Support to the OWF	+2,625
Wholesale price impact**	+7,164
Tax Hub Income	+1,834
Net Effect (M€, 2029 PV)	**+11,623**

Support to the OWF	+2,862
Wholesale price impact**	- 4,952
Tax Hub Income	+3,538
Net Effect (M€, 2029 PV)	**+1,448**

***Demand weighted impact at country prices*
(mEUR, Present Values over lifetime)

Conclusions

- Multiple studies have shown that energy islands could reduce significantly the total energy system cost while facilitating the integration of renewable energy

- Benefits and costs can be unequally distributed → A mechanism to ensure a fair distribution of welfare is required (TSOs vs Project Developers vs Governments/Consumers)

- The problem can be attacked by different sides – Free Market, Market Design based solutions, **Support Schemes**

- We believe that an effective design of international auctions can lead to a fairer distribution of welfare by financing joint auctions through money pool

Thank you for your attention!

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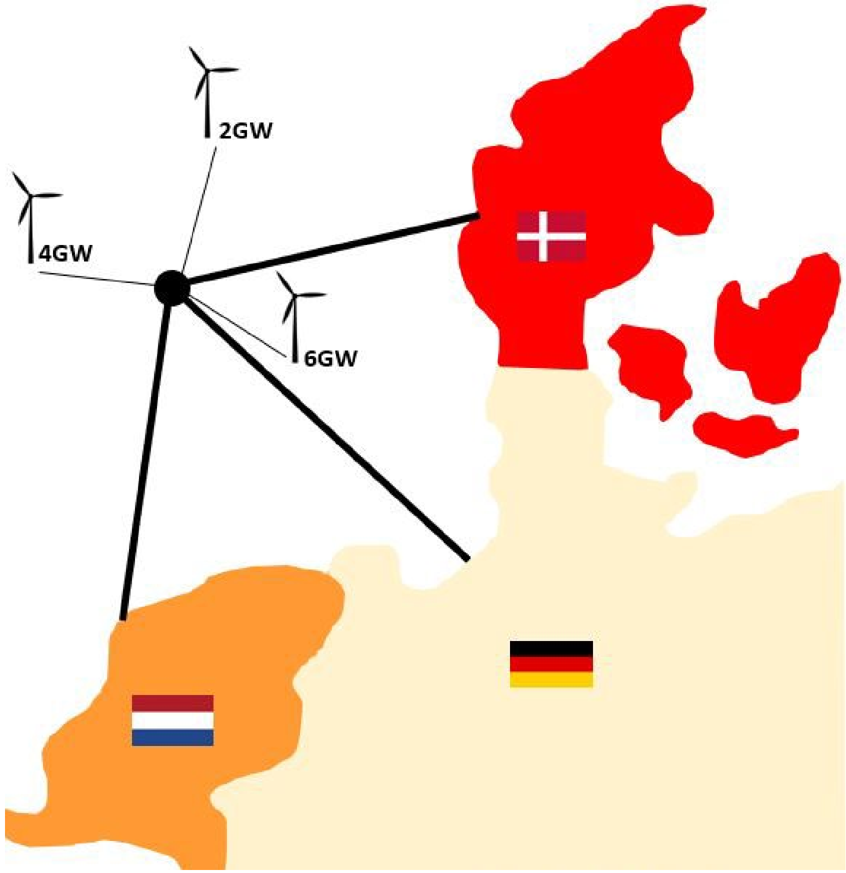


