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Market Setup Impact on Price Dynamics and Income Distribution
A study commissioned by the North Sea Wind Power Hub consortium

Background Report

8 OCTOBER 2020

North Sea Wind Power Hub Programme

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Market Setup Impact on Price Dynamics and Income Distribution study

- **The North Sea Wind Power Hub (NSWPH) consortium has joined forces to develop concepts and solutions for supplying the large capacities required to generate energy from renewable sources at the lowest possible environmental impact and cost.**
- **The NSWPH programme sees it as their responsibility to structure and inform the discussion amongst policymakers on the main topics.**
- **One of the primary discussion topics is the market setup for hybrid projects – essentially defining how offshore windfarms are allocated to specific bidding zones and how cross-zonal capacity between these bidding zones is allocated.**
- **To inform these discussions, the NSWPH consortium commissioned a study by AFRY Management Consulting to provide insights into the effects of two different market setups under two physical configurations for the hub.**
- **The study is entitled 'Market Setup Impact on Price Dynamics and Income Distribution'.**

- **The 'Market Setup Impact on Price Dynamics and Income Distribution' study is co-financed by the Connecting Europe Facility of the European Union.**

North Sea Wind Power Hub Programme

Co-financed by the Connecting Europe Facility of the European Union

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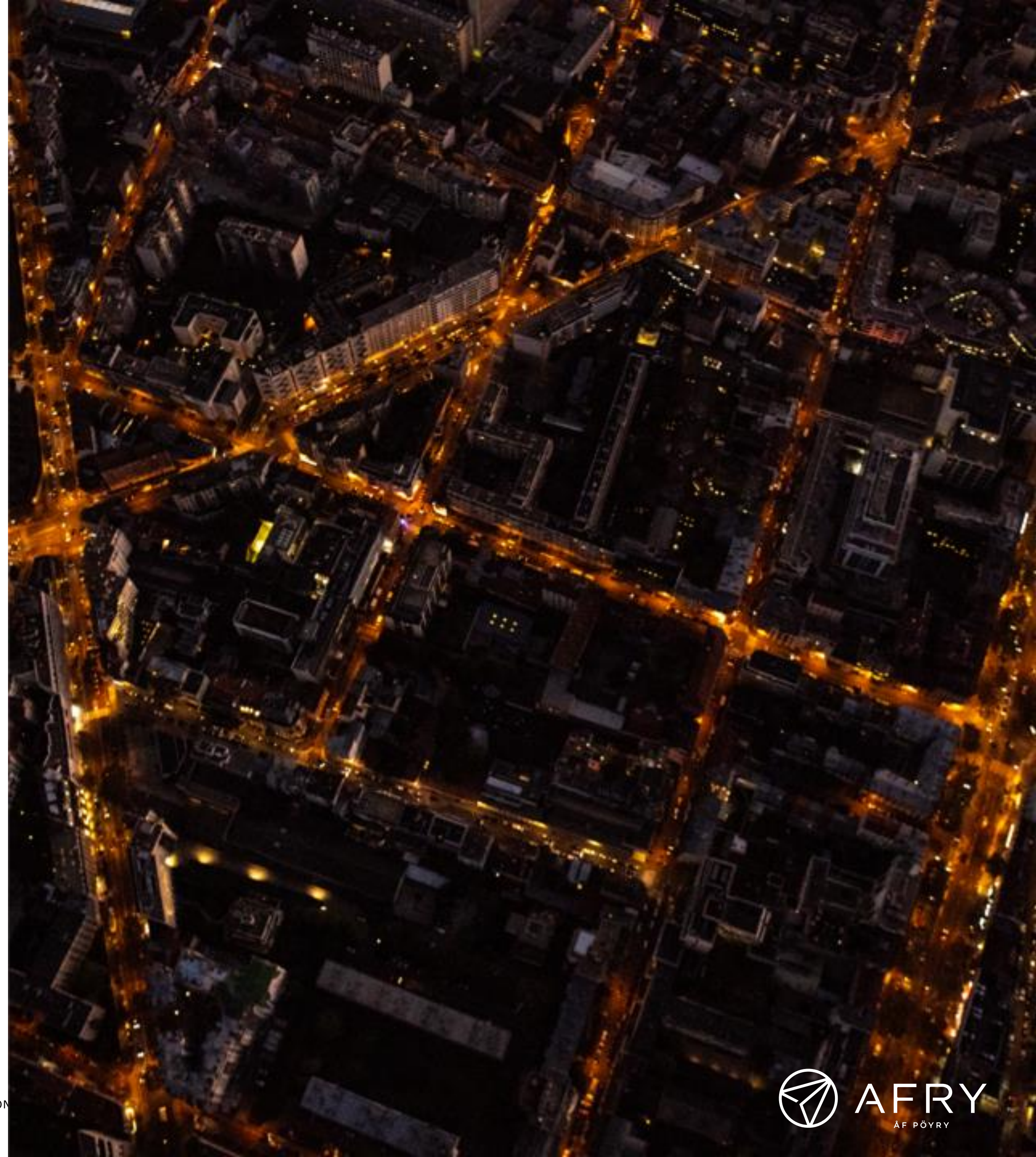

North Sea Wind Power Hub Consortium is focused on facilitating the large scale roll-out and integration of North Sea offshore wind

CHALLENGES & STATE-OF-PLAY

- The North Sea Wind Power Hub (NSWPH) consortium (1) has joined forces to develop concepts and solutions for supplying the large capacities required to generate energy from renewable sources at **the lowest possible environmental impact and cost**. One of the consortium's aim is to facilitate the large scale roll-out and integration of North Sea offshore wind.
- Currently, the approach to plan, design and operate offshore grid infrastructure is predominantly nationally focused and lacking a **total energy system perspective that allows for synergies and cost-efficient development and operation of the offshore infrastructure.**
- Due to:
  i. the scale of the offshore wind roll-out required to meet the Paris Agreement climate targets;
  ii. the short time window for realisation; and
  iii. the unfolding energy transition as a whole;

  a **new approach to offshore wind connection and grid integration is required**, thereby creating the need to revisit current processes and regulatory frameworks for the infrastructure involved.

BENEFITS OF A COORDINATED APPROACH

- To ensure security of supply now and in the future, whilst facilitating the large scale roll-out and integration of North Sea offshore wind at maximum benefit for society, the consortium is seeking to develop an internationally coordinated approach that is based on a total energy system view and integral energy infrastructure planning:
  i. **across national borders**, to efficiently use the offshore wind resources through integral maritime spatial planning and to connect and balance energy markets across Europe;
  ii. including **hybrid** assets, to ensure an efficient use of the energy infrastructure through combined use of grid connection and interconnection infrastructure; and
  iii. **across energy sectors**, to provide large scale flexibility through sector-coupling and storage, reduce curtailment and decarbonise the energy system as a whole.

1. TenneT Netherlands, TenneT Germany, Energinet and Gasunie: ‘Market setup options to integrate hybrid projects into the European electricity market’ Discussion Paper

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Focus here is on price and income dynamics for two 'Market Setups' in respect of bidding and pricing arrangements for hub connected assets

STUDY OBJECTIVES

- In order to realise NSWPH's vision, governments and offshore wind farm (OWF) developers need to be on board. Moreover, the NSWPH programme sees it as their responsibility to structure and inform the discussion amongst policymakers on the main topics. One of the primary discussion topics is the market setup for hybrid projects – essentially defining how OWFs are allocated to specific bidding zones and how cross-zonal capacity between these bidding zones is allocated.
- To inform these discussions, this study, commissioned by the NSWPH consortium, provides insights into the effects of **two different market setups** under **two physical configurations** for the hub **– the focus is on the potential impact of market setups on electricity price dynamics and on income outcomes for relevant stakeholders**. The analysis is conducted for 2035 taking ENTSO-E's TYNDP 2020 'National Trends' as the basis for the market scenario.
- The market setups and physical configurations considered in the study are set out below.

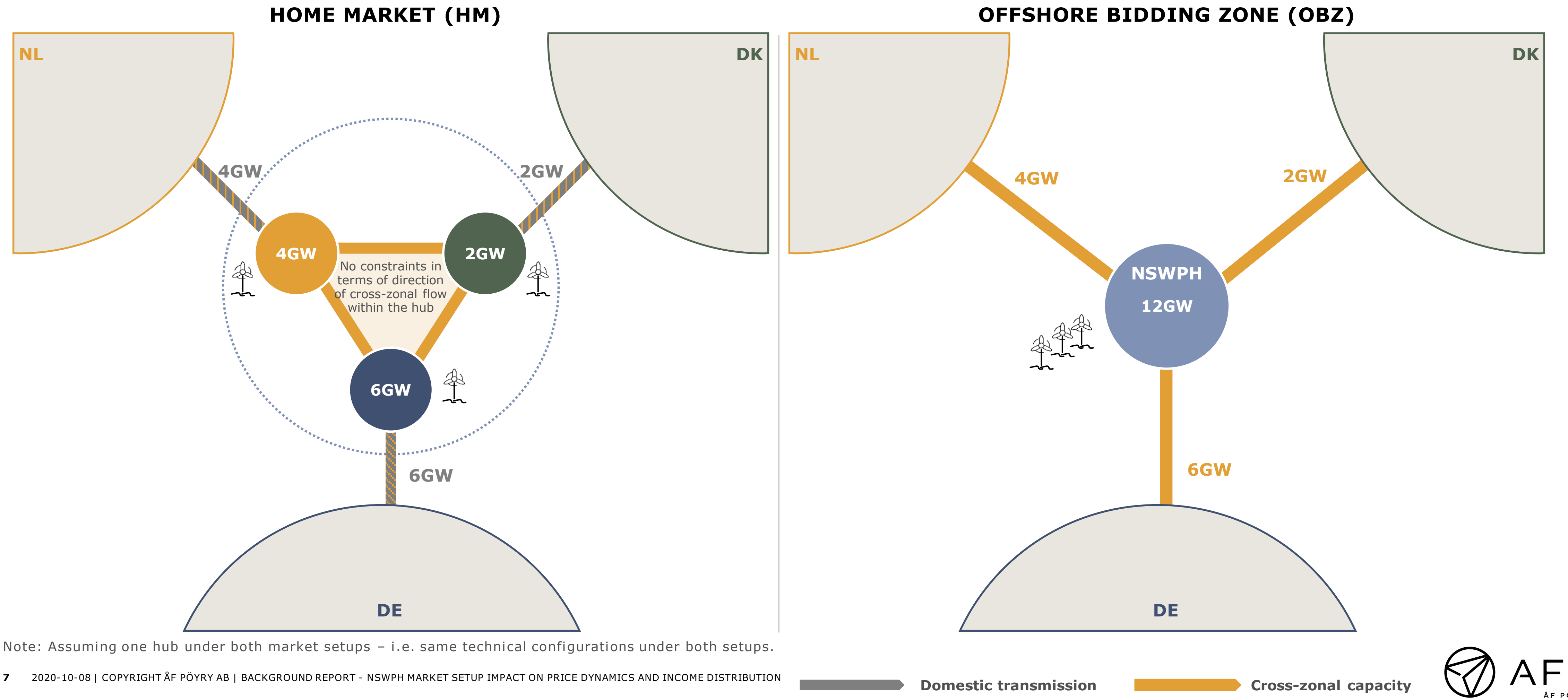
SCOPE

MARKET SETUPS	**HOME MARKET**	OWFs connected to the hub bid into, are dispatched into and receive the market price for their home market (HM). Each cable between the hub and a HM is a 'hybrid' asset, with its available cross-zonal capacity constrained by capacity use by the OWFs for transmission of their generation output.
	OFFSHORE BIDDING ZONE	A separate offshore bidding zone (OBZ) is created for the hub-connected OWFs, into which they submit bids and are dispatched. All hub-connected cable capacity is released as cross-zonal capacity to the market and the offshore generation is matched with onshore demand via market coupling.
PHYSICAL CONFIGURATIONS	**CORE**	Includes OWFs and onshore systems associated with Denmark (DK), Germany (DE) and the Netherlands (NL), as the central elements of the hub and spoke arrangements. 12GW of OWF capacity is connected to the hub in total, with 12GW of transmission capacity to shore.
	CORE PLUS	Broadens the hub and spoke arrangements from the Core Configuration to additionally include OWFs and onshore systems associated with Great Britain (GB) and Norway (NO). Again, 12GW of OWF capacity is connected to the hub in total, with 12GW of transmission capacity to shore (although the allocation is different than for the Core Configuration, as set out in next slides).

INTRODUCTION: PHYSICAL CONFIGURATIONS

Core case based on 6GW, 4GW and 2GW of OWF capacity from DE, NL and DK respectively, with matching transmission capacities to respective shore

For illustration purposes

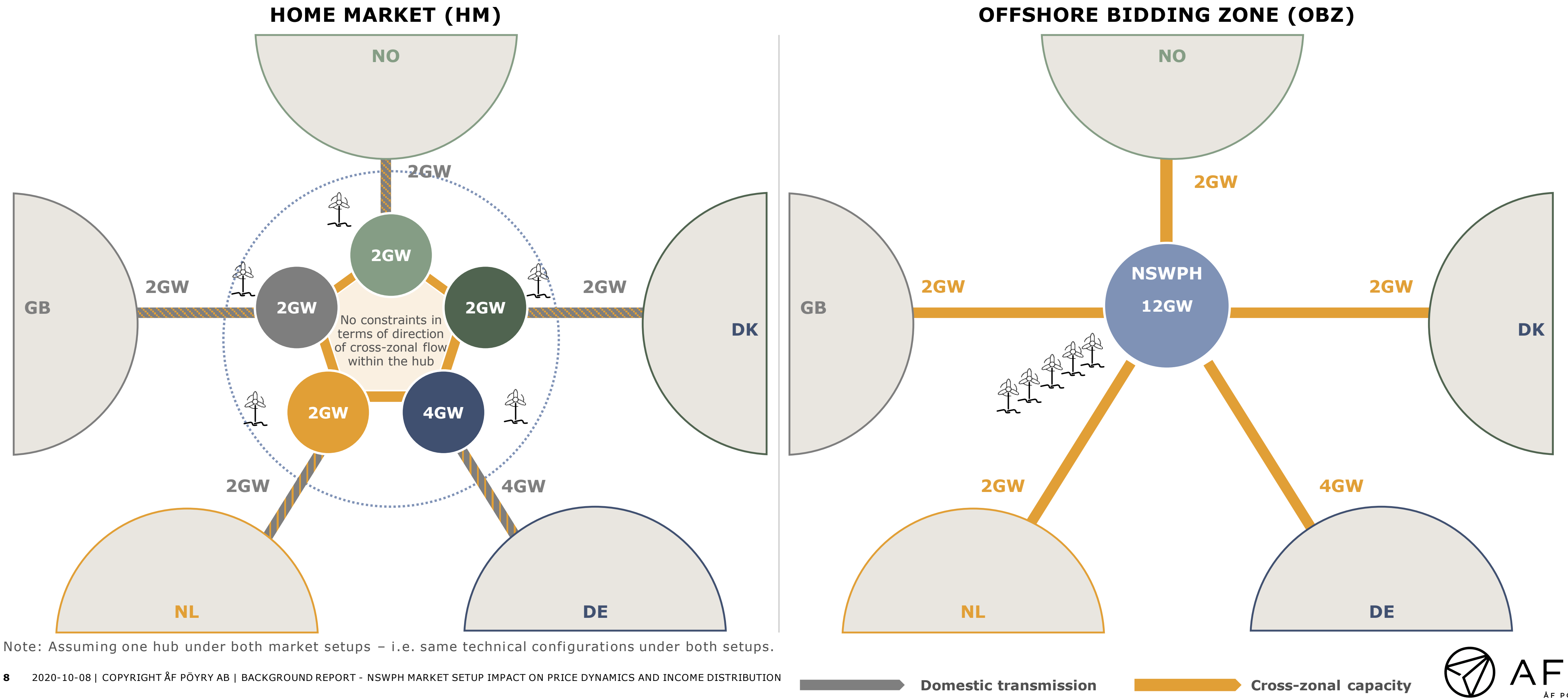


Note: Assuming one hub under both market setups – i.e. same technical configurations under both setups.

INTRODUCTION: PHYSICAL CONFIGURATIONS

Core+ case based on 4GW of OWF capacity from DE and 2GW from each of NL, DK, GB and NO, with matching transmission capacities to each shore

For illustration purposes



Note: Assuming one hub under both market setups – i.e. same technical configurations under both setups.

Market Setup Impact on Price Dynamics & Income Distribution

STRUCTURE

- **Section 1: Executive Summary,** including the main messages of this study
- **Section 2: Study Characteristics & Assumptions,** including supporting information in relation to the market scenario and assumptions, plus a description of the scope
- **Section 3: Core Configuration,** including the results of the Core Configuration
- **Section 4: Core Plus Configuration,** including the results of the Core + Configuration
- **Section 5: Core vs. Core+ High-Level Comparisons,** including comparisons between the two Configurations
- **Annex: Supporting Information,** such as modelling background and additional results

CONVENTIONS

- All monetary values quoted in this report are in Euros in real 2019 prices , unless otherwise specified
- Annual data relates to the calendar year running from 1 January to 31 December 2035
- Unless otherwise specified, results are presented as an average of three historical weather-years, i.e. 2012, 2014 & 2018
- The source for all tables, figures and charts is AFRY Management Consulting

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2. Study Characteristics & Assumptions
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4. Core Plus Configuration
5. Core vs. Core+ High-Level Comparisons

– Annex: Supporting Information

Effects of market setup choice on overall welfare are small, but distributional impacts need to be considered in development of any bidding arrangements

MAIN MESSAGES

1. **More efficient direction of flows under the Offshore Bidding Zone setup than under the Home Market setup**
   While overall flows and utilisation of hub related transmission assets are broadly comparable between market setups, the OBZ setup delivers greater flows to higher priced markets.
2. **Socio-economic welfare under the Home Market setup and Offshore Bidding Zone setup is similar**
   Difference in aggregate socio-economic welfare (1) outcome is negligible if hub includes Denmark, Germany and Netherlands only, but the addition of Great Britain and Norway to the hub adds greater diversity which helps to provide a marginal positive socio-economic effect under the OBZ setup.
3. **Large distributional transfers linked to the market setup choice**
   Adopting the OBZ setup leads to income transfer from producers, notably hub-connected OWFs, to interconnectors compared to the HM setup:
   a. **Hub-connected OWFs can expect lower capture revenues under the Offshore Bidding Zone setup than under the Home Market setup**
      OBZ price is generally below onshore market prices, driving lower OWF capture revenues in most cases and the reduction in producer surplus mentioned above.
   b. **Congestion rent potential is greater under the Offshore Bidding Zone setup than under the Home Market setup**
      By definition, flows to/from the hub are classed as cross-zonal flows under the OBZ setup, allowing congestion rent to be generated in respect of these flows.

CONCLUSIONS

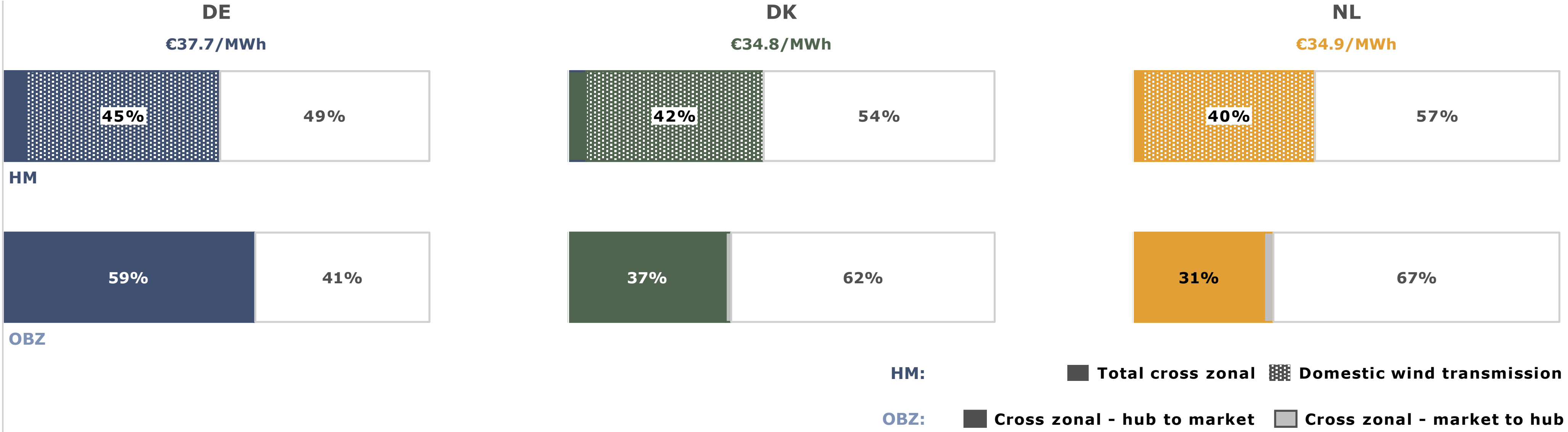
1. **Effects of market setup choice on socio-economic welfare are small, but potential benefits of OBZ setup are enhanced when there is more diversity in the hub-connected markets**
2. **Distributional impacts will need to be considered in development of any offshore bidding zone arrangements**

1. Socio-Economic Welfare analysis includes impact on consumers and producers surpluses, and on congestion rent potential, from the wholesale electricity market.

More efficient direction of flows under the OBZ setup than under the HM setup

Average electricity price under the HM setup and utilisation rates by type & direction of flow

CORE
DE, DK & NL



COMMENTS

- The charts show the utilisation rates for hub-connected transmission assets for the year 2035 by type (in the HM) and direction (in the OBZ), defined as the physical flow accounting for losses divided by the capacity of each spoke under the Core Configuration (1). The average electricity price per market is also provided under the HM setup (2).
- While overall flows on and utilisation of hub related transmission assets are broadly comparable between market setups, the OBZ setup delivers greater flows to higher priced markets. For example, in the Core Configuration, total flows over the transmission assets are at similar levels under both market setups (with the difference being around 1%). However, when switching to the OBZ setup, the utilisation of the spoke connecting the German market to the hub is higher, driven by a strong(er) price signal.

1. Results under the Core+ Configuration show a similar direction overall | 2. Prices under the OBZ setup are very similar with differences being less than 0.5%

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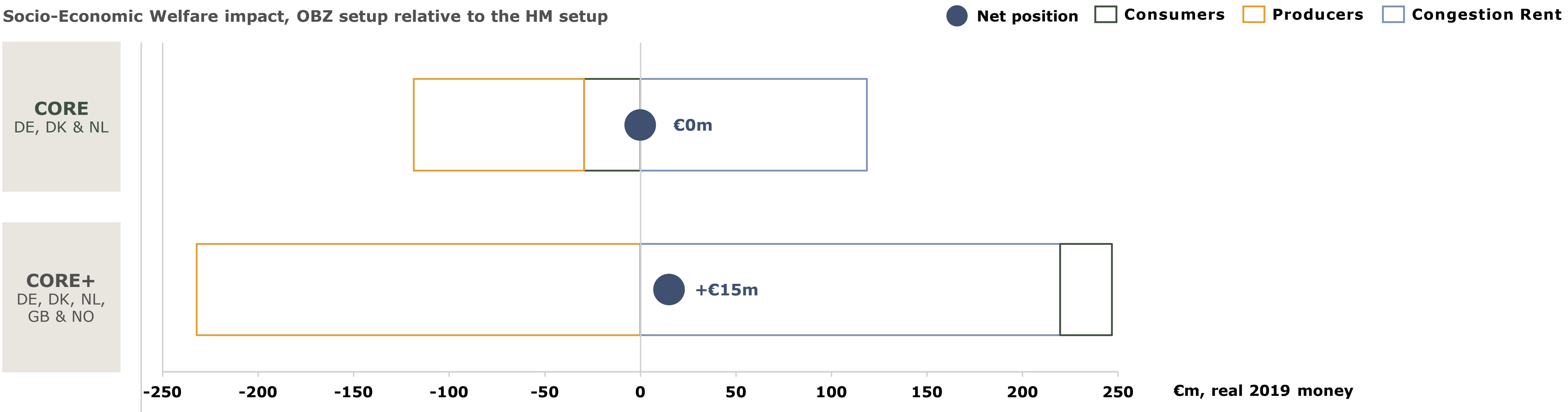
MAIN MESSAGE #2

Socio-economic welfare under the HM setup and OBZ setup is similar

Socio-Economic Welfare impact, OBZ setup relative to the HM setup

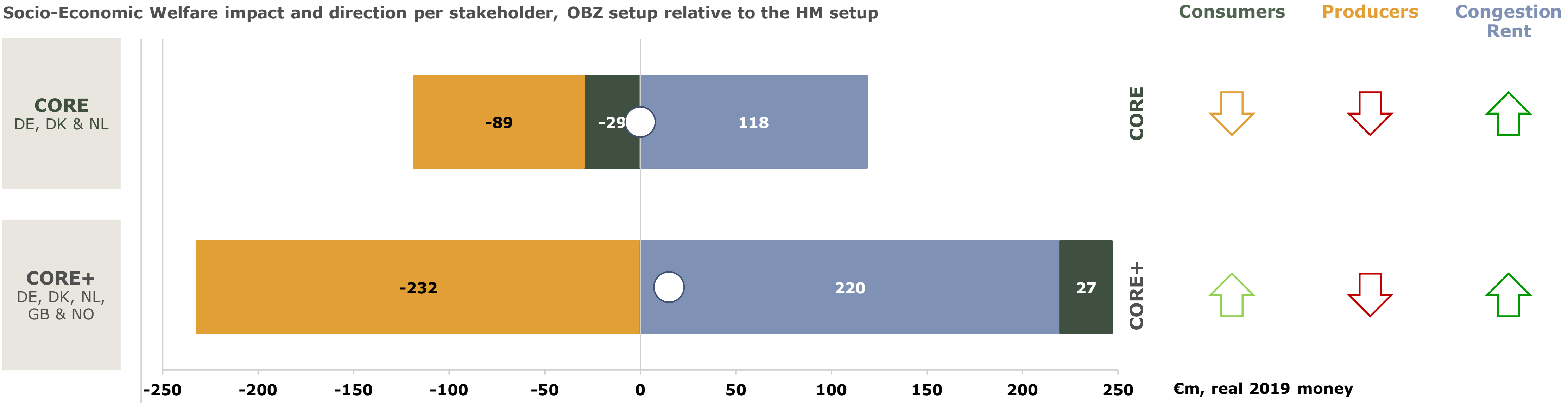


COMMENTS

- The chart provides a summary of the socio-economic welfare assessment for the Core and the Core+ Configurations for the modelled year 2035. The impact is relative to the HM setup (i.e. positive numbers indicate a higher welfare under the OBZ setup; negative numbers indicate a lower welfare under the OBZ setup).
- The difference in aggregate socio-economic welfare outcome is negligible if the hub includes Denmark, Germany and the Netherlands only (net position is €0m), but the addition of Great Britain and Norway to the hub adds greater diversity, which helps to provide a marginal positive socio-economic effect under the OBZ setup (net position is +€15m).

