



Offshore Renewables Export Surplus WS2 – Electricity Interconnection Quantitative Assessment Report

A report to the Department for the Environment, Climate and Communications

NOVEMBER 2023

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AFRY and BVGA have been commissioned by DECC to provide an economic analysis of the potential for Offshore Renewable Energy (ORE) surplus

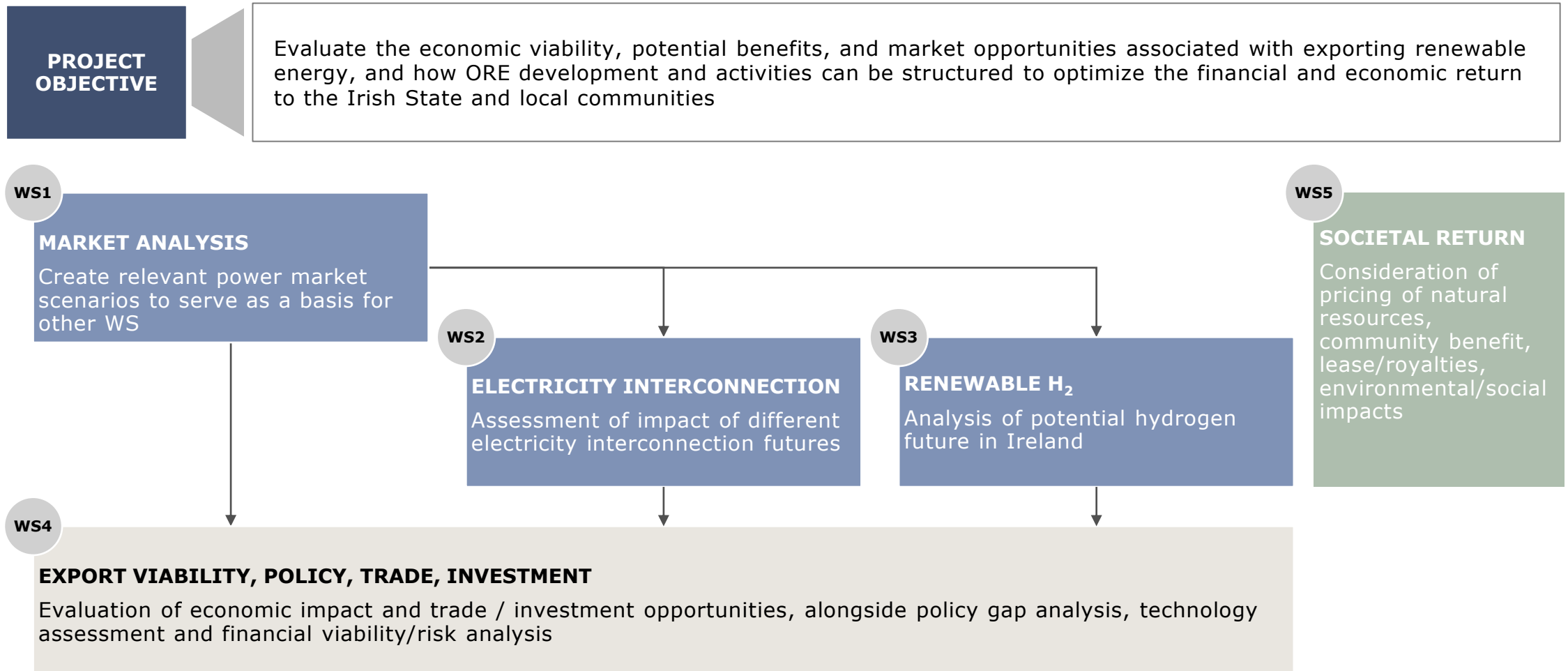
BACKGROUND

- Ireland has ambitious climate action targets for 2030 as well as a legally binding target of achieving net zero emissions by 2050.
- Offshore renewables are expected to play a key role in delivering on 2030 and 2050 targets.
- Furthermore, because of Ireland’s maritime endowment, there is potential to capture significantly more offshore renewable energy (ORE) than would be needed to satisfy domestic energy requirements.
- However, it is uncertain what the optimal use of any ORE surplus might be. More specifically, whether ORE surplus should be exported as electricity, hydrogen (or hydrogen derivative) or if instead it should be ‘refined’ and used to produce new value-added products and services domestically (perhaps data centres or green steel or green aluminium).
- Consequently, the Department of the Environment, Climate and Communications (“DECC” or “the Client”) has requested AFRY Management Consulting Limited (“AFRY”) and BVG Associates Limited (“BVGA”) provide an economic assessment of the potential for ORE surplus.

SCOPE

- The broad scope of work includes the following elements:
 - Market analysis
 - Financial analysis
 - Socioeconomic impact analysis
 - Policy and regulatory analysis
 - Risk analysis
- This will be delivered via 5 Workstreams (WS):
 - WS1 – Market Analysis
 - WS2 – Electricity Interconnection
 - WS3 – Renewable Hydrogen Development
 - WS4 – Export Viability, Policy Considerations, Trade and Investment Opportunities
 - WS5 – Optimised Financial and Economic Return to the State and Local Communities

This study has five discrete but interlinked Workstreams



WS2 is an extension from WS1 scenario framework and focuses on the interconnector aspect with this report considering the quantitative side

BACKGROUND

- The assessments of electricity interconnection, renewable hydrogen and economic impact require a view of the future energy sector both in Ireland and in Europe / Great Britain (GB).
- Areas of uncertainty include:
 - The level of domestic power and hydrogen demand
 - Fuel and carbon prices
 - The evolution of the capacity and generation mix
 - Power prices in the Irish Single Electricity Market (SEM) as well as neighbouring markets
 - Generation economics and the need (or lack thereof) for some form of support.
- Ultimately, the primary focus of WS1 is to create the scenarios of the Irish (and interconnected European) energy market in 2030, 2040 and 2050 that form the basis for analysis in subsequent WS.

SCOPE

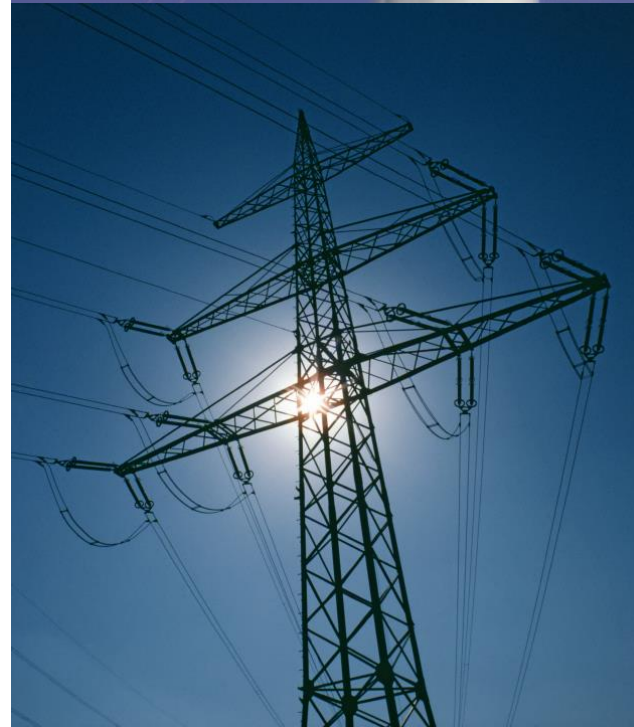
- Workstream 2 has two main focus areas. First, based on the cases developed in Workstream 1, it considers on a quantitative basis, outcomes for the Irish electricity system and for electricity interconnection specifically under the cases examined. This allows for analysis of the impacts of different interconnector futures across the cases and the effects of the drivers behind the different cases on outcomes.
- Second, it considers on a qualitative basis issues relating to the regulatory and commercial models for progressing further interconnection. This includes for instance looking at the economic rationale for hybrid IC, regulatory funding models for IC and other potential revenues than the congestion rent.

Abbreviations

ARA	Amsterdam-Rotterdam-Antwerp	FRA	France	TES	Tomorrow's Energy Scenario report (published by EirGrid)
BBL	Barrel	GB	Great Britain	TSO	Transmission System Operator
BECCS	Bioenergy with CCS	GHG	Greenhouse gas	TYNDP	Ten Year Network Development Plan
BESS	Battery energy storage system	GW	Gigawatt	TWh	Terawatt hour
BVGA	BVG Associates	H2	Hydrogen	V2G	Vehicle to grid
CAP	Climate Action Plan	IC	Interconnector	WS	Workstream
CCGT	Combined cycle gas turbine	Li-ion	Lithium ion		
CCS	Carbon capture and storage	LNG	Liquefied natural gas		
CH₄	Methane (i.e. natural gas)	MW	Megawatt		
CHP	Combined heat and power	MWh	Megawatt hour		
CIF	Cost, insurance and freight	NBP	National Balancing Point		
DAM	Day Ahead Market	NI	Northern Ireland		
DECC	Department of the Environment, Climate and Communications	OCGT	Open cycle gas turbine		
DNZ	Domestic Net Zero	Ofgem	Office of Gas and Electricity Markets		
ENTSO-E	European Network of Transmission System Operators for Electricity	ORE	Offshore renewable energy		
ETS	Emissions Trading Scheme	PHES	Pumped hydro energy storage		
EV	Electric vehicle	RES-E	Renewable electricity generation		
Fe-air	Iron-air	ROI	Republic of Ireland		
FES	Future Energy Scenario report (published by National Grid ESO)	SEM	Single Electricity Market		
		SEMC	SEM Committee		
		SS	Self-Sustaining (TES 2023 scenario)		

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KEY MESSAGES

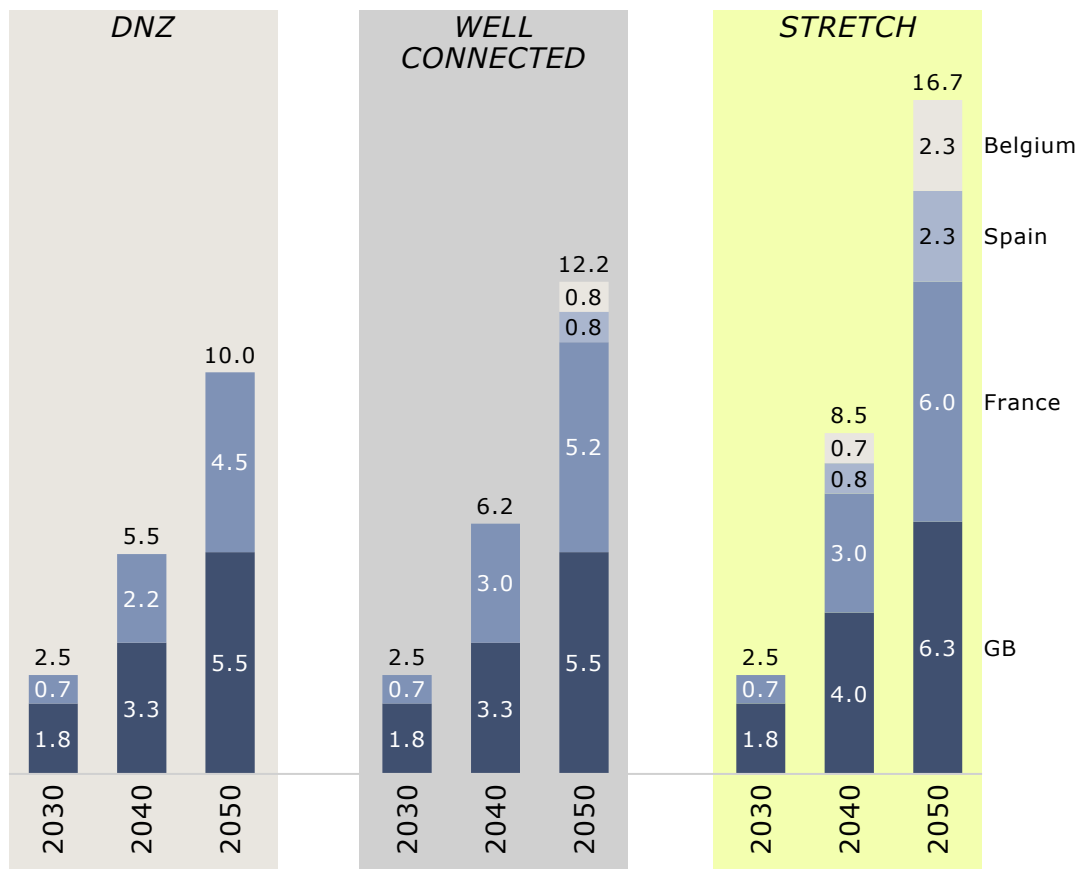
7 scenarios have been modelled in WS1 and are further examined in WS2 with a focus on interconnection

Scenario Name	Domestic demand	Offshore MW	IC MW	Other capacity mix	Connected markets
1. Domestic Net Zero (DNZ)	TES Self-Sustaining (SS)	TES SS	10GW by 2050 (15% of Ireland installed generation capacity)	TES SS with additional H2-fuelled capacity	Aligned with TYNDP 2022 Global Ambition (power sector net zero by 2050)
2. 37GW ORE DNZ IC	DNZ	37GW	DNZ	DNZ	DNZ
3. 37GW ORE Well Connected IC	DNZ	37GW	Well Connected (12.2GW by 2050)	DNZ	DNZ
4. 37GW ORE Stretch IC	DNZ	37GW	Stretch (16.7GW by 2050)	DNZ	DNZ
5. 50GW ORE DNZ IC	DNZ	50GW	DNZ	DNZ	DNZ
6. 50GW ORE Well Connected IC	DNZ	50GW	Well Connected	DNZ	DNZ
7. 50GW ORE Stretch IC	DNZ	50GW	Stretch	DNZ	DNZ

KEY MESSAGES

Different levels of cross border electricity interconnection capacity have been tested in the different scenarios with up to 17GW in the Stretch pathway

IRELAND ELECTRICITY INTERCONNECTOR PATHWAYS (GW)



RATIONALE

- The underlying assumption of both the DNZ and Well Connected electricity interconnector pathways is that Ireland meets the European interconnector target of 15% of installed generation capacity. We have assumed that this applies to grid-connected generation capacity for the purposes of this study.
- For the Well Connected pathway, we assume the installed generation capacity base is the capacity from the 37GW offshore wind pathway. The additional on-grid capacity of this pathway results in c.2GW of additional interconnection in the Well Connected interconnector pathway by 2050.
- For the Stretch pathway, we have increased the interconnection percentage to 20% from 15%. This is then combined with the additional offshore wind capacity from the 50GW offshore wind pathway to derive a pathway with 66% more electricity interconnection by 2050 than in the underlying DNZ scenario.

We have identified four key messages to take away and two conclusions from this report

MAIN MESSAGES

- 1. The economic viability interconnection capacity in the DNZ scenario is low**
 By 2050, around 10GW of interconnector capacity is assumed to be built in the DNZ scenario, but this has low profitability. Without the additional offshore wind, as explored in the 37GW and 50GW ORE scenarios, in the DNZ case there is not enough cheap energy to export from Ireland to support the level of assumed interconnection capacity on a merchant basis.
- 2. In the 37GW and 50GW ORE scenarios, interconnector economics are generally improved, looking most promising for connections to GB and then France, with links to Belgium and Spain less attractive options**
 In the 37GW and 50GW ORE scenarios, potential congestion rent revenues are reasonably comparable for links to the different connected markets i.e. GB, France, Belgium and Spain. However, taking into account the interconnector CAPEX, which varies significantly with cable distance, GB then France appear the most promising markets.
- 3. Congestion rent revenues are reduced the greater the level of interconnection assumed**
 In the Stretch scenario, 17GW of interconnector capacity is built in total by 2050, compared to 12GW in the Well connected and 10GW in the DNZ cases respectively. Comparing the 37GW Well connected to the 37GW Stretch indicates a decrease of more than 30% in the revenues for a new link with GB. As more interconnection capacity is built, the price spread between the two connected markets reduces, which adversely impacts the congestion rent revenues of all interconnection.
- 4. Increasing interconnection capacity brings socio-economic welfare benefits for Ireland, but negative impacts in the connected markets in most cases**
 Increased interconnection capacity brings socio-economic welfare¹ benefits to Ireland, driven by higher producer surplus for Ireland as the offshore wind avoids curtailment and can export to the connected markets. However, GB, France and Spain all see dis-benefits overall, with positive consumer surplus impacts stemming from cheaper electricity prices being more than outweighed by reductions in producer surplus.