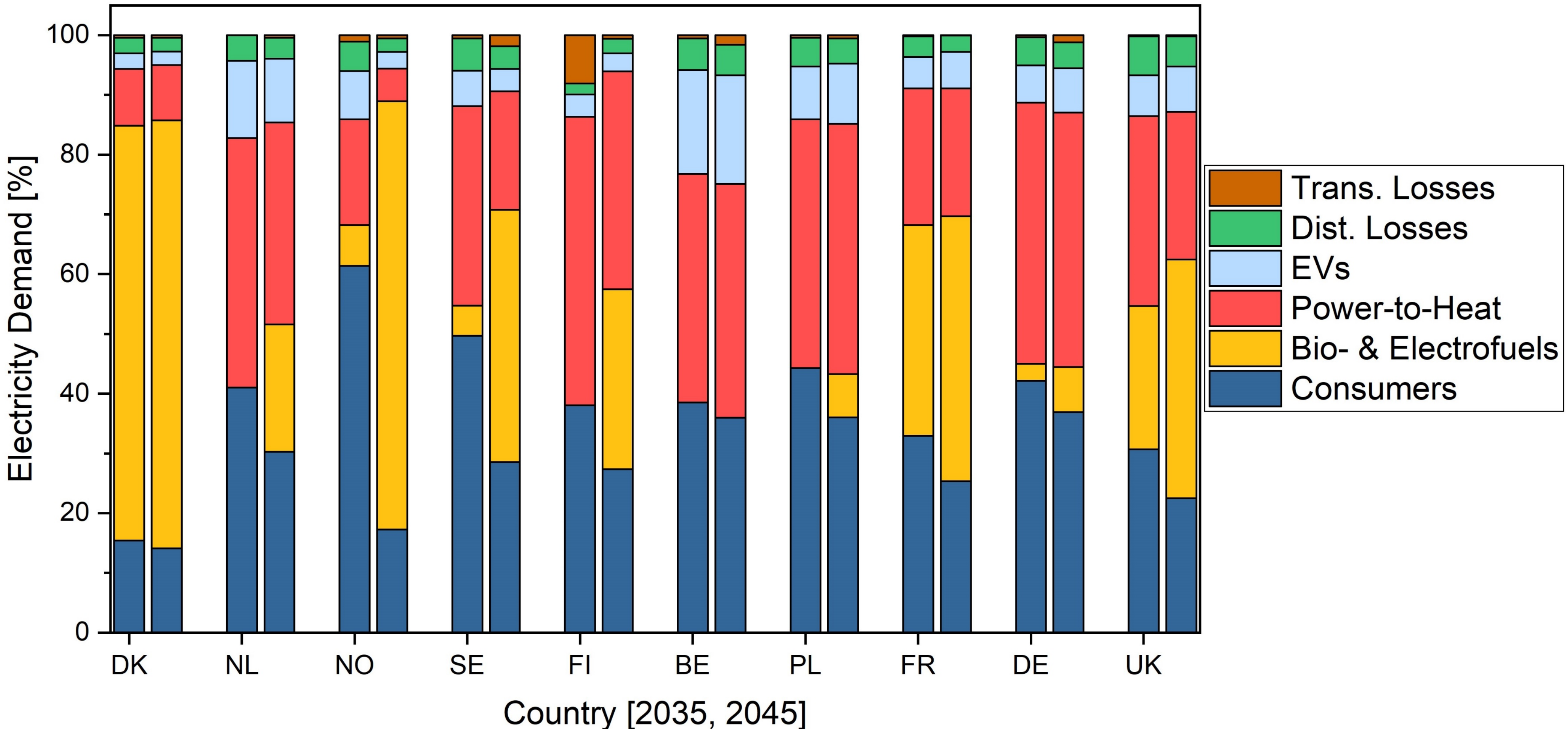
Financing of a joint auction through auction pool: Different options (Scenario 1 = Support required)

					Contribution to joint support pool			
	Installed capacity in hub	RES volumes received	Net Effect without reallocation	CfD Payment without pool*	Option 1: based on installed capacities	Option 2: based on received volumes	Option 3: net effects	Option 4: net effects w/o trans.
	17%	13%	-1,437	-1,641	-1,996	-1,527	+2,472	+2,620
	33%	32%	+1,750	-3,641	- 3,876	- 3,759	- 715	- 1,388
	50%	55%	+38,031	-6,464	-5,874	-6,460	-13,504	-12,977
TOTAL	100%	100%	+38,344	-11,746	-11,746	-11,746	-11,746	-11,746
Per country	33%	33%	+12,781	-3,915				