Large distributional transfers linked to the market setup choice

Socio-Economic Welfare impact and direction per stakeholder, OBZ setup relative to the HM setup



COMMENTS

- The chart provides a summary of the socio-economic welfare assessment for the Core and the Core+ Configurations for the modelled year 2035. The impact is relative to the HM setup (i.e. positive numbers indicate a higher welfare under the OBZ setup; negative numbers indicate a lower welfare under the OBZ setup). The arrows show the direction of the impact per stakeholder.
- The main distributional transfers stem from the following: the HM setup has larger producer surplus, notably for the hub-connected OWFs, while the OBZ setup exhibits greater congestion rent.
- Consumer surplus is negative if the hub includes DK, DE and NL only. This is mainly driven by a negative impact on the Dutch consumers (1), as lower OWF generation flows towards the NL shore under the OBZ setup (instead, it flows to DE triggered by a stronger price signal). The addition of GB and NO to the hub leads to an overall positive consumer surplus. This is driven by a positive impact mainly on the German consumers, benefiting from increased flows from zones with notably lower prices (i.e. GB & NO). However, the overall impact on consumers is limited for both physical configurations.

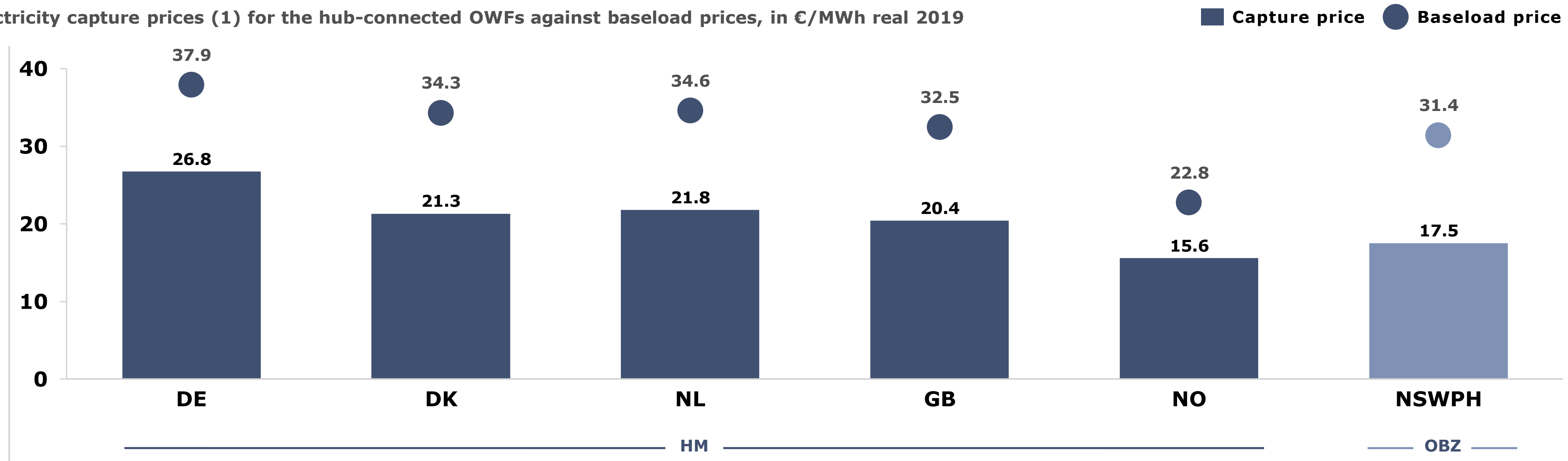
1. For example, the demand-weighted average price in NL increases by €0.14/MWh in the OBZ setup compared to the HM setup

MAIN MESSAGE #3A

Hub-connected OWFs can expect lower capture revenues under the OBZ setup than under the HM setup

Wholesale electricity capture prices (1) for the hub-connected OWFs against baseload prices, in €/MWh real 2019

CORE+
DE, DK, NL, GB & NO



COMMENTS

- The chart shows for the Core+ Configuration (2) and for the modelled year 2035: i. the capture price, defined as the unit wholesale electricity revenue of the hub-connected OWF per MWh accounting for the hourly profile and shape of prices and generation; and ii. the baseload price, defined as the annual time-weighed average wholesale electricity price representative for a 'baseload' generator.
- The OBZ price is generally below onshore market prices (Norway is the exception in the Core+ Configuration), driving lower OWF capture revenues in most cases and the reduction in producer surplus mentioned above. For example, total revenue for the hub-connected OWFs drops by 10% in the Core Configuration (i.e. from €1,130m under the HM to €1,015m under the OBZ setup), and by 20% in the Core+ Configuration (i.e. from €1,055m under the HM to €849m under the OBZ setup).

1. Defined as the wholesale electricity market revenue per unit of generation | 2. Similar results for the Core Configuration

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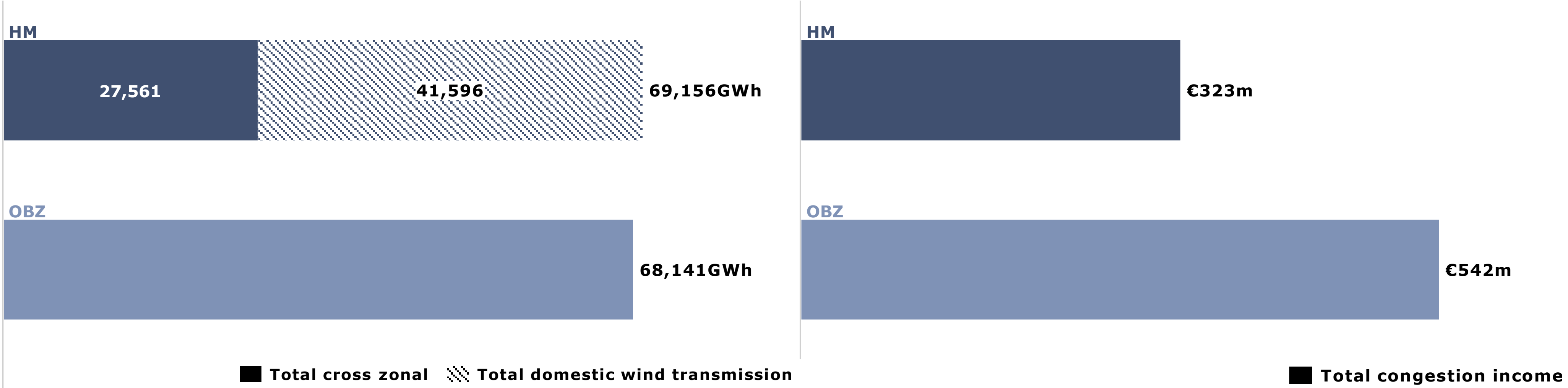
MAIN MESSAGE #3B

Congestion rent potential is greater under the OBZ setup than under the HM setup

Annual physical flows, incl. losses by type of flow & annual total congestion income

CORE+
DE, DK, NL, GB & NO



COMMENTS

- The chart on the left-hand side shows the hub related transmission assets' physical flows accounting for losses, as triggered by commercial signals, i.e. electricity price spreads, at the day-ahead stage. The chart on the right-hand side shows the estimated total congestion income. The charts compare the two market setups for the year 2035 under the Core+ Configuration (1).
- By definition, flows to/from the hub are classed as cross-zonal flows under the OBZ setup, allowing congestion rent to be generated in respect of these flows. For example, total congestion income increases six fold in the Core Configuration (i.e. from €25m under the HM setup to €149m under the OBZ setup), and by 70% in the Core+ Configuration (i.e. from €323m under the HM setup to €542m under the OBZ setup).
- Overall flows on transmission assets are around 1% lower under the OBZ setup. The main reason for this is the account taken of hub to shore transmission losses under the different market setups. Under the OBZ setup, flows to shore may not be scheduled when price differences are small, as the costs of losses will not be covered by the price differential. However, under the HM setup, larger flows to shore can be scheduled as most flows are within-zone rather than cross-zonal and so the cost of losses does not need to be covered in the same way.

1. While overall flows and congestion income are lower under the Core Configuration, the comparisons between the HM and the OBZ setup are of similar magnitude

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– Annex: Supporting Information

Two different market setups in respect of bidding and pricing arrangements for hub connected assets are examined

MARKET SETUPS	DESCRIPTION
HOME MARKET (HM)	– OWFs connected to the hub bid into, are dispatched into and receive the market price for their home market. Each cable between the hub and a HM is a 'hybrid' asset, with its available cross-zonal capacity constrained by capacity use by the OWFs for transmission of their generation output.
OFFSHORE BIDDING ZONE (OBZ)	– A separate offshore bidding zone (OBZ) is created for the OWFs, in which they submit bids and are dispatched. All hub-connected cable capacity is released as cross-zonal capacity to the market and, via market coupling, the offshore generation is matched with onshore demand.

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The different market setups are tested under two different physical configurations for the hub

CONFIGURATIONS	PHYSICAL CHARACTERISTICS
CORE CONFIGURATION	– **Markets linked to hub:** – Denmark (DK), Germany (DE) and the Netherlands (NL), as the central elements of the hub and spoke arrangements – **OWFs:** – DE: 6GW, NL: 4GW, DK: 2GW – total of 12GW – All OWFs within 25km from hub – **Hub:** – Transmission connection capacity to an onshore system matching the assumed OWF capacity for that market – c. 200-220km from the shores of Germany, Denmark and the Netherlands
CORE PLUS (+) CONFIGURATION	– **Markets linked to hub:** – Broadens the hub and spoke arrangements from the Core Configuration to include Great Britain (GB) and Norway (NO), in addition to DK, DE and NL – **OWFs:** – DE: 4GW, DK: 2GW, NL: 2GW, GB: 2GW, NO: 2GW – total of 12GW – All OWFs within 25km from hub – **Hub:** – Transmission connection capacity to an onshore system matching the assumed OWF capacity for that market – c. 200-220km from the shores of Germany, Denmark and the Netherlands; c. 300km from the shore of GB; and c. 480km from the shore of Norway

We have examined two market inefficiencies, linked to wind forecast errors and negative prices

VARIATIONS	DESCRIPTION & THEORETICAL IMPACT
LINKED TO WIND FORECAST ERRORS	– The HM setup requires reservation of transmission capacity to shore for hub-connected OWFs to cater for flows from OWFs to their home markets (domestic transmission), which **reduces the capacity available** for cross zonal flows (1). – By factoring wind forecast error into the capacity allocation process within the market modelling, rather than adopting a perfect foresight approach, we are able to assess the effects that this has on metrics such as **overall utilisation of offshore transmission and socio-economic welfare impact**.
LINKED TO NEGATIVE ELECTRICITY PRICES	– In the event of negative prices in a connected bidding zone, under the HM setup a potential inefficiency exists in that: – the hub-connected OWF is not scheduled, as, even with zero marginal cost, it is more expensive than the flows from its home bidding zone; – capacity on the spoke between the negative priced bidding zone and the hub is used to export from that bidding zone, via the hub and to other hub connected markets; and – some of the **available cross-zonal capacity linked to the hub remains unused**.

1. This is not the case in the OBZ, as all flows from the hub are cross zonal and capacity to allow these flows is allocated via the market coupling process.

Comparison Framework

MARKET SETUP	**Home Market** OWFs connected to the hub bid into, are dispatched into and receive the market price for their home market	**Offshore Bidding Zone** OWFs connected to the hub bid into, are dispatched into and receive the market price for a specific offshore bidding zone
PHYSICAL CONFIGURATIONS	**Core Configuration** Markets: DE, DK & NL	**Core+ Configuration** Markets: DE, DK, NL, GB & NO
EFFICIENCY VARIATIONS	1. Linked to wind forecast errors and the requirement to reserve transmission capacity to shore for hub-connected OWFs to cater for flows from the OWFs to their home markets (domestic transmission) 2. Linked to potentially inefficient use of interconnection capacity in case of negative electricity prices in connected bidding zones	

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– Annex: Supporting Information

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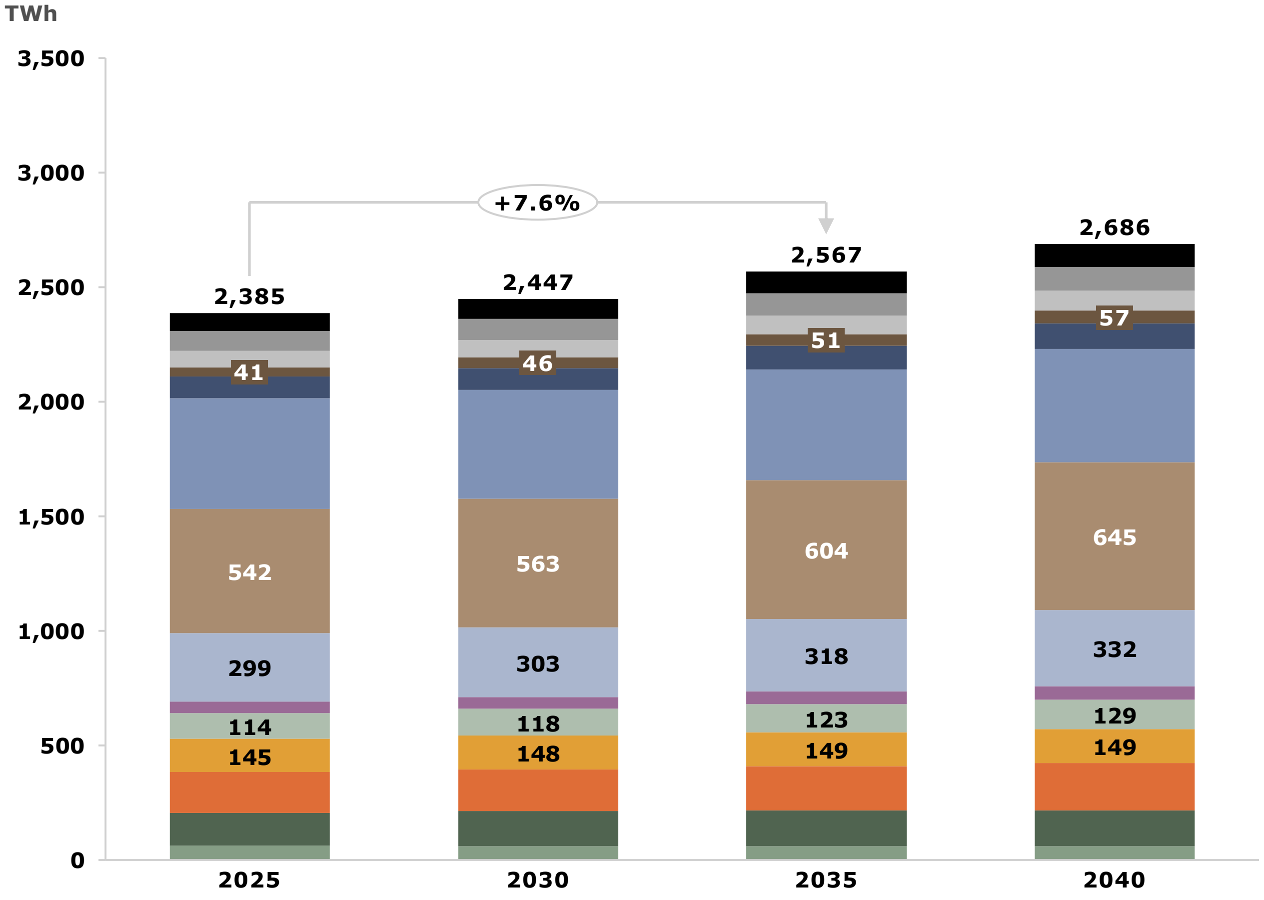
The ‘National Trends’ TYNDP 2020 scenario forms the basis of the market scenario for the assessment

Scenario	**National Trends (NT)**	**Global Ambition (GA)**	**Distributed Energy (DE)**
Climate target	**Based on National Energy and Climate Plans (NECPs)**	**Compliant with the 1.5°C target of the Paris Agreement**	**Compliant with the 1.5°C target of the Paris Agreement**
Description	Central bottom-up scenario. In accordance with the governance of the energy union and climate action rules, as well as on further national policies and climate targets already stated by the EU member states. Compliant with the EU’s 2030 Climate and Energy Framework (32 % renewables, 32.5 % energy efficiency) and EC 2050 Long-Term Strategy with an agreed climate target of 80–95 % CO_2 reduction compared to 1990 levels.	Looks at a future that is led by economic development in **centralised generation.** Economies of scale lead to significant cost reductions in emerging technologies such as offshore wind, but also imports of energy from cheaper sources are considered as a viable option.	Embraces a **de-centralised approach to the energy transition.** A key feature of the scenario is the role of the energy consumer, who actively participates in the energy market and helps to drive the system’s decarbonisation by investing in small-scale solutions and circular approaches.

National Trends includes growing demand in most of the markets reflecting assumptions of a strong uptake in electric vehicles and heat pumps

ANNUAL DEMAND IN THE NW EUROPEAN MARKETS – NATIONAL TRENDS



2035 data is interpolated between 2030 and 2040 values from the TYNDP scenario

COMMENTS

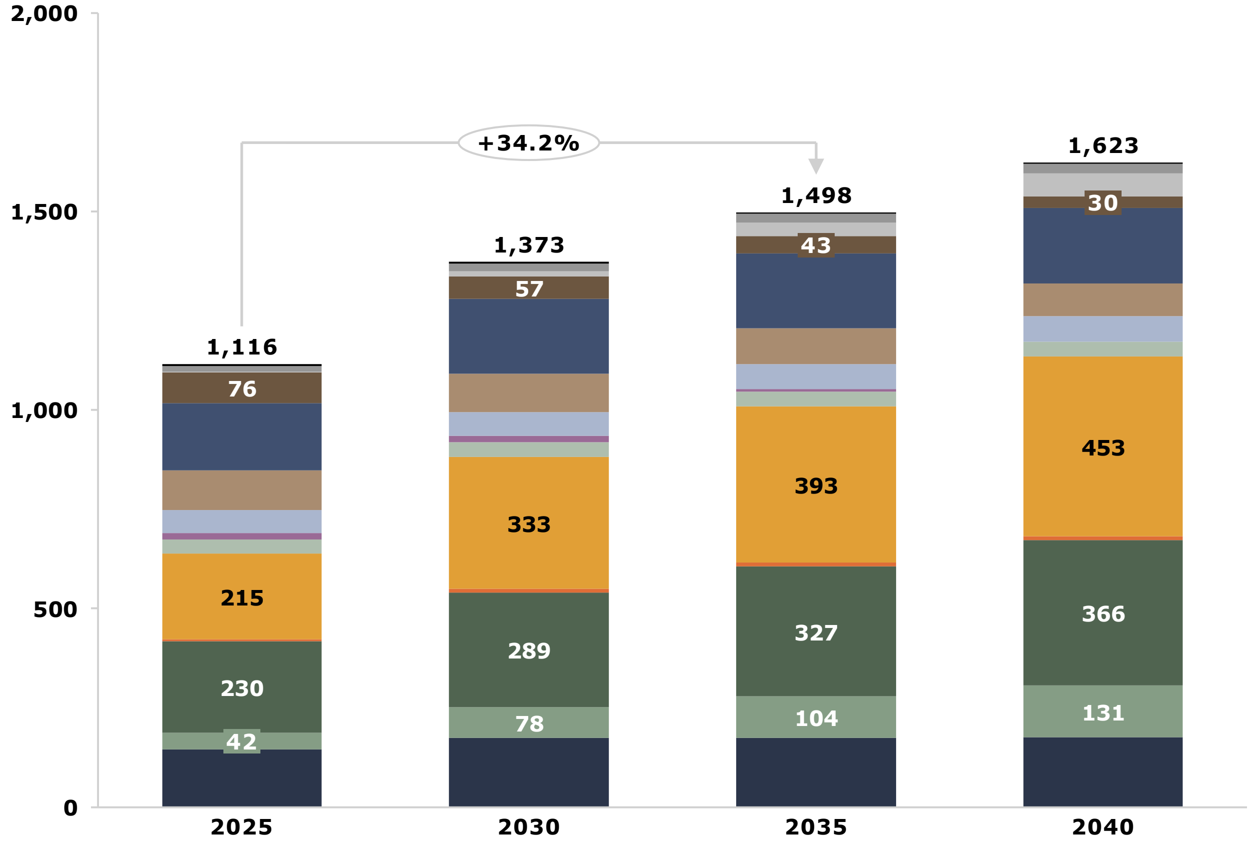
- The National Trends scenario sets out its demand forecast for 2025, 2030 and 2040. The analysis in this report is conducted for 2035. To derive 2035 values for demand, we have linearly interpolated between the demand values in 2030 and 2040.
- The annual demand is a key component of the TYNDP scenario reflecting the underlying assumptions in terms of growing EV demand and electrification of the heat system.
- The hourly TYNDP demand profiles were used for each country modelled to reflect the flexibility of the demand in terms of EV behaviour, non flexible demand etc.
- Demand growth rates vary by market. All five Core / Core+ markets see their annual demand levels increase by the mid-2030s, with Germany having the biggest increase (12% compared to 2025) and Norway the smallest increase (3% increase compared to 2025 levels).

CAPACITY MIX

National Trends includes significant additional capacities across all markets to support growing demand, coal decommissioning and RES targets

EU-28 CAPACITY MIX – NATIONAL TRENDS

GW



2035 data is interpolated between 2030 and 2040 values from the TYNDP scenario

COMMENTS

- The National Trends scenario sets out its plan for 2025, 2030 and 2040. To derive 2035 values, we have linearly interpolated between the capacity values in 2030 and 2040.
- Detailed technical assumptions and characteristics are based on AFRY's in house data sets, e.g. efficiencies, start-up costs, plant availability profiles, etc.
- The National Trends scenario assumes a high growth of RES capacity, while a significant part of the fossil-fuel capacity is expected to gradually decommission. More specifically:
  - c.45% of coal capacity is decommissioned by 2035 (compared to 2025 levels);
  - onshore wind sees a 40% increase;
  - offshore wind more than doubles its capacity; and
  - solar PV increases by more than 80%.

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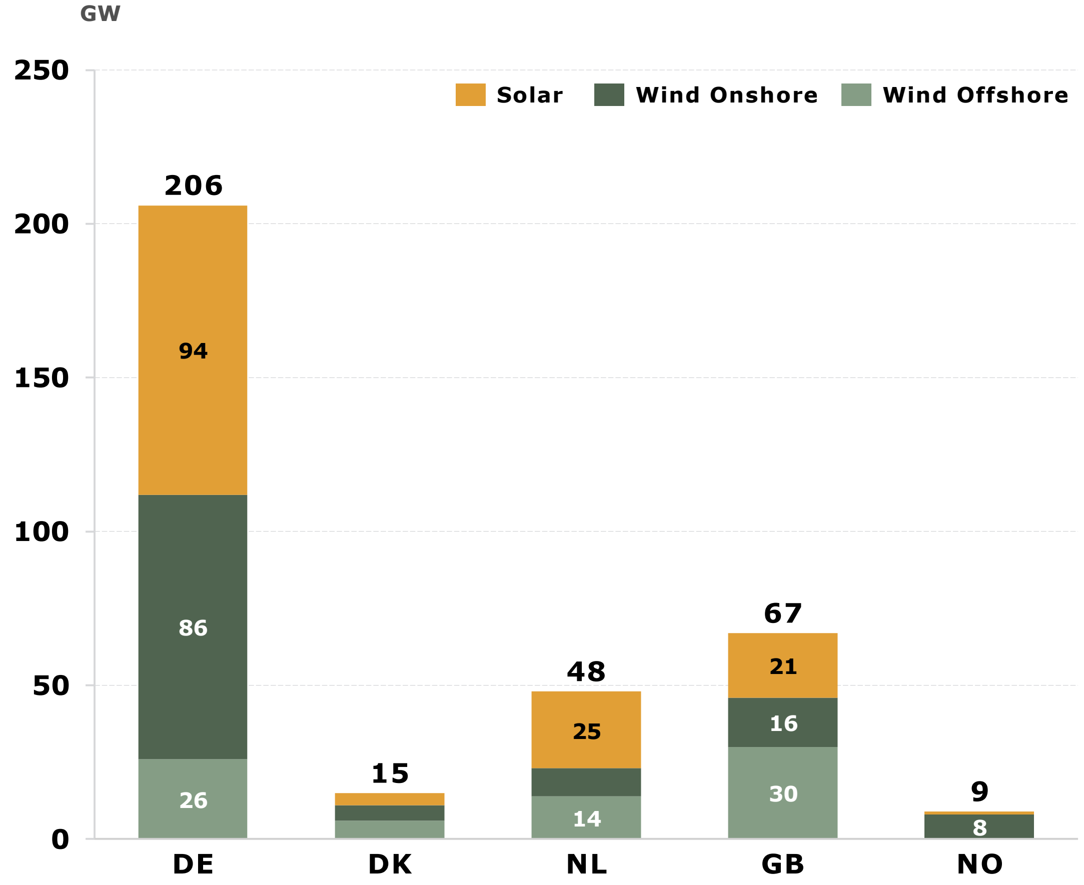
RES penetration reaches 75% by 2040 in National Trends, with significant capacity in the Core / Core+ markets in 2035

LOW CARBON PENETRATION TARGETS EU-28 – NATIONAL TRENDS

	RES-E wind	RES-E solar	RES-E hydro	Total RES Penetration
2025	19%	8%	20%	47%
2030	29%	12%	21%	64%
2040	42%	15%	16%	75%