CONCLUSIONS

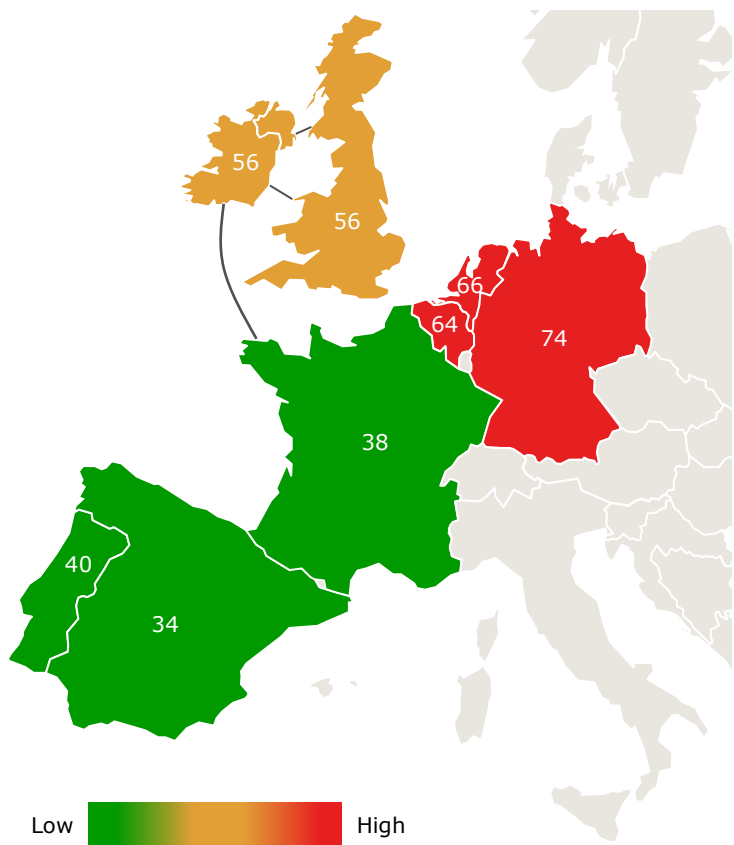
- 1. 5-6GW of interconnection from Ireland to each of GB and France could be economically viable in the 37GW, 50GW ORE scenarios, but not in the DNZ scenario, while interconnection from Ireland to either Belgium or Spain appears likely to be economically challenging in general**
- 2. While Ireland may expect socio-economic welfare benefits from increased interconnection, each of GB, France and Spain look set for negative impacts creating a challenging environment for progression of projects**

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

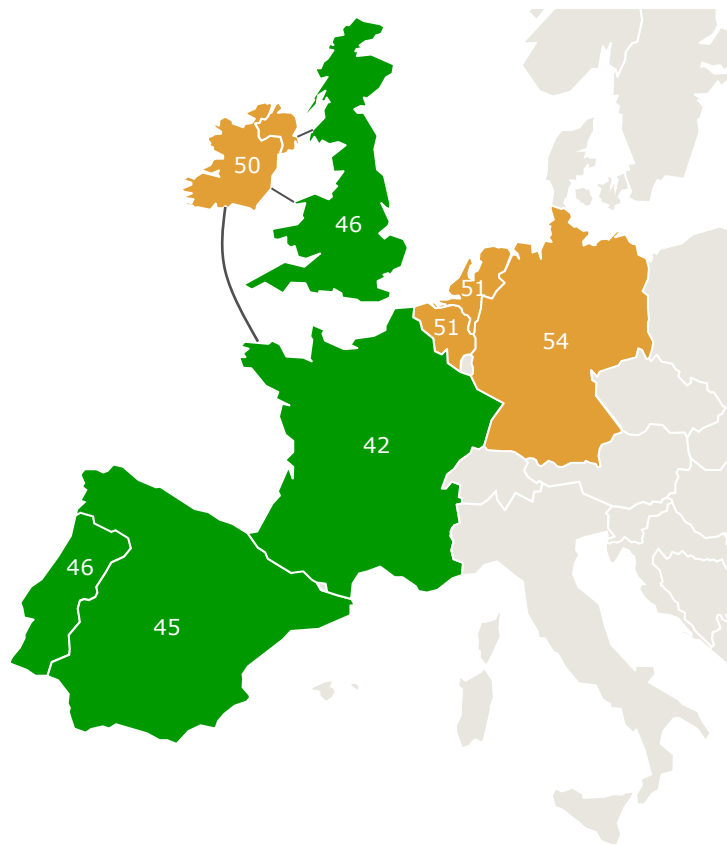
KEY MESSAGES

In the DNZ scenario, SEM baseload power prices are mid-range compared to other markets in 2030 before becoming the lowest by 2050

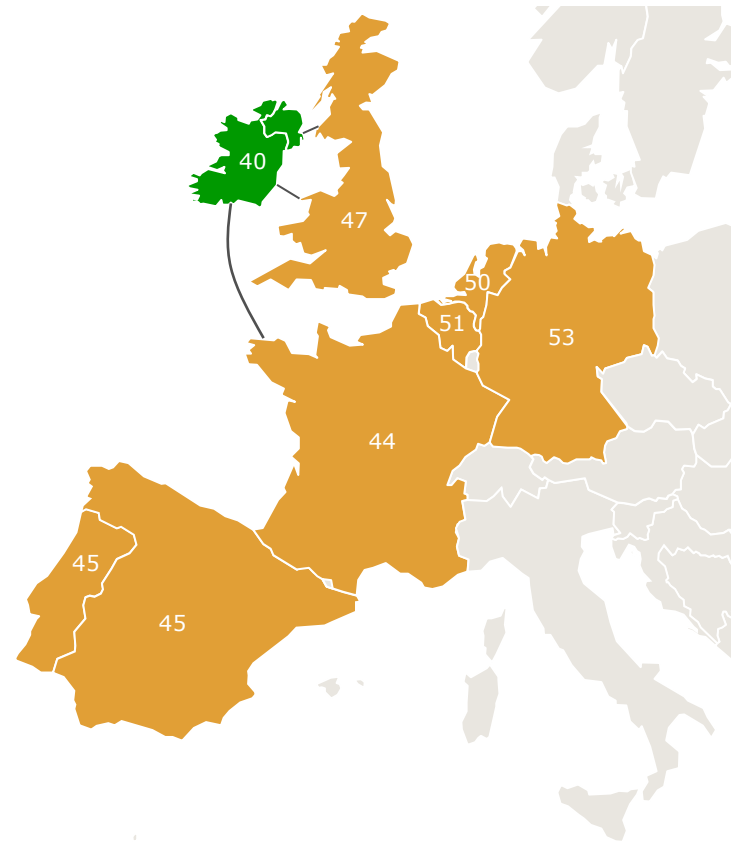
**2030 BASELOAD POWER PRICE
(€/MWH, REAL 2022 PRICES)**



**2040 BASELOAD POWER PRICE
(€/MWH, REAL 2022 PRICES)**



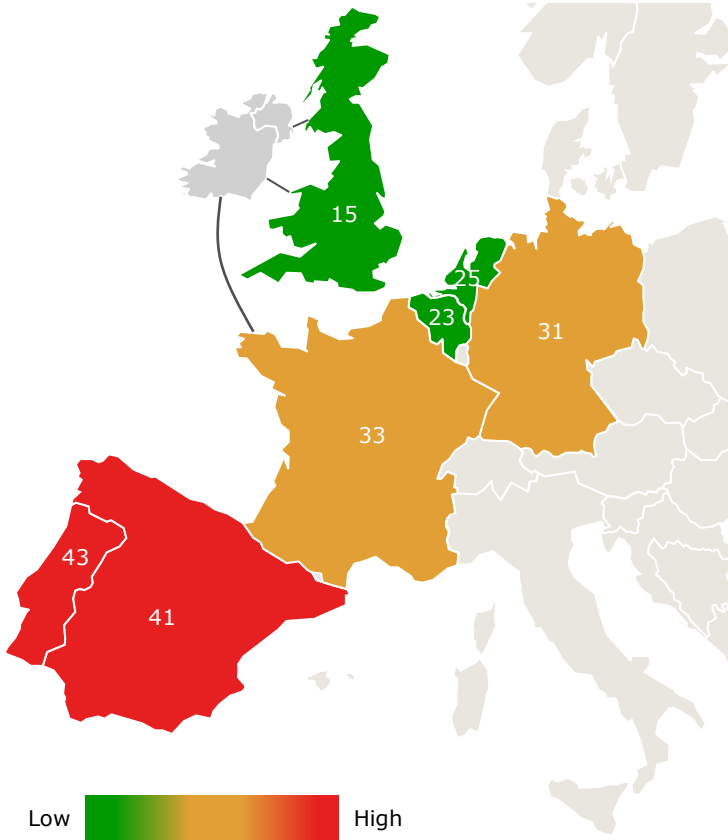
**2050 BASELOAD POWER PRICE
(€/MWH, REAL 2022 PRICES)**



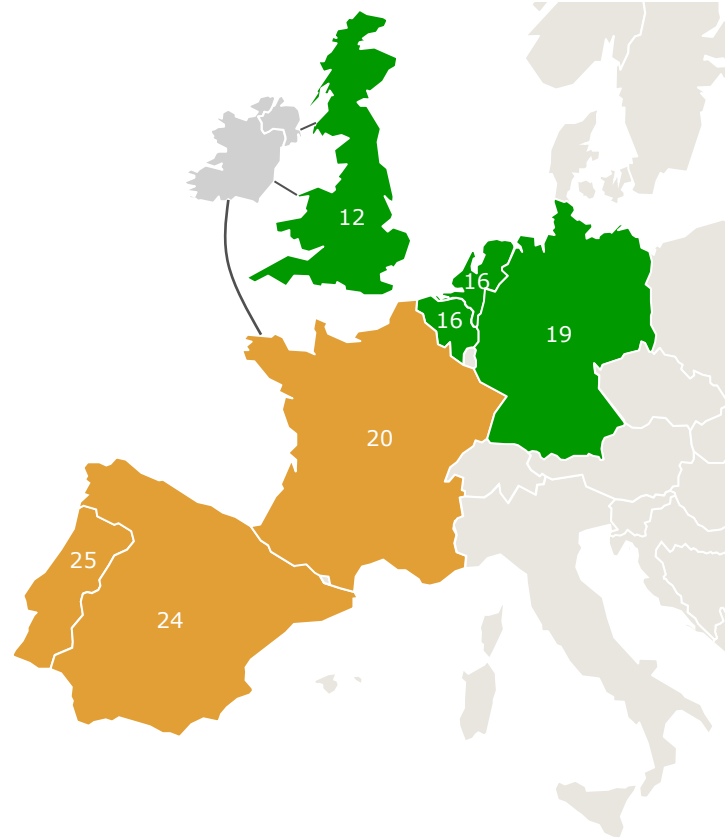
KEY MESSAGES

Average hourly absolute spreads between SEM-other markets are wide in DNZ case and, although narrowing, remain in the range €9-17/MWh by 2050

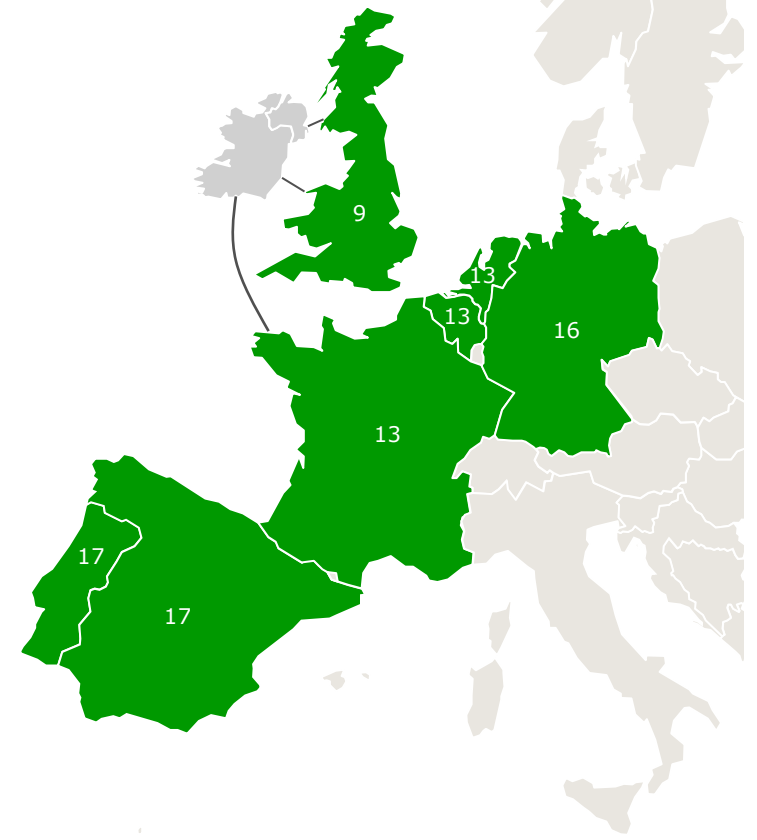
2030 AVERAGE ABSOLUTE HOURLY POWER PRICE DIFFERENCE (€/MWH, REAL 2022 PRICES)



2040 AVERAGE ABSOLUTE HOURLY POWER PRICE DIFFERENCE (€/MWH, REAL 2022 PRICES)



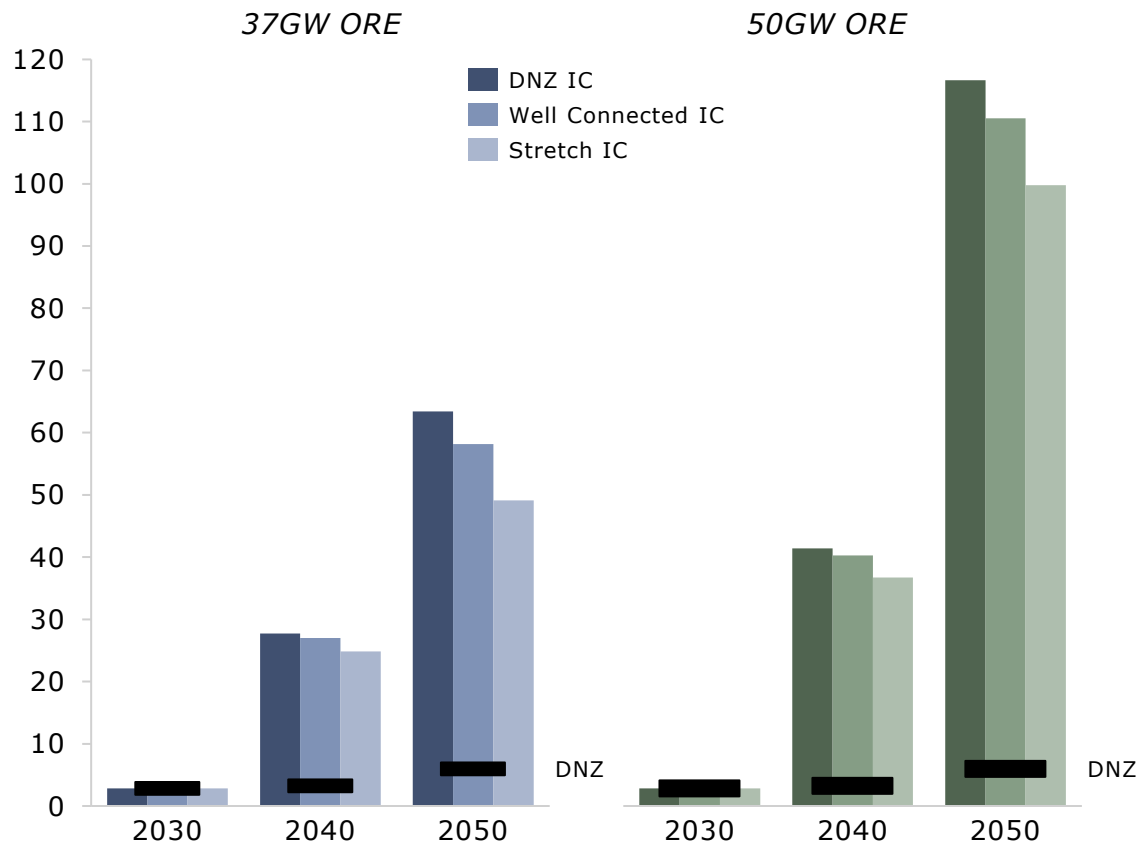
2050 AVERAGE ABSOLUTE HOURLY POWER PRICE DIFFERENCE (€/MWH, REAL 2022 PRICES)



KEY MESSAGES

In both the 37GW and 50GW ORE pathways, surplus energy production is very substantial

IRELAND ORE SURPLUS (TWH)



Note: Contribution of off-grid ORE is included above.

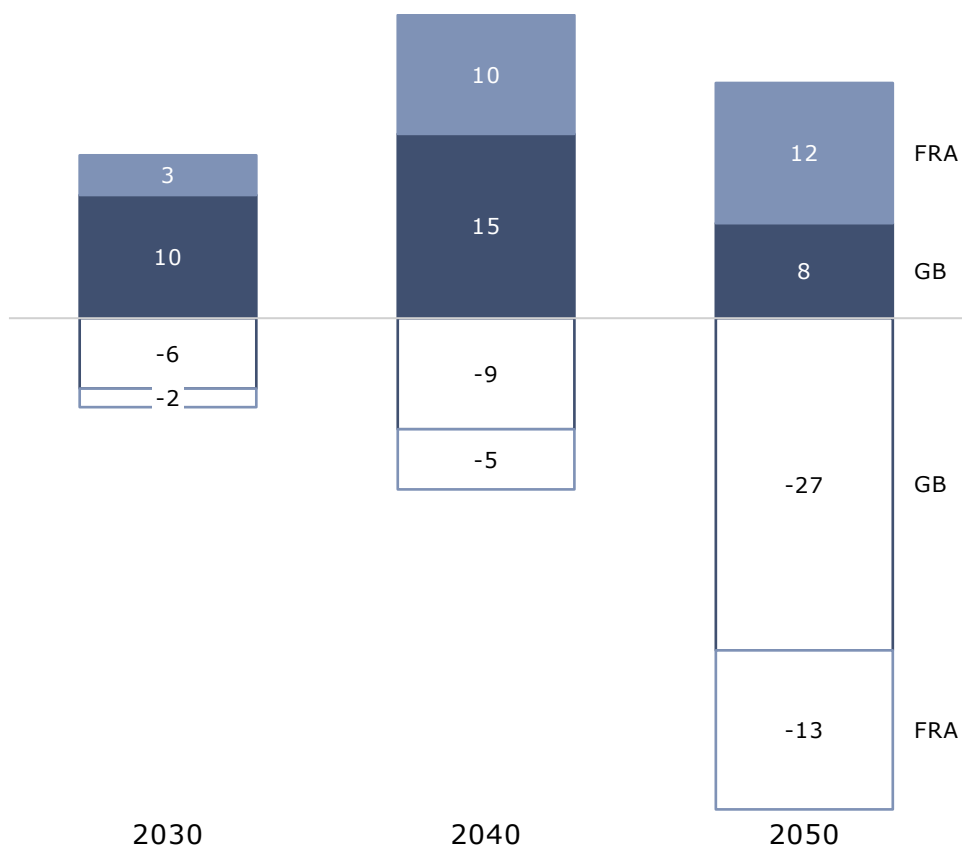
DISCUSSION

- After exporting as much energy as possible via electricity interconnectors, this study suggests the residual ORE surplus in the 37GW and 50GW ORE pathways is very substantial.
 - In the 37GW ORE pathway, regardless of the amount of interconnection built, ORE surplus amounts to around double today's power demand in Ireland by 2050. Compared to expected 2050 domestic power demand of c.135TWh, ORE surplus is a little under half of annual demand.
 - Turning to the 50GW ORE pathway, ORE surplus is 100TWh in the Stretch IC pathway, not far from projected 2050 domestic demand. To put it another way, the amount of ORE surplus would be sufficient to power Ireland on its own.
- Irish ORE surplus falls as electricity IC is added as some of the surplus can be sold in adjacent power markets.