(all numbers in M€, 2029 PV over 25 years lifetime)

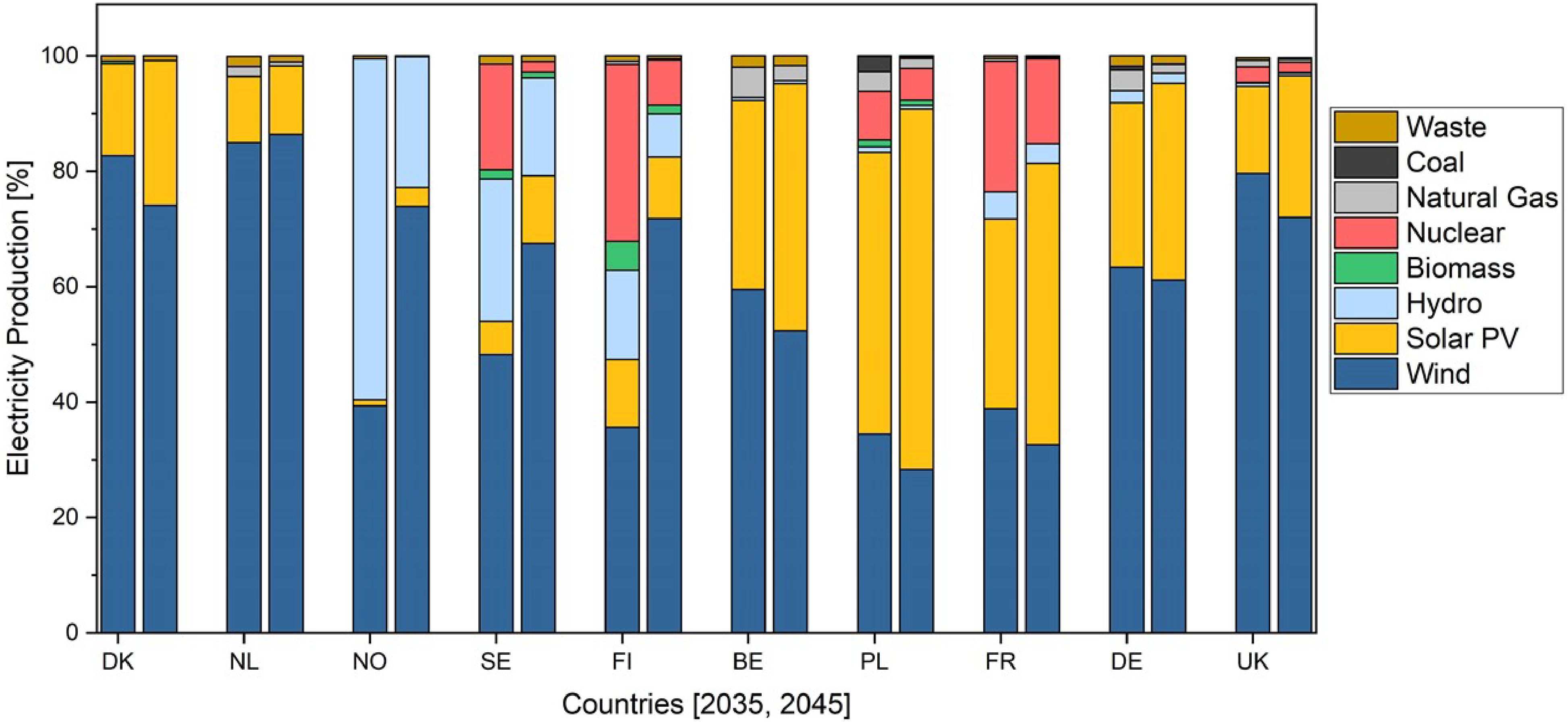
** Based on production delivered from country OWF into hub*