+60%

CORE(+) MARKETS RES CAPACITY (2035) – NATIONAL TRENDS



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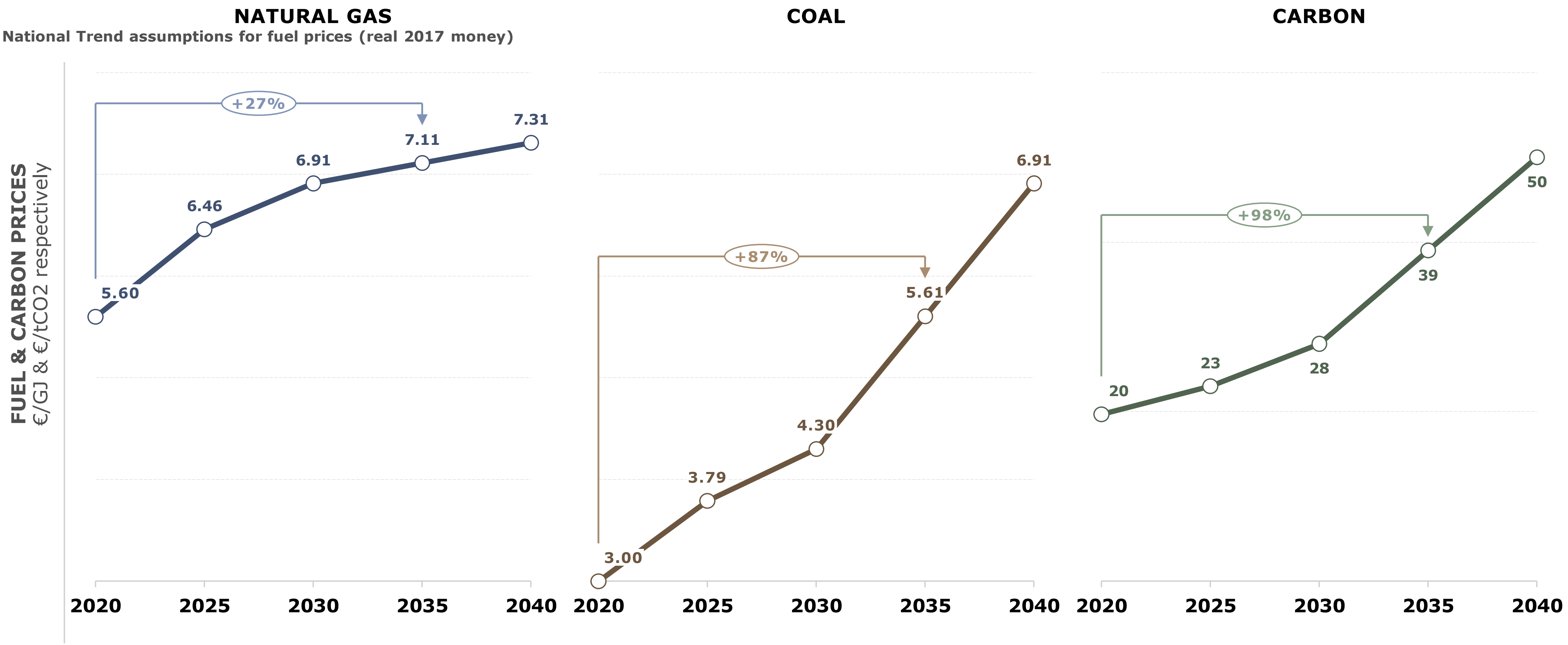
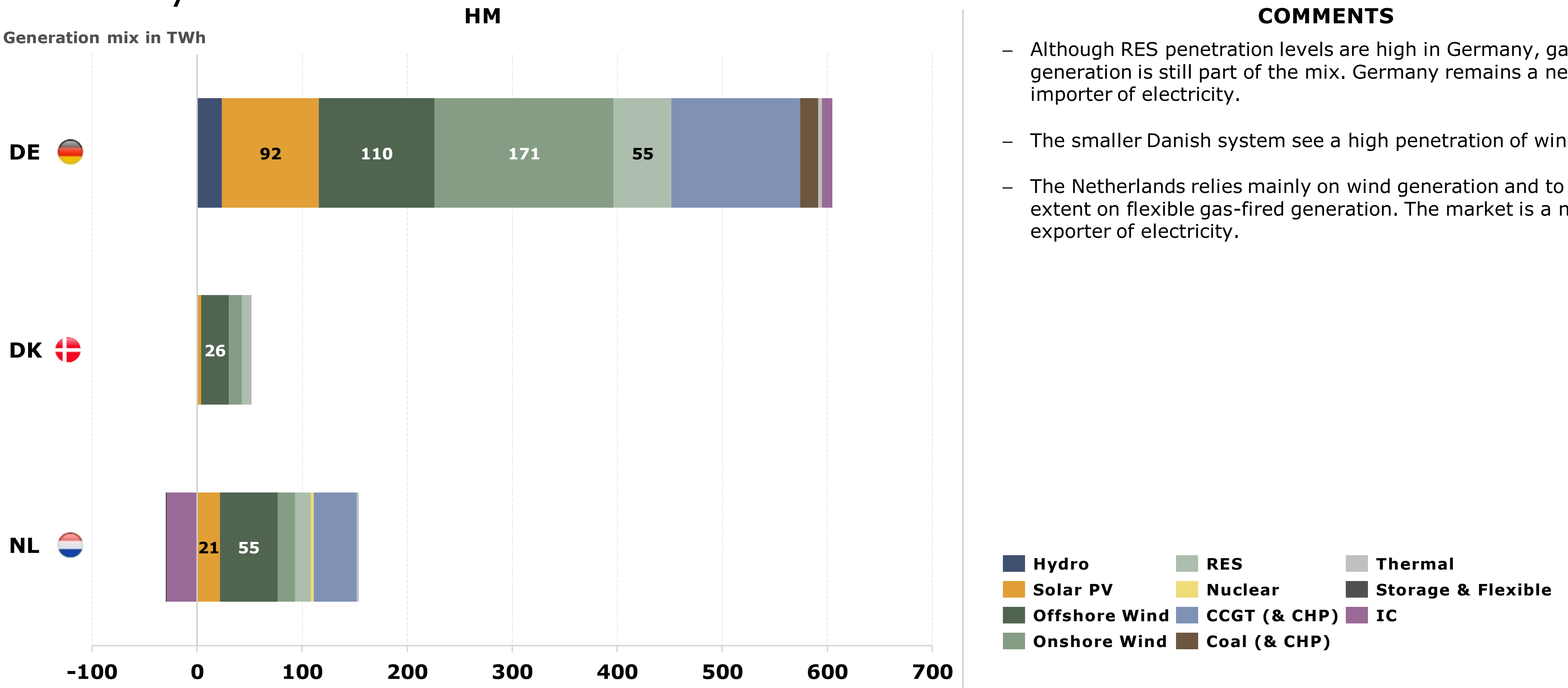
National Trends assumes increasing fuel and carbon prices



2035 data is interpolated between 2030 and 2040 values from the TYNDP scenario. Underlying profiles (e.g. monthly , seasonal, etc.) are based on AFRY's assumptions

ANNUAL GENERATION MIX

Based on National Trends inputs, the modelled generation mix has a high level of low carbon generation, with gas-fired generation still evident in Germany



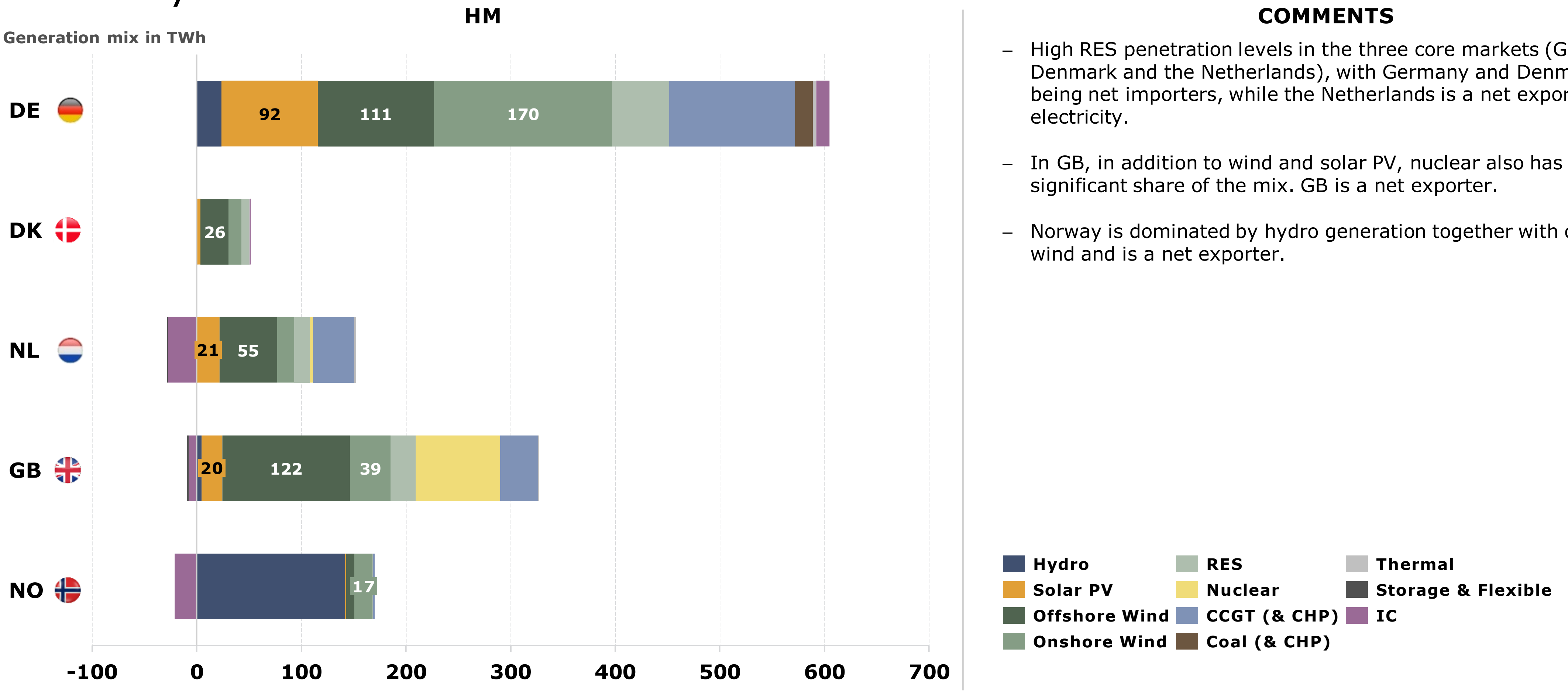
COMMENTS

- Although RES penetration levels are high in Germany, gas-fired generation is still part of the mix. Germany remains a net importer of electricity.
- The smaller Danish system see a high penetration of wind.
- The Netherlands relies mainly on wind generation and to a lesser extent on flexible gas-fired generation. The market is a net exporter of electricity.

RES include biofuels and small-scale RES; thermal include engines, gas turbines oil-fired generation; and storage & flexible include batteries, pumped storage, electrolysis, etc.

ANNUAL GENERATION MIX

Based on National Trends inputs, the modelled generation mix has a high level of low carbon generation, with gas-fired generation still evident in Germany



COMMENTS

- High RES penetration levels in the three core markets (Germany, Denmark and the Netherlands), with Germany and Denmark being net importers, while the Netherlands is a net exporter of electricity.
- In GB, in addition to wind and solar PV, nuclear also has a significant share of the mix. GB is a net exporter.
- Norway is dominated by hydro generation together with onshore wind and is a net exporter.

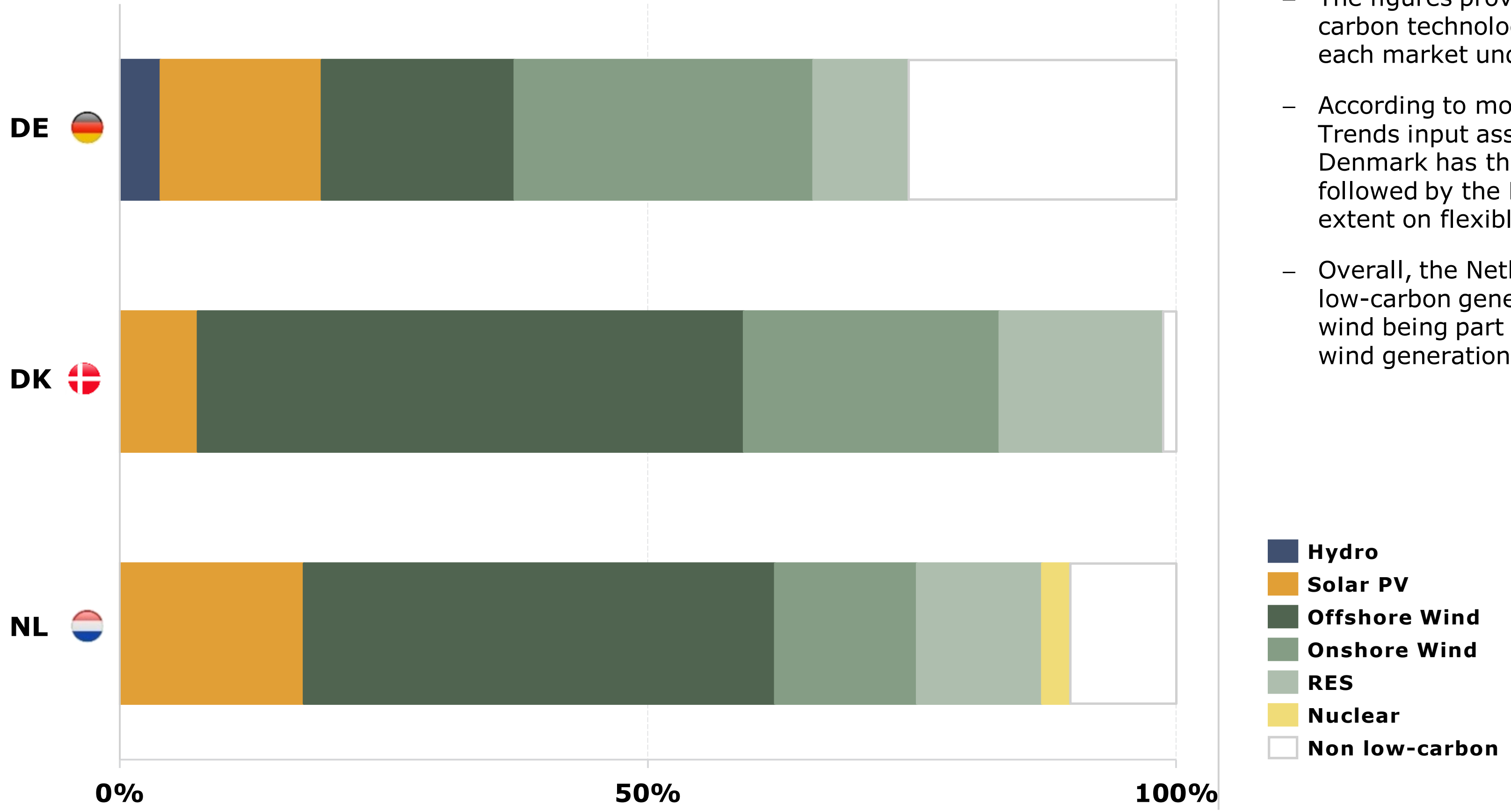
RES include biofuels and small-scale RES; thermal include engines, gas turbines oil-fired generation; and storage & flexible include batteries, pumped storage, electrolysis, etc.

PENETRATION OF LOW CARBON TECHNOLOGY AS A % OF DEMAND

Based on National Trends inputs, there is high RES penetration levels across all Core markets

HM

Penetration of each technology as a % of demand



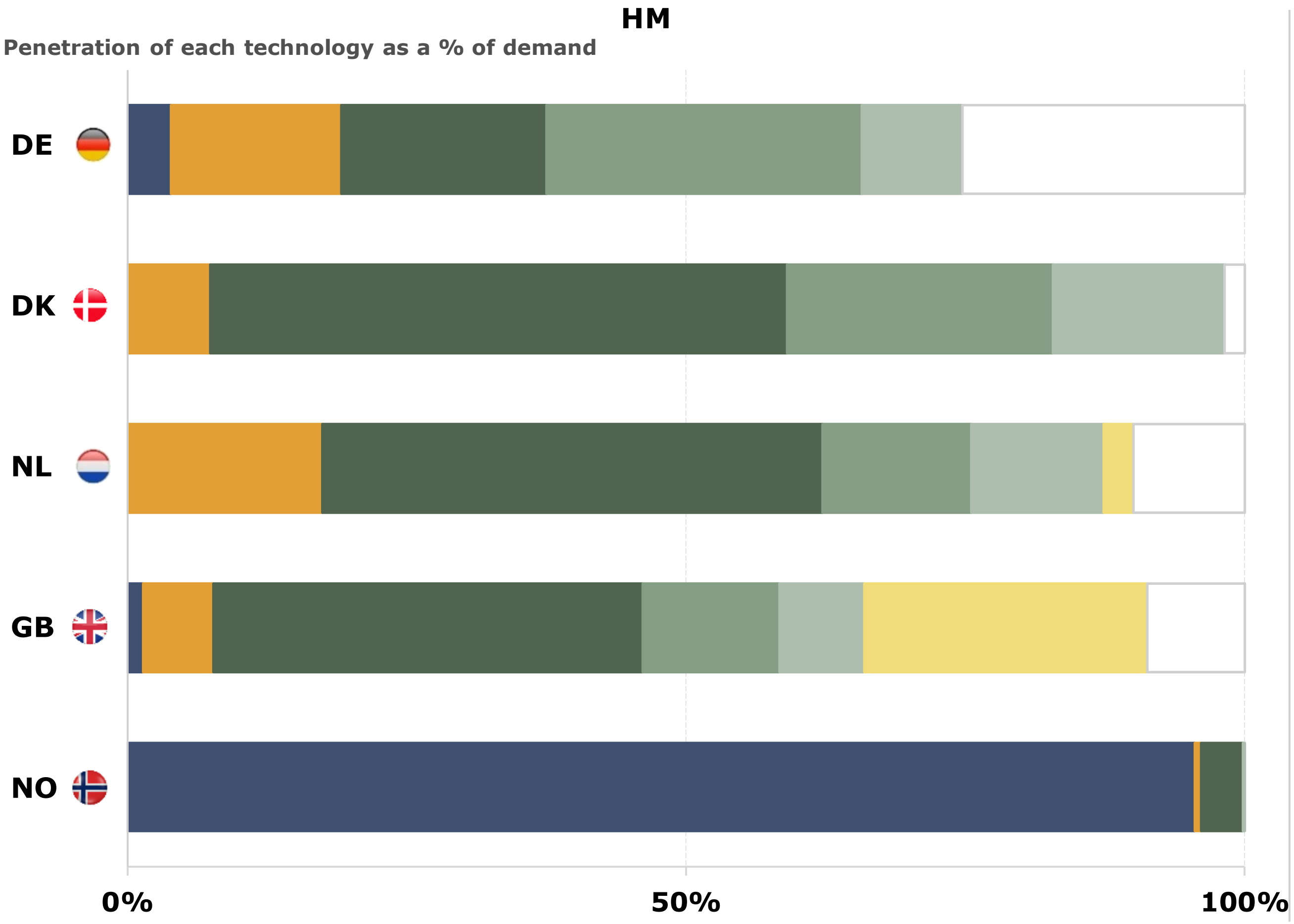
RES include biofuels and small-scale RES

COMMENTS

- The figures provided here show the penetrations of each low-carbon technology as a % of the overall national demand within each market under the Home Market setup.
- According to modelling results based on TYNDP20 National Trends input assumptions, among the three core markets, Denmark has the highest levels of low-carbon penetration, followed by the Netherlands and Germany, which rely to some extent on flexible gas-fired generation.
- Overall, the Netherlands and Germany have a more balanced low-carbon generation mix, with solar, offshore and onshore wind being part of the (low-carbon) mix. Denmark relies on wind generation to deliver its targets.

PENETRATION OF LOW CARBON TECHNOLOGY AS A % OF DEMAND

Based on National Trends inputs, there is high RES and hydro penetration levels across all Core+ markets



RES include biofuels and small-scale RES

COMMENTS

- The figures provided here show the penetrations of each low-carbon technology as a % of the overall national demand within each market under the Home Market setup.
- According to modelling results based on TYNDP20 National Trends input assumptions, among the core+ markets, Norway has the highest levels of low-carbon penetration (exceeding its domestic demand and thus exporting to the rest of the markets), followed by Denmark, GB and the Netherlands.
- For Norway, this is primarily due to its hydro generation. For GB, low-carbon penetration levels are driven by offshore wind and to a lesser extent nuclear and onshore wind. In Denmark, overall wind penetration levels are high.
- Overall, Netherlands and Germany have a more balanced low-carbon generation mix, with solar, offshore and onshore wind being part of the (low-carbon) mix.

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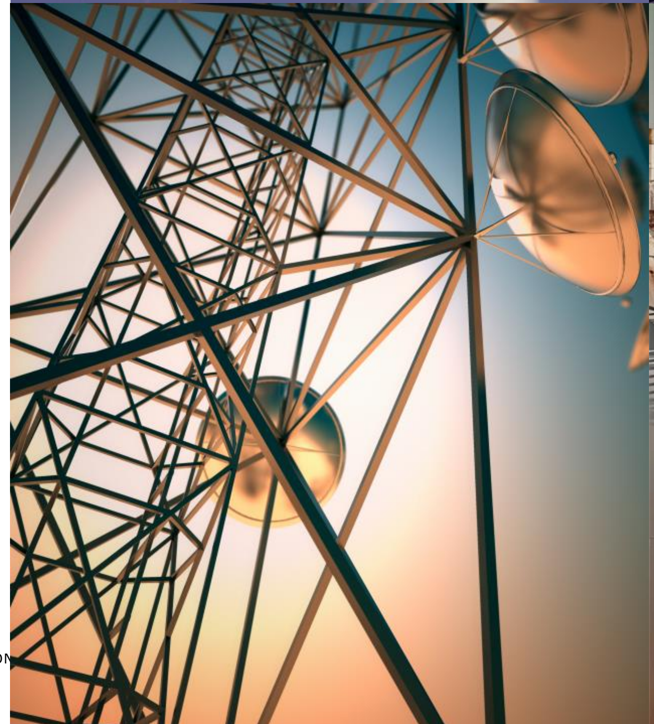

SUPPORTING INFORMATION

Introduction to the Core Configuration results

i. Market-Wide Results

- This section focuses on a range of market indicators and provides comparisons of the HM setup against the OBZ setup. This background information supports and helps explain NSWPH specific operation patterns and outcomes.
- Summary of findings:
  - The relatively loose NW European electricity systems together with high RES levels keep electricity prices low, while high interconnector levels among the core markets mean that prices remain well-correlated. Under the OBZ setup, prices for the NSWPH are below national market prices.
  - Generally across the majority of indicators, the setup choice has only a marginal effect (with impact on prices less than 0.5%).

ii. Operation of the hub-connected OWFs

- This section provides an assessment of the generation and capture revenue of the hub-connected OWFs under both market setups.
- Summary of findings:
  - The choice of market setup has only a small impact on the generation volumes of the hub-connected OWFs overall. However, the OWFs are expected to capture a lower revenue under the OBZ setup driven by a lower Offshore Bidding Zone price compared to onshore market prices (i.e. the prices in Germany, Denmark and the Netherlands). Total revenue for the hub-connected OWFs drops by 10% (i.e. from €1,130m under the HM to €1,015m under the OBZ setup).

iii. Operation of the NSWPH transmission assets

- This section provides an assessment of the operation of the NSWPH transmission assets, incl. utilisation of the assets by type of flow and direction and annual congestion income linked to the cross-zonal operation of the assets.
- Summary of findings:
  - Limited cross-zonal flows and congestion rent potential under the HM setup, as transmission assets are mainly used for transit of the hub-connected OWF generation to home markets. By definition, under the OBZ setup all flows are considered 'cross-zonal', thus increasing cross-zonal operation and congestion rent potential. Total congestion income increases six fold (i.e. from €25m under the HM setup to €149m under the OBZ setup).

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SUPPORTING INFORMATION

Introduction to the Core Configuration results

iv. Societal impacts

- This section provides the socio-economic welfare assessment, including impact on the consumer & producer surpluses and congestion rent potential. It also provides an overview of the impact on the cost of (thermal) dispatch.
- Summary of findings:
  - At overall market and societal levels, the choice of market setup has no noticeable impact (with net position on the overall SEW assessment being €0m). There are marked distributional effects between the market setups, however. Switching from the HM setup to the OBZ setup involves a transfer from OWFs to interconnectors (i.e. congestion rent potential) and vice versa; in other words, producers benefit under the HM setup, with interconnectors benefitting under the OBZ setup.
  - The OBZ setup makes better use of the interconnections hence using a more efficient plant mix overall and lowering cost of dispatch.

v. Impact of potential inefficiencies

- This section provides the results of the two efficiency variations.
- Summary of findings:
  - When factoring wind forecast error into the capacity allocation process, cross-zonal flows are reduced (although the absolute impact of reduced available cross-zonal capacity is limited, given the low utilisation rates for cross-zonal flows). At the same time, transmission of hub-connected OWF generation to the home market onshore systems is higher. The net effect is marginal, with overall transmission usage reducing by less than 1% when factoring in wind forecast error.
  - No noticeable inefficiency in the Home Market setup linked to negative prices, as the occurrence and level of negative prices are correlated between the markets.