KEY MESSAGES

As a result of the price dynamics, the SEM transitions from being a net importer of power to a significant net exporter by 2050 in the DNZ scenario

**SEM INTERCONNECTOR IMPORTS / (EXPORTS)
(TWH)**



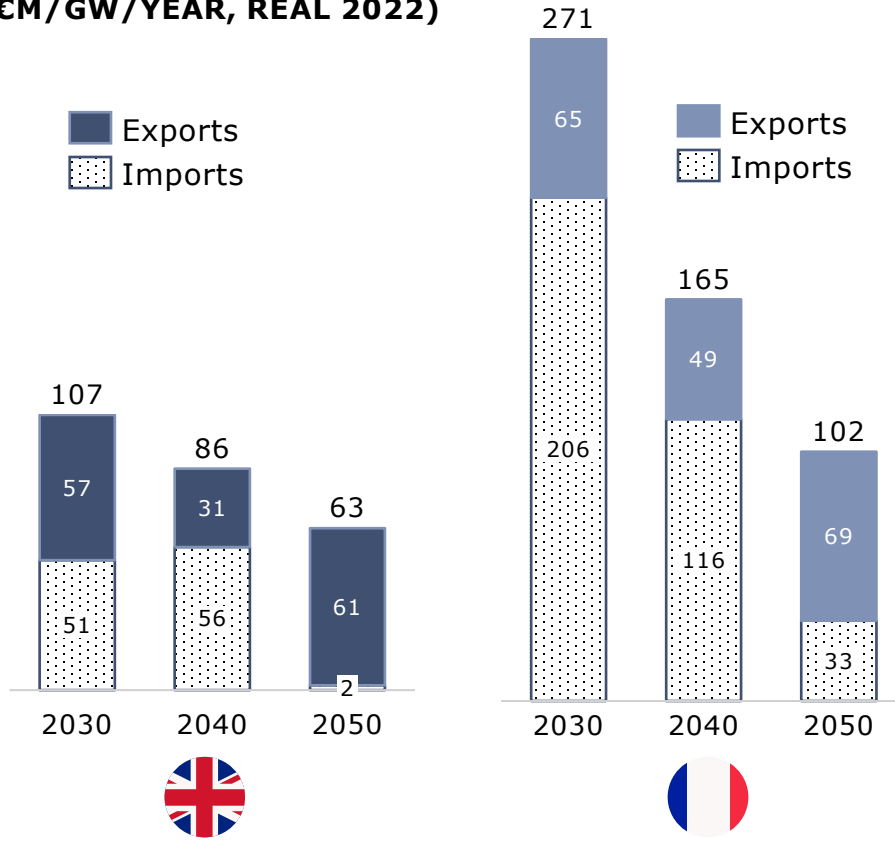
DISCUSSION

- In 2030 and 2040, the SEM is a net importer of power from GB and France. Thus, even in a 2040 world where there is 42GW of wind / solar capacity across the island of Ireland and 10GW of offshore wind, the SEM imports c.10TWh of electricity in hours when power prices in GB and France are cheaper than they are in Ireland.
- In 2050, because of assumed renewables capacity growth exceeding demand growth, there are many more hours where power prices in the SEM are very low and there is more opportunity to export power to GB and France. This results in the SEM becoming a net exporter in 2050.
- Imports / exports are typically skewed towards GB. This can be attributed to both higher IC capacity with GB (c.1GW in all years) as well as lower assumed losses on interconnectors with GB (<3%) than those with France (c.5%). The latter means spreads between the SEM and France need to be larger than spreads between the SEM and GB in order for the interconnectors to be utilised.
- Consequently, despite there generally being larger spreads between the SEM and France in 2050 than between the SEM and GB, there are more flows with GB.

KEY MESSAGES

While the share of export revenues grows, average congestion rent per GW of IC decreases over time in the DNZ case due to increased interconnection

AVERAGE CONGESTION RENT REVENUES PER GW IC IN THE DNZ (€M/GW/YEAR, REAL 2022)



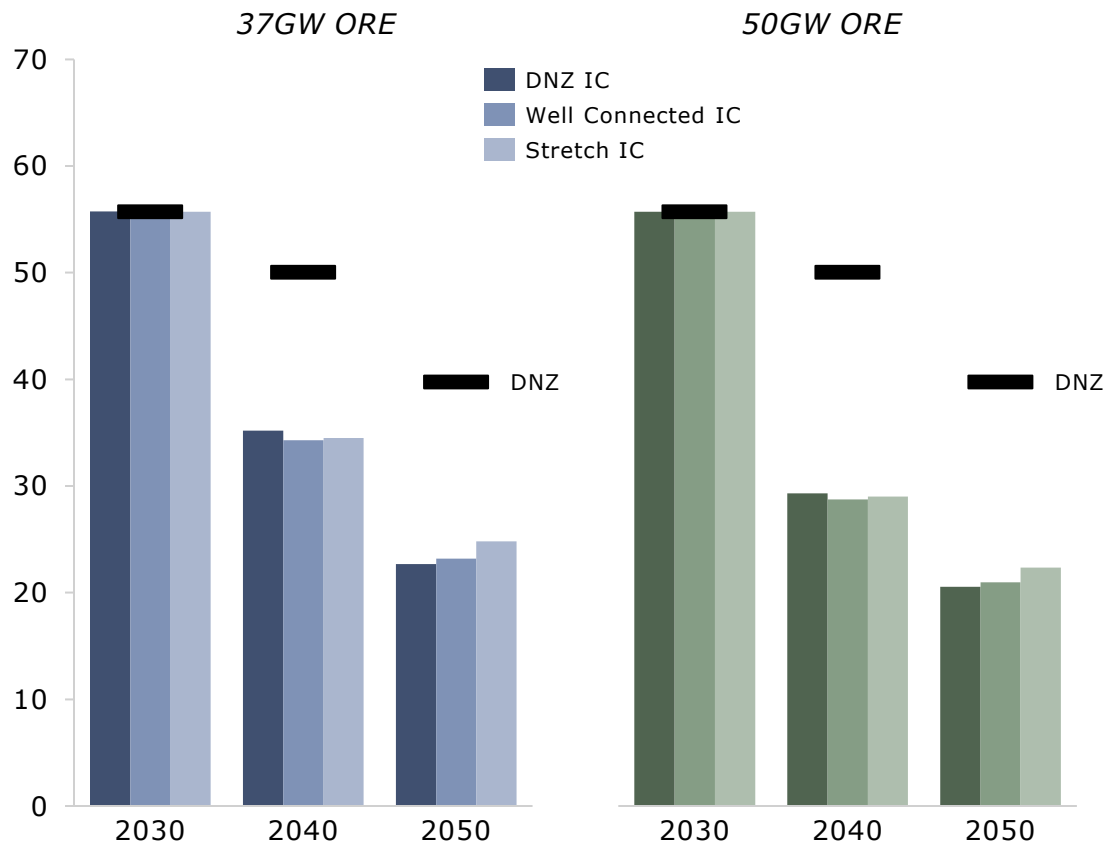
DISCUSSION

- The congestion rents presented here represent the average revenues per GW of IC between the SEM and the connected country with capacity changing over time e.g. 700MW in 2030 and 3,750MW in 2050 for FRA to the SEM.
- The dotted part of the bars represents the congestion rent from importing to the SEM and solid blue part of the bars represents the congestion rent from exporting from the SEM. We can see that the dotted part reduces significantly for France over the years and that for GB it becomes close to zero by 2050. For GB, this stems from the fact that GB prices are consistently higher than in the SEM on an hourly basis by 2050 and there is not much room for export from GB to the SEM.
- On the other hand, for both GB and FRA, the solid blue part remains relatively important indicating the congestion rent value of renewables export potential even in the DNZ scenario.

KEY MESSAGES

With much more ambitious offshore wind buildout, Irish power prices drop significantly by 2040 and 2050 in the 37GW and 50GW ORE scenarios

SEM BASELOAD WHOLESALE POWER PRICE (€/MWH, REAL 2022 PRICES)



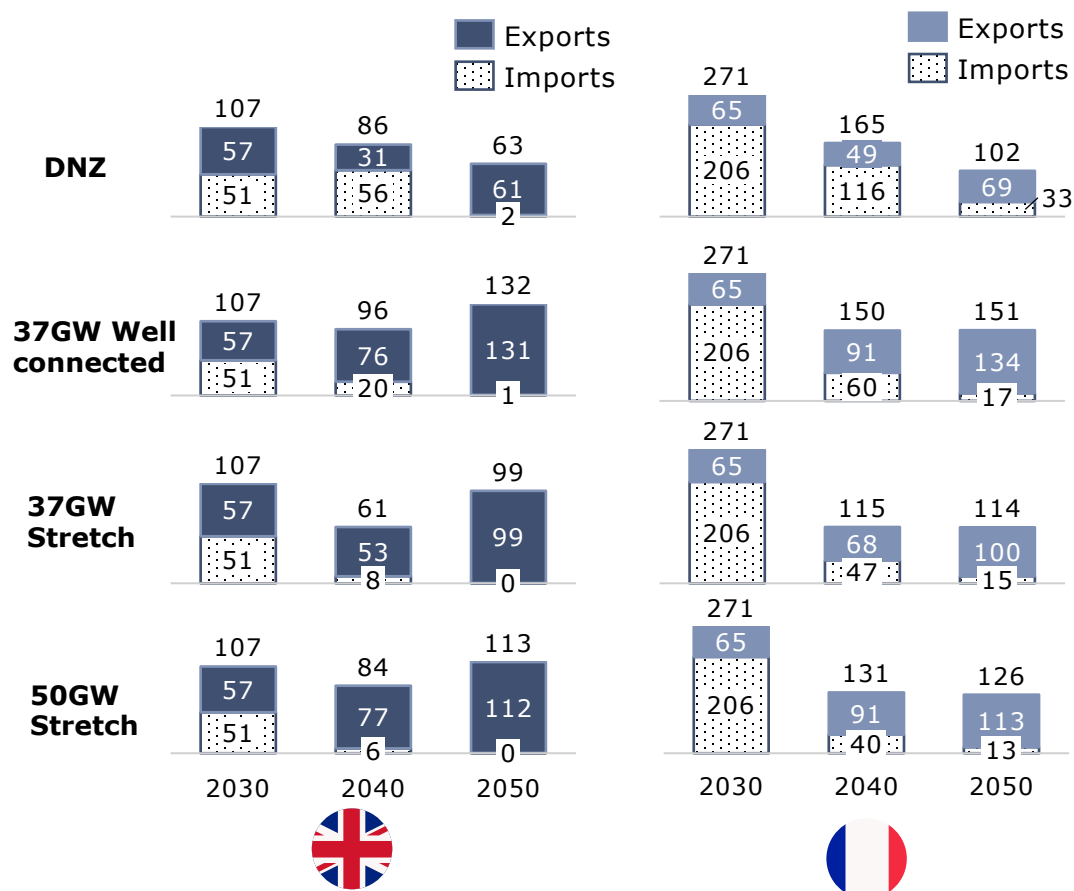
DISCUSSION

- Going from 16GW of offshore wind capacity to 37GW results in significant drops in the cost of baseload power, driven by an increasing number of low (or even zero) priced hours. By 2050, this study suggests the reduction in power prices could be c.€15/MWh.
- Adding an additional 4GW of grid-connected offshore wind capacity in the 50GW ORE pathway results in wholesale power prices declining a little more, but differences vs. the 37GW ORE pathway are small. This is a result of most of the additional capacity in the 50GW ORE pathway being off-grid.
- In 2050, increasing electricity IC capacity (i.e. the difference between the sets of blue bars or between the sets of green bars) tends to increase power prices a little as it equalises prices to some extent between a very low priced SEM and more expensive adjacent markets. This impact is very muted in 2040, when price differentials between adjacent markets are limited.

KEY MESSAGES

Congestion revenues are expected to evolve over time reflecting the level of renewable energy to export and reduce with more interconnection

AVERAGE CONGESTION RENT REVENUES PER GW IC (€M/GW/YEAR, REAL 2022)



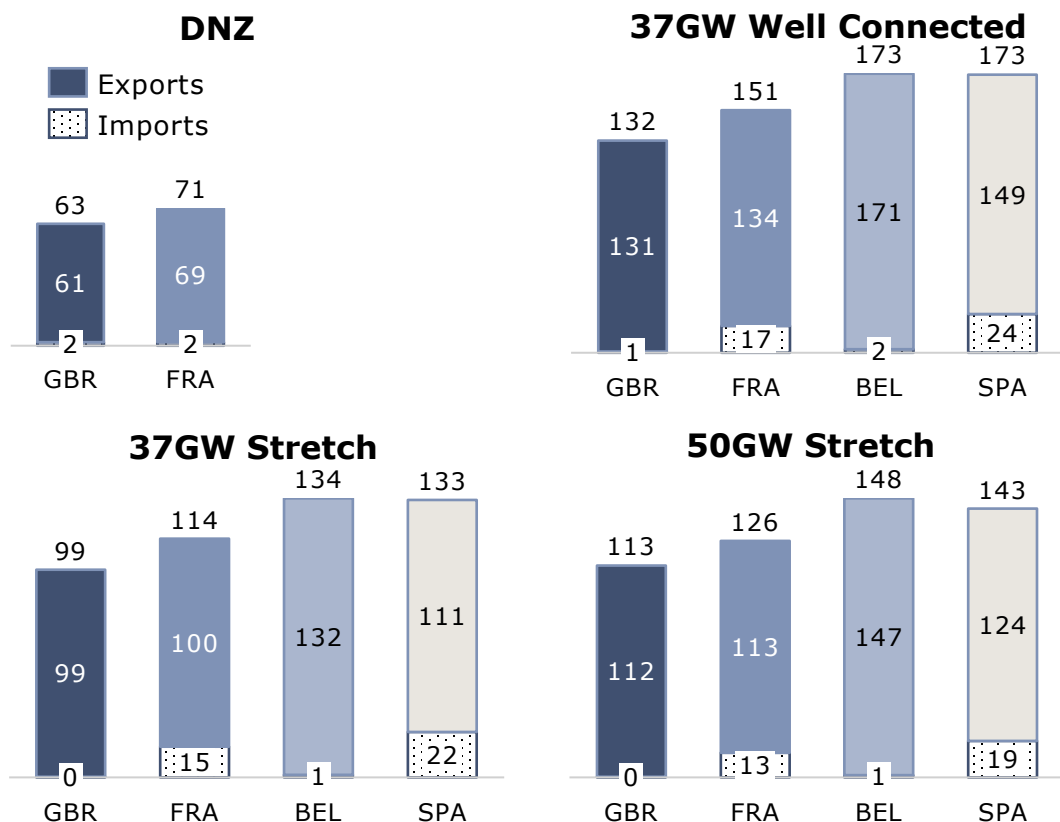
DISCUSSION

- 2030 is the same as the DNZ case for all scenarios as the DNZ is the starting point for the rest of the seven scenarios. The focus here is on 4 scenarios: DNZ, 37GW Well connected, 37GW Stretch, 50GW Stretch.
- Relative to the DNZ case, there is a significant increase in the average congestion rent by 2050 in the other scenarios. This is particularly the case for the solid blue parts of the bars, which represent the revenues from export from the SEM stemming from the increased offshore wind generation and cheap prices.
- Comparing the 37GW Well Connected to the 37GW Stretch highlights the downward impact on average congestion rents of further increasing IC capacity. This is significant for both GB and France. In the case of France, in 2050 there is a decrease in revenues of roughly 25% (i.e. €114m in 37GW Stretch compared to €151m in 37GW Well Connected).
- Comparing the 37GW Stretch to 50GW Stretch indicates the export value of the extra wind at the highest level of assumed IC capacity. This indicates that there is a slight increase in average congestion rent revenues (e.g. for GB, an increase of around 10% by 2050).

KEY MESSAGES

Similar range of congestion revenues are expected for the different connected countries with a slight upside for Belgium and Spain

AVERAGE CONGESTION RENT REVENUES PER GW IC IN 2050 (€M/GW, REAL 2022)



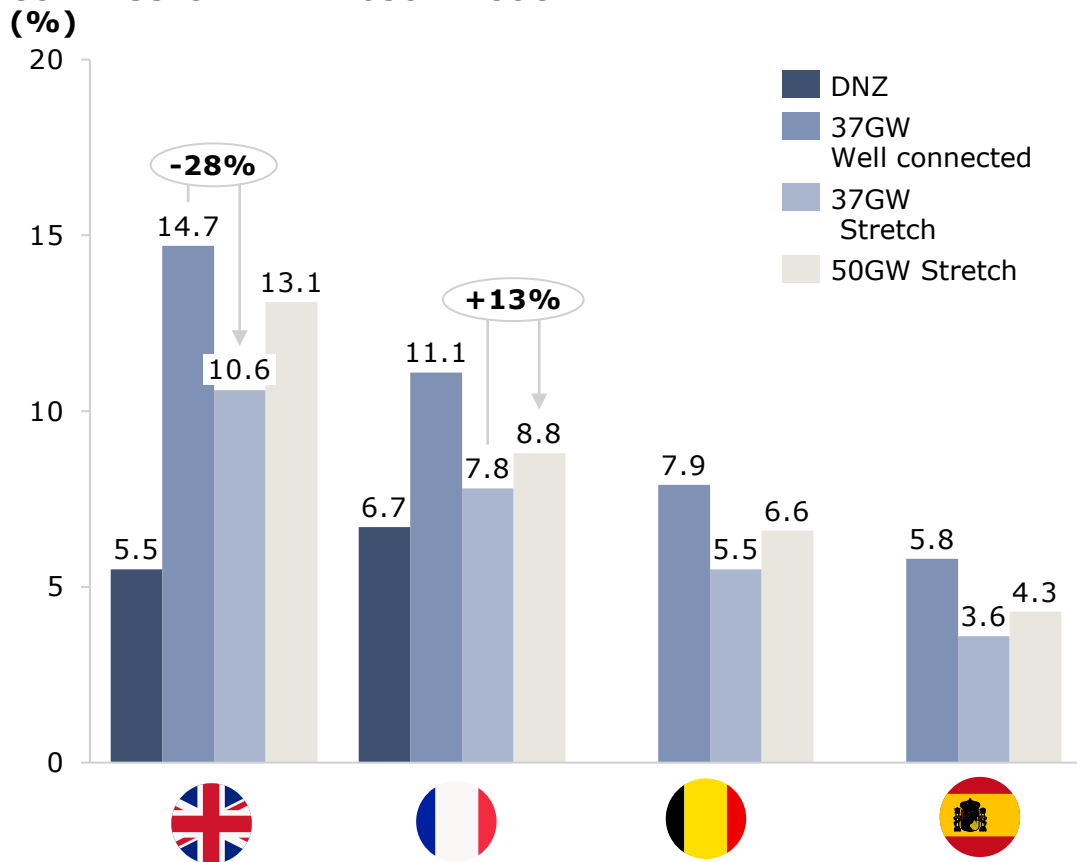
DISCUSSION

- The congestion rent values shown in the chart represent the average revenues per GW of IC capacity between the SEM and the connected country for 2050. In the DNZ IC assumptions, there are no interconnectors between Ireland and Belgium/Spain.
- Across all the countries and scenarios, the large majority of congestion revenue in 2050 comes from exports from Ireland linked to extra wind generation. The congestion rent value of exports from SEM is represented by the solid blue parts of the bars.
- The interconnection with France and Spain does display some congestion revenues coming from import into SEM, linked to extra solar generation in these countries.
- Consistent patterns can be observed across the scenarios, with the average congestion rent revenues decreasing the greater the IC capacity i.e. from DNZ IC to Well Connected to Stretch. This stems from the fact that as IC capacity grows, price spreads decrease, which ultimately reduces the congestion rent potential of all IC.