Results – Electricity: Demand (N1)



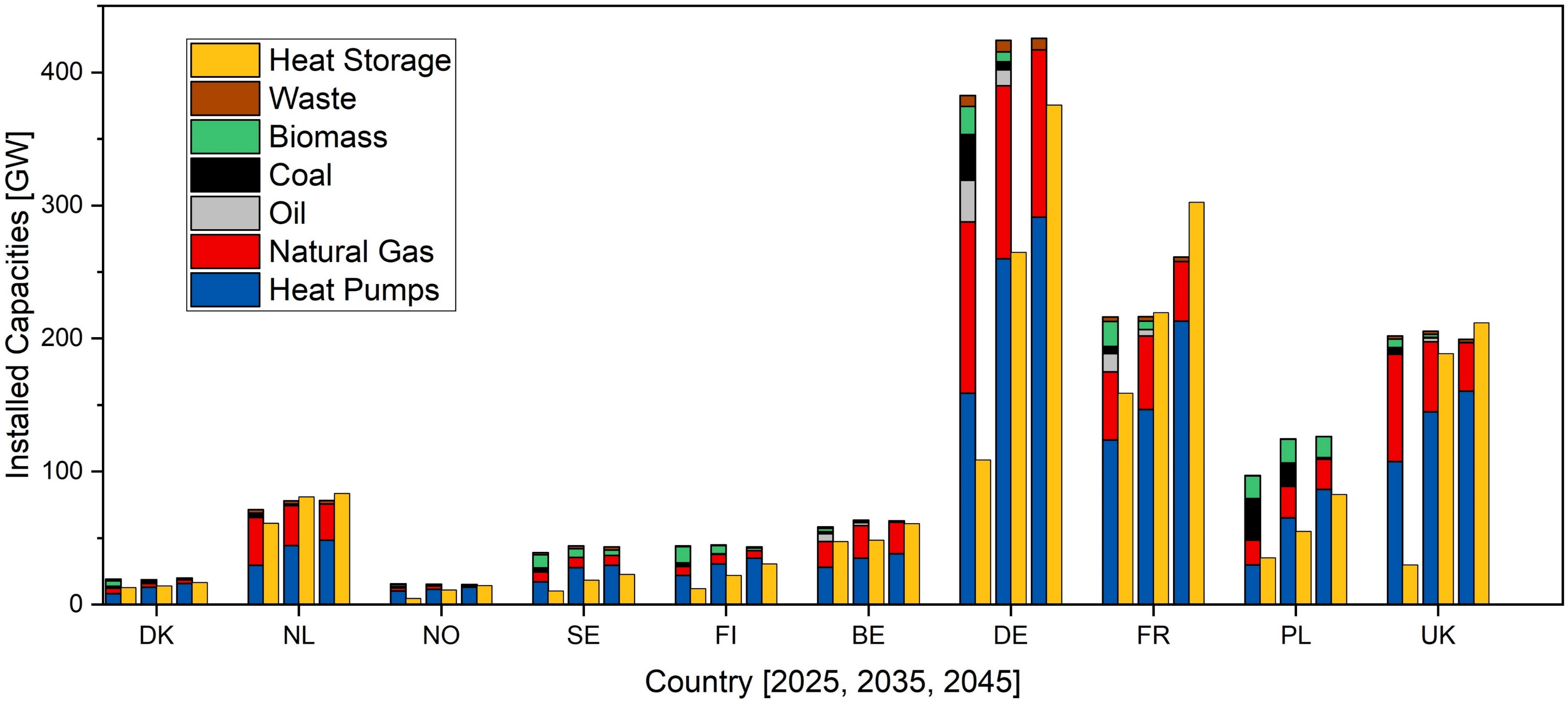
Mario Garzón González

Results – Electricity: Generation (N1)