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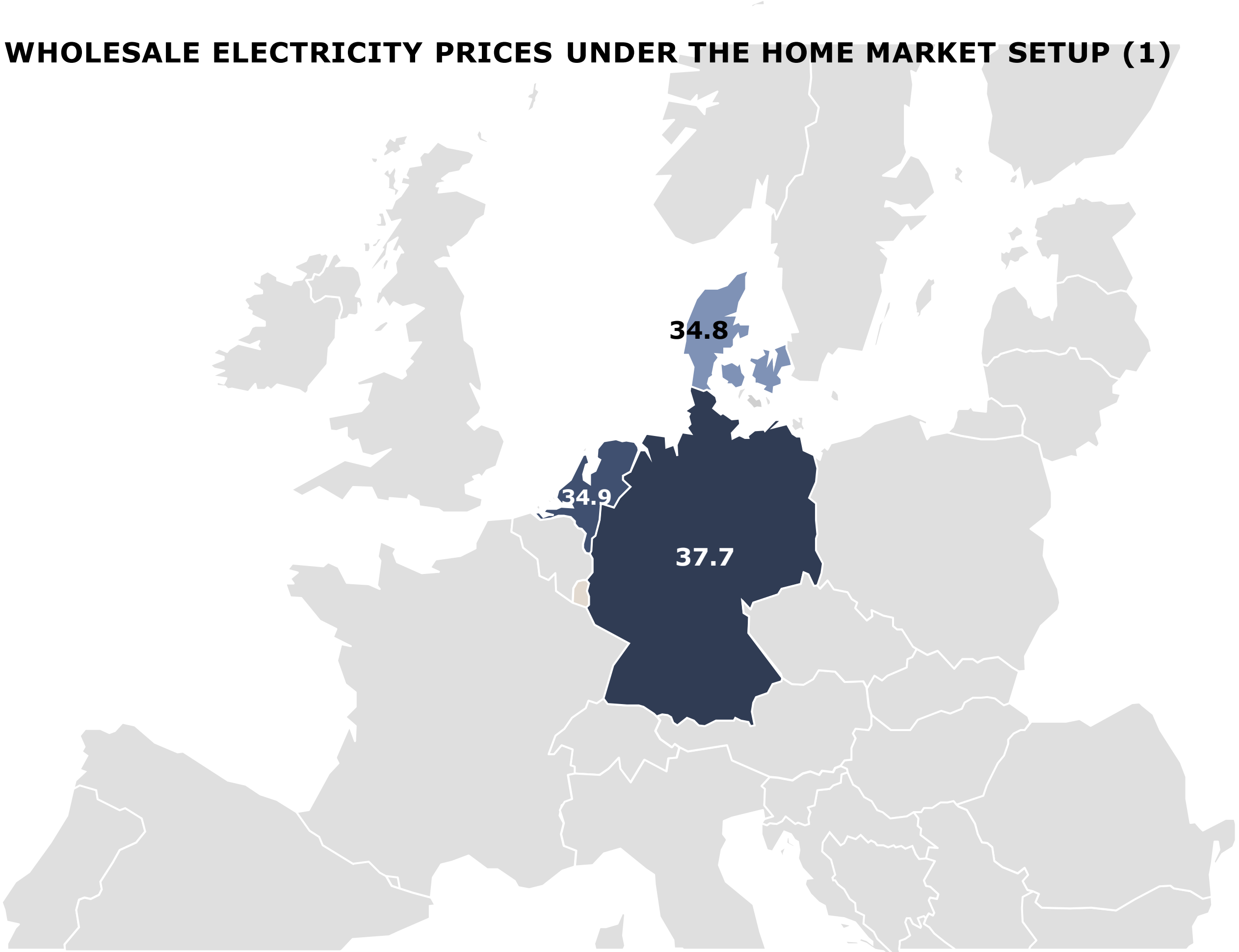
ANNUAL AVERAGE DAY-AHEAD WHOLESALE ELECTRICITY PRICES

Annual prices in the three core markets are at similar levels under HM setup

WHOLESALE ELECTRICITY PRICES UNDER THE HOME MARKET SETUP (1)



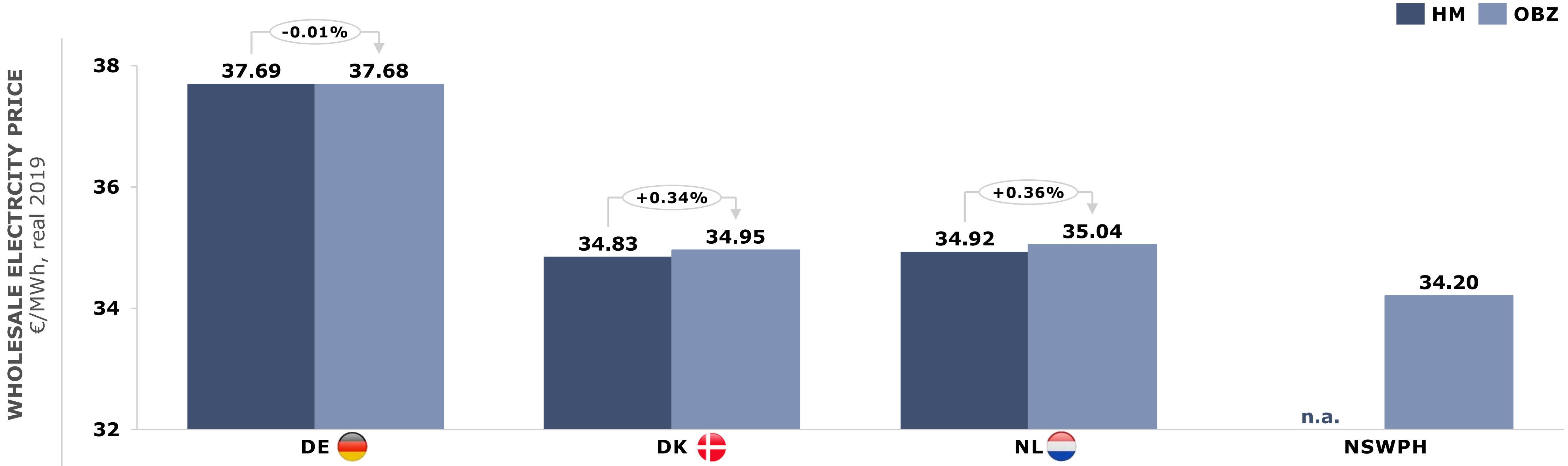
COMMENTS

- The annual average electricity price in the German market is the highest of the core markets. This is primarily driven by remaining coal and gas capacity within the market combined with higher carbon and coal prices, which almost double by 2035 relative to 2020 values. This has an upward effect on prices in Germany relative to neighbouring markets.
- The average market price in Denmark is at €31.2/MWh, however the price for the (western) DK1 zone connected to the hub is higher at €34.8/MWh. For the remainder of this report, when we refer to the Danish price, we will be using the zonal price for DK1. Of the three core markets, Denmark has the higher penetration of wind which puts a downwards pressure on its electricity prices.
- Dutch electricity prices are similar to the Danish (DK1) prices.

1. For the remainder of this report when we refer to the Danish price, we will be using the zonal price for DK1 also referred to as Jutland

ANNUAL AVERAGE DAY-AHEAD WHOLESALE ELECTRICITY PRICES UNDER THE TWO MARKET SETUPS

National prices are more or less the same under the OBZ setup, with the OBZ price itself below onshore market prices



COMMENTS

- Under the OBZ setup, increased (hub-connected) OWF generation flows towards Germany (triggered by a higher electricity price in Germany) thus producing a marginal downward effect on German electricity price relative to the HM setup (see section 3iii for the physical flows).
- Conversely, as less of the hub-connected OWF generation flows towards the Dutch and Danish markets under the OBZ setup, prices in these markets see a marginal increase compared to the HM setup (see section 3iii for the physical flows).
- The OBZ electricity prices are determined – at an hourly level – by the prices in its neighbouring markets. For a large part of the year, prices among the core markets are fairly correlated and therefore the NSWPH price is close to the core markets' price. When prices among the core markets are not correlated, usually the NSWPH price is set by the core market with the lowest price (e.g. periods when there is full export flow towards the DE shore but partial flows on the NL or DK cables) (1). The resulting average price for the OBZ is therefore lower than the average prices in the three core markets.

1.Due to losses on the IC cables, the hourly prices between the NSWPH and the respective 'price-setting' core market are never equal.

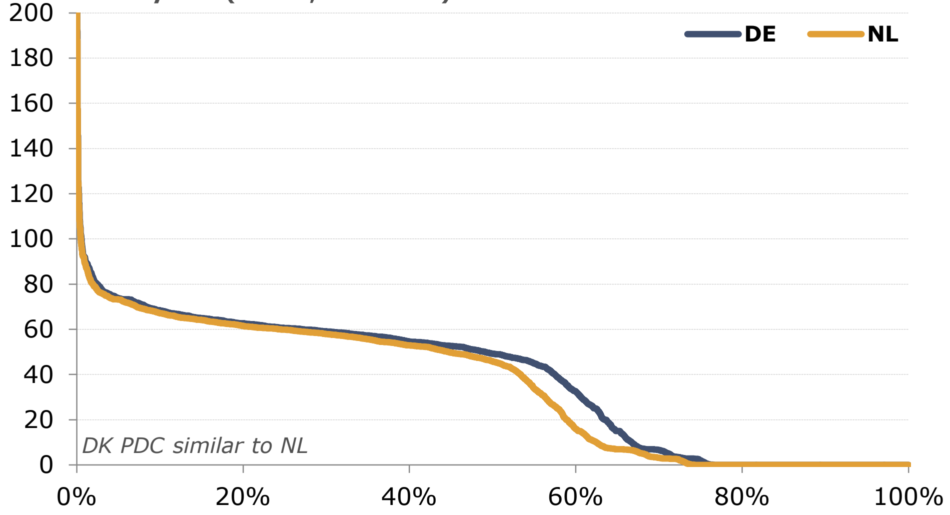
PRICE DURATION CURVE (PDC) OF DAY-AHEAD WHOLESALE ELECTRICITY PRICES

Hourly prices are very similar between the three core markets in both market setups

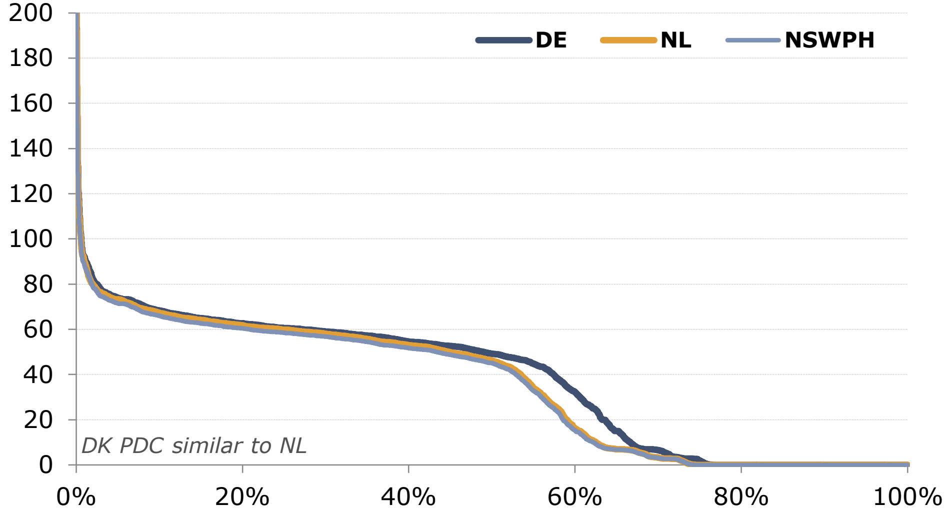
PDC examples – incl. all weather years (i.e. 26,280 hours)

WHOLESALE ELECTRICITY PDC
€/MWh, real 2019

HM



OBZ



	HM				OBZ			
	DE	**DK**	**NL**	**NSWPH**	**DE**	**DK**	**NL**	**NSWPH**
% of low-priced periods (1)	**25%**	**25%**	**27%**	**n.a.**	**25%**	**25%**	**27%**	**27%**
% of high-priced periods (1)	**0.6%**	**0.5%**	**0.5%**	**n.a.**	**0.6%**	**0.6%**	**0.6%**	**0.5%**

COMMENTS

- Price shapes are very similar between the three core markets. Electricity prices remain below €2/MWh for around 25% of the time for all three markets – driven by the high RES penetration levels as explained previously. Prices only rise above €100/MWh for less than 1% of the time.
- Results are very similar between the HM setup and the OBZ setup.

1. Here, prices below €2/MWh are considered as low-priced periods and prices over €100/MWh are considered as high-priced periods

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TOTAL RES CURTAILMENT LEVELS

Total RES curtailment is similar between the two market setups

Overall RES (total wind & solar PV) curtailment levels for the core markets and the NSWPH in TWh

COMMENTS

- Overall renewable generation curtailment (i.e. resulting from rational economic dispatch of renewable generation, rather than driven by onshore transmission system issues and / or local constraints) is at similar levels between the two market setups for both configurations (the difference between the two setups is lower than 0.5%).
- The shift of (hub-connected OWF) curtailment from the core markets to the NSWPH results from the definition of the two market setups, given that the OWFs are no longer part of each market's generation mix and are instead part of the NSWPH zone.

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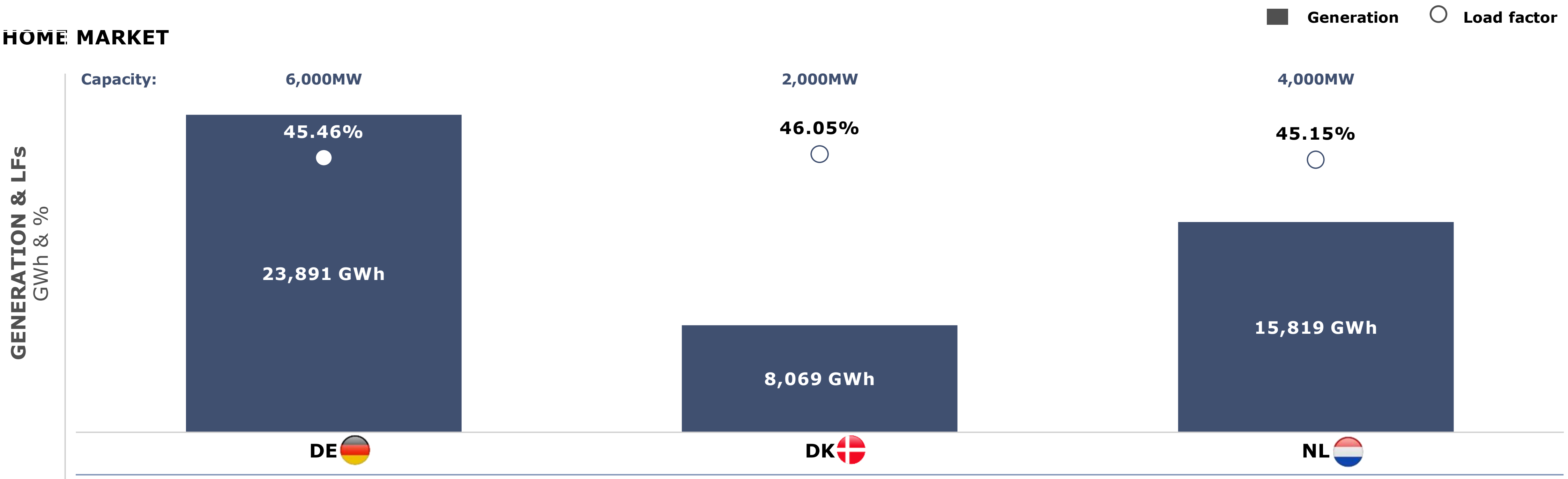
Core

HUB-CONNECTED OWF GENERATION VOLUMES

Load factors for the hub-connected OWFs are c. 45%

HOME MARKET



COMMENTS

- The chart shows the hub-connected OWF generation volumes and load factors (from a commercial perspective) for each of the bidding zones under the HM setup.
- Load factors for hub-connected OWFs are very similar between the three core markets. Variations between the core markets are driven by different economic curtailment levels for offshore wind (i.e. resulting from rational economic dispatch of renewable generation, rather than driven by onshore transmission system issues and / or local constraints).

HUB-CONNECTED OWF GENERATION VOLUMES

Total hub-connected OWF generation is broadly similar between the two market setups

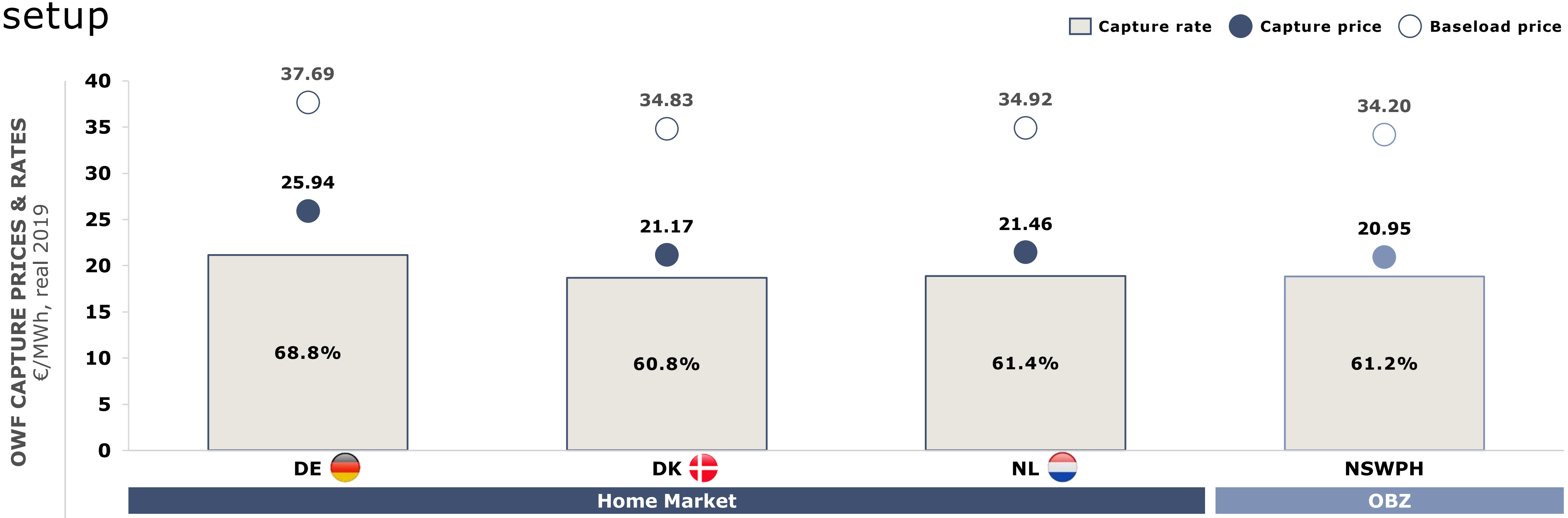
	HM			OBZ
Available generation at the hub platforms i.e. based on the expected wind speeds, power curves, etc.	50.10 TWh			50.10 TWh
Available generation at the respective bidding zones i.e. under the HM setup accounting for the losses on the spokes	48.74 TWh			50.10 TWh
Final generation & LFs post economic curtailment, at the respective bidding zones i.e. accounting for the volumes that need to be curtailed in each bidding zone	47.78 TWh (45.45%)			48.44 TWh (46.08%)
physical perspective	DE	DK	NL	
Final generation post economic curtailment, per bidding zone i.e. accounting for the volumes that need to be curtailed in each bidding zone	23.89	8.07	15.82	48.44 TWh
Domestic wind transmission of OWF (TWh) & % of overall generation i.e. flows into the respective home market from a physical perspective	23.80 99.6%	7.31 90.6%	14.11 89.2%	n.a.
Curtailment volume – bidding zone(s)	0.96TWh [48.74TWh-47.78TWh]			1.66TWh [50.10TWh-48.44TWh]

COMMENTS

- Under the OBZ setup, the available generation of the hub-connected OWFs in the bidding zone is marginally higher (compared to the HM setup) due to lower overall transmission losses.
- There is higher curtailment in the OBZ setup due to convergence of prices in periods of high wind output in the core markets.
  - Under the OBZ setup, for a cross-zonal flow to be scheduled, the price difference between zones must be large enough to at least cover the costs of transmission losses along the hub to shore spoke. If price differences are small, flows will not be scheduled as the costs of losses will not be covered.
  - Under the HM setup, flows from a hub-connected OWF via the hub to its own onshore system are not cross-zonal and are not driven by price signals. Furthermore, the cost of transmission losses on the hub to shore spoke does not affect flows as they are within zone.
- More information is provided in the Annex.

OWF CAPTURE PRICES AND RATES

Capture prices for hub-connected OWFs generally decrease under the OBZ setup



COMMENTS

- The chart shows: i. the capture price, defined as the unit revenue of the hub-connected OWF per MWh accounting for the hourly profile and shape of prices and generation; ii. the baseload price, defined as the annual time-weighed average wholesale electricity price representative for a 'baseload' generator; and iii. the capture rate defined as the capture price divided by the baseload price and indicating how much of the baseload price the hub-connected OWF can capture.
- As prices in the OBZ are lower than in the core markets, we would expect hub-connected OWF revenues to be lower on a per MWh basis in the OBZ setup.
- The impact is higher for the German hub-connected OWFs, compared to Danish and/ or Dutch counterparts (i.e. the German OWF capture price is €25.94/MWh under the HM setup vs. €20.95/MWh under the OBZ setup).

OWF CAPTURE PRICE & REVENUE – COMPARISON WITH MARKET-WIDE FIGURES

OWF capture revenues are 10% lower under the OBZ setup versus HM setup

		HM			OBZ
		DE	DK	NL	NSWPH
Baseload price €/MWh, real 2019		37.69	34.83	34.92	34.20
Capture price €/MWh, real 2019	Hub-connected OWF	25.94	21.17	21.46	20.95
	Market-wide OWF	27.09	23.52	22.44	
Capture rate % of baseload	Hub-connected OWF	68.8%	60.8%	61.4%	61.2%
	Market-wide OWF	71.9%	67.5%	64.3%	
Capture revenue €m/GW, real 2019	Hub-connected OWF	103.3	85.4	84.9	84.6
	Market-wide OWF	115.7	97.1	90.1	
Overall hub-connected OWF capture revenue €m, real 2019		1,130			1,015

-10%

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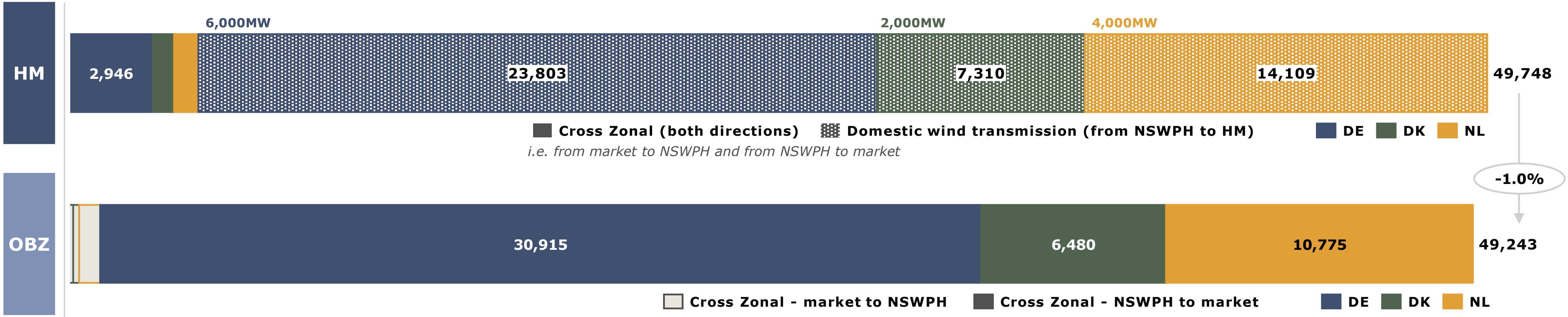
USAGE OF TRANSMISSION ASSETS

Transmission of hub-connected OWF generation to the onshore systems is the main source of flow on hub-related transmission assets

Annual physical flows in GWh, incl. losses, by type of flow (e.g. cross-zonal or domestic transmission of hub-connected wind)



COMMENTS

- The chart shows physical flows accounting for losses on the transmission assets, as triggered by electricity price spreads, at the day-ahead stage.
- Under the HM setup, the assets are mainly used to transfer a hub-connected OWF's generation to its home market (for c. 90% of the total flow). Cross-zonal flows remain limited and, where evident, are mainly towards the German market (and specifically to export the Dutch hub-connected OWF to Germany).
- All flows under the OBZ setup are considered 'cross-zonal'. The majority of the flows are related to hub-connected OWF generation transferring wind to the onshore systems. Very limited flows are linked to exports from the national onshore systems (c. 2% of the total flow).

Home Market vs. Offshore Bidding Zone

- Total flows under the OBZ setup are marginally lower compared to the HM setup (by c.1%). The direction of flow changes with the NSWPH-DE spoke having overall increased flows due to the German market's strong price signal triggering an increased flow linked to the hub-connected OWF, while the remaining spokes have reduced overall flows. This marginal difference in the overall flow is mainly due to the (marginally) higher hub-connected OWF curtailment levels seen in the OBZ setup (see section 3ii).

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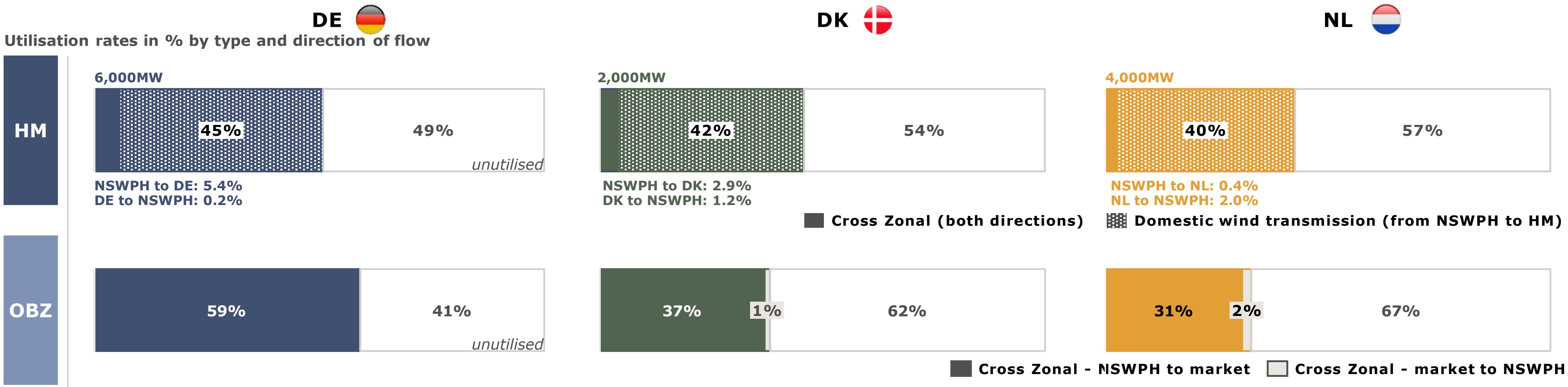
USAGE OF TRANSMISSION ASSETS

The OBZ setup allows for increased utilisation on German spokes in response to relatively higher German prices

Utilisation rates in % by type and direction of flow



COMMENTS

- The charts show the utilisation rates of the transmission assets by type and direction, defined as the physical flow accounting for losses divided by the capacity of each spoke.
- Under the HM setup, the transmission assets are used for around 45-50% of the time. With domestic wind transmission accounting for c. 40-45% of the flow, the assets are only used for c. 2-5% of the time to transfer cross-zonal flows.
- Utilisation under the OBZ setup varies for the different spokes connecting the onshore systems to the hub. For example, the NSWPH-DE spoke is used for c. 60% of the time, primarily to transfer the hub-connected OWF generation to the German shore where the price signal is stronger. This leads to lower utilisation on the Danish and Dutch spokes.

Home Market vs. Offshore Bidding Zone

- Utilisation rates for the German spoke are higher under the OBZ setup, as the German market has a higher price thus triggering a higher flow from the hub-connected OWFs. The Danish and Dutch spokes are utilised less under the OBZ setup, as reduced hub-connected OWF generation is flowing to these two markets (where the price signal is weaker). The choice of market setup has no notable impact on cross-zonal flows from the various onshore systems to the hub.

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SUPPORTING INFORMATION

There are three main reasons why the utilisation rates for cross-zonal flows from the onshore systems, i.e. excluding the flows linked to the hub-connected OWF, remain low

01
Limited Price Spreads

- **Wholesale electricity price spreads between the three core markets are generally low, providing practically no signal for cross-zonal flows.**
  For example, under both setups, absolute price spreads between any of the three markets are smaller than €2/MWh for c. 85-90% of the time.

02
Constrained Cross-Zonal Capacity

- **Under the Home Market setup, cross-zonal capacity of the transmission assets is constrained to handle the internal flow of OWF generation.**
  For example, assuming an hour when the hub-connected OWFs are all generating at 90% load factor, and the electricity price spread between the Netherlands (low-priced zone) and Germany (high-priced zone) is strong, the maximum cross-zonal flow into the German market is 0.6GW (i.e. 6.0GW – 5.4GW), as the DE hub-connected OWF generation (generating at 90% * 6.0GW = 5.4GW) would need to be accommodated first.

03
Physical Setup

- **Overall utilisation of the assets is restricted by the spoke(s) with the lowest capacity.**
  For example, assuming an hour when the hub-connected OWF is zero and the electricity price spread between Denmark (low-priced zone) and Germany (high-priced zone) is strong, the maximum flow from Denmark into the German market can be 2GW, as it is restricted by the capacity of the DK-NSWPH spoke. In this case, the utilisation rate of the DE-NSWPH spoke is only 33.0% (2GW/6GW).