KEY MESSAGES

Considering the investment needed, financial returns looks more promising for IC connecting to GB then France, with Belgium and Spain less attractive

AVERAGE INTERNAL RATE OF RETURN (IRR) OF IRISH IC COMMISSIONED IN 2050 BY COUNTRY



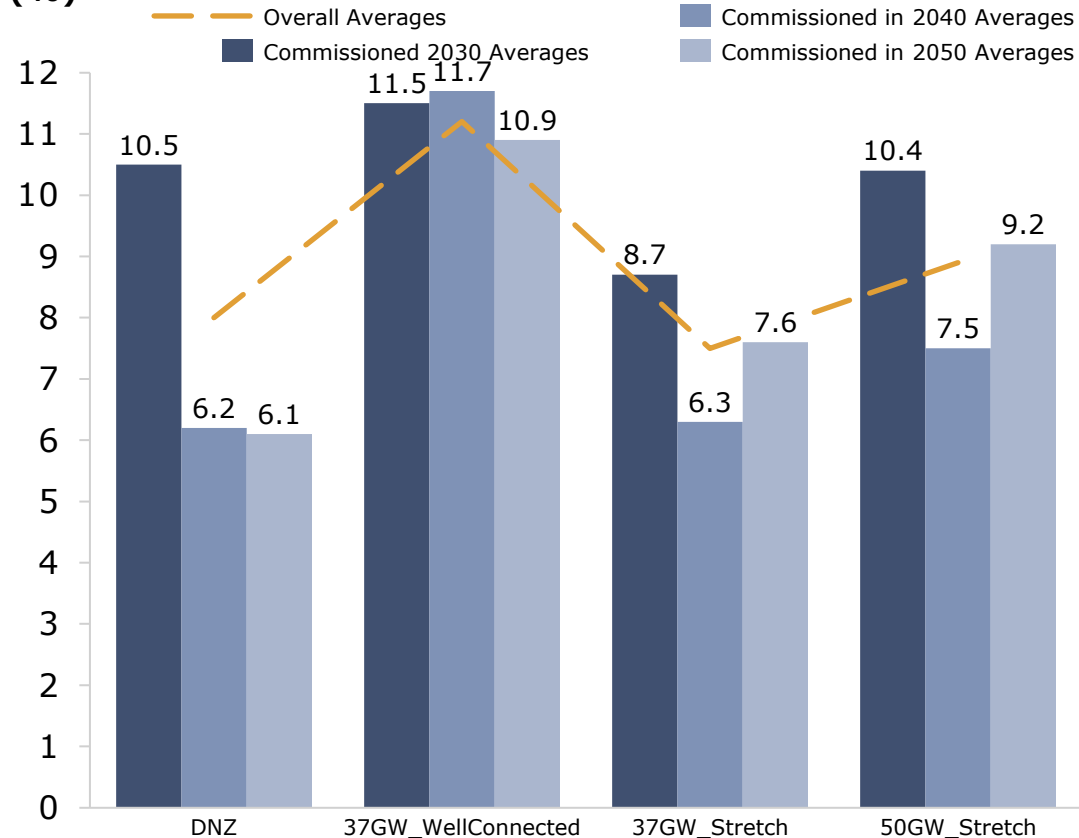
DISCUSSION

- The IRR reflects a combination of the IC congestion rents and the investment cost which varies significantly with the assumed cable distance between Ireland and the connected market. GB ICs have the highest IRRs in the 37GW/50GW+ scenarios as the congestion revenues are similar to the other markets but the CAPEX is significantly lower due to the shorter cable distance e.g. GB compared to Spain.
- In the DNZ case, only GB and France are connected to Ireland. For both markets, this case sees the lowest IRRs.
- For all connecting markets, the 37GW Well Connected case sees the largest IRRs.
- Increasing interconnection, which is observed between the 37GW Well Connected and the 37GW Stretch, shows a substantial decrease in IRRs e.g. -28% for GB due to the cannibalisation effect of increased IC capacity reducing average congestion rents on all IC.
- In the 50GW Stretch scenario, additional offshore wind resources further push down SEM prices, which increases congestion revenues thereby increasing IRRs e.g. +13% for French IC.

KEY MESSAGES

Returns on IC investment look good overall in all scenarios, with significant variations depending on year commissioned and scenario

AVERAGE INTERNAL RATE OF RETURN (IRR) OF IRISH IC BY SCENARIO AND COMMISSIONED YEARS (%)



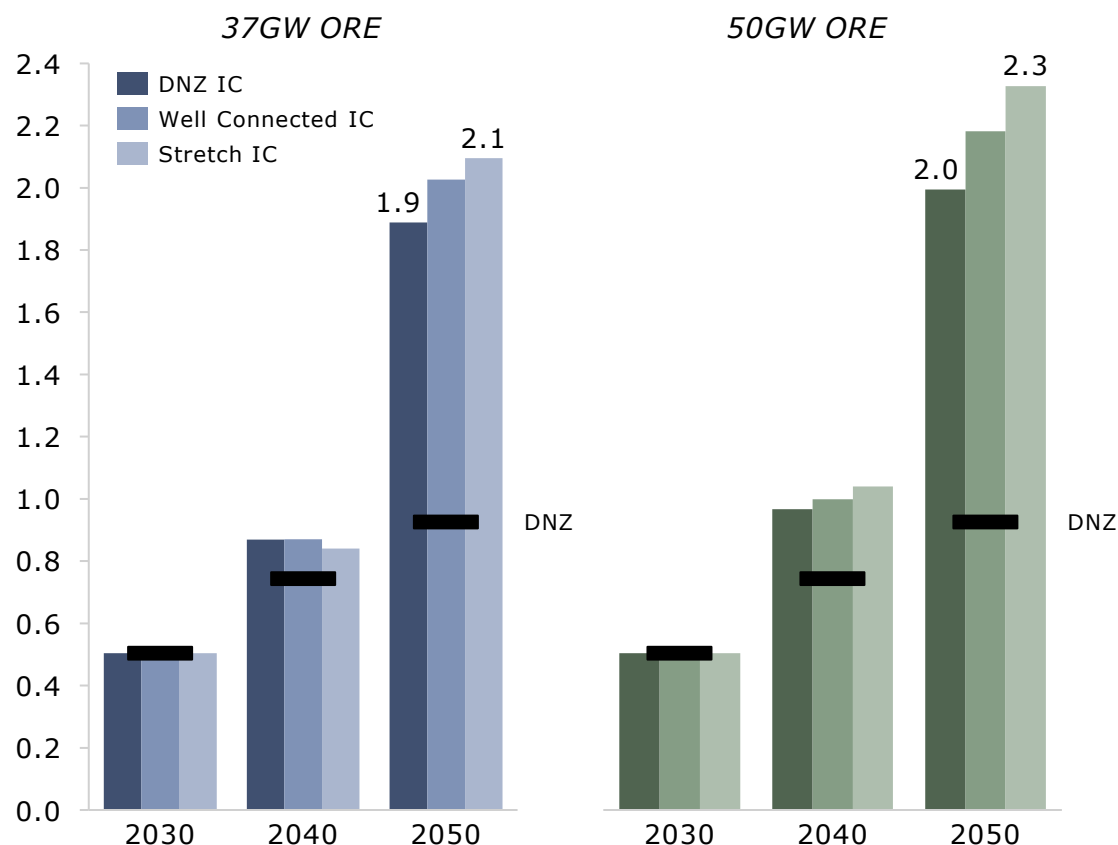
COMMENTARY

- In the DNZ case, limited amount of offshore wind to export from Ireland means that the IRRs in 2040-2050 becomes lower compared all the other scenarios.
- Among the four scenarios shown here, the 37GW Well Connected case presents the highest IRRs on average, potentially indicating a better balance in terms of the ratio between the available wind to export and the level of IC.
- In 2030, there is more congestion rent per IC as there is less interconnection and there is both revenues from export from and import to the SEM whereas by 2050, the revenues are concentrated on exports from SEM. Increased IC means there is a cannibalisation effect as the price spread with the connected market decreases - this effect is captured by comparing between the Well Connected and the Stretch 37GW pathways.

KEY MESSAGES

Total congestion revenues double in 37GW ORE compared to DNZ scenario and increase by 4-5 times between 2030 and 2050 to reach ~ €2bn per year

TOTAL CONGESTION RENT FROM IRISH INTERCONNECTION (€ BILLIONS, REAL 2022 PRICES)



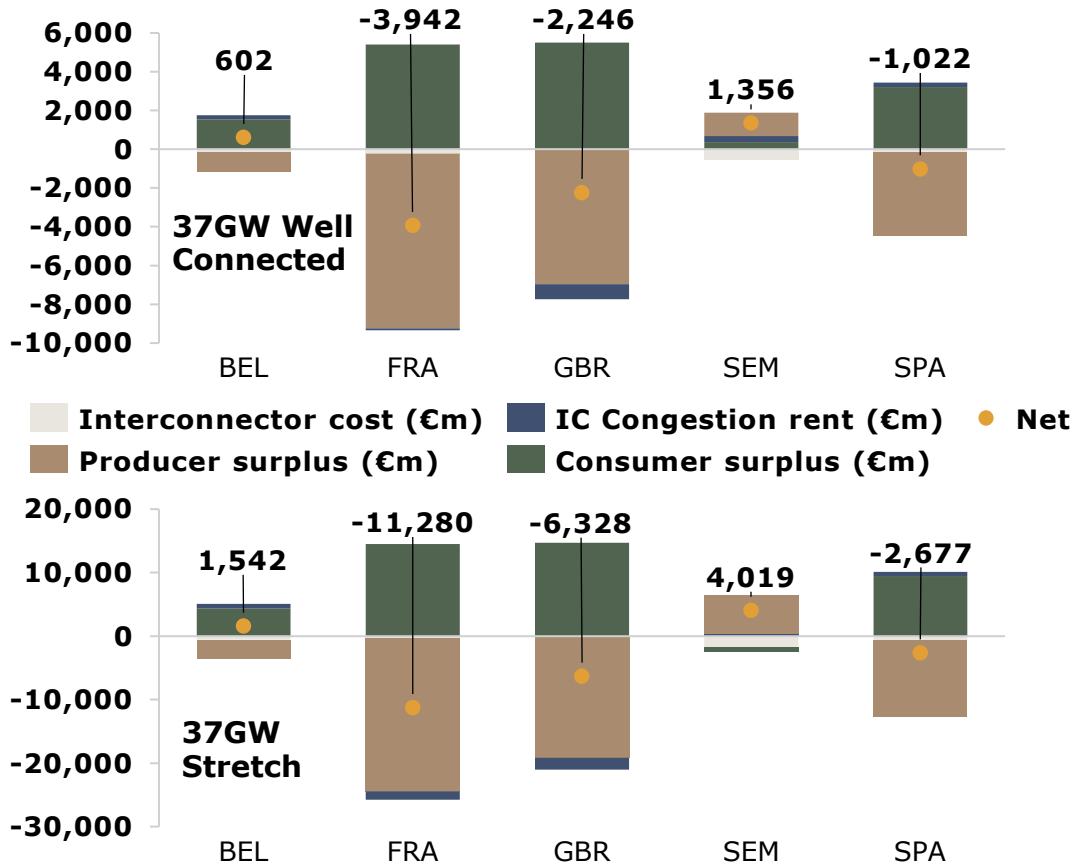
DISCUSSION

- The graph displays the total congestion rent which includes both revenues from Ireland to the connected country. There is an expectation that there would be a split of revenues between the two connected countries.
- Bringing additional wind combined with additional IC increases congestion revenues significantly compared to the DNZ case, with the biggest gap appearing in 2050 where there is twice as much total congestion revenue.
- Increasing IC capacity between the 37GW DNZ IC and Stretch IC cases slightly increases the total revenues by €0.2bn per year by 2050 thanks to additional flows. In the 50GW scenarios there is a slight increase to provide an additional €0.3bn per year by 2050 as there is more offshore wind output available to export.

KEY MESSAGES

With 37GW ORE, the overall socio-economic welfare impacts of increasing IC are overall positive for Ireland and Belgium but negative in aggregate

SOCIO-ECONOMIC WELFARE IMPACT COMPARED TO 37GW DNZ SCENARIO IN 2030-2055 (€M, REAL 2022 MONEY)



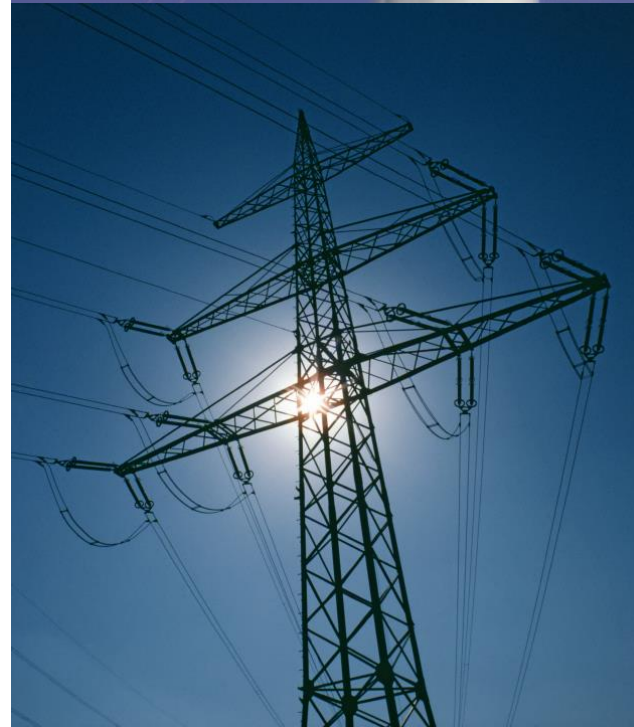
Note: 1) Contribution of off-grid ORE is included above. 2) Values shown on the chart represent Net SEW only

DISCUSSION

- Socio-Economic Welfare (SEW) impact analysis is a combination of different indicators, namely consumer surplus, producer surplus and IC congestion rent impacts, as well as IC cost. Positives value represent overall benefits for the country.
- Belgium and Ireland both have positive impacts overall, while the other countries are negatively impacted overall. This is consistent across both graphs and more amplified in the 37GW Stretch.
- While they have negative impacts overall, the connected markets all experience positive consumer surplus impact, however, in both 37GW Well Connected and 37GW Stretch scenarios.
- In comparison to the 37GW DNZ scenario, the upper left graph shows the SEW impacts of moving to the 37GW Well Connected scenario and the lower left graph shows the impacts of moving to the 37GW Stretch scenario.
- The calculations produce a net present value of the impacts over 25 years starting from 2030 with extrapolation between the modelled years 2030, 2040 and 2050. The IC cost represents the total CAPEX cost split 50:50 between the connected countries, with the cost divided over 20 years to get an annual cost. The congestion rent represents the total congestion rent revenues for connected markets split 50:50 between them. A discount rate of 4% is then applied to the period.

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This study examines the economic potential for ORE surplus via counterfactual analysis

COUNTERFACTUAL ANALYSIS

- Counterfactual analysis is one way of demonstrating cause and effect. It is frequently used as the analytical framework for cost-benefit analysis¹ in the energy sector.
- By creating scenarios that differ only along one dimension, counterfactual analysis can allow for causation to be attributed to this dimension.
 - For example, if you wanted to examine the benefits to consumers of developing wind power, you could construct a scenario with no wind generation capacity and an alternative with 10GW of wind generation capacity. Any differences could be attributed to the 10GW of additional wind in the alternative scenario.
- This study relies on counterfactual analysis to explore the economic potential for ORE surplus.

BASELINE SCENARIO FOR COMPARISON: DOMESTIC NET ZERO

- The baseline Domestic Net Zero (DNZ) scenario that has been developed for this study is a world that achieves net zero in Ireland by 2050 without a specific focus on generating an ORE surplus.
- This is a world of high renewables, significant electrification of the entire economy and a significant amount of offshore wind (21GW in total by 2050), albeit an amount that falls short of government targets for 2040 and 2050.