Country	DK		NL		NO		SE		FI		BE		PL		FR		DE		UK	
Year	2035	2045	2035	2045	2035	2045	2035	2045	2035	2045	2035	2045	2035	2045	2035	2045	2035	2045	2035	2045
RES	99%	99%	96%	98%	100%	100%	80%	97%	68%	92%	93%	96%	85%	92%	77%	85%	94%	97%	95%	97%

Results – Heat: Generation (N1)



Costs: Investment and O&M

Total Costs [M€2029 PV]	**DK**	**NL**	**DE**
OWF CAPEX	4,342	9,703	14,364
Transmission Line	255	1,530	2,104
OPEX	2,163	4,326	6,489
Real annual OPEX [M€/year]	109	219	328

Home Price Market Option

Scenario	Total System Costs Savings Scenario vs Ref. Radial case [Avg. M€/year]	Avg. Elec. Price [€/MWh]			
		DK	NL	DE	HUB
Offshore Bidding Zone	2,501	40.2	41.8	42.4	40.5
Home Market Price	2,491	40.3	41.5	42.3	40.6

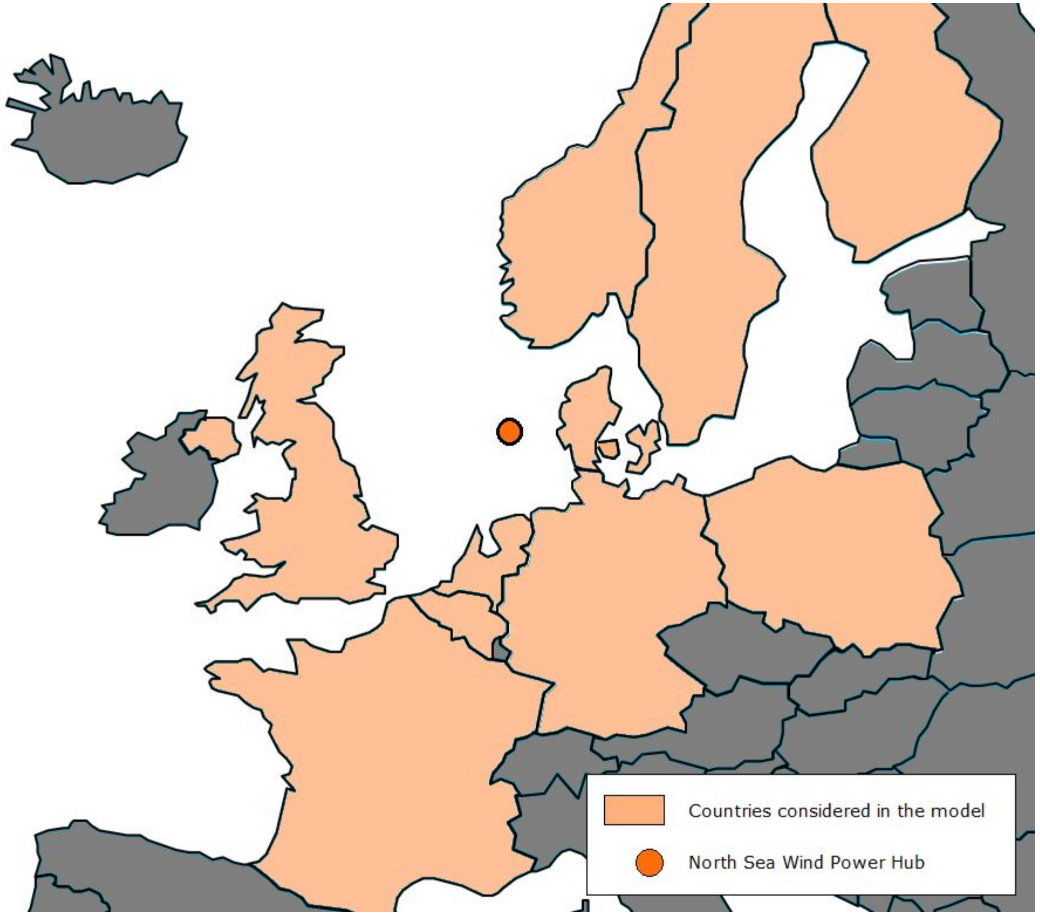
Results – Economic Analysis N5

Parameter [M€ - 2029 PV]	N5			N5 + TL		
	DK	NL	DE	DK	NL	DE
CFD [€/MWh]	63.02	65.1	69.6	66.52	76.0	80.4
Support	-1658	-3272	-5234	-2070	-5813	-8898
Trans. Line	-255	-1530	-2104	-255	-1530	-2104
Con. Rents	0	0	0	0	0	0
Total Sup.	-1913	-4802	-7338	-2070	-5813	-8898
Sum. Sup.	-14053			-16781		
Cons. Surplus	-	-	-	-	-	-
Final Balance	-	-	-	-	-	-

Disc. Prod [TWh]	97.5	193.3	280.9	97.5	193.3	280.9
Disc. Rev	6191	12638	19655	6491	14486	22322
LROE [€/MWh]	63.5	65.4	70.0	66.6	74.9	79.5

Methodology – Model Set Up

Countries Considered



Time Resolution

Step	Years	Seasons	Terms	Foresight
Invesment Run	3	16	24	Two years: 2025 & 2035 / 2045
Sto. and Plan. Maint.	3	364	6	One year: 2025 / 2035 / 2045