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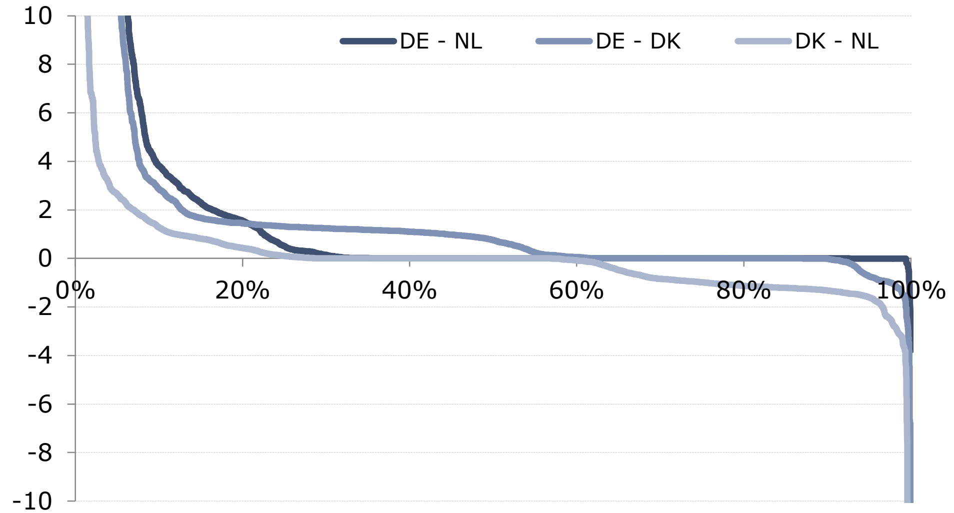
SUPPORTING INFORMATION

1. Wholesale electricity price spreads between the three core markets are generally low, providing practically no signal for cross-zonal flows

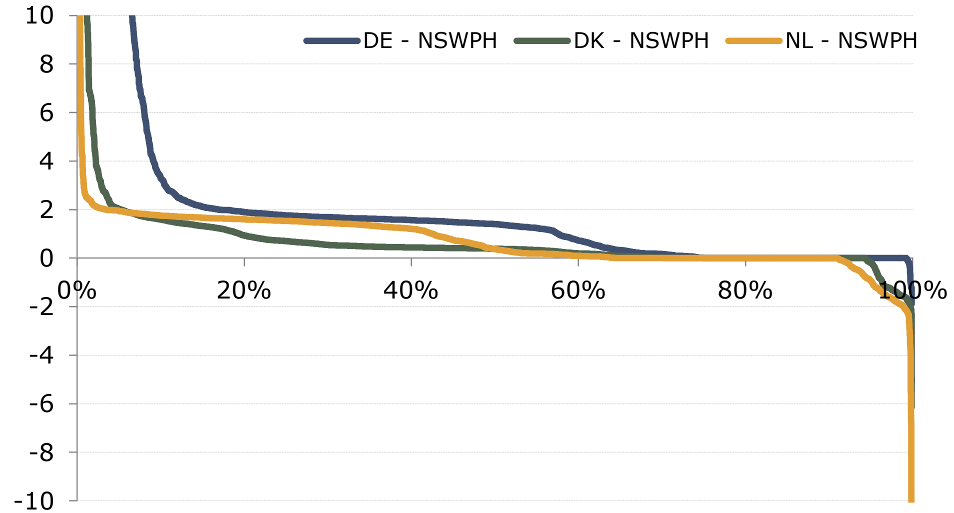
PDC of the price spreads, based on 2018 weather patterns

ELECTRICITY SPREAD PDC
€/MWh, real 2019

HM



OBZ



COMMENTS

- Under the HM setup, absolute price spreads between any of the two markets are smaller than €2/MWh for c. 85-90% of the time.
- Under the OBZ setup, absolute price spreads between the three core markets and the NSWPH are smaller than €2/MWh for c. 85-95% of the time.
- Results based on 2018 weather patterns.

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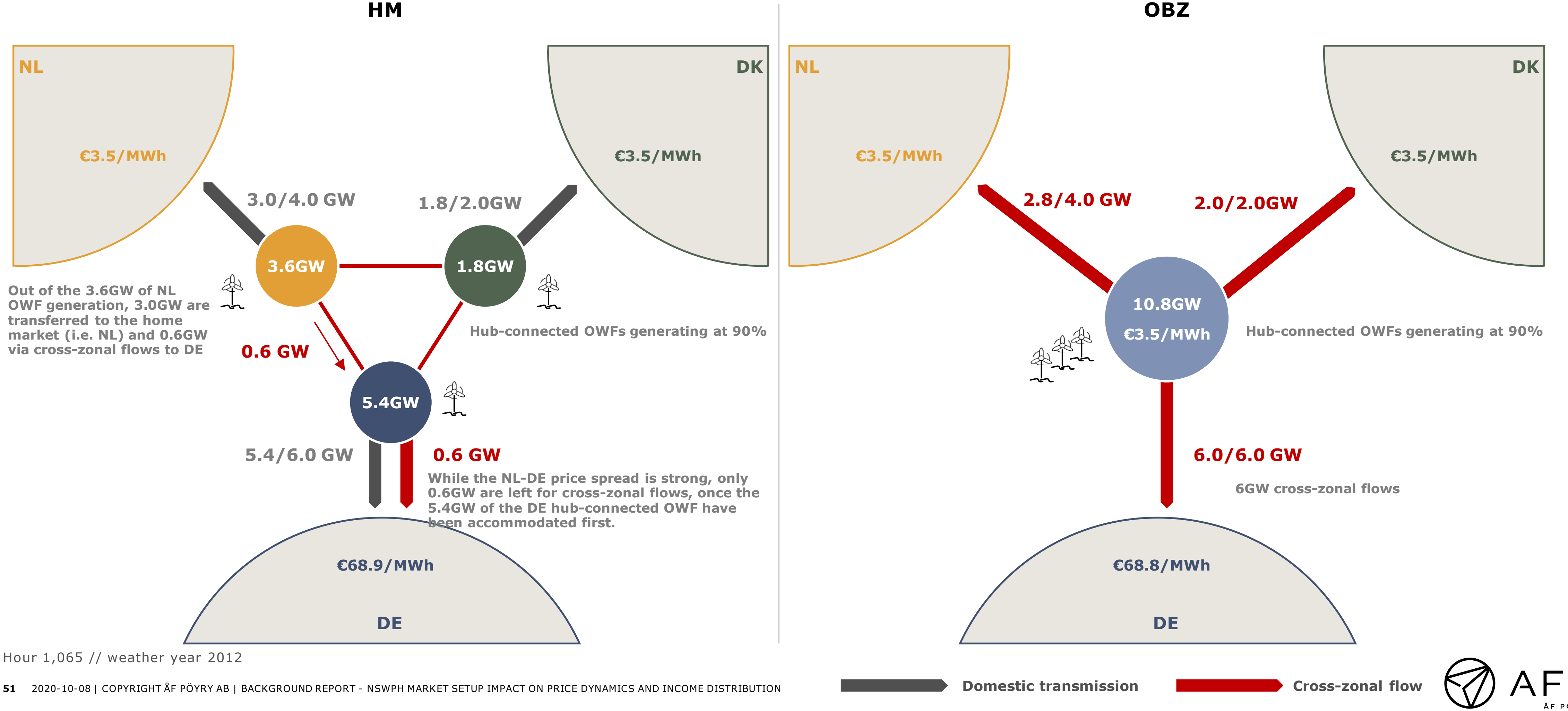
2. Under the Home Market setup, cross-zonal capacity of the transmission assets is constrained to handle the internal flow of OWF generation

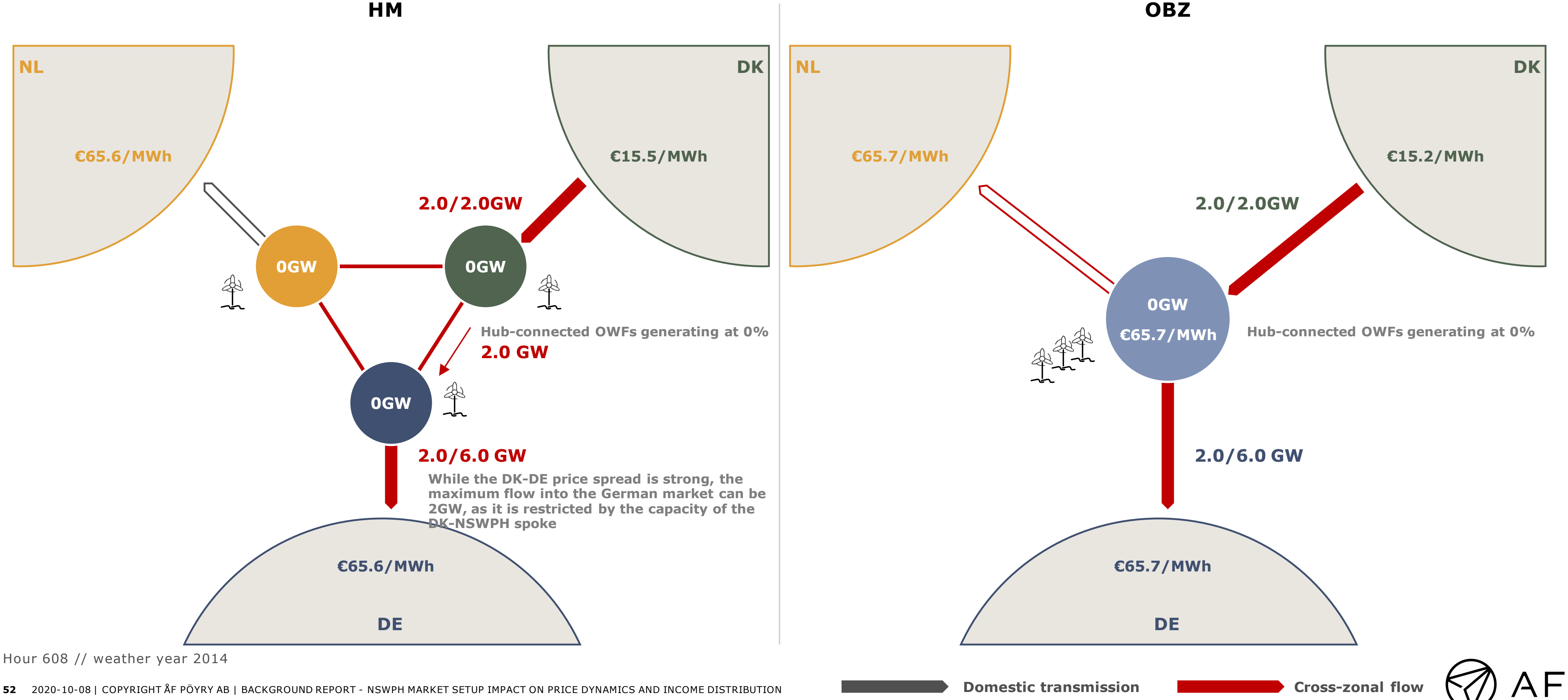
OBZ electricity prices do not account for losses in this example. Flows do not account for losses on this illustrative chart based on actual modelled results



Hour 1,065 // weather year 2012

3. Overall utilisation of the assets is restricted by the spoke(s) with the lowest capacity

OBZ electricity prices do not account for losses in this example. Flows do not account for losses on this illustrative chart based on actual modelled results

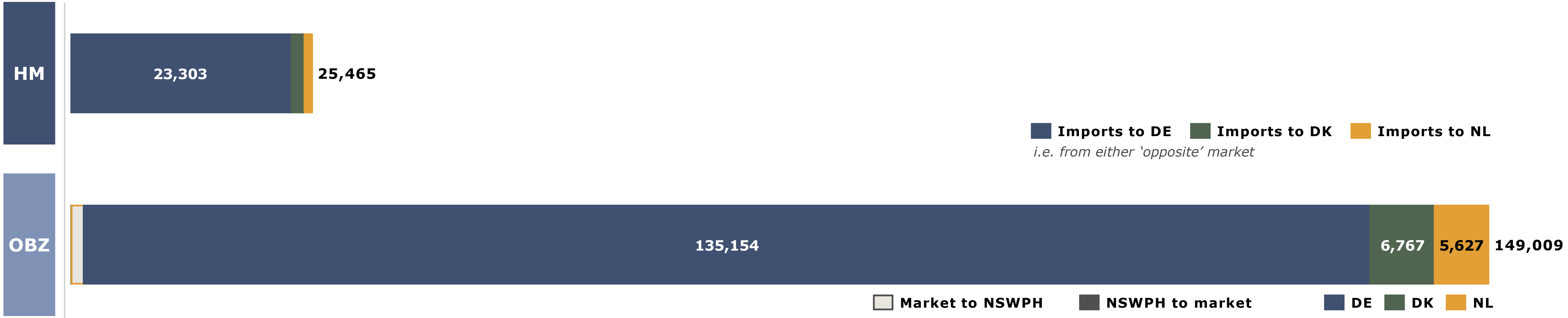


Hour 608 // weather year 2014

CONGESTION INCOME

Congestion income is low under the HM setup but much greater under the OBZ setup

Annual congestion income for the different spokes in 1,000s euros, real 2019 money



COMMENTS

- The chart shows the estimated annual congestion income for the different spokes, provided: a. HM setup: separately for the imports into the core markets from either opposite market; and b. OBZ setup: for each spoke and for both directions (i.e. from the onshore systems to the hub, and vice versa).
- Congestion income under the HM setup is very low, driven by low utilisation of the assets for cross-zonal flows. The main source of congestion income that is evident is linked to flows going to Germany, which represent c. 90% of the overall congestion income under the HM setup.
- Under the OBZ setup, the majority of congestion income comes from flows over spoke connecting the hub to the German market (c. 90% of the overall congestion income). This is driven by a stronger price signal for this market, with the DE-NSWPH price spreads being generally higher compared to the other two markets.

Home Market vs. Offshore Bidding Zone

- Although congestion income under the OBZ setup is up to six times higher compared to the HM setup, it is still relatively low for the scale of transmission capacity available (at max. €23m/GW for the DE spoke), driven by relatively low price spreads between the core markets.

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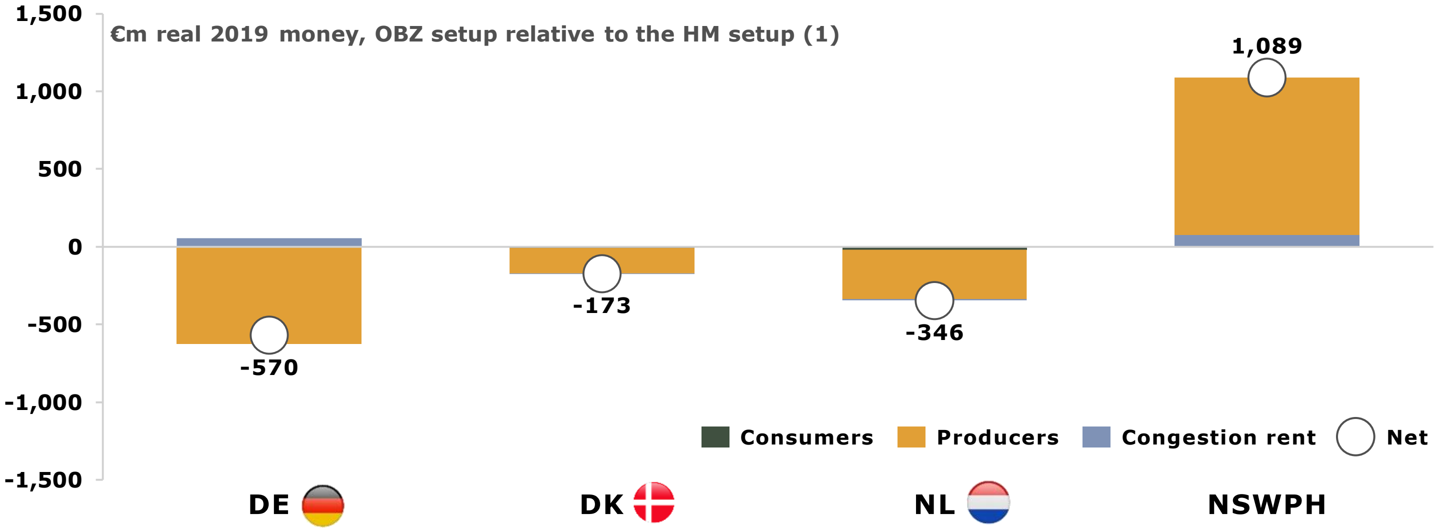
SOCIO-ECONOMIC WELFARE ASSESSMENT

No change in overall socio-economic outcome between market setups, but there are significant distributional shifts between producers and ICs

SOCIO-ECONOMIC WELFARE IMPACT PER MARKET



OVERALL WELFARE DISTRIBUTION

Stakeholders	*Welfare impact across the markets*
Consumers	⇩ **-€29m**
Producers	⇩ **-€89m**
Congestion Rent	⇧ **+€118m**
Net	**€0m**

COMMENTS

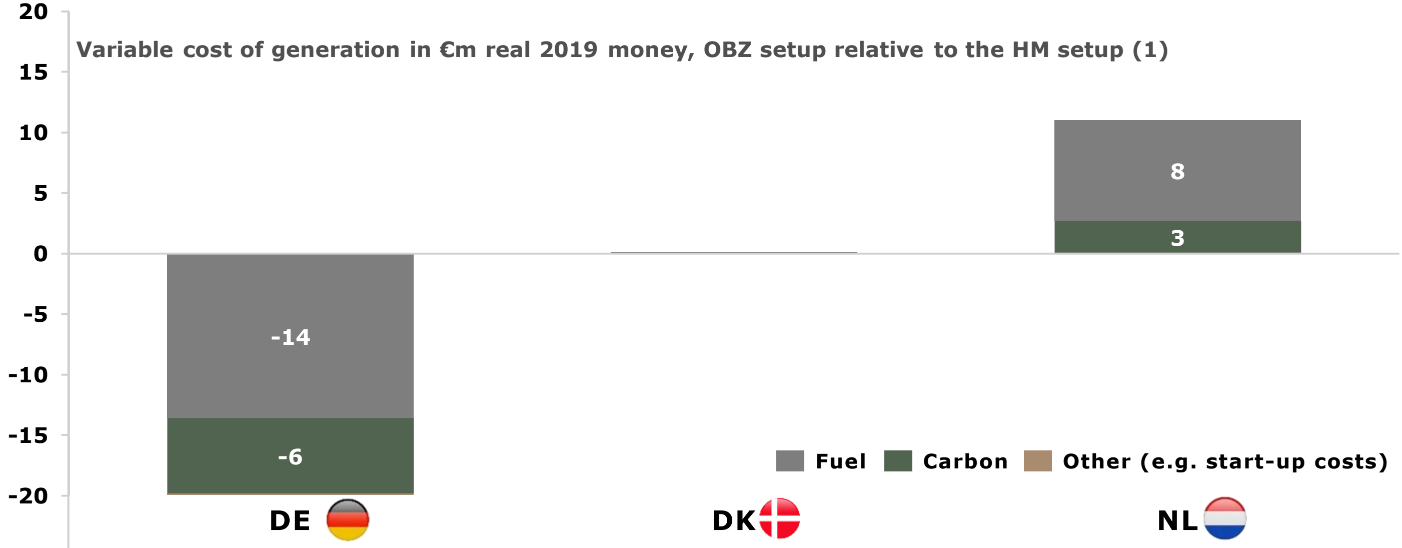
- The chart provides a summary of the socio-economic welfare assessment for each core market and the NSWPH. The impact is relative to the HM setup.
- There is almost no impact on consumer surplus, as wholesale prices remain relatively unaffected (less than 0.5% difference in prices for any of the core markets between the two market setups). The Annex provides more information on the impact on consumer surplus.
- There is a negative impact on overall producer surplus, driven by a lower capture revenue for the hub-connected OWFs under the OBZ setup. At a market level, the negative impact on producer surplus for Germany, Denmark and the Netherlands is mainly due to the fact that the 12GW of hub-connected OWFs are no longer bidding into these national markets, but are instead bidding into the OBZ itself as, by definition, they are part of the NSWPH zone (this also explains the positive producer surplus impact for the NSWPH zone).
- Higher congestion income under the OBZ setup.
- At overall market and societal levels, the choice of market setup has generally limited impact, however.

1. Positive numbers indicate a higher welfare under the OBZ setup; negative numbers indicate a lower welfare under the OBZ setup

BREAKDOWN OF VARIABLE COST OF DISPATCH

OBZ setup results in a marginally lower overall dispatch cost

IMPACT ON THE COST OF DISPATCH



TOTAL IMPACT ACROSS THE CORE MARKETS

Item	*Impact*	
Fuel	⇧	-€5m
Carbon	⇧	-€4m
Other	☐	-€0m
Total	⇧	-€9m

COMMENTS

- The chart shows the impact on the variable cost of (thermal) generation under the OBZ setup (relative to the HM setup) for each market. The impact is indicated as ‘positive’ when the difference is negative under the OBZ setup (i.e. implying better use of generation mix, leading to a lower cost of dispatch).
- Overall, the OBZ setup can make better use of the interconnections flows and, hence, uses a more efficient plant mix overall with a lower cost of dispatch (€8.9m lower than for the HM setup).
- There is a trade-off between Netherlands and Germany. The OBZ setup better reacts to price signals and exports more flows to Germany, thereby displacing some of its thermal generation. However, with less hub-connected OWF generation going to the Netherlands under the OBZ setup, additional thermal generation needs to be dispatched there to meet demand.
- Ultimately, the difference between the two setups remains very low compared to the overall cost of dispatch for the core markets (i.e. the delta is less than 0.1% of the total cost of dispatch).

1. Positive numbers indicate a higher dispatch cost under the OBZ setup (negative impact); negative numbers indicate a lower dispatch cost under the OBZ setup (positive impact).

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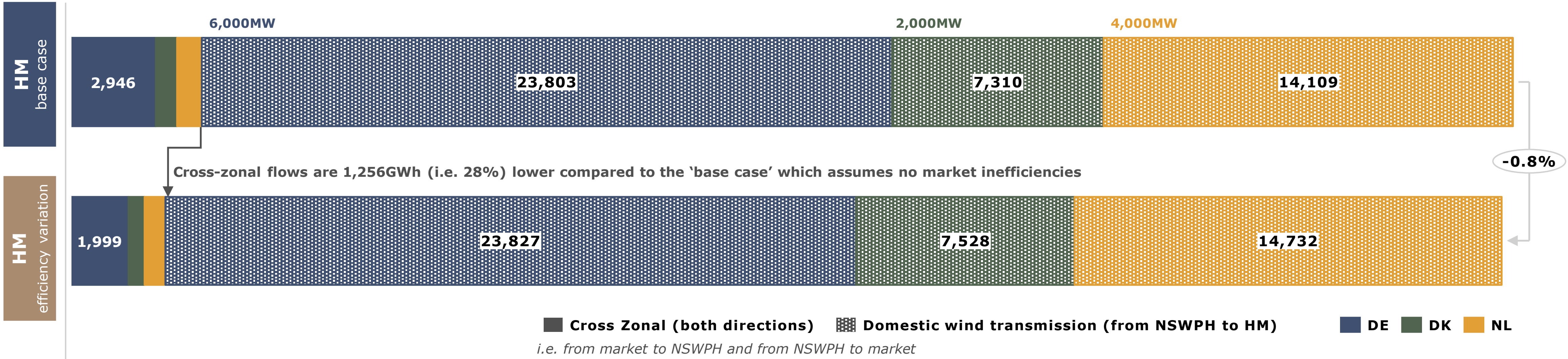
USAGE OF TRANSMISSION ASSETS

The absolute impact of reduced available cross-zonal capacity is limited

Annual physical flows in GWh, incl. losses by type of flow (e.g. cross-zonal or domestic transmission of hub-connected wind)

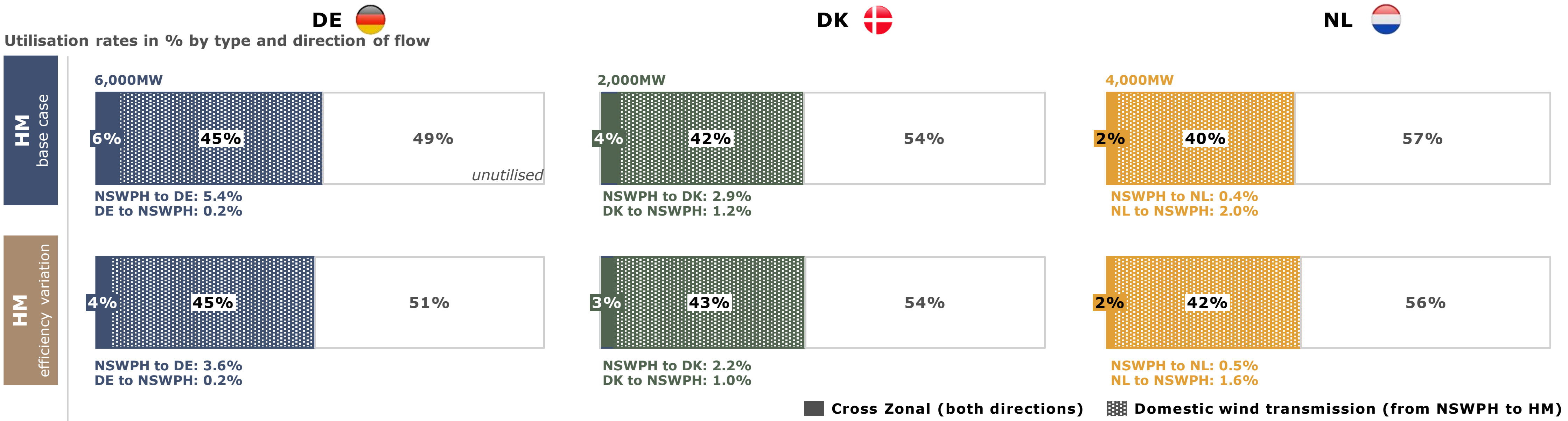


COMMENTS

- The chart shows physical flows accounting for losses on the transmission assets, as triggered by electricity price spreads, at the day-ahead stage. It differentiates between 'cross-zonal flows' and 'domestic wind transmission'.
- Under this variation, we assume that transmission capacity needed for wind is always 'overbooked' to allow for the potential export of additional wind output relative to day-ahead expectations in the event of wind forecast error. This means that the amount of transmission capacity available for cross-zonal flows is reduced compared to the 'base case'. Under this variation, overall cross-zonal flows are lower by 1,256GWh (c. 28%) compared to the 'base case'.
- At the same time, transmission of hub-connected OWF generation to the home market onshore systems is higher by around 865GWh (under the variation). This is mainly driven by generation from the Dutch and Danish OWFs going to their home market rather than Germany (as the cross-zonal capacity on the Germany spoke is now restricted).
- The net effect is marginal, however, with overall usage reducing by less than 1%. Additionally, intraday continuous trading may be expected to alleviate inefficiencies linked to forecast errors.