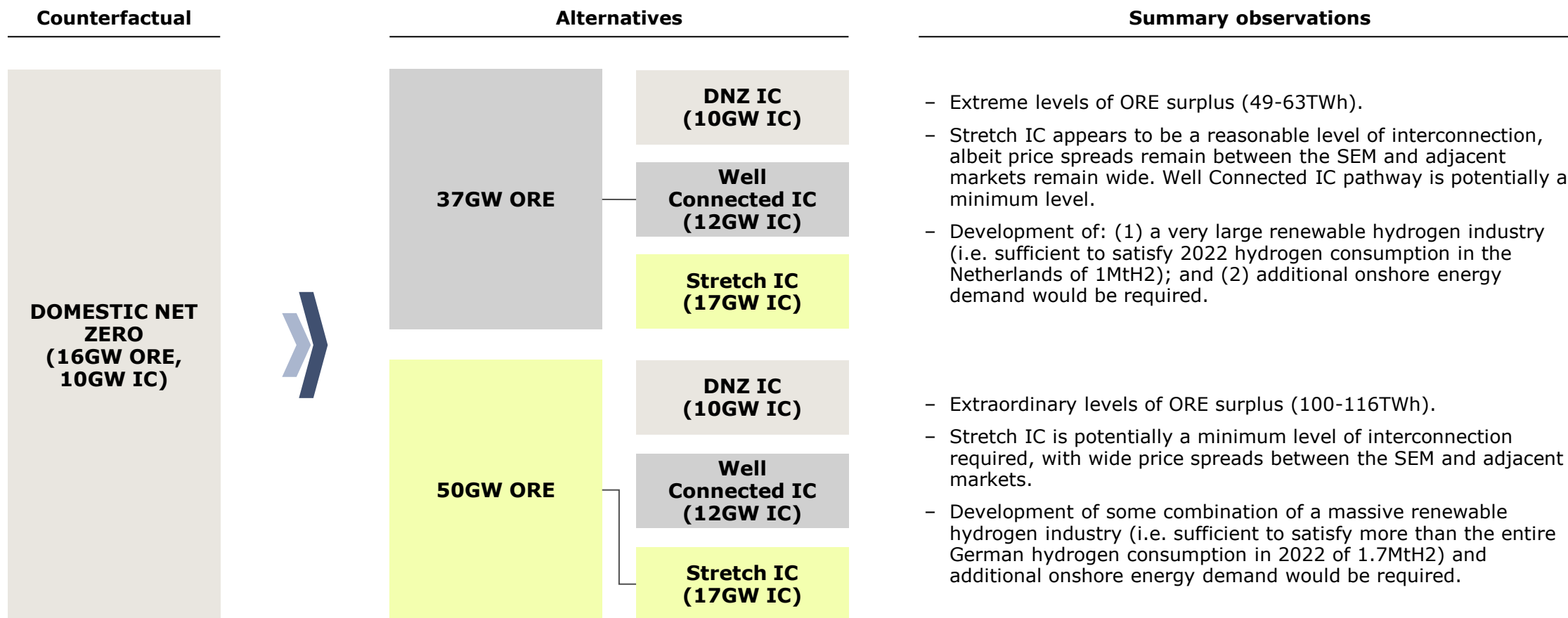
1. For example, ENTSO-E's entire Ten Year Network Development Plan (TYNDP) assessments or alternatively Ofgem's assessments for interconnectors seeking a cap and floor arrangement.

- For the avoidance of doubt, the DNZ scenario is not an expected or intended pathway and certainly should not be construed as DECC's baseline or reference scenario. Instead it is a plausible point of comparison to explore the economic potential of varying export-led scenarios.

ALTERNATIVE SCENARIOS

- The alternative scenarios explored in this study differ from the DNZ scenario in the amount of offshore wind and electricity interconnection.
- We have explored two alternative offshore wind pathways:
 - 37GW. This pathway sees offshore wind capacity reach the Government's targets of 20GW of installed capacity by 2040 and 37GW by 2050.
 - 50GW. This pathway represents a more aggressive target that sees capacity reach 25GW by 2040 and 50GW by 2050.
- We have also investigated two levels of electricity interconnection:
 - Well Connected. This pathway sees electricity interconnection reach 15% of total installed generation capacity in Ireland in the 37GW offshore wind scenario, equivalent to a little over 12GW.
 - Stretch. This pathway sees interconnector capacity reach 20% of total installed generation capacity in Ireland in the 50GW offshore wind scenario, equivalent to almost 17GW.

7 scenarios have been modelled: the underlying DNZ scenario and six combinations of offshore wind and interconnection pathways

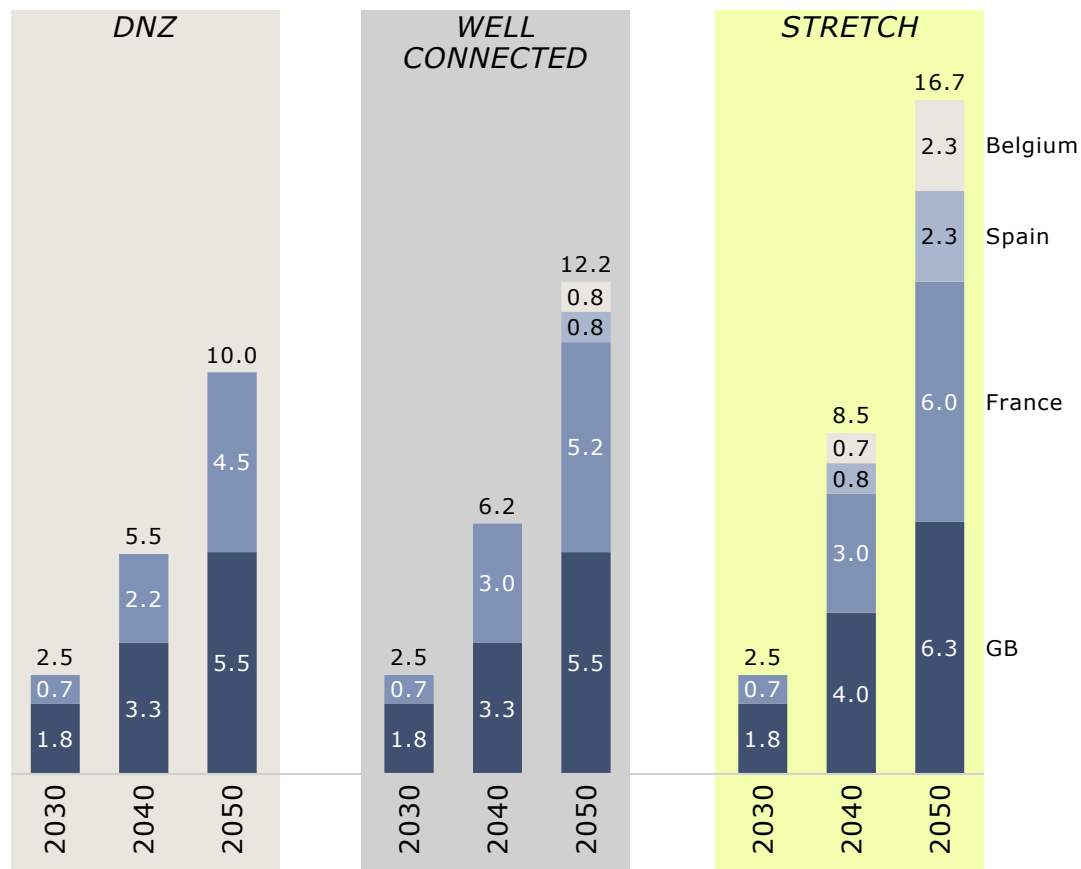


Note: Capacities in parentheses indicate 2050 values. Links between ORE and IC pathways indicate the ORE pathway the IC scenario has been sized against.

1. When comparing the difference in annual average baseload wholesale price across markets.

Cross border electricity interconnection capacity of up to 17GW has also been investigated

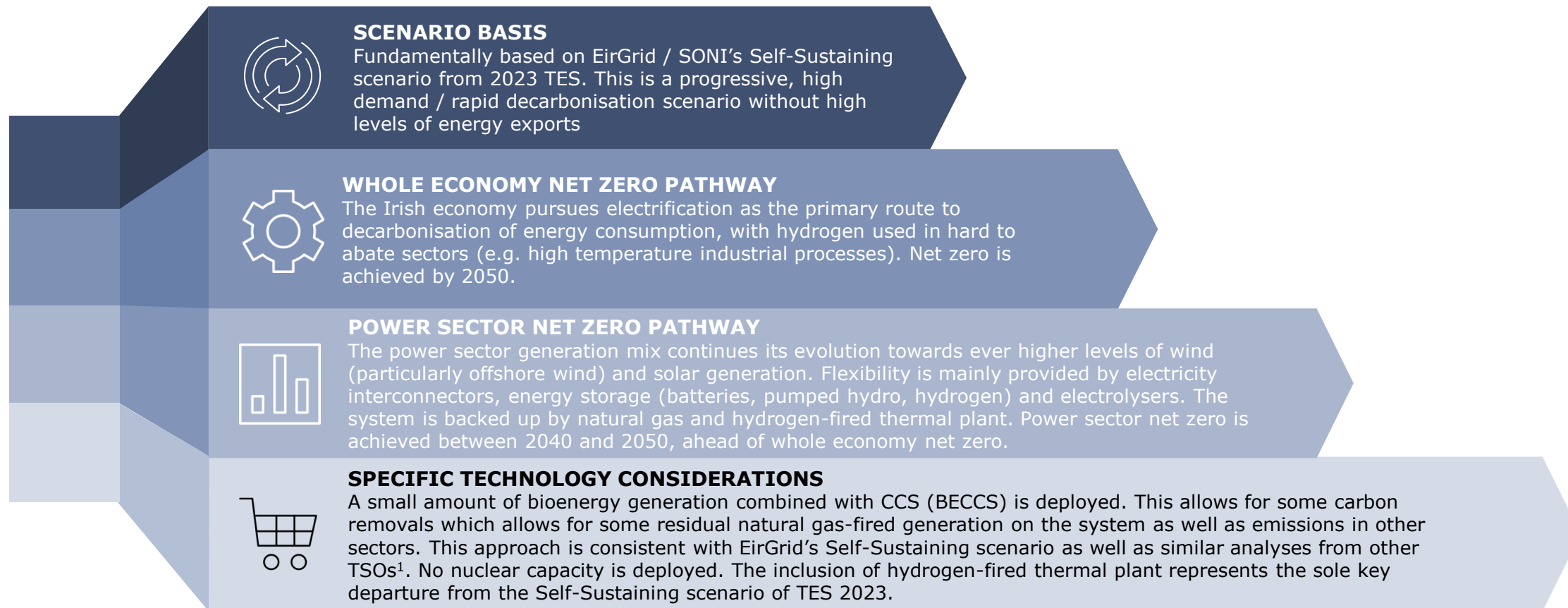
IRELAND ELECTRICITY INTERCONNECTOR PATHWAYS (GW)



RATIONALE

- The underlying assumption of both the DNZ and Well Connected electricity interconnector pathways is that Ireland meets the European interconnector target of 15% of installed generation capacity. We have assumed that this applies to grid-connected generation capacity for the purposes of this study.
- For the Well Connected pathway, we assume the installed generation capacity base is the capacity from the 37GW offshore wind pathway. The additional on-grid capacity of this pathway results in c.2W of additional interconnection in the Well Connected interconnector pathway by 2050. This capacity is built to continental Europe, notably with capacity to Spain and Belgium.
- For the Stretch pathway, we have increased the interconnection percentage (of installed generation capacity) to 20% from 15% in 2050. This is then combined with the additional offshore wind capacity from the 50GW offshore wind pathway to derive a pathway with 66% more electricity interconnection by 2050 than in the underlying DNZ scenario. Additional capacity is built to GB, France, Belgium and Spain, with the latter two markets seeing a notable increase in IC capacity.

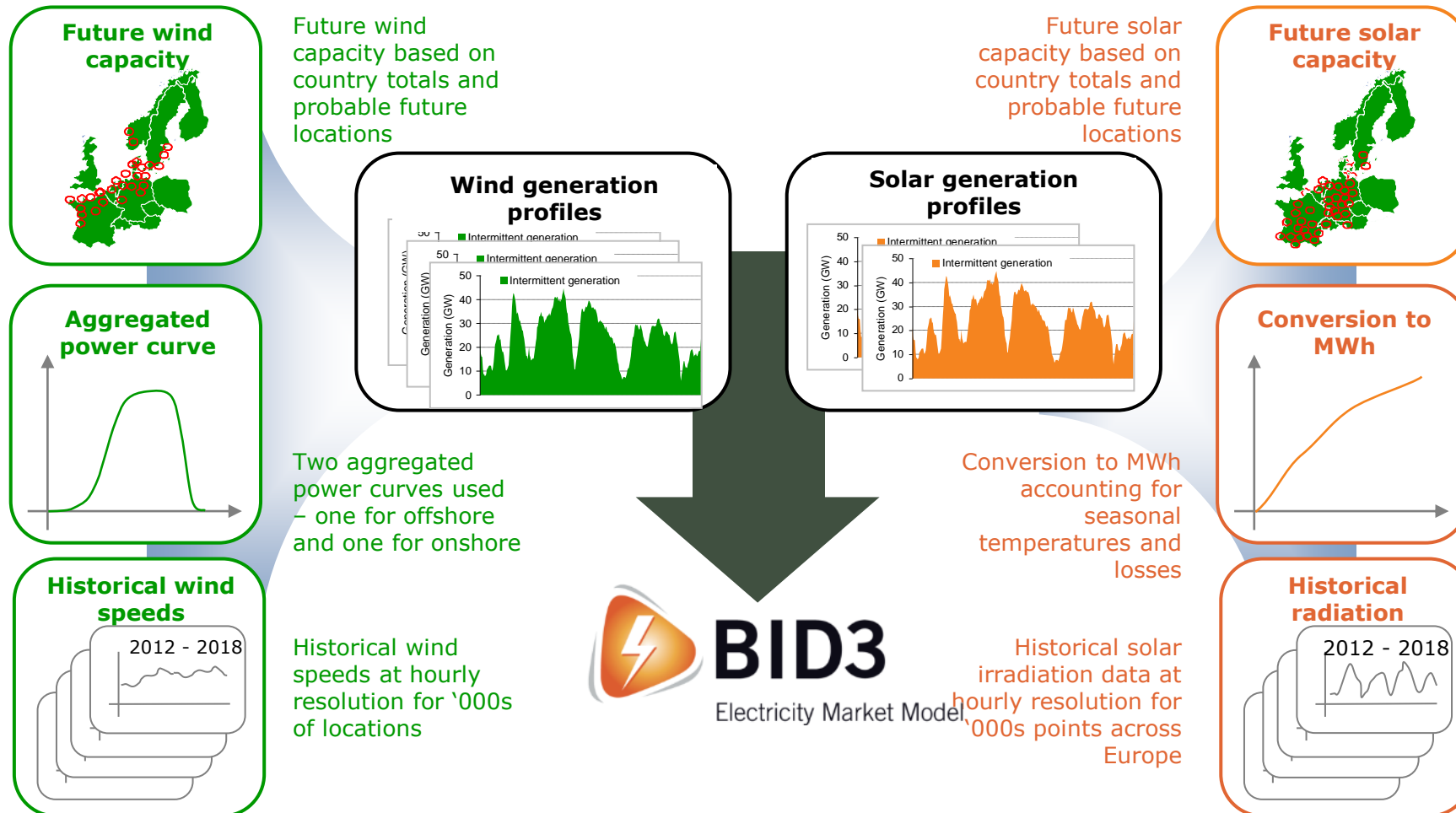
The Domestic Net Zero scenario draws heavily from published EirGrid scenarios and is one view (of many) of the energy sector's route to 2050



1. National Grid ESO, [Future Energy Scenarios 2023](#), July 2023.

APPROACH AND SCOPE

AFRY's model BID3 is used to provide dispatch from historical weather years to simulate variability on the future generation mix including IC



There are a number of limitations that readers should be aware of regarding this study

PATHWAY COST OPTIMALITY

The Domestic Net Zero scenario should not be viewed as the lowest cost pathway to achieving net zero in 2050. It is one of many pathways to net zero in 2050 and may or may not be 'cost optimal'.

SECURITY OF SUPPLY

The system is secure under typical weather conditions. This study has not investigated the impacts of weather extremes and sought to ensure the system is robust to these extremes.

SUBSIDIES

The higher deployment ORE and IC pathways should not be assumed to be subsidy-free pathways.



SYSTEM CONSTRAINTS

Network constraints (be they local or system wide) have not been modelled.

NATURAL GAS AVAILABILITY

Natural gas has been assumed to be available when needed, effectively requiring 24/7 supply. This validity of this assumption is likely to be increasingly at risk from 2040 onwards.

CARBON REMOVALS

The economics of carbon removal technologies and specifically bioenergy with CCS (BECCS) has not been evaluated. The study implicitly assumes a positive cost-benefit trade off for carbon removals will justify support if it is required.