Day-Ahead	3	364	24	One day

Methodology – Economic Analysis: Equations

Consumer Surplus Delta

$$\Delta Cs_{m,k,y} = \sum_{t,s,u} Cd^{ref}_{k,y,t,s,u} \cdot Ep^{ref}_{k,y,t,s.u} - \sum_{t,s,u} Cd_{m,k,y,t,s,u} \cdot Ep_{m,k,y,t,s,u} \qquad \forall\, m \in M,\ k \in K,\ y \in Y$$

(M) Scenario, (K) Country, (Y) Year

Methodology – Economic Analysis: Equations

Consumer Surplus Delta

$$\Delta Cs_{m,k,y} = \underbrace{\sum_{t,s,u} Cd^{ref}_{k,y,t,s,u} \cdot Ep^{ref}_{k,y,t,s.u} - \sum_{t,s,u} Cd_{m,k,y,t,s,u} \cdot Ep_{m,k,y,t,s,u}}_{\text{Demand * Energy Price (Ref.) - Demand * Energy Price (Scenario)}} \qquad \forall\, m \in M,\ k \in K,\ y \in Y$$

(M) Scenario, (K) Country, (Y) Year

Methodology – Economic Analysis: Equations

Consumer Surplus Delta

$$\Delta Cs_{m,k,y} = \sum_{t,s,u} Cd^{ref}_{k,y,t,s,u} \cdot Ep^{ref}_{k,y,t,s.u} - \sum_{t,s,u} Cd_{m,k,y,t,s,u} \cdot Ep_{m,k,y,t,s,u} \qquad \forall\, m \in M,\ k \in K,\ y \in Y$$

Producer Surplus Delta

$$\Delta Ps_{m,k,y} = \sum_{t,s,u} (Pg_{m,k,y,t,s,u} \cdot Ep_{m,k,y,t,s,u} - Cg_{k,y,t,s,u}) - \sum_{t,s,u} (Pg^{ref}_{k,y,t,s,u} \cdot Ep^{ref}_{k,y,t,s,u} - Cg^{ref}_{k,y,t,s,u})$$

$$\forall\, m \in M,\ k \in K,\ y \in Y$$

(M) Scenario, (K) Country, (Y) Year

Methodology – Economic Analysis: Equations

Consumer Surplus Delta

$$\Delta Cs_{m,k,y} = \sum_{t,s,u} Cd^{ref}_{k,y,t,s,u} \cdot Ep^{ref}_{k,y,t,s.u} - \sum_{t,s,u} Cd_{m,k,y,t,s,u} \cdot Ep_{m,k,y,t,s,u} \qquad \forall\, m \in M,\ k \in K,\ y \in Y$$