USAGE OF TRANSMISSION ASSETS

Reduced cross-zonal flows are offset by more wind radial operation



COMMENTS

- The charts show the utilisation rates of the transmission assets by type and direction, defined as the physical flow accounting for losses divided by the capacity of each spoke.
- Factoring in the wind forecast error means that there are lower cross-zonal flows from the hub to the German market because there is constrained availability on the cable compared to the 'base case'.
- This has a consequential impact on the Danish and Dutch spokes, for both of which there is increased wind radial operation (OWF generation that would have otherwise gone to the German market due to its price signal) and reduced cross-zonal flows compared to the 'base case'.

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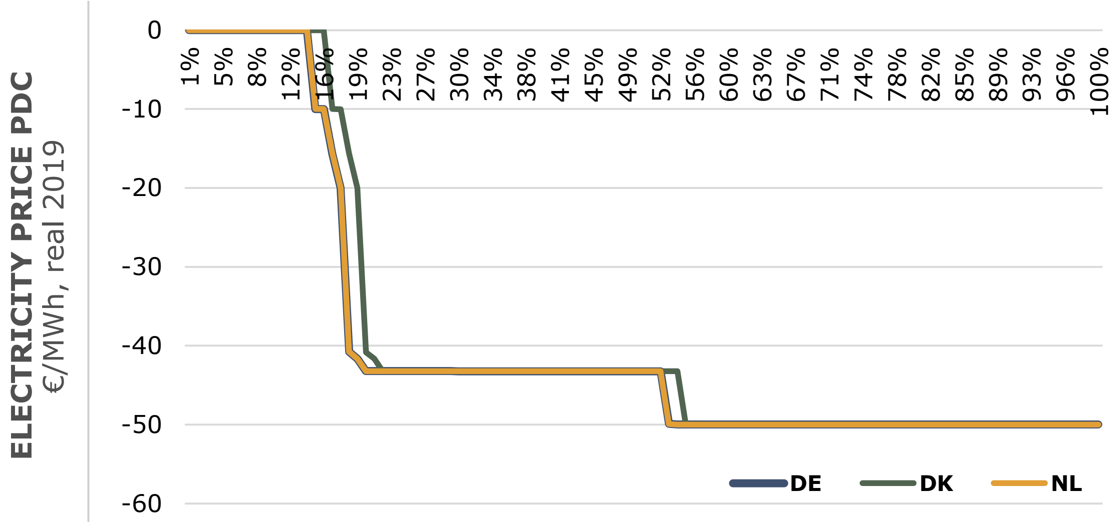
NEGATIVE PRICES

Negative pricing has no impact as occurrence and level of negative prices are correlated between the markets

HOME MARKET

PDC of the negative electricity prices – based on 2018 weather patterns



KEY FIGURES UNDER THE EFFICIENCY VARIATION

% of the hours when connected markets are negative/close to zero concurrently	**100%**
Average price difference between the connected markets when prices are negative	**€0.34/MWh**
Maximum price when at least one market has negative price	**€0.02/MWh**
% of the hours with negative prices in the connected markets	**1.59%**

COMMENTS

- In theory, potential inefficiencies could appear in the HM setup compared to the OBZ setup when there are negatives price in one of the price areas and not in the other one(s), leading to curtailment of the hub-connected OWF that is bidding into the HM zone with negative prices. This inefficiency can be avoided under the OBZ setup.
- However, prices in the core markets are highly correlated, meaning that, in our run to test the negative bidding inefficiency, there are no situations when there are negatives prices in one market and a price above €0.02/MWh in any of the other connected markets.
- NOTE: Our standard (base case) modelling suggests that occurrence of negative prices in 2035 would be almost non-existent as the number renewables power plants with subsidies that allow negative bidding dwindles. In our modelling exercise to test the negative bidding inefficiency, around 60% of all renewables was required to bid negatively to result in negative prices in the core markets in around 1.6% of periods. The main runs do not produce any negative prices.

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SUPPORTING INFORMATION

Introduction to the Core+ Configuration results

i. Market-Wide Results

- This section focuses on a range of market indicators and provides comparisons of the HM setup against the OBZ setup. This background information supports and helps explain some of the NSWPH specific operation patterns and outcomes.
- Summary of findings:
  - The relatively loose NW European electricity systems together with high RES levels keep electricity prices low, while high interconnector levels among the core markets mean that prices remain well-correlated. Prices in GB and Norway are less correlated than those of other hub-connected markets driven by differences in the generation mix. Under the OBZ setup, wholesale prices for the NSWPH are generally below national market prices (the only exception is Norway).
  - Generally across the majority of indicators, the market setup choice has only a marginal effect on these indicators (with impact on prices less than 0.5%).

ii. Operation of the hub-connected OWFs

- This section provides an assessment of the generation and capture revenue of the hub-connected OWFs under both market setups.
- Summary of findings:
  - The choice of market setup has only a small impact on the generation volumes of the OWFs overall. However, the hub-connected OWFs are expected to capture a lower revenue under the OBZ setup driven by a lower Offshore Bidding Zone price compared to the onshore market prices (i.e. the prices in Germany, Denmark, the Netherlands and GB). The only exception is Norway where prices are lower compared to the Offshore Biding Zone. Total revenue for the hub-connected OWFs drops by 20% (i.e. from €1,055m under the HM to €849m under the OBZ setup).

iii. Operation of the NSWPH transmission assets

- This section provides an assessment of the operation of the NSWPH transmission assets, incl. utilisation of the assets by type of flow and direction and annual congestion income linked to the cross-zonal operation of the assets.
- Summary of findings:
  - Transmission of hub-connected OWF generation to the onshore systems is the main source of flow, with some cross-zonal flow linked to Norway and GB. By definition, under the OBZ setup all flows are considered 'cross-zonal' thus increasing cross-zonal operation and congestion rent potential. Total congestion income increases by 70% (i.e. from €323m under the HM setup to €542m under the OBZ setup).

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SUPPORTING INFORMATION

Introduction to the Core+ Configuration results

iv. Societal impacts

- This section provides the socio-economic welfare assessment, including impact on the consumer & producer surpluses and congestion rent potential. It also provides an overview of the impact on the cost of (thermal) dispatch.
- Summary of findings:
  - At overall market and societal levels, the choice of market setup has generally limited (positive) impact (with net position on the overall SEW assessment of €15m). There are marked distributional effects between the market setups, however. Switching between the HM and OBZ setups involves a transfer from OWFs to interconnectors (i.e. congestion rent potential) and vice versa; in other words, producers benefit under the HM setup, with interconnectors benefitting under the OBZ setup.
  - The OBZ setup makes better use of interconnections hence using a more efficient plant mix overall and lowering cost of dispatch.

v. Impact of potential inefficiencies

- This section provides the results of the two efficiency variations.
- Summary of findings:
  - When factoring wind forecast error into the capacity allocation process, cross-zonal flows are reduced. At the same time, transmission of hub-connected OWF generation to the home market onshore systems is higher. The net effect is limited with overall usage reducing by around 4% when factoring in wind forecast error.
  - No noticeable inefficiency in the Home Market setup linked to negative prices, as the occurrence and level of negative prices are correlated between the markets.

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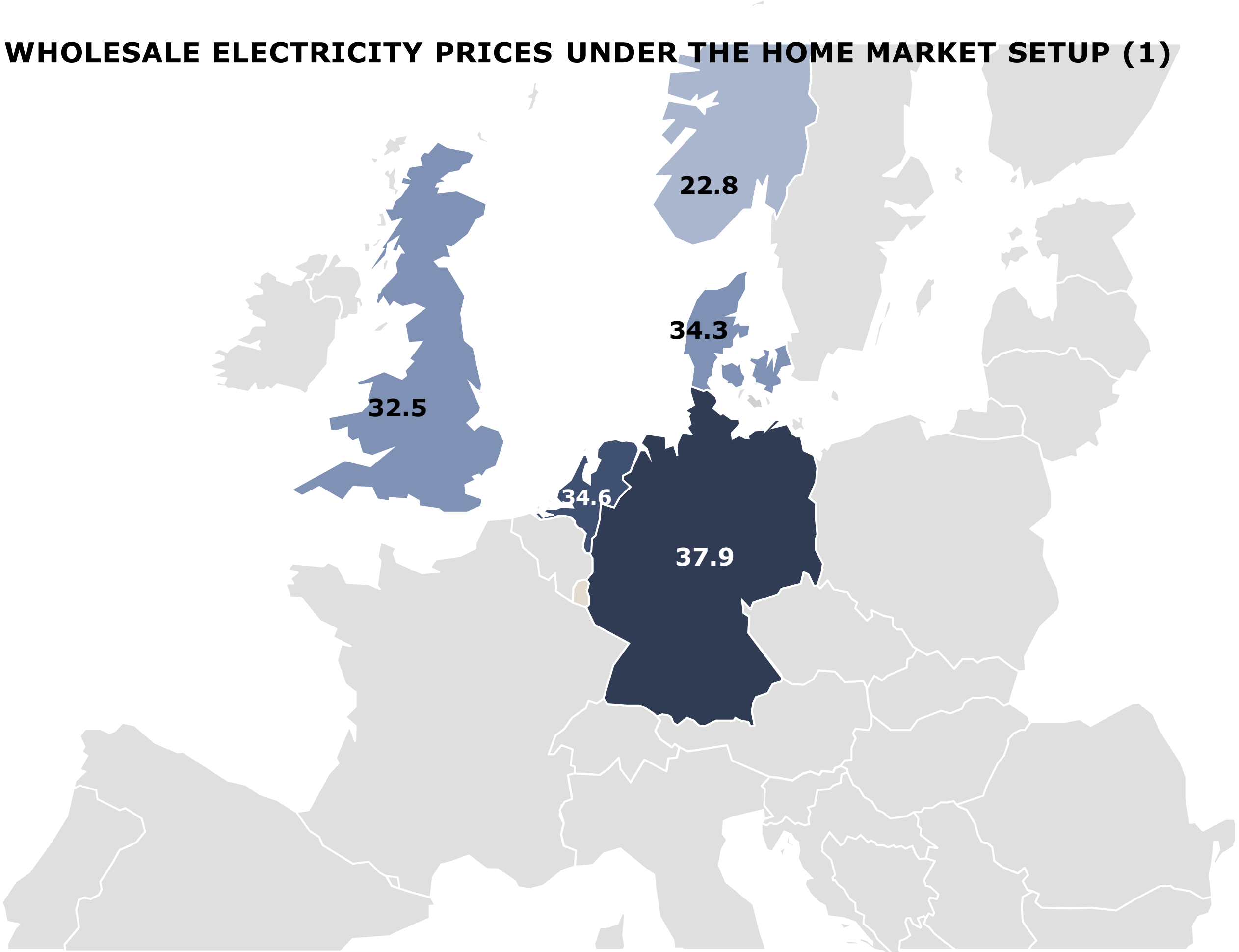
ANNUAL AVERAGE DAY-AHEAD WHOLESALE ELECTRICITY PRICES

Annual prices in the three core market are at similar levels, with lower prices in GB and particularly Norway

WHOLESALE ELECTRICITY PRICES UNDER THE HOME MARKET SETUP (1)



COMMENTS

- The annual average electricity price in the German market is the highest of the core+ markets. This is primarily driven by remaining coal and gas capacity within the market combined with higher carbon and coal prices, which almost double by 2035 relative to 2020 values. This has an upward effect on prices in Germany relative to neighbouring markets.
- The average market price in Denmark is at €34.3/MWh, with Dutch electricity prices broadly the same at €34.6/MWh.
- Prices in the core plus markets, i.e. GB and Norway, are lower than prices in the three core markets and bring the potential for higher spreads between the connected markets. In GB, this is the result of high RES and nuclear penetration, while in Norway prices remain low driven by high levels of hydro generation. Norwegian prices are sensitive to the underlying weather patterns modelled and specifically to the hydro conditions. For example in the TYNDP National Trends scenario, prices for the various Norwegian zones can range between c.€3-40/MWh in 2030 and between c.€6-45/MWh in 2040.
- The two market setups are modelled under a consistent set of assumptions. This means that while the level of wholesale electricity prices could impact on the individual metrics and absolute results for the two market setups, the comparisons between the setups and ultimately the core conclusions remain unchanged.

1. For the remainder of this report when we refer to the Norwegian price, we will be using the zonal price for the most southern zone NO2

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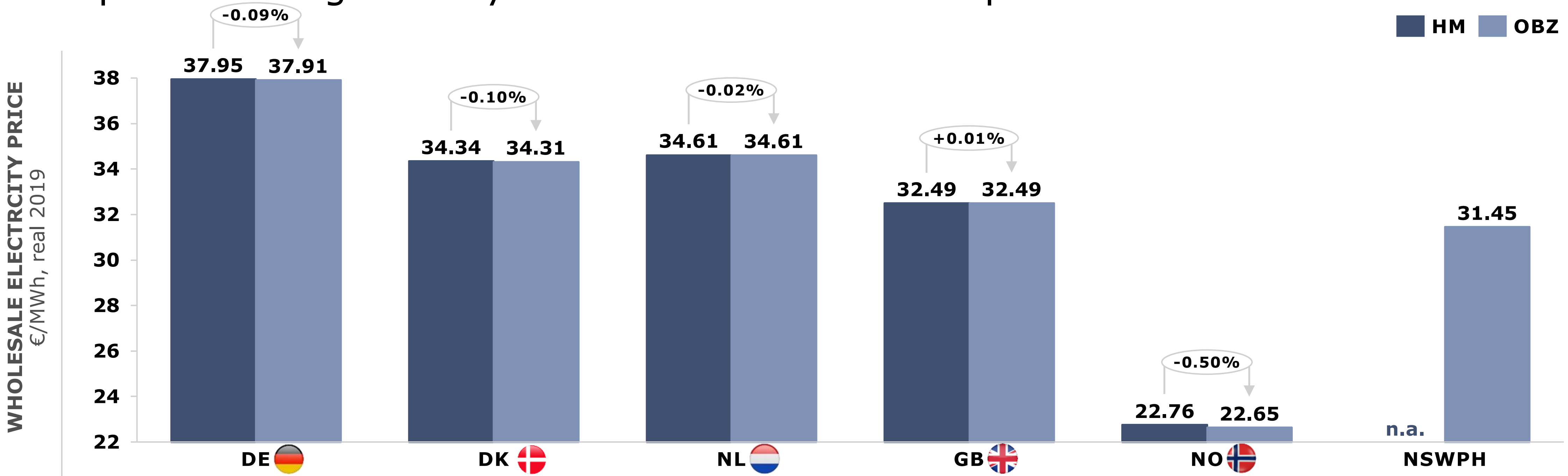
ANNUAL AVERAGE DAY-AHEAD WHOLESALE ELECTRICITY PRICES UNDER THE TWO MARKET SETUPS

National prices are more or less the same under the OBZ setup, with the OBZ price itself generally below onshore market prices



COMMENTS

- The impact of the OBZ setup on annual average electricity prices is limited. For all markets, the impact is lower than 0.5%.
- The OBZ electricity prices are determined – at an hourly level (1) – by the prices in its neighbouring markets. With the exception of Norway, the annual average price that results for the OBZ is lower than the national onshore prices.

1.Due to losses on the IC cables, the hourly prices between the NSWPH and the respective 'price-setting' core+ market are never equal.

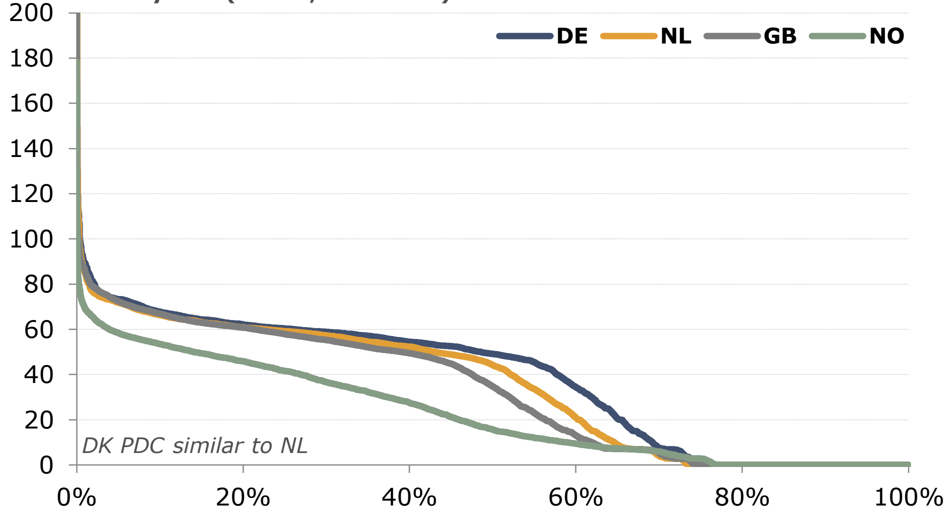
PRICE DURATION CURVE (PDC) OF DAY-AHEAD WHOLESALE ELECTRICITY PRICES

Hourly prices are very similar between the five core+ markets in both market setups

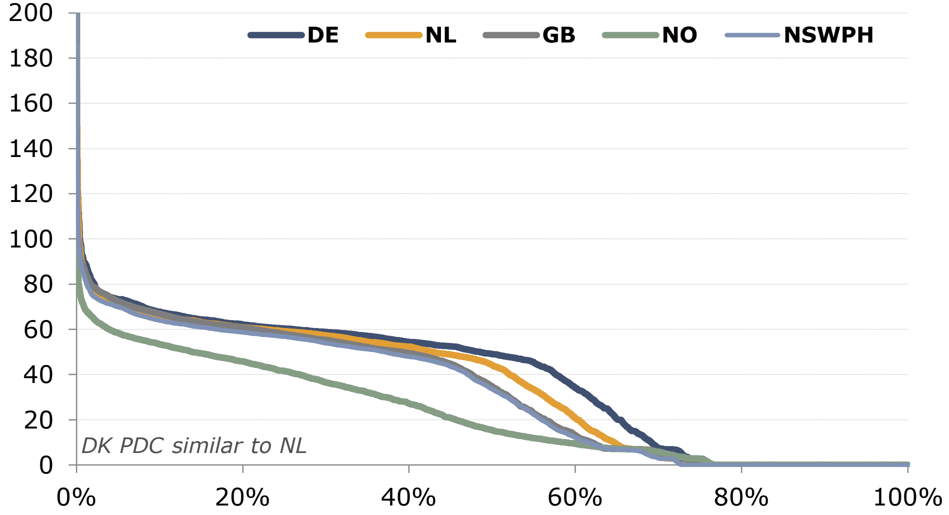
PDC examples – incl. all weather years (i.e. 26,280 hours)

WHOLESALE ELECTRICITY PDC €/MWh, real 2019

HM



OBZ



	HM						OBZ					
	DE	**DK**	**NL**	**GB**	**NO**	**NSWPH**	**DE**	**DK**	**NL**	**GB**	**NO**	**NSWPH**
% of low-priced periods (1)	**24%**	**25%**	**27%**	**26%**	**24%**	n.a.	**25%**	**25%**	**27%**	**26%**	**24%**	**28%**
% of high-priced periods (1)	**0.4%**	**0.3%**	**0.3%**	**0.2%**	**0.1%**	n.a.	**0.4%**	**0.3%**	**0.3%**	**0.2%**	**0.1%**	**0.3%**

COMMENTS

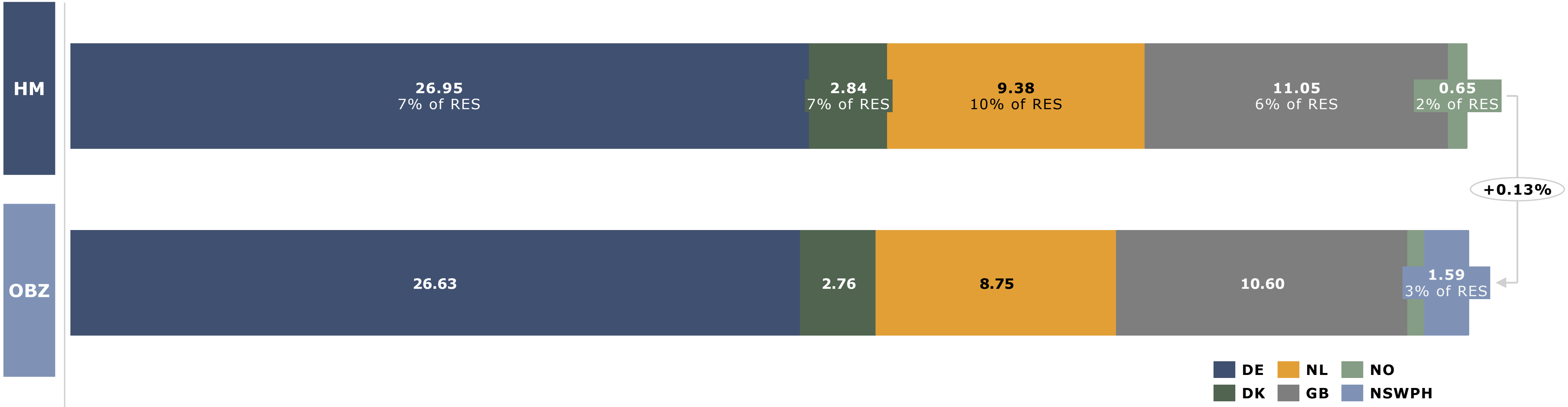
- Price shapes are very similar between the three core markets, while GB and particularly Norway prices are generally lower across the period. Electricity prices remain below €2/MWh for around 25% of the time for all five markets – driven by the high RES and hydro penetration levels as explained previously. Prices only rise above €100/MWh for less than 1% of the time.
- Results are very similar between the HM setup and the OBZ setup.

1. Prices in low-priced periods are below €2/MWh; prices in high-priced periods are over €100/MWh

TOTAL RES CURTAILMENT LEVELS

Total RES curtailment is similar between the two market setups

Overall RES (total wind & solar PV) curtailment levels for the core markets and the NSWPH in TWh (and % of total RES generation)



COMMENTS

- Overall renewable generation curtailment (i.e. resulting from rational economic dispatch of renewable generation, rather than driven by onshore transmission system issues and / or local constraints) is at similar levels between the two market setups for both configurations (the difference between the two setups is lower than 0.2%).
- The shift of hub-connected OWF curtailment from the core+ markets to the NSWPH results from the definition of the two market setups, given that the OWFs are no longer part of each market's generation mix and are instead part of the NSWPH zone.

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HUB-CONNECTED OWF GENERATION VOLUMES

Load factors for the hub-connected OWF are c. 45%

HOME MARKET

COMMENTS

- The chart shows the hub-connected OWF generation volumes and load factors (from a commercial perspective) for each of the bidding zones under the HM setup.
- Load factors for hub-connected OWFs are very similar between the five core+ markets. Variations between the markets are driven by different economic curtailment levels for offshore wind (i.e. resulting from rational economic dispatch of renewable generation, rather than driven by onshore transmission system issues and / or local constraints).

HUB-CONNECTED OWF GENERATION VOLUMES

Total hub-connected OWF generation is broadly similar between the two market setups

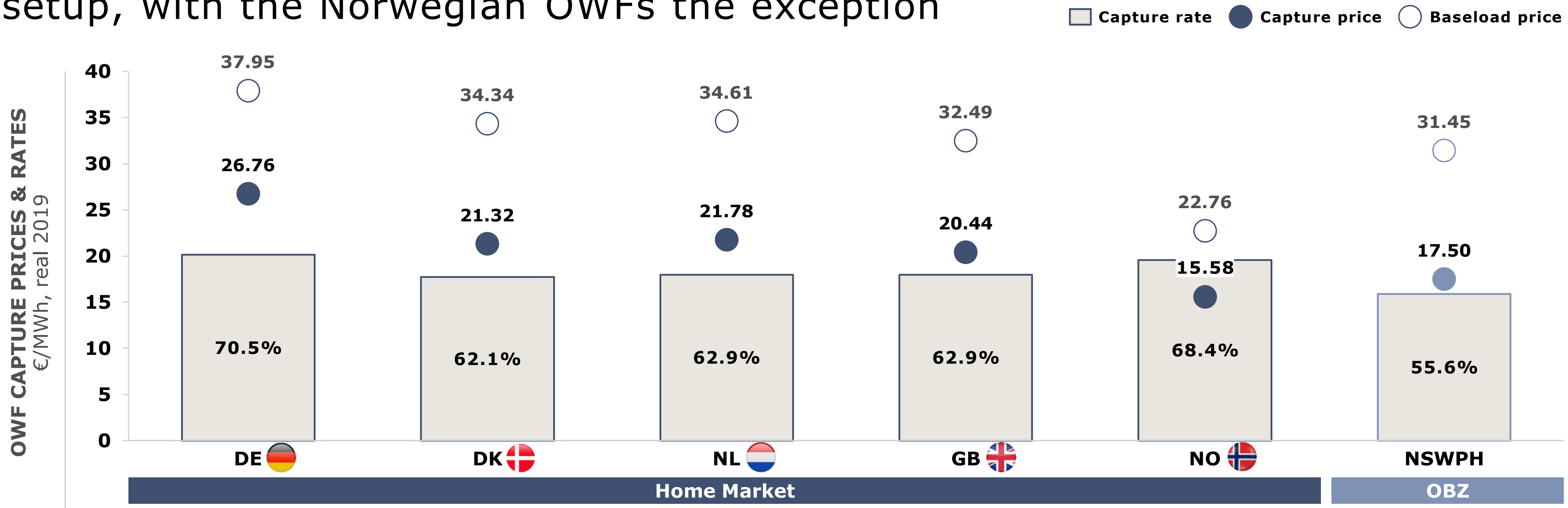
	HM					OBZ
Available generation at the hub platforms i.e. based on the expected wind speeds, power curves, etc.	50.10 TWh					50.10 TWh
Available generation at the respective bidding zones i.e. under the HM setup accounting for the losses of the spokes	48.60 TWh					50.10 TWh
Final generation & LFs post economic curtailment, at the respective bidding zones i.e. accounting for the volumes that need to be curtailed in each bidding zone	47.74 TWh (45.41%)					48.50 TWh (46.14%)
physical perspective	DE	DK	NL	GB	NO	
Final generation post economic curtailment, per bidding zone i.e. accounting for the volumes that need to be curtailed in each bidding zone	15.92	8.05	7.91	7.88	7.98	48.50 TWh
Domestic wind transmission of OWF (TWh) & % of overall generation i.e. flows into the respective home market from a physical perspective	15.47 97.2%	7.87 97.7%	7.02 88.7%	5.62 71.4%	5.61 70.4%	n.a.
Curtailment volume – bidding zone(s)	0.86TWh [48.60TWh-47.74TWh]					1.60TWh [50.10TWh-48.50TWh]

COMMENTS

- Under the OBZ setup, the available generation of the hub-connected OWFs in the bidding zone is marginally higher (compared to the HM setup) due to lower overall transmission losses.
- There is higher curtailment in the OBZ setup due to convergence of prices in periods of high wind output in the core markets.
  - Under the OBZ setup, for a cross-zonal flow to be scheduled, the price difference between zones must be large enough to at least cover the costs of transmission losses along the hub to shore spoke. If price differences are small, flows will not be scheduled as the costs of losses will not be covered.
  - Under the HM setup, flows from a hub-connected OWF via the hub to its own onshore system are not cross-zonal and are not driven by price signals. Furthermore, the cost of transmission losses on the hub to shore spoke does not affect flows as they are within zone.
- More information is provided in the Annex.