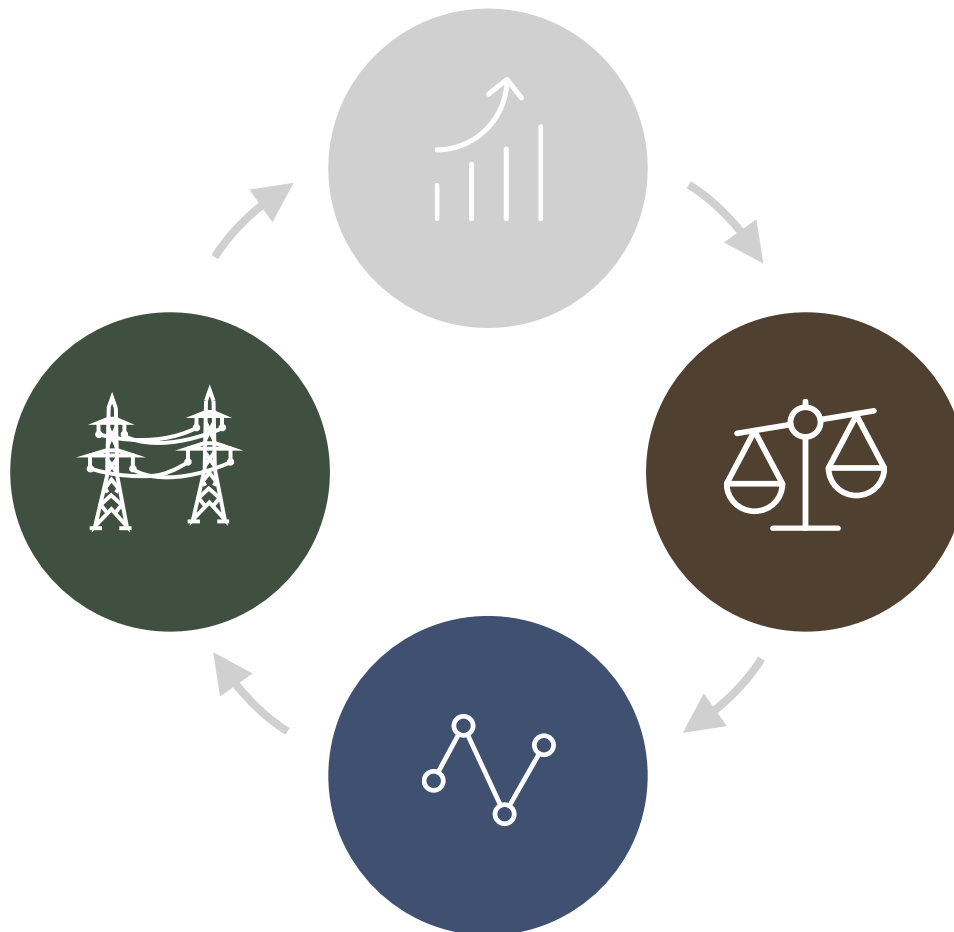
The modelling scope refers to point to point interconnectors, congestion rent potential and socio-economic welfare, with proxy for not connected markets

Revenues sources

- **Our focus is on congestion rent only** as this is the principal revenue that will make or break a project
- Capacity market revenue is the subject of considerable uncertainty given regulatory decisions concerning ongoing interconnector participation and de-rating factors, plus variability of capacity market clearing prices

Interconnector type

- **We focus on point-to-point interconnectors only within modelling** and not Multi-Purpose Interconnectors



Socio-economic welfare (SEW) analysis

- **We provide a SEW impact assessment for any incremental projects that are not included in our baseline**
- SEW analysis looks at the impact of a project on consumer surplus, producer surplus and congestion rent surplus
- A positive SEW is generally a requirement for regulatory approvals

Not connected market

- **For markets that are not connected with IC in the study, we focus on the price differentials as a proxy**
- We have assessed price differentials based on assumed short run marginal costs for Icelandic generation

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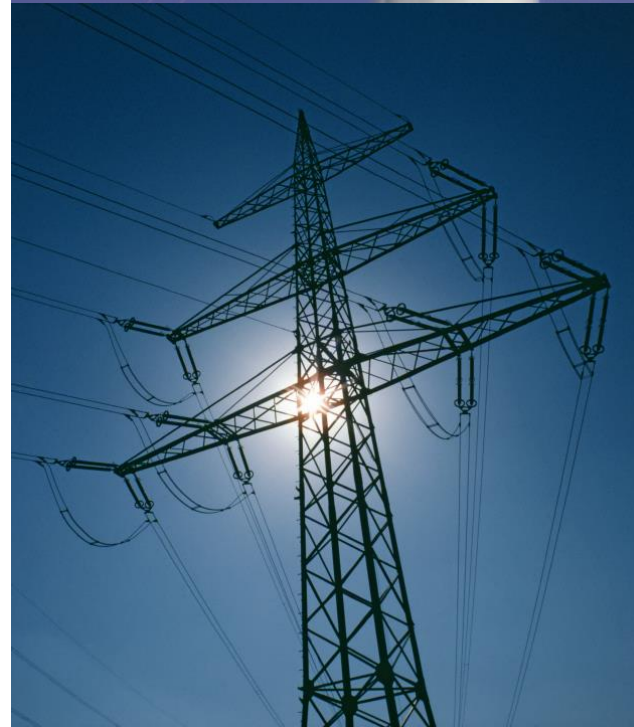
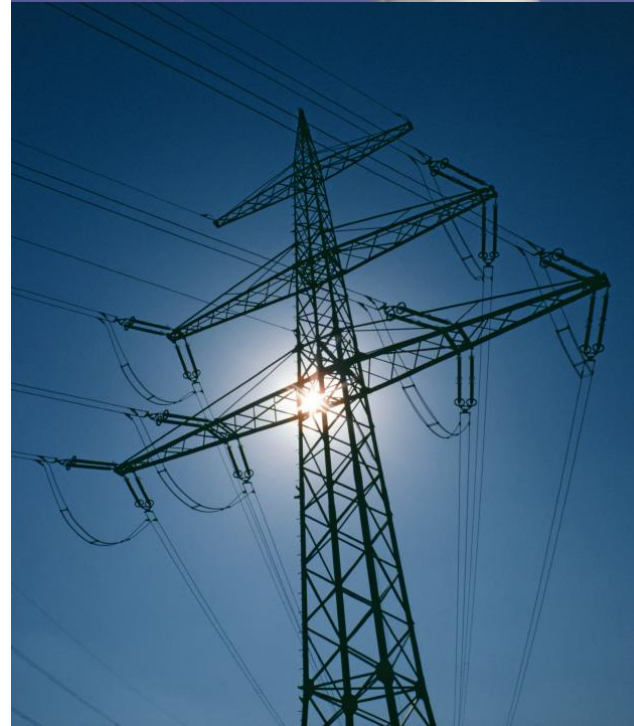


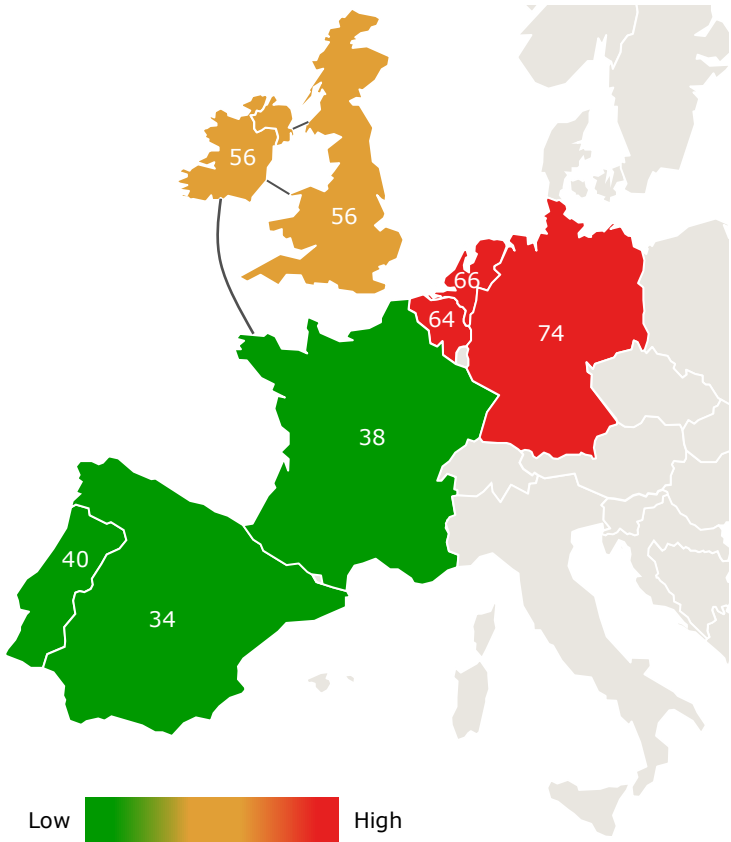
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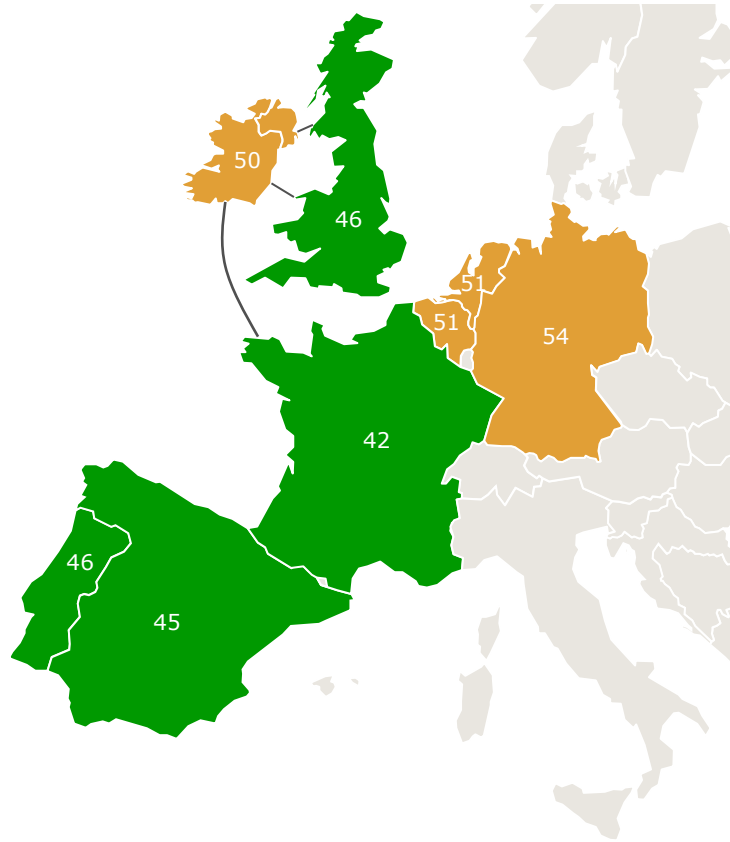


In the DNZ scenario, SEM baseload power prices are mid-range compared to other markets in 2030 before becoming the lowest by 2050

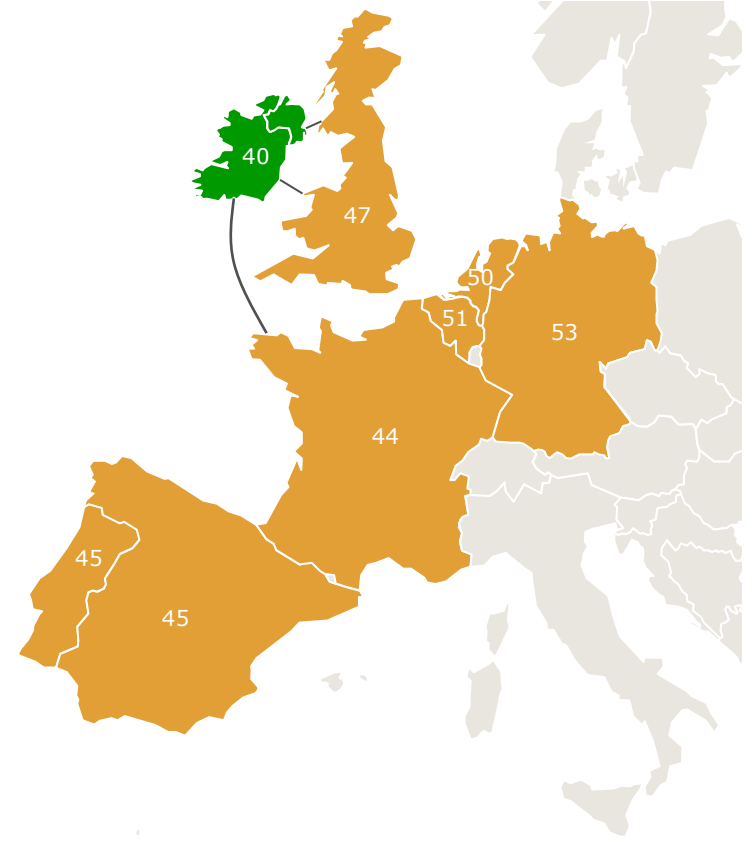
2030 BASELOAD POWER PRICE (€/MWH, REAL 2022 PRICES)



2040 BASELOAD POWER PRICE (€/MWH, REAL 2022 PRICES)

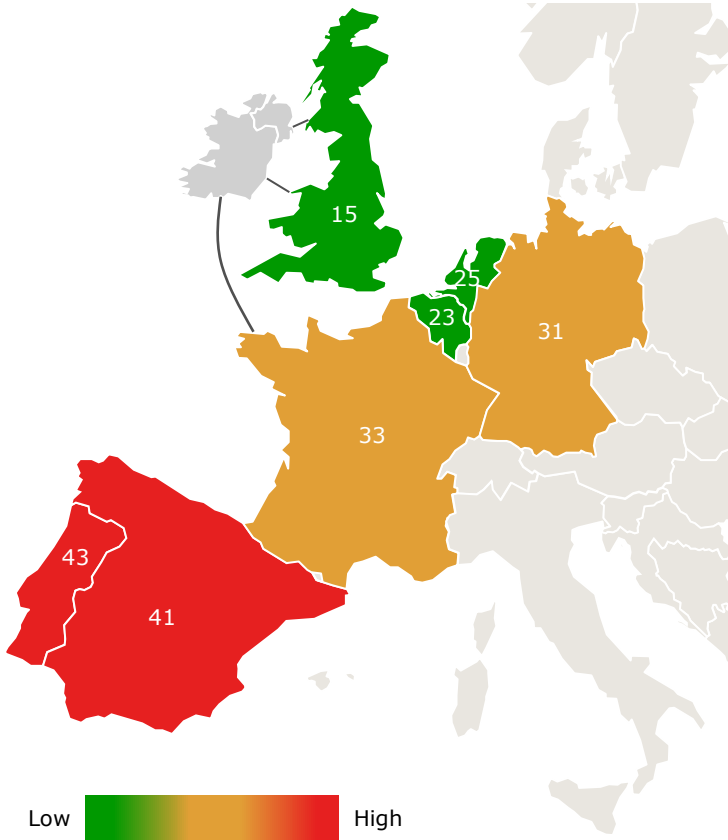


2050 BASELOAD POWER PRICE (€/MWH, REAL 2022 PRICES)

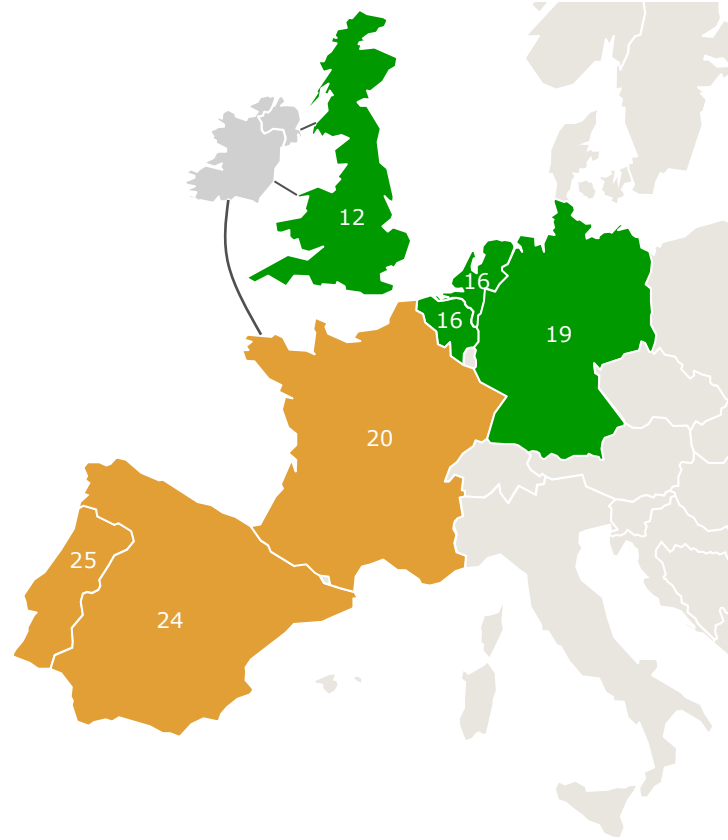


Average hourly absolute spreads between SEM-other markets are wide in DNZ case and, although narrowing, remain in the range €9-17/MWh by 2050

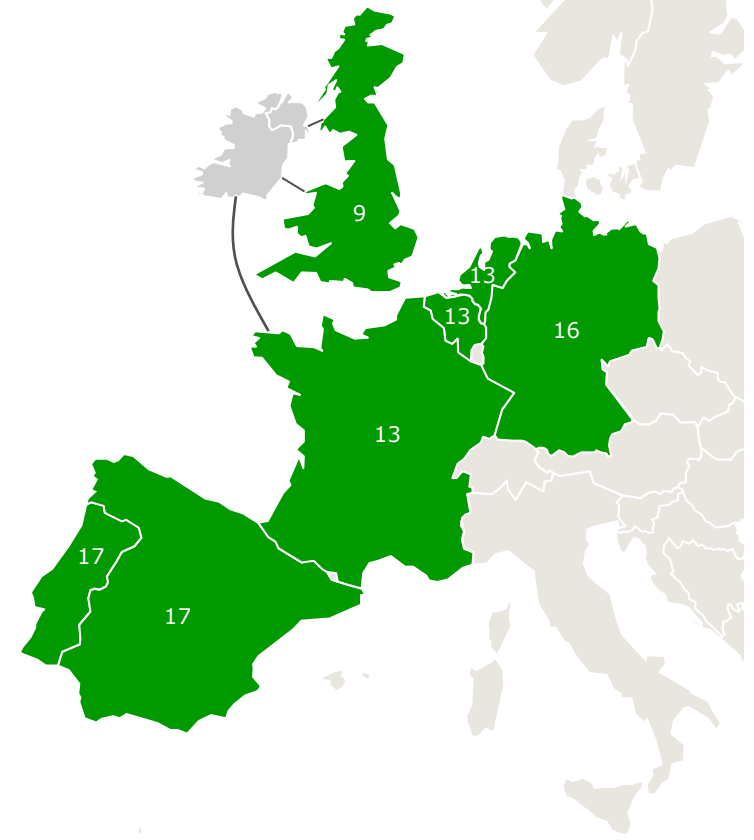
2030 AVERAGE ABSOLUTE HOURLY POWER PRICE DIFFERENCE (€/MWH, REAL 2022 PRICES)