Producer Surplus Delta

$$\Delta Ps_{m,k,y} = \sum_{t,s,u} \underbrace{(Pg_{m,k,y,t,s,u} \cdot Ep_{m,k,y,t,s,u} - Cg_{k,y,t,s,u})}_{\text{Revenues - Costs (Scenario)}} - \underbrace{\sum_{t,s,u} (Pg^{ref}_{k,y,t,s,u} \cdot Ep^{ref}_{k,y,t,s,u} - Cg^{ref}_{k,y,t,s,u})}_{\text{Revenues - Costs (Ref)}} \qquad \forall\, m \in M,\ k \in K,\ y \in Y$$

(M) Scenario, (K) Country, (Y) Year

Mario Garzón González

Methodology – Economic Analysis: Equations

Consumer Surplus Delta

$$\Delta Cs_{m,k,y} = \sum_{t,s,u} Cd^{ref}_{k,y,t,s,u} \cdot Ep^{ref}_{k,y,t,s.u} - \sum_{t,s,u} Cd_{m,k,y,t,s,u} \cdot Ep_{m,k,y,t,s,u} \qquad \forall\, m \in M,\ k \in K,\ y \in Y$$

Producer Surplus Delta

$$\Delta Ps_{m,k,y} = \sum_{t,s,u} (Pg_{m,k,y,t,s,u} \cdot Ep_{m,k,y,t,s,u} - Cg_{k,y,t,s,u}) - \sum_{t,s,u} (Pg^{ref}_{k,y,t,s,u} \cdot Ep^{ref}_{k,y,t,s,u} - Cg^{ref}_{k,y,t,s,u})$$

$$\forall\, m \in M,\ k \in K,\ y \in Y$$

TSO Surplus → Congestion Rents

(M) Scenario, (K) Country, (Y) Year

Methodology – Economic Analysis: Assumptions

Transmission Lines Costs

Location	DK - Hub km	DK - Hub M€/GW	NL - Hub km	NL - Hub M€/GW	DE - Hub km	DE - Hub M€/GW
L1	310	310-465	250	250-375	310	310-465
L3	100	100-150	300	300-450	275	275-412

Data provided by PROMOTioN project

OWF Cost	Data
Invesment CAPEX [M€/MW]	1.57
Hub CAPEX * [M€/MW]	0.19
Fixed O&M [€/MW/year]	36,053
Variable O&M [€/MWh]	2.7
Lifetime [year]	30

Danish Energy Agency. Technology Data - Generation of Electricity and District heating. Technical report. 2020.
*M J Koivisto and J Gea-Bermudez. NSON-DK energy system scenarios-Edition 2. Technical report. 2018.

Country	DK	NL	DE
Tax rate *	22%	25%	30%
Private disc. rate **	8%	8%	8%
Socio-economic disc. rate	4%	4%	4%
Inflation	1%	1%	1%

* KMPG. Corporate tax rates table. Technical report. 2020.
**Roland Berger and European Commission. NSWPH in the context of the North Seas Offshore Energy Clusters study. 2018, pages 5–6.

North Sea Wind Power Hub Consortium

Formed by:

TSOs Energinet and Tennet, the Port of Rotterdam, and Gasunie, an European energy infrastructure company

Objective:

Add the techno-economic perspective to facilitate discussions between policy makers and North Sea stakeholders

'Hub-and-Spoke' concept:

Modular hubs that connects offshore wind farms and interconnection capacity between multiple countries.

- Increase the utilisation rate of the asset
- Reduce overall costs
- Modularity allows step-by-step approach adjusted to the needs of the system

Optimal capacity: 10-15 GW (12GW chosen)

Ref. case: 6 GW Germany, 4 GW The Netherlands, 2 GW Denmark