OWF CAPTURE PRICES AND RATES

Capture prices for hub-connected OWFs generally decrease under the OBZ setup, with the Norwegian OWFs the exception



COMMENTS

- The chart shows: i. the capture price, defined as the unit revenue of the hub-connected OWF per MWh accounting for the hourly profile and shape of prices and generation; ii. the baseload price, defined as the annual time-weighed average wholesale electricity price representative for a 'baseload' generator; and iii. the capture rate defined as the capture price divided by the baseload price and indicating how much of the baseload price the hub-connected OWF can capture.
- As prices in the OBZ are generally lower than in most of the core+ markets, we would expect hub-connected OWF revenues to be lower on a per MWh basis in the OBZ setup, particularly in the case of German hub-connected OWFs.
- The only exception is Norway, where OWF capture prices are lower under the HM setup and thus we would expect OWF revenue to increase under the OBZ setup.

OWF CAPTURE PRICE & REVENUE – COMPARISON WITH MARKET-WIDE FIGURES

OWF capture revenues are 20% lower under the OBZ setup versus HM setup

		HM					OBZ
		DE	DK	NL	GB	NO	NSWPH
Baseload price €/MWh, real 2019		37.95	34.34	34.61	32.49	22.76	31.45
Capture price €/MWh, real 2019	**Hub-connected OWF**	26.76	21.32	21.78	20.44	15.58	17.50
	Market-wide OWF	28.00	23.53	22.72	21.44	*No additional OWF*	
Capture rate % of baseload	**Hub-connected OWF**	70.5%	62.1%	62.9%	62.9%	68.4%	55.6%
	Market-wide OWF	73.8%	68.5%	65.6%	66.0%	*No additional OWF*	
Capture revenue €m/GW, real 2019	**Hub-connected OWF**	106.5	85.9	86.1	80.5	62.1	70.7
	Market-wide OWF	120.3	97.0	91.6	87.5	*No additional OWF*	
Overall hub-connected OWF capture revenue €m, real 2019		1,055					849

-20%

For Denmark results are provided for the (western) DK1 zone also referred to as Jutland; for Norway results are provided for the most southern zone NO2

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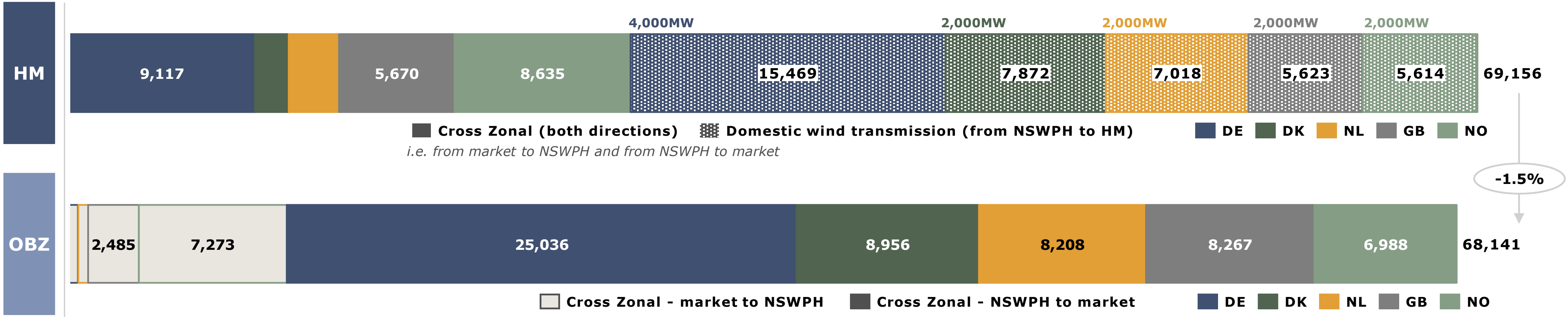
USAGE OF TRANSMISSION ASSETS

Transmission of hub-connected OWF generation to the onshore systems is the main source of flow, with some cross-zonal flow linked to Norway and GB

Annual physical flows in GWh, incl. losses by type of flow (e.g. cross-zonal or domestic transmission of hub-connected wind)



COMMENTS

- The chart shows physical flows accounting for losses on the transmission assets, as triggered by electricity price spreads, at the day-ahead stage.
- Under the HM setup, the assets are primarily used to transfer the hub-connected OWF's generation to its home market (for c. 60% of the total flow). Regarding cross-zonal flows, these are mostly seen on the Germany, Norway and GB spokes (mainly in the direction to Germany and also from Norway to the NSWPH, while the GB-NSWPH spoke is used roughly equally for both directions).
- All flows under the OBZ are considered 'cross-zonal'. The majority of the flows are related to the hub-connected OWF generation transferring wind to the onshore systems. Some flows are linked to exports from the national onshore systems (c. 16% of the total flow), mainly from Norway and GB.

Home Market vs. Offshore Bidding Zone

- Total flows under the OBZ setup are marginally lower compared to the HM setup (by c.1.5%). The direction of flow changes with the NSWPH-DE spoke having overall increased flows due to the German market's strong price signal triggering an increased flow linked to the hub-connected OWF, while the remaining spokes have reduced flows. This marginal difference in the overall flow is mainly due to the (marginally) higher hub-connected OWF curtailment levels seen in the OBZ setup (section 4ii).

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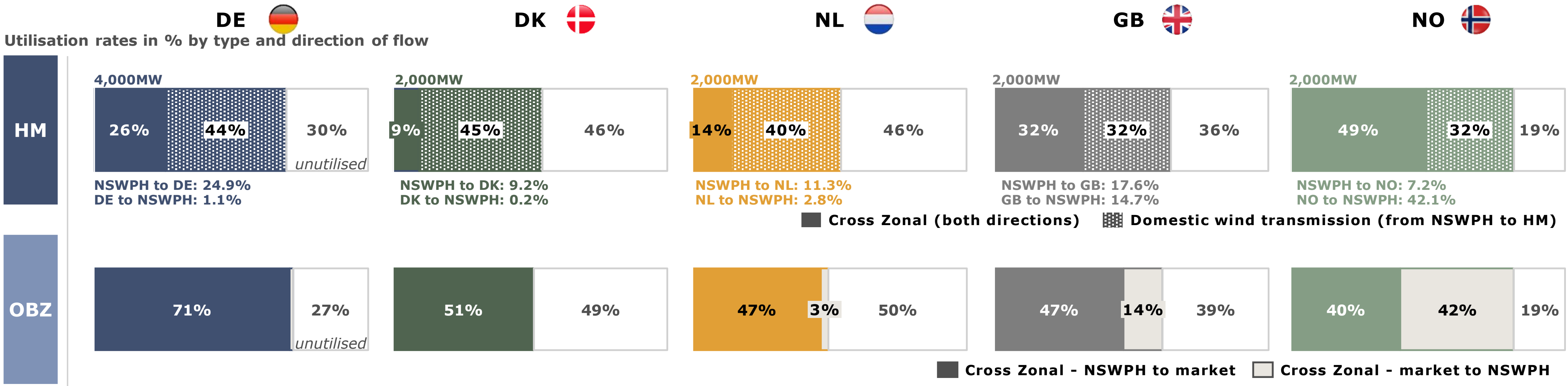
USAGE OF TRANSMISSION ASSETS

The OBZ setup allows for increased utilisation on German and Norwegian spokes in response to price signals



COMMENTS

- The charts show the utilisation rates of the assets by type and direction, defined as the physical flow accounting for losses divided by the capacity of each spoke.
- Under the HM setup, in addition to domestic wind transmission (varying between 32% and 45%), the spokes are used to transfer cross zonal flows primarily from the hub-connected OWF as well as from the Norwegian and GB shores to Germany and, to a lesser extent, to the GB and Dutch shores.
- Similarly, utilisation under the OBZ setup varies for the different spokes. For example, the NSWPH-DE spoke is used for c. 70% of the time, mainly to transfer the hub-connected OWF generation to the German shore where the price signal is stronger. This leads to lower utilisation on the Danish and Dutch spokes. Utilisation of the GB and Norwegian spokes remains high, driven by flows from the onshore systems.

Home Market vs. Offshore Bidding Zone

- Utilisation rates for the German spoke are higher under the OBZ setup, as the German market has a higher price thus triggering a higher flow from the hub-connected OWFs. The Danish, Dutch and GB spokes are utilised less under the OBZ setup, while the Norwegian spoke utilisation rates remain around the same levels.

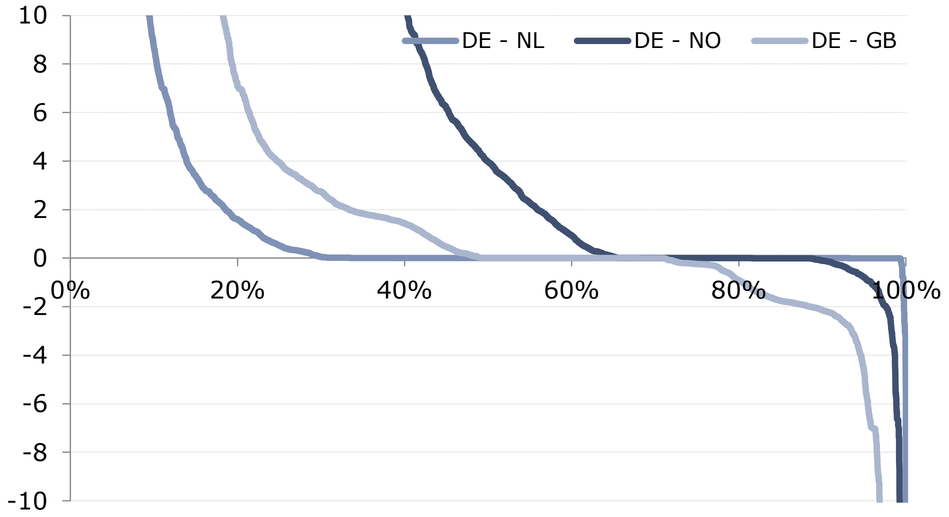
SUPPORTING INFORMATION

In the Core+ case, prices in GB and Norway have a weaker correlation to prices in the three core markets, which supports cross-zonal flows

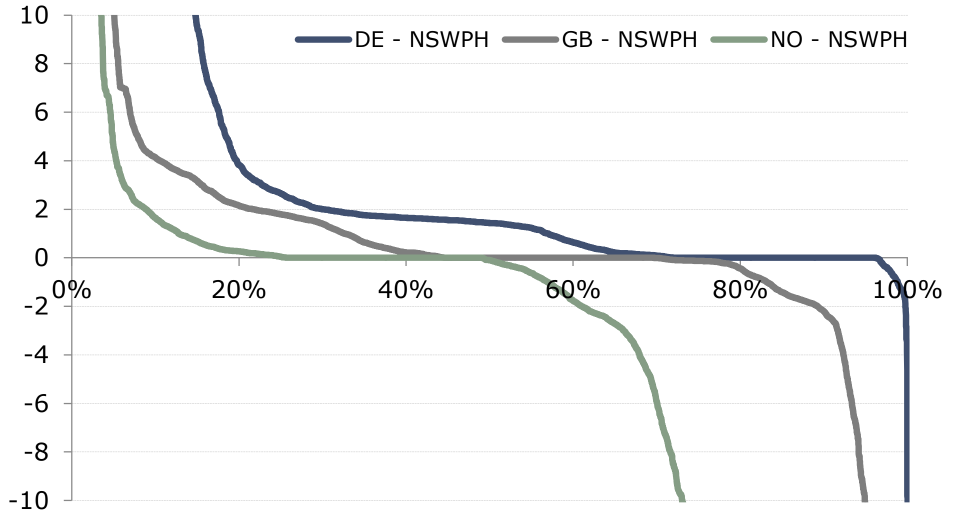
PDC of the price spreads, based on 2018 weather patterns

ELECTRICITY SPREAD PDC
€/MWh, real 2019

HM



OBZ



COMMENTS

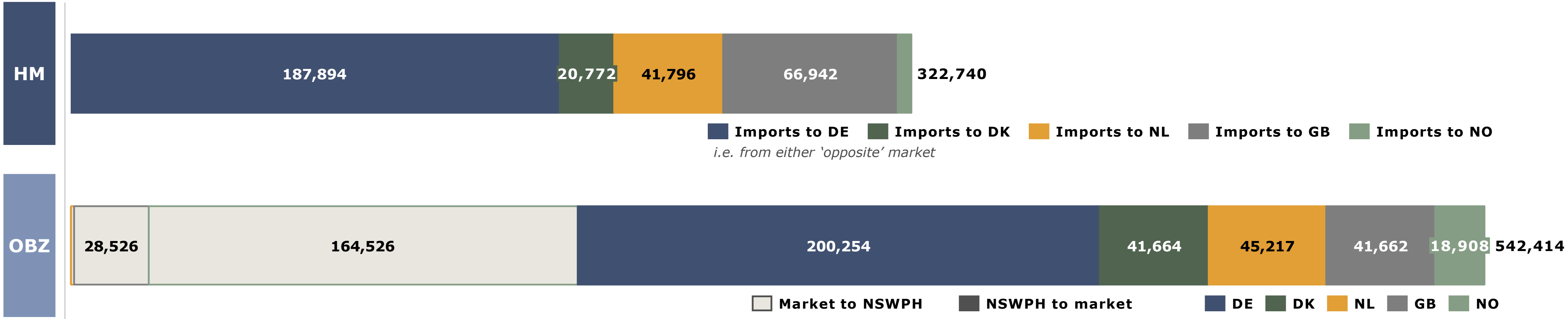
- Under the HM setup, price spreads (in either direction) between Germany and Norway are higher than €2/MWh for c. 60% of the time, while between Germany and GB price spreads are higher than €2/MWh for c. 45% of the time.
- Under the OBZ setup, price spreads between the NSWPH and both Denmark and the Netherlands are smaller than €2/MWh for c. 85% of the time. In the case of Germany and GB, the price spread versus the NSWPH is below €2/MWh for c. 70% of the time. Finally, the Norway-NSWPH price spread is below €2/MWh for c. 50% of the time.
- Results based on 2018 weather patterns.

For Denmark electricity prices are provided for the (western) DK1 zone also referred to as Jutland; for Norway electricity prices are provided for the most southern zone NO2

CONGESTION INCOME

Relatively high congestion income, driven by increased diversity between the hub-connected markets, with the OBZ setup showing greater potential

Annual congestion income for the different spokes in 1,000s euros, real 2019 money



COMMENTS

- The chart shows the estimated annual congestion income for the different spokes, provided: a. HM setup: separately for the imports into the core markets from either opposite market; and b. OBZ setup: for each spoke and for both directions (i.e. from the onshore systems to the hub, and vice versa).
- The main source of congestion income under the HM setup is linked to cross-zonal flows towards Germany (c. 60% of the total income), as well as flows to the GB market (c. 20% of the income). When focusing on the opposite direction, the main source of this income is linked to exports from Norway (1).
- Under the OBZ setup, the majority of the rent income comes from the spoke connecting the hub to the German market (c. 37% of the overall income) – as well as from the spoke connecting Norway to the hub (c. 30% of the total income).

Home Market vs. Offshore Bidding Zone

- Congestion income under the OBZ setup is c.70% higher compared to the HM setup (congestion income under the OBZ setup is close to €92m/GW for the Norwegian spoke and around €50m/GW for the German spoke).

1. The rent linked to exports from Norway is included in the numbers shown above (i.e. imports to DE, DK, NL & GB).

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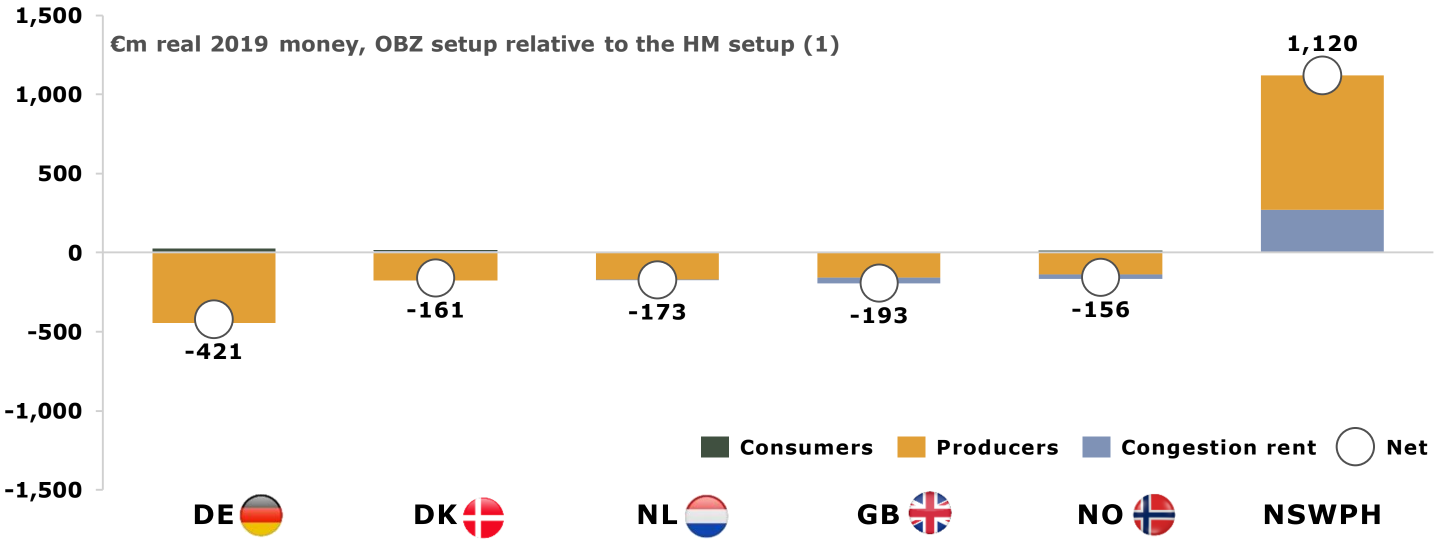
SOCIO-ECONOMIC WELFARE ASSESSMENT

Overall socio-economic outcome is marginally better under the OBZ setup, including an increase in consumer surplus, but with distributional shifts

SOCIO-ECONOMIC WELFARE IMPACT PER MARKET



OVERALL WELFARE DISTRIBUTION

Stakeholders	*Welfare impact across the markets*
Consumers	**+€27m**
Producers	**-€232m**
Congestion Rent	**+€220m**
Net	**+€15m**

COMMENTS

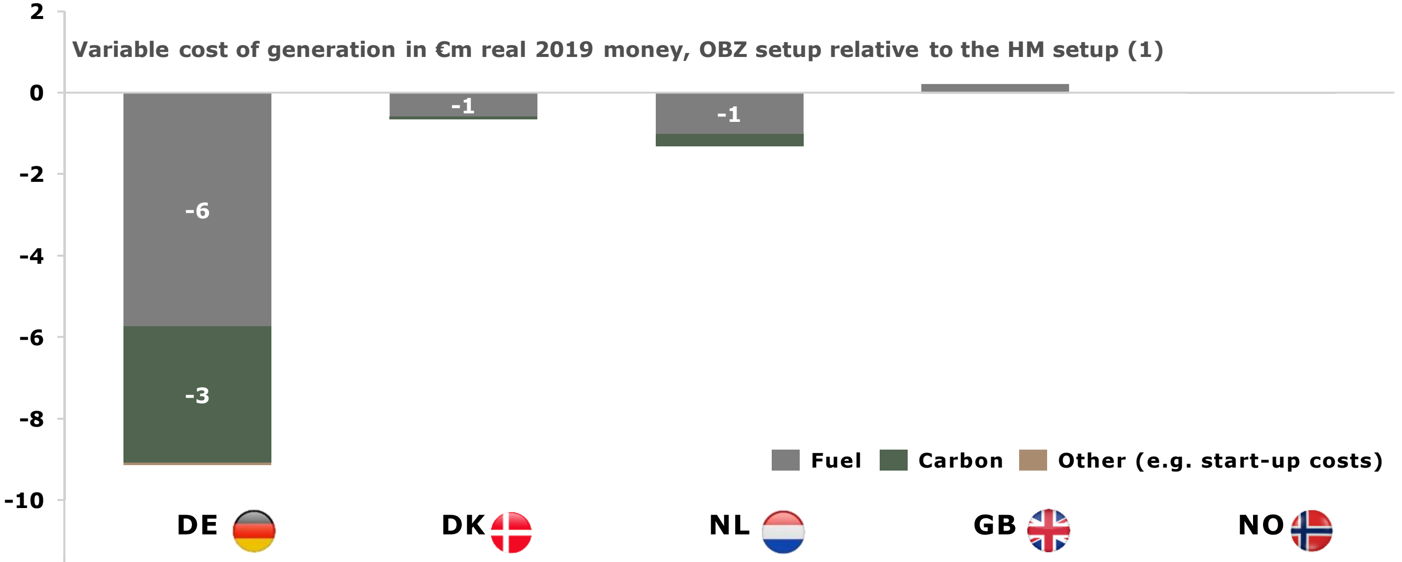
- The chart provides a summary of the socio-economic welfare assessment for each core+ market and the NSWPH. The impact is relative to the HM setup.
- There is almost no impact on consumer surplus (either at a market-level or overall), as wholesale prices remain relatively unaffected (less than 0.5% difference between the two setups for any of the core markets). The Annex provides more information on the impact on consumer surplus.
- There is a negative impact on overall producer surplus, driven by an overall lower capture revenue for the hub-connected OWFs under the OBZ setup. At a market level, the negative impact on producer surplus for the core+ markets is mainly due to the fact that the 12GW of hub-connected OWF is no longer bidding in these national markets, but under the OBZ setup, by definition they are part of the NSWPH zone (this also explains the positive impact under for the NSWPH).
- Higher congestion income under the OBZ setup.
- When a wider diversity of markets are connected to the NSWPH (as under the Core+ configuration), the OBZ setup can exhibit more notable benefits, driven by (marginally) positive effects on overall consumer wholesale electricity costs.

1. Positive numbers indicate a higher welfare under the OBZ setup; negative numbers indicate a lower welfare under the OBZ setup

BREAKDOWN OF VARIABLE COST OF DISPATCH

OBZ setup results in a marginally lower dispatch cost, with lower fuel and carbon costs

IMPACT ON THE COST OF DISPATCH



TOTAL IMPACT ACROSS THE CORE+ MARKETS

Item	*Impact*
Fuel	-€7m
Carbon	-€4m
Other	€0m
Total	-€11m

COMMENTS

- The chart shows the impact on the variable cost of (thermal) generation under the OBZ setup (relative to the HM setup) for each market. The impact is indicated as 'positive' when the difference is negative under the OBZ setup (i.e. implying better use of generation mix, leading to a lower cost of dispatch).
- The OBZ setup can make better use of the interconnections flows hence using a more efficient plant mix overall with a lower cost of dispatch (€10.9m lower than for the HM setup).
- The impact is stronger in the German market, due to increased flows from the hub-connected OWFs displacing some of its thermal generation. This is also the result of the larger spoke to Germany compared to the other markets (i.e. 4GW for Germany as opposed to 2GW for other markets).
- Ultimately, the difference between the two setups remains very low compared to the overall cost of dispatch for the core+ markets (i.e. the delta is less than 0.1% of the total cost of dispatch).

1. Positive numbers indicate a higher dispatch cost under the OBZ setup; negative numbers indicate a lower dispatch cost under the OBZ setup

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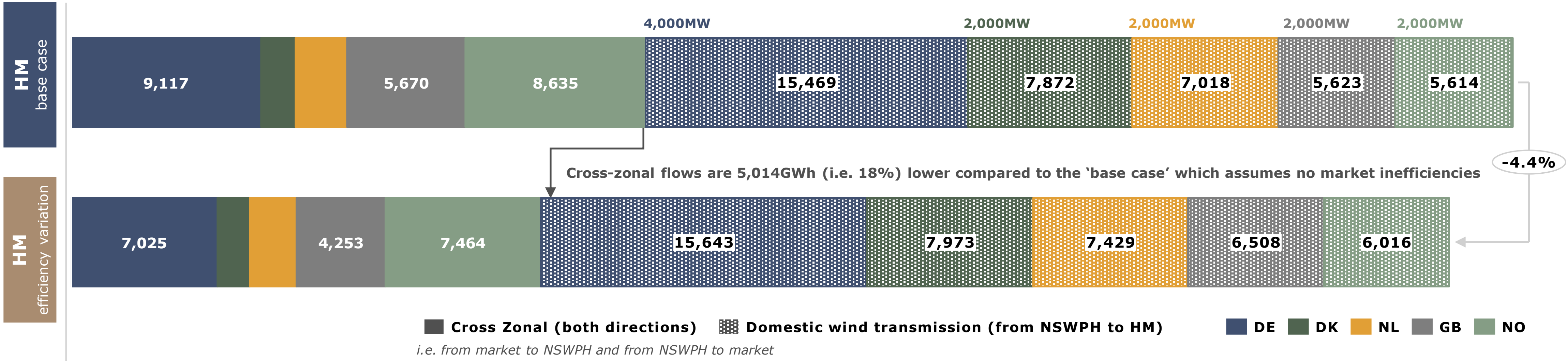
USAGE OF TRANSMISSION ASSETS

Wind forecast error means that cross-zonal flows are lower, although transmission of hub-connected OWF generation to home-markets is higher

Annual physical flows in GWh, incl. losses by type of flow (e.g. cross-zonal or domestic transmission of hub-connected wind)



COMMENTS

- The chart shows physical flows accounting for losses on the transmission assets, as triggered by electricity price spreads, at the day-ahead stage. It differentiates between 'cross-zonal flows' and 'domestic wind transmission'.
- Under this variation, we assume that transmission capacity needed for wind is always 'overbooked' to allow for the potential export of additional wind output relative to day-ahead expectations in the event of wind forecast error. This means that the amount of transmission capacity available for cross-zonal flows is reduced compared to the 'base case'. Under this variation, overall cross-zonal flows are lower by 5,014GWh (c. 18%) compared to the 'base case'.
- Transmission of hub-connected OWF generation to the home market onshore systems is higher by around 1,975GWh (under the variation). This is mainly driven by Dutch, GB and Norwegian OWF generation going to the home markets rather than the German shore.
- The net effect is limited, however, with overall usage reducing by around 4%. Additionally, intraday continuous trading may be expected to alleviate inefficiencies linked to forecast errors.