2040 AVERAGE ABSOLUTE HOURLY POWER PRICE DIFFERENCE (€/MWH, REAL 2022 PRICES)

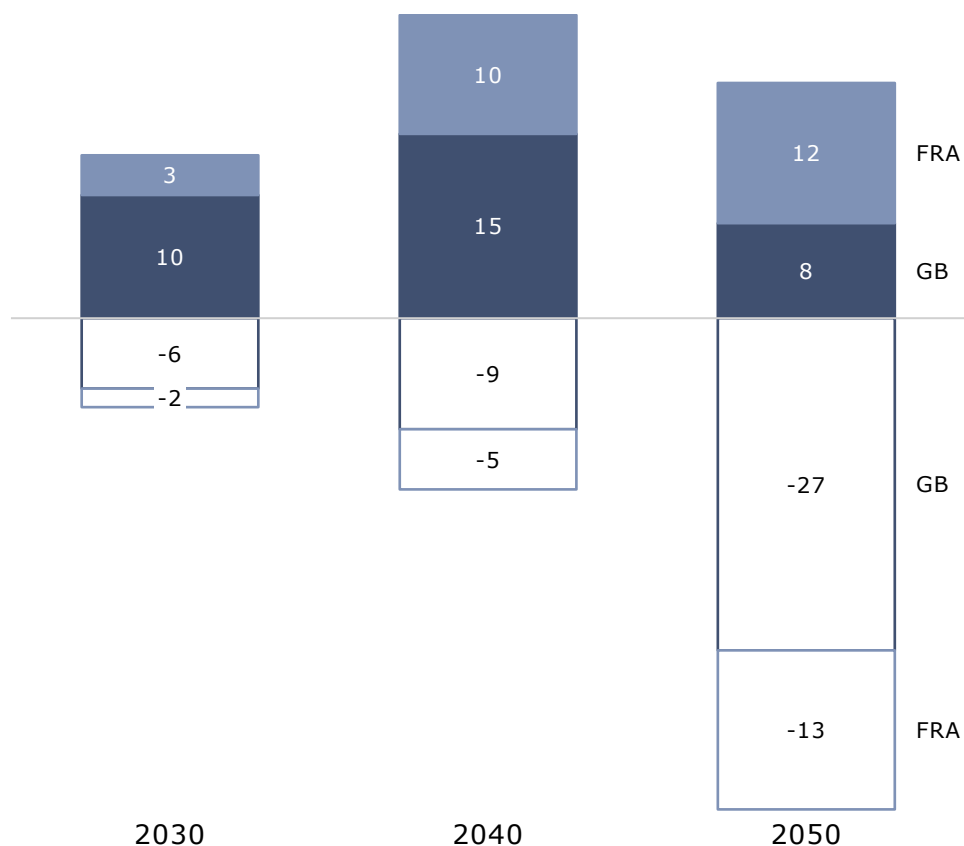


2050 AVERAGE ABSOLUTE HOURLY POWER PRICE DIFFERENCE (€/MWH, REAL 2022 PRICES)



As a result of the price dynamics, the SEM transitions from being a net importer of power to a significant net exporter by 2050 in the DNZ scenario

**SEM INTERCONNECTOR IMPORTS / (EXPORTS)
(TWH)**

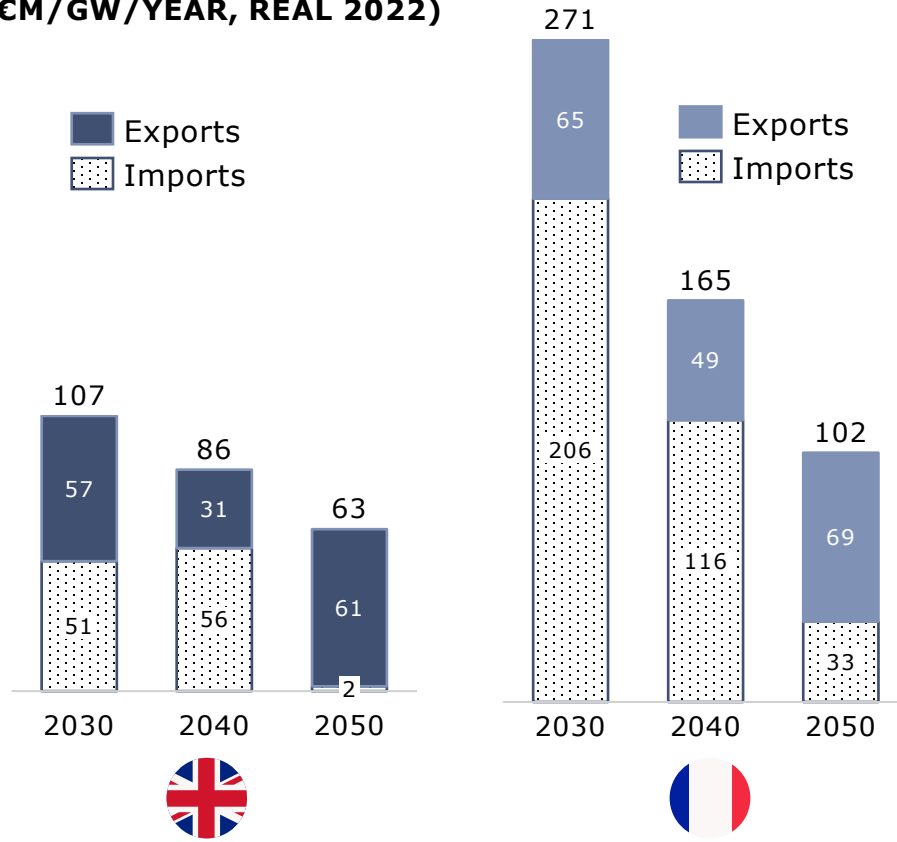


DISCUSSION

- In 2030 and 2040, the SEM is a net importer of power from GB and France. Thus, even in a 2040 world where there is 42GW of wind / solar capacity across the island of Ireland and 10GW of offshore wind, the SEM has a net import position of c.10TWh.
- In 2050, because of assumed renewables capacity growth exceeding demand growth, there are many more hours where power prices in the SEM are very low and there is more opportunity to export power to GB and France. This results in the SEM being a net exporter in 2050.
- Imports / exports are typically skewed towards GB. This appears largely related to the lower assumed losses on interconnectors with GB (<3%) than those with France (c.5%). This means spreads between the SEM and France need to be larger than spreads between the SEM and GB in order for the interconnectors to be utilised.
- Consequently, despite there generally being larger spreads between the SEM and France in 2050 than between the SEM and GB, there are more flows with GB.

While the share of export revenues grows, average congestion rent per GW of IC decreases over time in the DNZ case due to increased interconnection

AVERAGE CONGESTION RENT REVENUES PER IC IN THE DNZ (€M/GW/YEAR, REAL 2022)

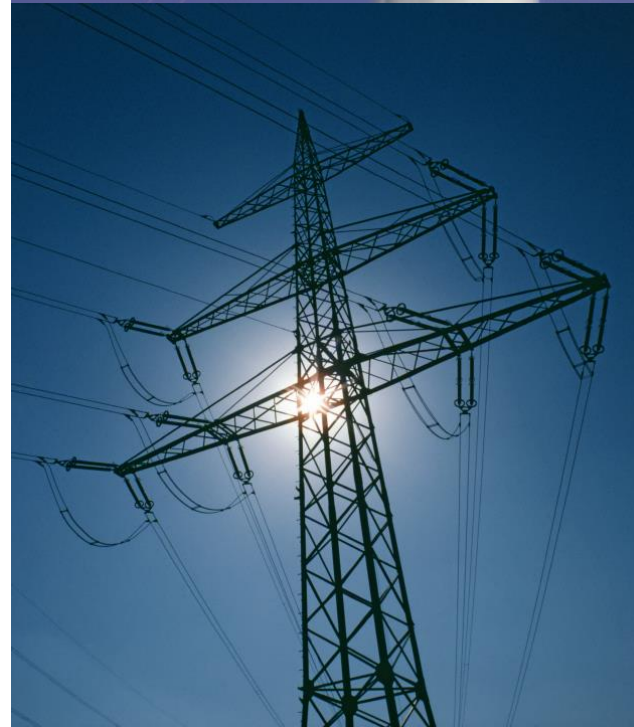


DISCUSSION

- The congestion rents presented here represent the average revenues per GW of IC between the SEM and the connected country with capacity changing over time e.g. 700MW in 2030 and 3,750MW in 2050 for FRA to the SEM.
- The dotted part of the bars represents the congestion rent from importing to the SEM and solid blue part of the bars represents the congestion rent from exporting from the SEM. We can see that the dotted part reduces significantly for France over the years and that for GB it becomes close to zero by 2050. For GB, this stems from the fact that GB prices are consistently higher than in the SEM on an hourly basis by 2050 and there is not much room for export from GB to the SEM.
- On the other hand, for both GB and FRA, the solid blue part remains relatively important indicating the congestion rent value of renewables export potential even in the DNZ scenario.

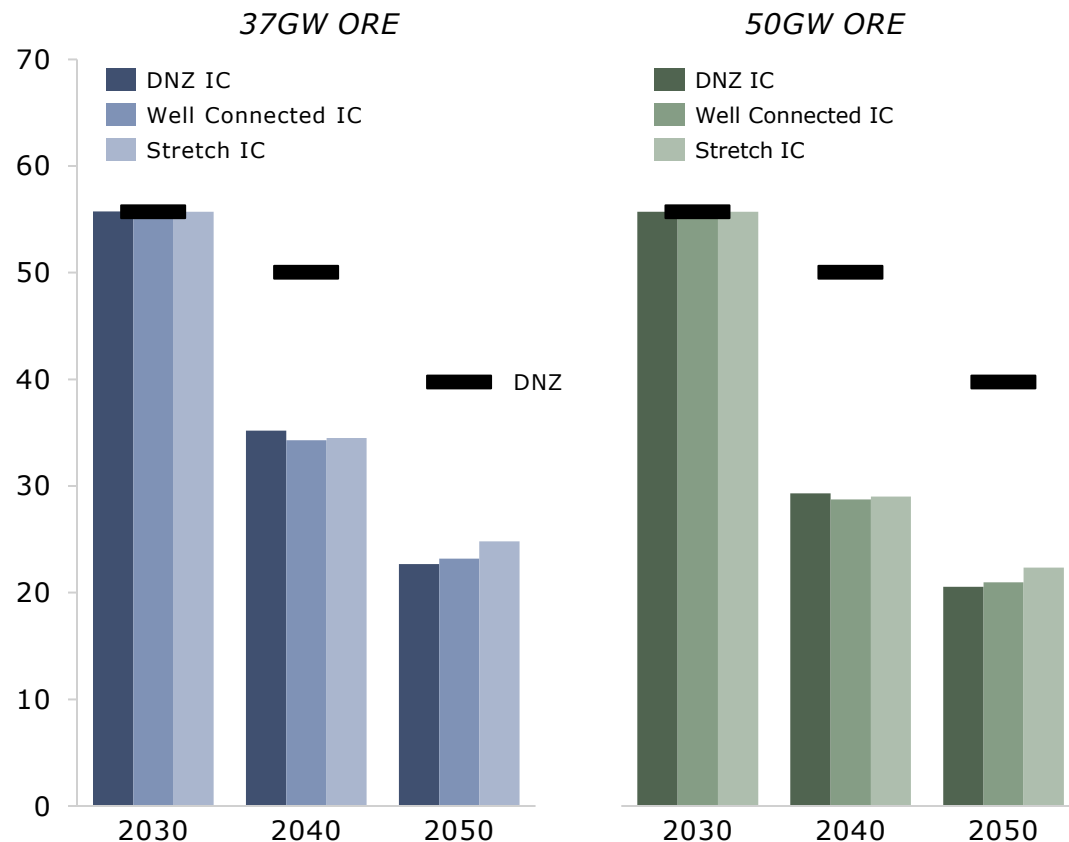
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With much more ambitious offshore wind buildout, Irish power prices drop significantly by 2040 and 2050 in the 37GW and 50GW ORE scenarios

SEM BASELOAD WHOLESALE POWER PRICE (€/MWH, REAL 2022 PRICES)

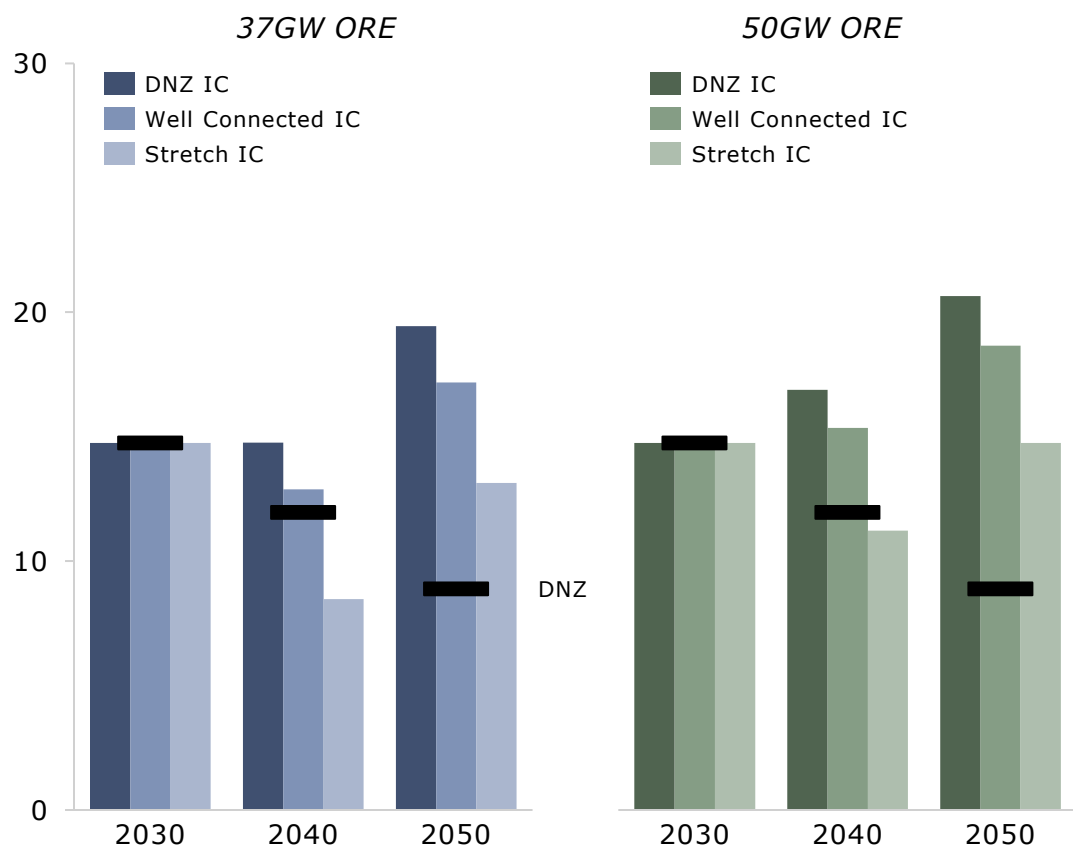


DISCUSSION

- Going from 16GW of offshore wind capacity to 37GW results in significant drops in the cost of baseload power, driven by an increasing number of low (or even zero) priced hours. By 2050, this study suggests the reduction in power prices could be c.€15/MWh.
- Adding an additional 4GW of grid-connected offshore wind capacity in the 50GW ORE pathway results in wholesale power prices declining a little more, but differences vs. the 37GW ORE pathway are small. This is a result of most of the additional capacity in the 50GW ORE pathway being off-grid.
- In 2050, increasing electricity IC capacity (i.e. the difference between the sets of blue bars or between the sets of green bars) tends to increase power prices a little as it equalises prices to some extent between a very low priced SEM and more expensive adjacent markets. This impact is very muted in 2040, when price differentials between adjacent markets are limited.

With a price drop due to increased offshore wind in the SEM, there are higher price spreads between the SEM and connected markets such as GB

ABSOLUTE HOURLY PRICE SPREAD BETWEEN THE SEM AND GB (€/MWH, REAL 2022 PRICES)