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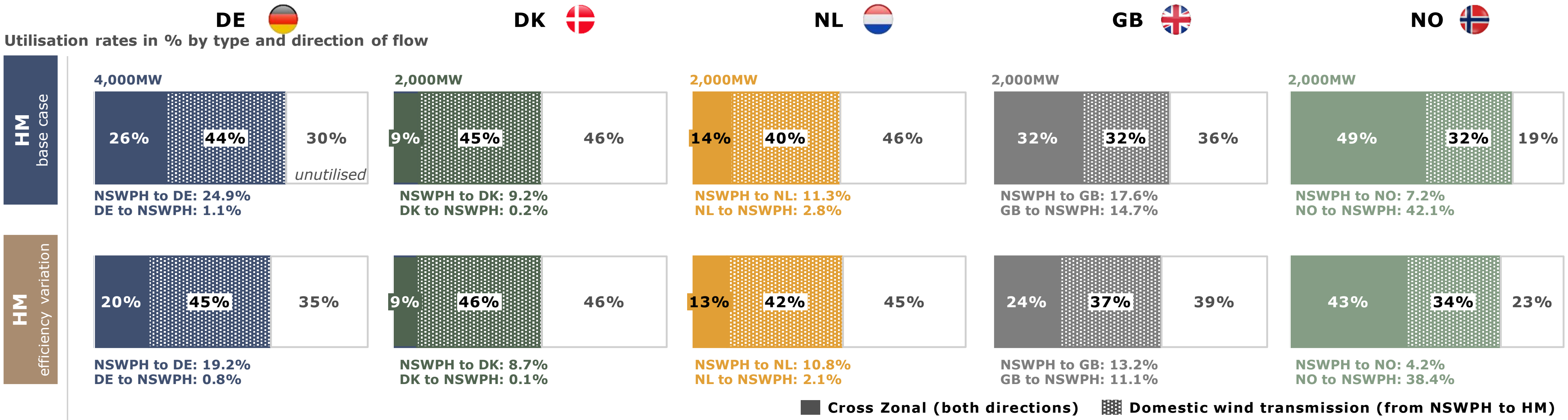
Core +

Linked to wind forecast errors

Lower utilisation rates for the spokes that are used for cross-zonal flows, although impact is somewhat mitigated by increased wind radial operation



COMMENTS

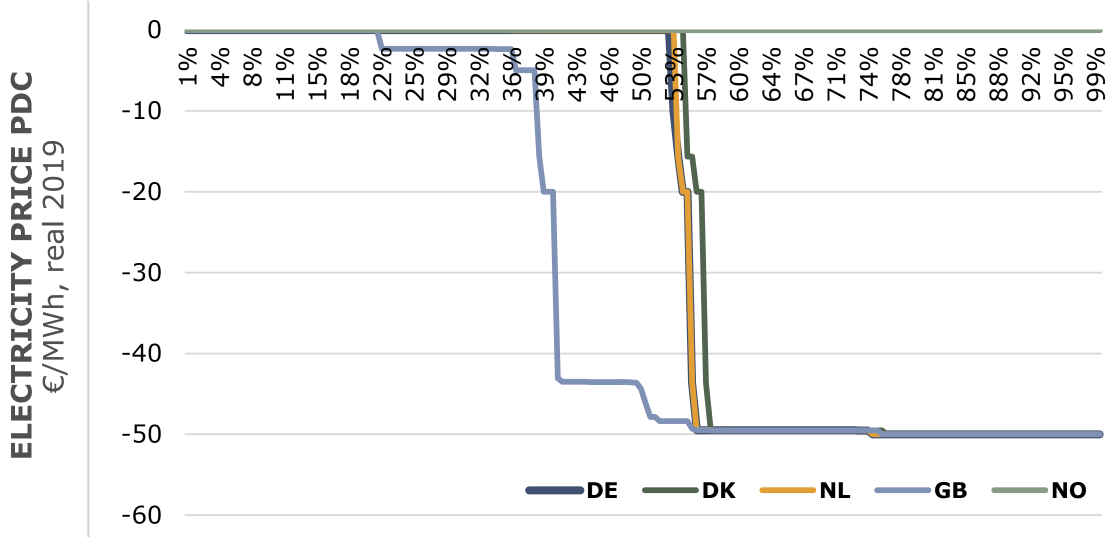
- The charts show the utilisation rates of the transmission assets by type of use (either cross-zonal or domestic wind transmission), defined as the physical flow accounting for losses divided by the capacity of each spoke.
- On the German spoke, there are lower cross-zonal flows from the hub to the German market under the efficiency variation driven by a constrained availability on the cable.
- For the Danish and Dutch spokes, there is almost no impact, as reduced cross-zonal flows are offset by increased wind radial operation.
- In the case of the GB and Norwegian spokes, there are lower cross-zonal flows in either direction under the efficiency variation, but these are, to some extent, counterbalanced by increased wind radial operation (OWF generation that would have otherwise gone to the German market due to its price signal).

NEGATIVE PRICES

With more diversity in the price formation, some marginal inefficiencies could appear under the HM setup in case of potential negative prices

HOME MARKET

PDC of the negative electricity prices – based on 2018 weather patterns



KEY FIGURES UNDER THE EFFICIENCY VARIATION

% of the hours when connected markets are negative/close to zero concurrently	**87.2%**
Average price difference between the connected markets when prices are negative	**€9.92/MWh**
Maximum price when at least one market has negative price	**€64.31/MWh**
% of the hours with negative prices in the connected markets	**3.18%**

COMMENTS

- In theory, potential inefficiencies could appear in the HM setup compared to the OBZ setup when there are negatives price in one of the price areas and not in the other one(s), leading to curtailment of the hub-connected OWF that is bidding into the HM zone with negative prices. This inefficiency can be avoided under the OBZ setup.
- The core+ markets are less correlated in terms of prices than the core markets, meaning that cases of negatives prices in one market and positive prices elsewhere can occur, leading to an inefficiency in the HM setup. However, the frequency of cases is still minor – i.e. only 13% of the time when there are negative prices in any price area is there a price above €1/MWh in one of the other price areas.
- NOTE: Our standard modelling suggests that occurrence of negative prices in 2035 would be almost non-existent as the number renewables power plants with subsidies that allow negative bidding dwindles. In our modelling exercise to test the negative bidding inefficiency, around 60% of all renewables was required to bid negatively to result in negative prices in the core markets in around 3.2% of periods. The main runs do not produce any negative prices.

For Denmark electricity prices are provided for the (western) DK1 zone also referred to as Jutland; for Norway electricity prices are provided for the most southern zone NO2

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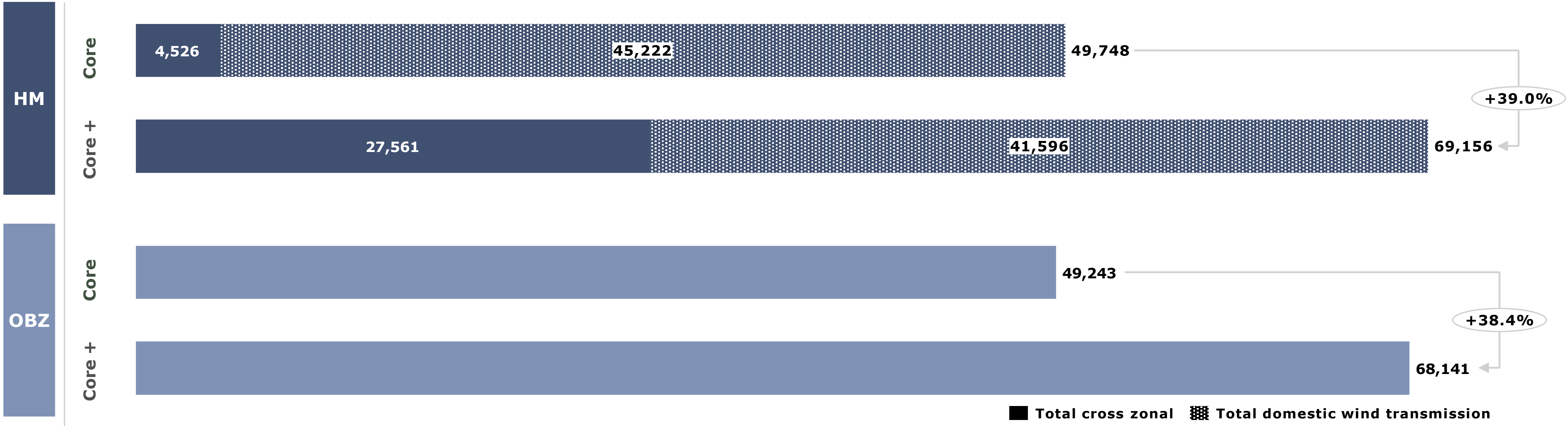
Increased overall usage under the Core+ driven by the addition of GB and Norway to the hub, adding greater diversity and increasing cross-zonal flows

Annual physical flows in GWh, incl. losses by type of flow (e.g. cross-zonal or domestic transmission of hub-connected wind)



COMMENTS

- The chart shows physical flows accounting for losses on the transmission assets, as triggered by electricity price spreads, at the day-ahead stage.
- Under both market setups, increased diversity between the hub-connected markets (i.e. higher price spreads among some of the markets under the Core+) increases cross-zonal flows and improves the usage of the NSWPH transmission assets overall under the Core+ Configuration.

Effects of market setup choice on welfare are generally small, but potential benefits of the OBZ setup are enhanced under the Core+

CORE CONFIGURATION

Stakeholders	*Welfare impact across the markets*
Consumers	⇩ **-€29m**
Producers	⇩ **-€89m**
Congestion Rent	⇧ **+€118m**
Net	**€0m**

CORE+ CONFIGURATION

Stakeholders	*Welfare impact across the markets*
Consumers	⇧ **+€27m**
Producers	⇩ **-€232m**
Congestion Rent	⇧ **+€220m**
Net	⇧ **+€15m**

COMMENTS

- The chart provides a summary of the socio-economic welfare assessment for each Core or Core+ market as appropriate and the NSWPH. The impact is relative to the HM setup.
- Effects of market setup choice on welfare are generally small, but potential benefits of OBZ setup are enhanced when there is more diversity in the hub-connected markets as is the case under the Core+ Configuration.
- There are large distributional transfers linked to market setup choice under both configurations.

1. Positive numbers indicate a higher welfare under the OBZ setup; negative numbers indicate a lower welfare under the OBZ setup

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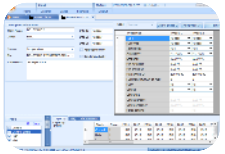
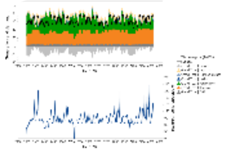
BID3 is the leading electricity market simulation software – combining powerful simulations with user-friendliness

BID3 is the cornerstone of AFRY capabilities	BID3 is used everyday by AFRY to provide services to utilities, investors, banks, and projections using it underpins all our 50 market reports worldwide and valuation services
Extensive client base	BID3 is used by 15 TSOs and energy companies, as well as extensively by AFRY
User-friendly with excellent visualisation	BID3 has been designed to be very user friendly, meaning that the training and implementation time is very low. It is built around the ability to visualise all of your data
High quality datasets available	Our datasets come fully benchmarked with a high-quality backcast of 2012-18. Datasets are taken from the data use ourselves for our modelling work, guaranteeing the highest quality
Detailed hydro, wind and solar modelling	We use the model to underpin our extensive modelling work in 'intermittency' including detailed simulations of historical weather patterns, along with sophisticated hydro modelling
Fast and powerful	Designed to allow computing power to be focused where it is needed, and handles modelling of 8760 hours with large numbers of countries, power stations, renewables, hydro and demand-side management with ease.

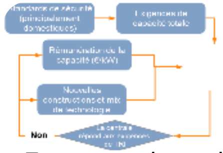
BID3 projects physical operation (generator output, electricity flows, emissions) and economic behaviour (electricity prices, revenues)

Key features

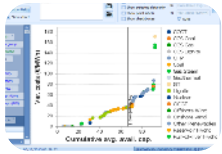

Detailed power station database

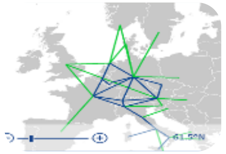

Flexible charting and pivoting of any data

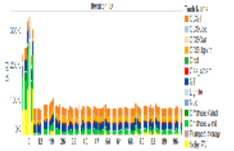

Zonal, FBMC and nodal pricing

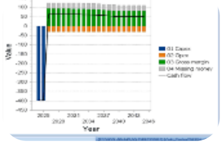

Energy-only and energy + capacity markets

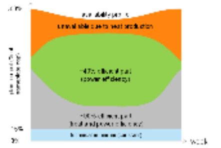

Sophisticated hydro modelling

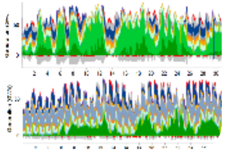

Supply curves, marginal plant


Flexible pricing areas + fixed flows

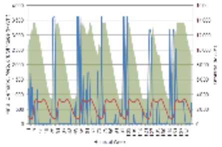

Auto Build module


Profitability, IRR calculations

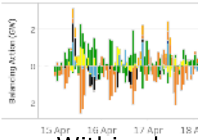

Detailed CHP modelling

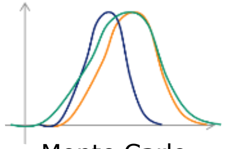

Intermittent generation


Reserve and response


Demand-side management

Short-term modelling


Within-day calculations


Monte Carlo analysis

Inputs and outputs of BID3

Inputs

- **Power station data** (efficiency, capacity, fuel, MSG, …)
- **Demand**
- **Fuels, commodity prices**
- **Interconnectors**
- **Weather data (hourly wind, solar, demand, hydro…)**
- **New build/retiral**

BID3
Electricity Market Model

Economic new build of all technologies

Outputs

- **Prices**
- **Load factors**
- **Interconnection**
- **Emissions**
- **Plant revenue**

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MARKET EFFICIENCY VARIATIONS – APPROACH

Potential inefficiencies could appear under the HM setup due to wind forecast inaccuracies leading to an 'over-reservation' of the transmission assets

Capacity booking

The nature of the HM setup implies a reservation of the transmission capacity from the hub to the shore for the OWF to their home markets. This has the effect of reducing the capacity available for cross zonal flows.

Approach

In our standard modelling, we assume perfect foresight i.e. OWF hourly forecast and generation are the same meaning also that the reservation of the transmission capacity is perfect. In reality, there could be higher or lower wind output compared to the forecast, with implications for transmission reservation capacity requirements. To examine the effects of this, our approach for the market efficiency variation assumes that, based on the relative wind forecast, capacity needed for wind is always 'inflated or overbooked' to allow for additional wind (i.e. sufficient reserve margin).

Wind forecast

To explore that potential inefficiency, we have used the (D-1) EC00 data (1) provided by Energy Quantified from 2017 until today, which is currently the most used forecast for day-ahead market coupling. We have analysed the difference between the forecast and the outturn in case of higher wind outputs to extract a correlation between the wind error and the actual generation.

Error margins

We have used a P95 value meaning that the wind error margin (i.e. to account for extra outturn generation) covers 95% of the time when there is a higher wind output than the (D-1) EC00 forecast (1). The timescale of the day-ahead forecast and the use of a P95 value combine to result in an overall 'conservative approach' – i.e. it errs on the side of a larger overbooking capacity to cover wind forecast error.

Results

The correlation is then used to 'over-reserve' the transmissions asset compared to our standard run e.g. the OWF generation is the same but the allocated transmission capacity for the cross border flows is reduced to allow for the potential of extra generation in case of higher wind output than forecast.

Even under this conservative approach to reducing the capacity available for cross zonal flows, the impact on the overall utilisation of the assets is limited with overall usage reducing by less than 1% in the Core Configuration. Lower cross-zonal flows are counterbalanced by increased transmission of hub-connected OWF generation to the home market onshore systems.

1. The data used for the (D-1) EC00 forecast is from between 24h up to 48h before the outturn. The calculation process based on this data then starts at midnight and is published between 7-8 am for the next day e.g. for Tuesday's wind forecast, the calculation will start at midnight on Sunday and be published at 7-8 am the Monday.

MARKET EFFICIENCY VARIATIONS – APPROACH

Potential inefficiencies could appear when there are negative prices. However no negative prices were observed in our standard modelling, so an additional run was made to artificially create these situation and observe the outcomes

'Base Case'

Our standard (base case) modelling suggests that occurrence of negative prices in 2035 would be almost non-existent as the number of renewables power plants with subsidies that allow negative bidding dwindles

Bidding behaviour

In order to artificially create situations with negative prices, we had to assume that around 60% of RES in 2035 would be bidding negatively (which is not the case in our standard modelling).

Run with negative prices

With more RES bidding negatively, we create a situation where negatives prices are observed in the market, although the number of negative price periods still remains relatively minor (less than 2% of the time in the Core, and less than 4% of the time in the Core+).

Results

Our analysis suggests that there is no noticeable inefficiency in the HM setup linked to negative prices, as the occurrence and level of negative prices are correlated between the markets.

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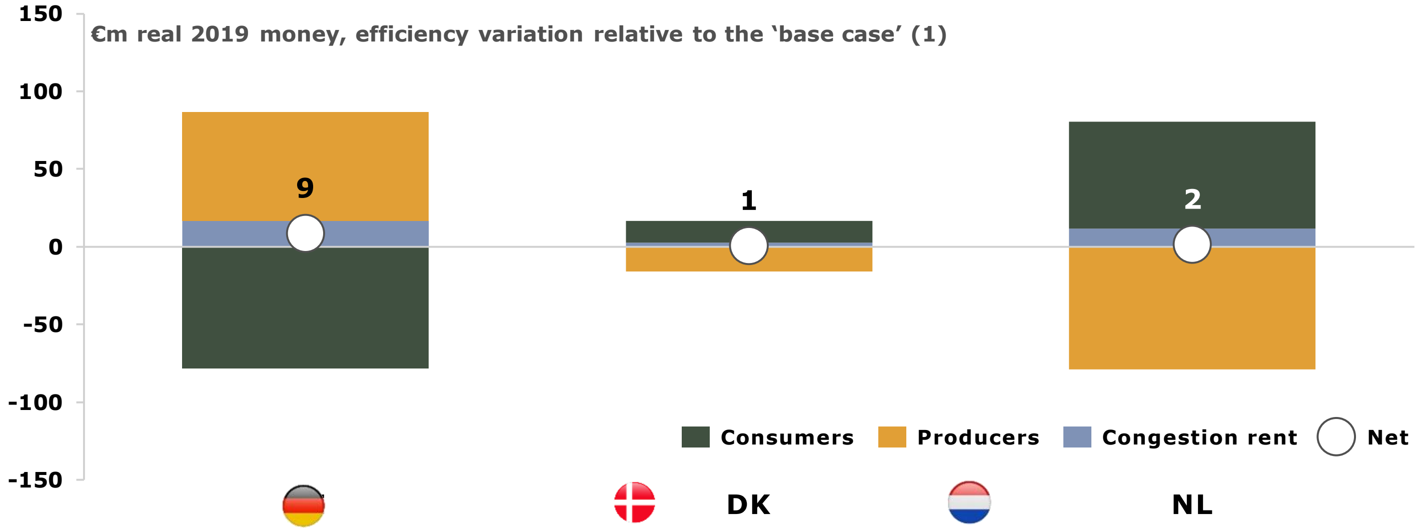
SOCIO-ECONOMIC WELFARE ASSESSMENT

Wind error margin has limited impact on socio-economic outcomes

SOCIO-ECONOMIC WELFARE IMPACT PER MARKET



OVERALL WELFARE DISTRIBUTION

Stakeholders	*Welfare impact across the markets*
Consumers	↑ +€5m
Producers	↓ -€26m
Congestion Rent	↑ +€31m
Net	+€10m

COMMENTS

- The chart provides a summary of the socio-economic welfare assessment for each core market and the NSWPH. The impact is relative to the HM setup.
- Factoring in the wind error margin causes marginal shifts of flows, with reduced flows going to Germany causing a marginal increase in German prices mirrored by a decrease in prices in Netherlands and Denmark. This has a negative effect for the German consumers and a positive effect for Dutch and Danish consumers.
- Conversely, reduced flows to Germany result in a benefit for the German producers, with the opposite applying for the Dutch and Danish producers.
- Overall for the three markets, the wind margin error means marginally higher congestion rent potential due to greater price spreads, lower revenues for producers, and improved consumer surplus due to lower prices. The net impact is negligible, however.

1. Positive numbers indicate a higher welfare under the inefficiency HM run setup; negative numbers indicate a lower welfare under the base case HM run setup

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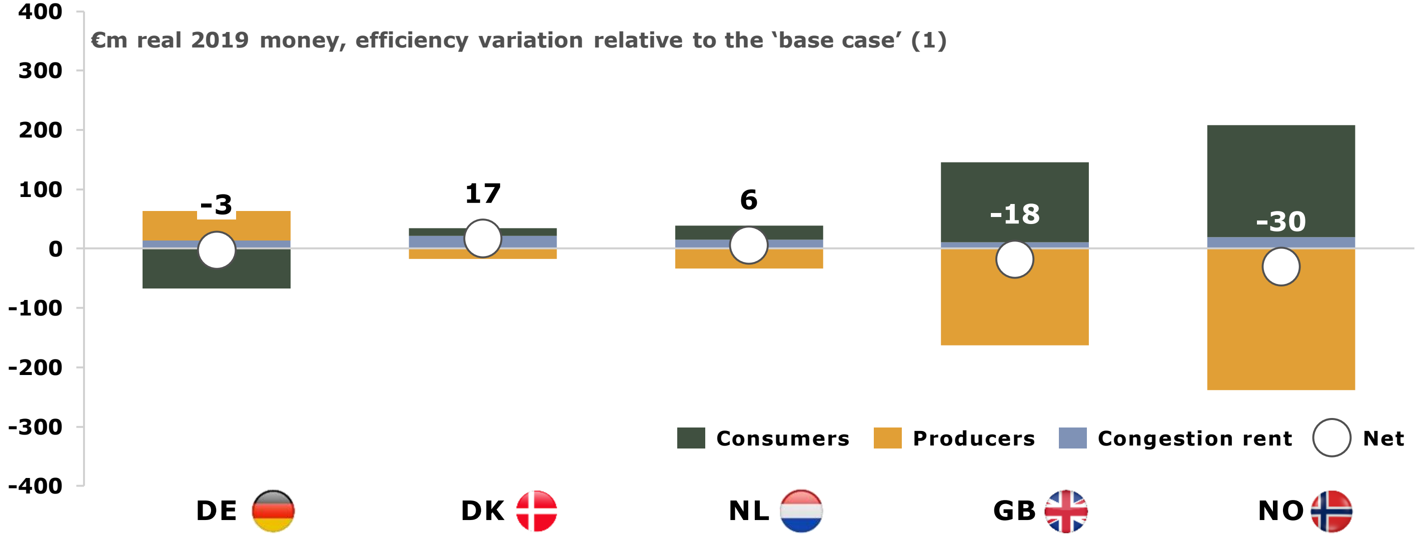
SOCIO-ECONOMIC WELFARE ASSESSMENT

Wind error margin has limited impact on socio-economic outcomes

SOCIO-ECONOMIC WELFARE IMPACT PER MARKET



OVERALL WELFARE DISTRIBUTION

Stakeholders	*Welfare impact across the markets*	
Consumers	⇧	+€293m
Producers	⇩	-€403m
Congestion Rent	⇧	+€81m
Net	⇩	-€29m

COMMENTS

- The chart provides a summary of the socio-economic welfare assessment for each core+ market and the NSWPH. The impact is relative to the HM setup.
- Factoring in the wind error margin causes marginal shifts of flows, with reduced flows going to Germany causing a marginal increase in German prices mirrored by a decrease in prices in all the remaining connected markets. This has a negative impact on the German consumers and a negative on the German producers. The opposite is true for the other connected markets.
- Overall for the five markets, it means marginally higher congestion rent potential due to greater price spreads, lower revenues for producers capturing a lower price (especially in GB and Norway) and improved consumer surplus due to lower prices. The net impact is limited, however.

1. Positive numbers indicate a higher welfare under the inefficiency HM run setup; negative numbers indicate a lower welfare under the base case HM run setup

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Q1: Why is consumer surplus effect of switching to OBZ setup negative in the Core configuration and positive in the Core+?

Core Configuration

- The overall consumer surplus effect is driven by the combination of consumer surplus effects in each of the Core markets. In aggregate, the switch to OBZ setup leads to a reduction in consumer surplus across the three markets collectively. The following points contribute to this overall position:
  - The biggest impact is on the Dutch consumers. The OBZ setup leads to reduced hub-connected OWF flows to the Dutch market. In this setup, flows from the hub to an onshore system occur in response to price signals between two price zones. Because the price signal is weaker in the Netherlands (with generally lower prices), some of the NL hub-connected OWF is flowing towards the other markets (e.g. utilisation on the NL spoke has dropped from 40% to 31%). This pushes prices upwards in the Dutch market – for example the demand-weighted average price increases by €0.14/MWh.
  - There is a marginal impact on the German and Danish consumers. For example, the impact on (demand-weighted average) prices in Germany is less than €0.01/MWh.

Core+ Configuration

- The addition of GB and NO to the hub leads to an overall positive consumer surplus. This is driven by a positive impact mainly on the German consumers, benefiting from increased flows from zones with notably lower prices (i.e. GB & NO).

Q2: How are losses treated?

Home Market (HM) setup

- Under the Home Market setup, losses on the transmission lines that connect each (hub-connected) OWF to its home market are handled explicitly. This means that the OWF volume that reaches its respective onshore connection point is reduced by e.g. 2.7% for the core markets (1). Under the HM setup, OWFs bid into their respective home market at a price close to €0/MWh. As long as they are within the merit order, the OWF volumes are dispatched into the national systems.

- When there is a price spread among the connected markets large enough to trigger a cross-zonal flow, then the OWF generation may be 'directed' to a different market (instead of its home market). This price spread needs to be large enough to at least cover the costs of transmission losses along the hub to shore cable. In this case, the OWF will receive the price of the home market and this OWF volume will be classed as 'cross-zonal flow'.

Offshore bidding Zone (OBZ) setup

- Under the Offshore Bidding Zone setup, by definition, all OWF volumes are classed as cross-zonal and therefore losses are handled implicitly. This means that in order for a cross-zonal flow to be triggered between the hub and a connected market, the price spread needs to be large enough to at least cover the costs of transmission losses along the hub to shore cable.

- For example between the hub and each of the core markets the following constraint needs to be met: PriceMarketA > PriceHub / (1-2.7% losses), for a flow to be triggered from the hub towards Market A.

1. The Core+ markets include a higher loss factor to account for a longer cable to the shores (e.g. 3.1% for the connection to GB; 4.0% for the connection to Norway).

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