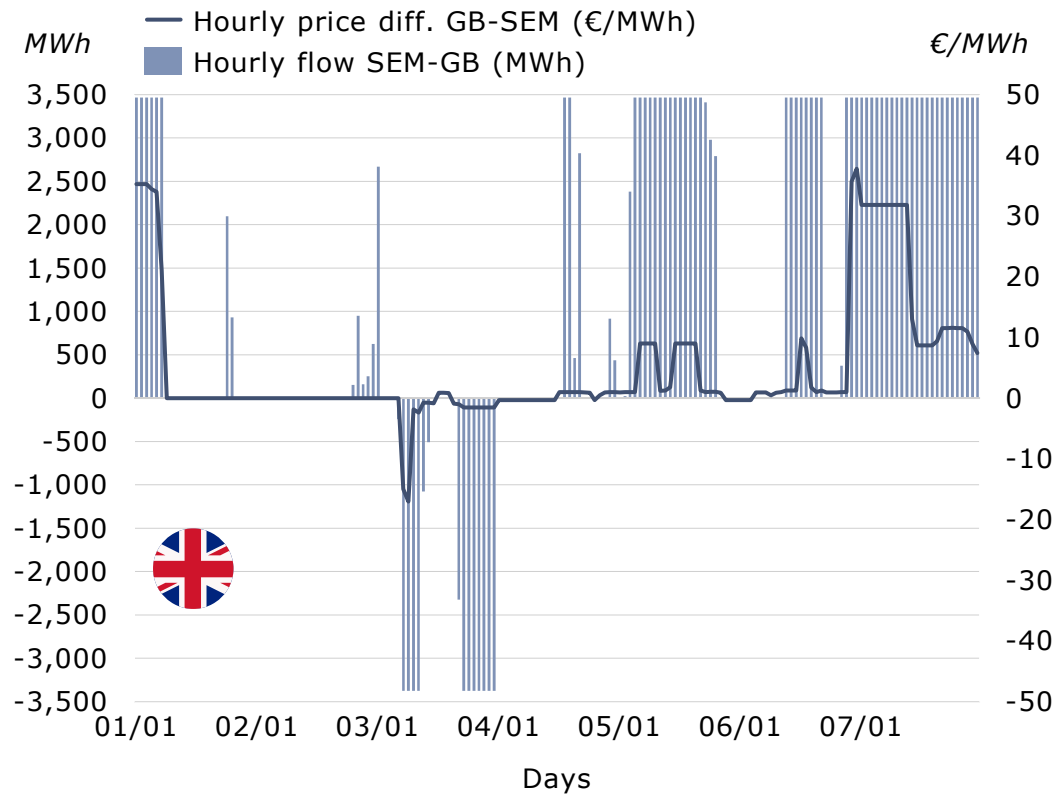


DISCUSSION

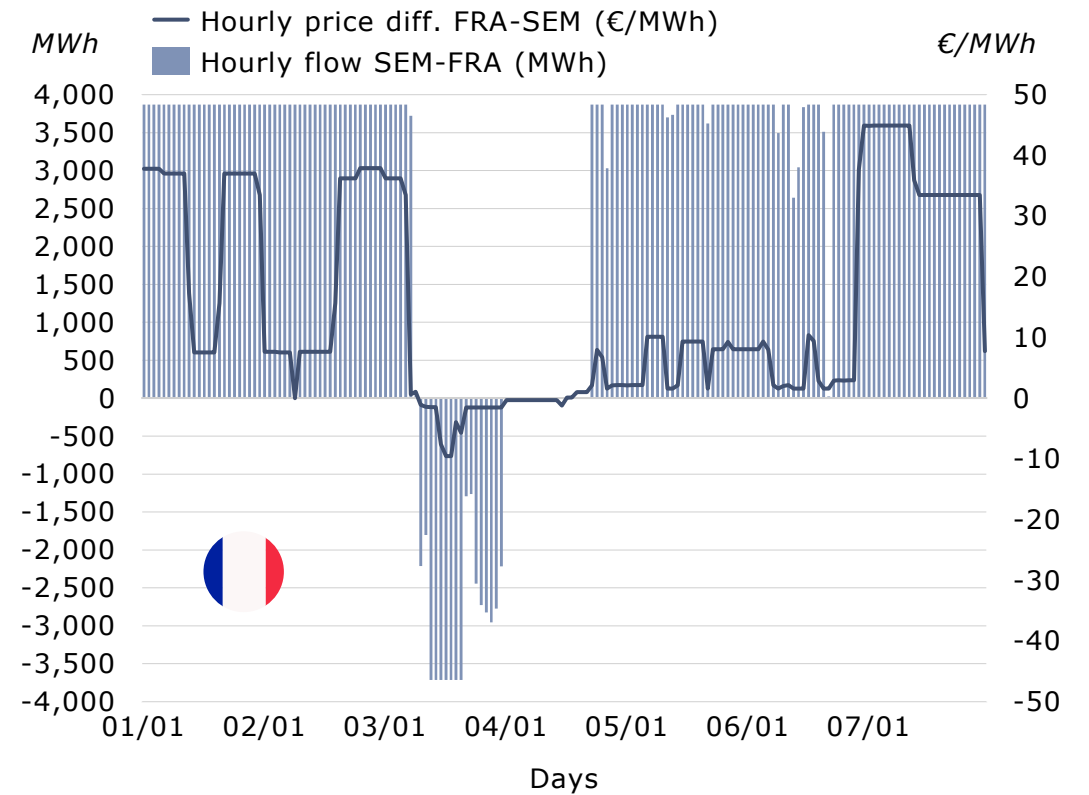
- The chart captures the average absolute hourly price spread between the SEM and GB for all modelled years and weather years; e.g. in the first hour of 2050 for the weather year 2015, GB modelled price is €35/MWh and SEM price is €0/MWh which means an absolute spread of €35/MWh for this hour and weather year. The values are then averaged for the modelled years across all the hours of the different weather years.
- The absolute hourly price is a useful proxy for understanding the potential congestion revenues from an interconnector, as this captures potential revenues both from imports and exports e.g. a baseload price difference can be zero but the absolute hourly price difference can highlight a lot of value with a mix of revenues coming from both import and export.
- The absolute price spread is significantly higher by 2050 in all the scenarios compared to the DNZ scenario due to the much lower price in the SEM increasing the gap with GB prices. In the 37GW and 50GW scenarios, the increase in IC significantly reduces the absolute price spread as the increase in IC supports price convergence between the two connected markets, here the SEM and GB.

IC is utilised when there is a sufficient price spread between the two markets at least sufficient to cover transmission losses

DNZ HOURLY FLOWS (MWh) AND PRICE DIFFERENCE (€/MWh, REAL 2022) – 2050, WEEK 1, WEATHER YEAR 2015

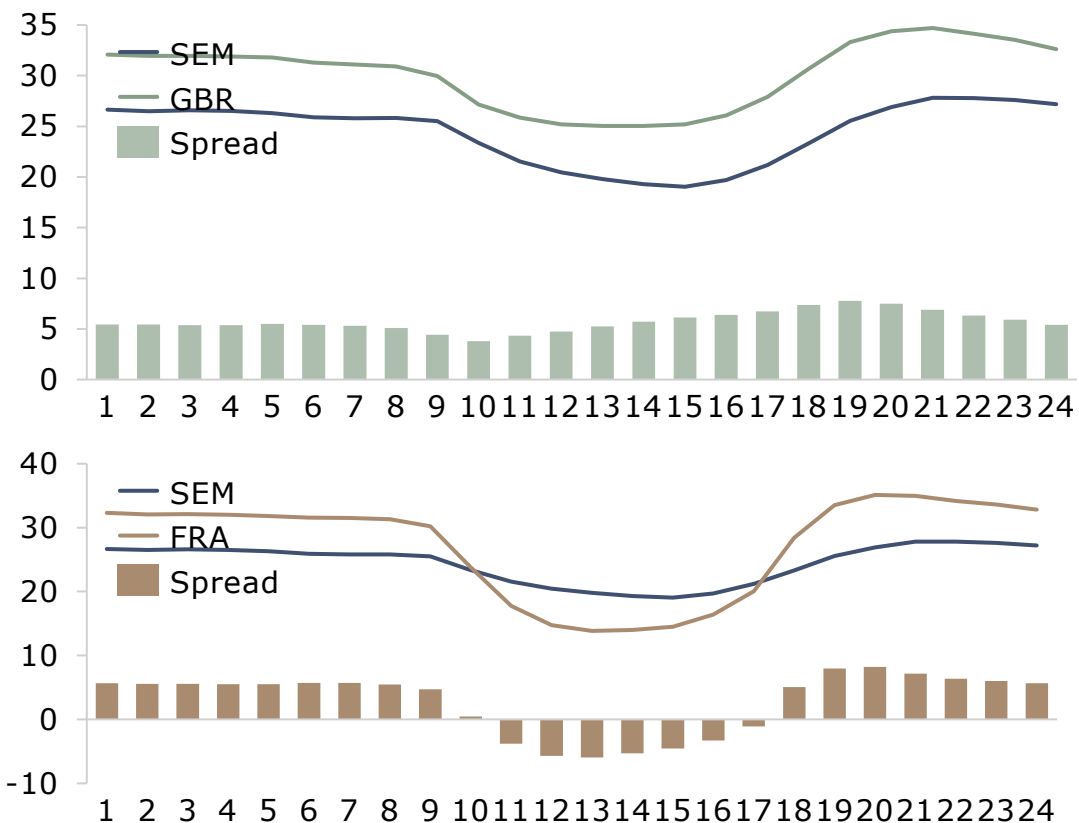


DNZ HOURLY FLOWS (MWh) AND PRICE DIFFERENCE (€/MWh, REAL 2022) – 2050, WEEK 1, YEAR 2015



In the DNZ scenario, average hourly prices show a small positive spread between the SEM and GBR with more variation between the SEM and FRA

**HOURLY AVERAGE PRICE IN 2050 - DNZ
(€/MWH, REAL 2022 PRICES)**



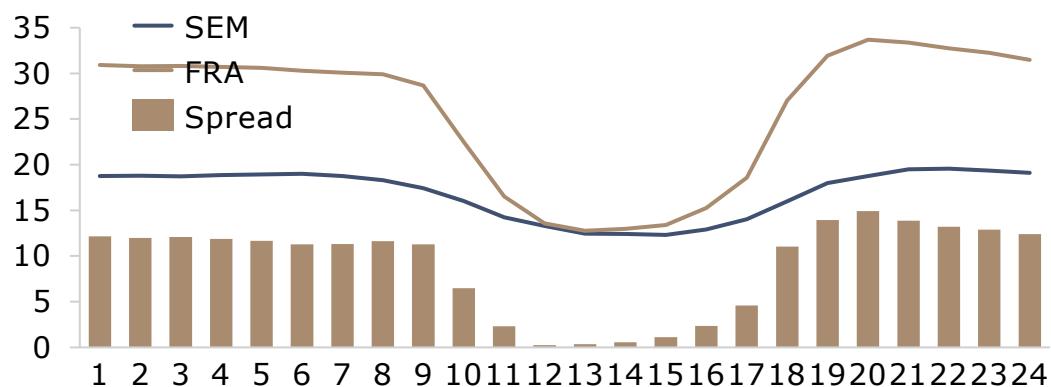
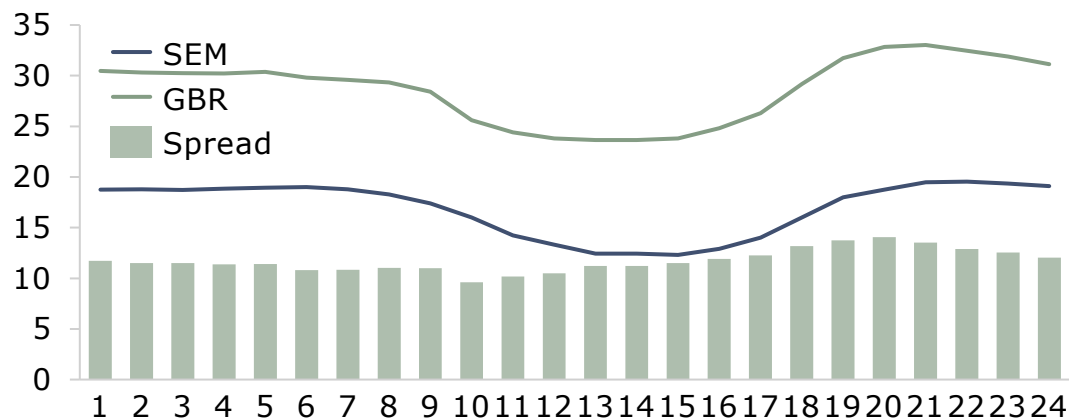
DISCUSSION

- The solid lines represent the average hourly price in 2050 for SEM and the connected market and the column the spread between SEM and connected market, the top chart is for GB and the bottom one for FRA both in 2050.
- Spreads are expected to be positive around the range of €5-10/MWh for all hours of the day on average between GB and the SEM indicating consistent higher prices in GB which means consistent export from SEM to GB when there is a sufficient spread.
- A different picture can be seen for France where typically French prices would be higher during the night and lower around midday than SEM. This is due to the fact that France has a lot of solar power capacity by 2050 in the DNZ scenario which means there is potential export from France to the SEM when there is extra solar generation¹.

1: For avoidance of doubt, the full generation capacity mix for France, including its nuclear fleet, is reflected in the analysis.

In the 37GW Well Connected scenario, larger average hourly spreads are expected due to extra offshore wind pushing down the prices in the SEM

HOURLY AVERAGE PRICE IN 2050 - 37GW WELL CONNECTED (€/MWH, REAL 2022 PRICES)



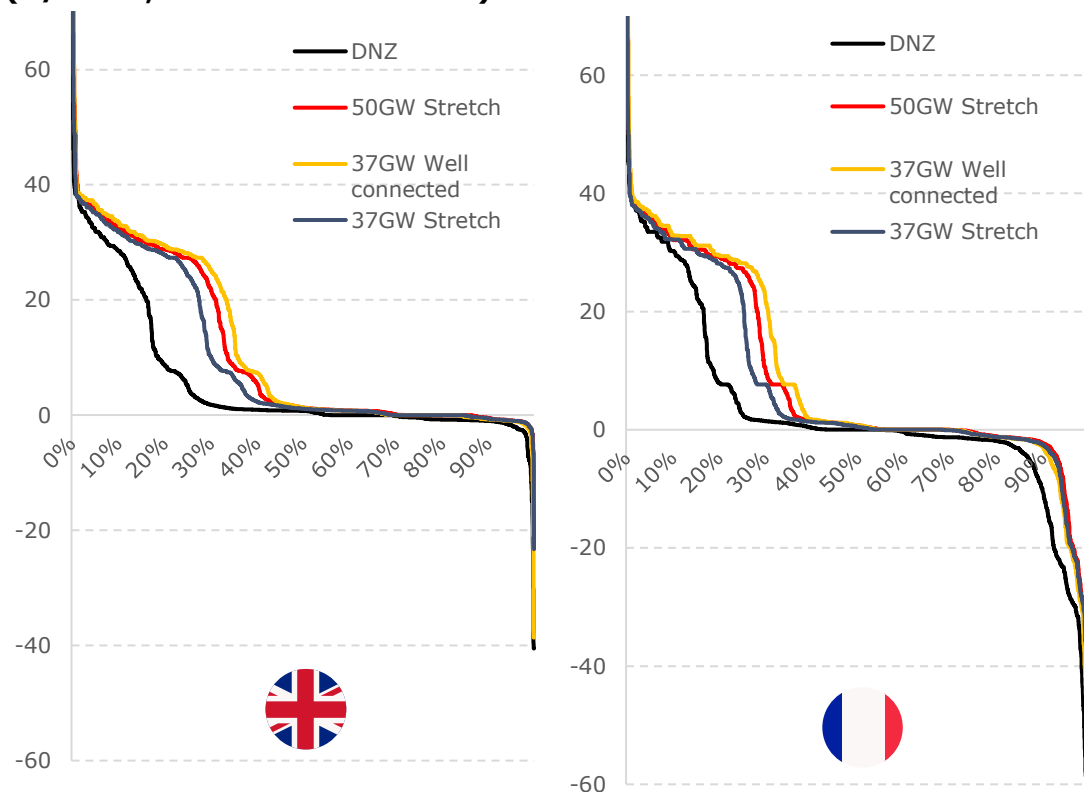
DISCUSSION

- The solid lines represent the average hourly price in 2050 for SEM and the connected market and the column the spread between SEM and connected market, the top chart is for GB and the bottom one for FRA both in 2050.
- Spreads are expected to be positive around the range of €10-15/MWh for all hours of the day on average between GB and the SEM indicating consistent higher prices in GB which means consistent export from SEM to GB when there is a sufficient spread.
- Similar spreads are expected around €10-15/MWh during the evening and night with France, while around midday average prices tend to equalise with the SEM due to the solar generation pushing down the price. The average spread at noon is very close to zero but this does not mean there are no export or import flows. At an hourly level, the SEM has lower prices in some instances and higher prices in others, with the latter typically when there is extra solar generation¹.

1: For avoidance of doubt, the full generation capacity mix for France, including its nuclear fleet, is reflected in the analysis.

By 2050, a price spread above €20/MWh between SEM and connected markets is expected in more than a third of hours in the 37/50GW ORE cases

PRICE SPREAD DURATION CURVE IN 2050, SEM TO CONNECTED MARKETS, 2015 WEATHER YEAR (€/MWH, REAL 2022 PRICES)

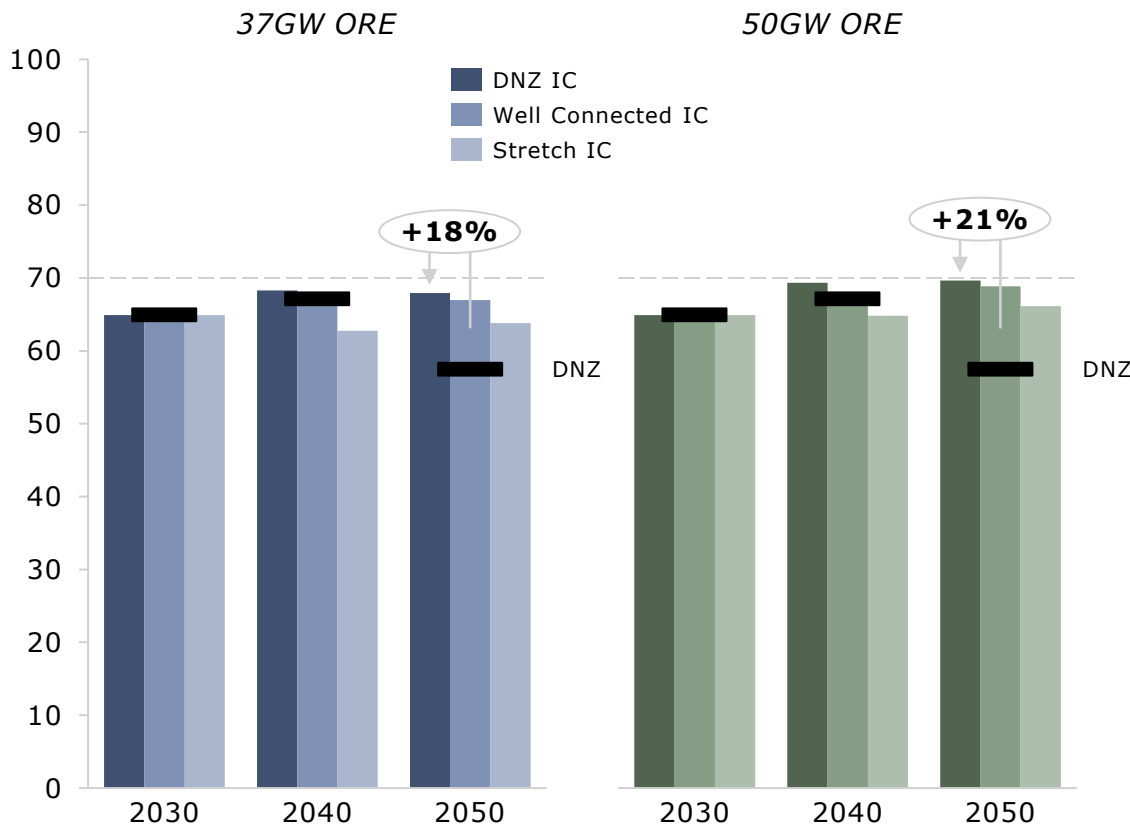


DISCUSSION

- The price spread duration curves depicted on the left represent the hourly price differences between the connected market and the SEM for 2050 using 2015 weather year pattern. There are 8760 values, representing every hour, which are sorted from the highest to the lowest with positive values indicating a higher price in the connected market e.g. FRA or GBR than in the SEM.
- The chart shows that, in most hours, both FRA and GBR have higher wholesale prices than the SEM, which means there is potential to export from the SEM to those two markets, with the level of price spread indicating the congestion rent revenue potential.
- Compared to the DNZ case, the price spread duration curves shift to the right in the higher ORE and higher IC capacity pathways. This indicates greater congestion rent revenue potential in these pathways, linked to increased renewables export.
- There is a deeper tail for France on the right side of the graph indicating that France is cheaper than the SEM in up to ~10% of hours, meaning that there would be congestion revenues from exports from France to the SEM.

There is a higher use of IC for all scenarios compared to DNZ scenario with a decrease in utilisation as IC grows

SEM INTERCONNECTOR GROSS UTILISATION (%)



Note: Gross utilisation is defined as the sum of absolute Imports and Exports divided by the product of capacity and 8760 hours in a year.

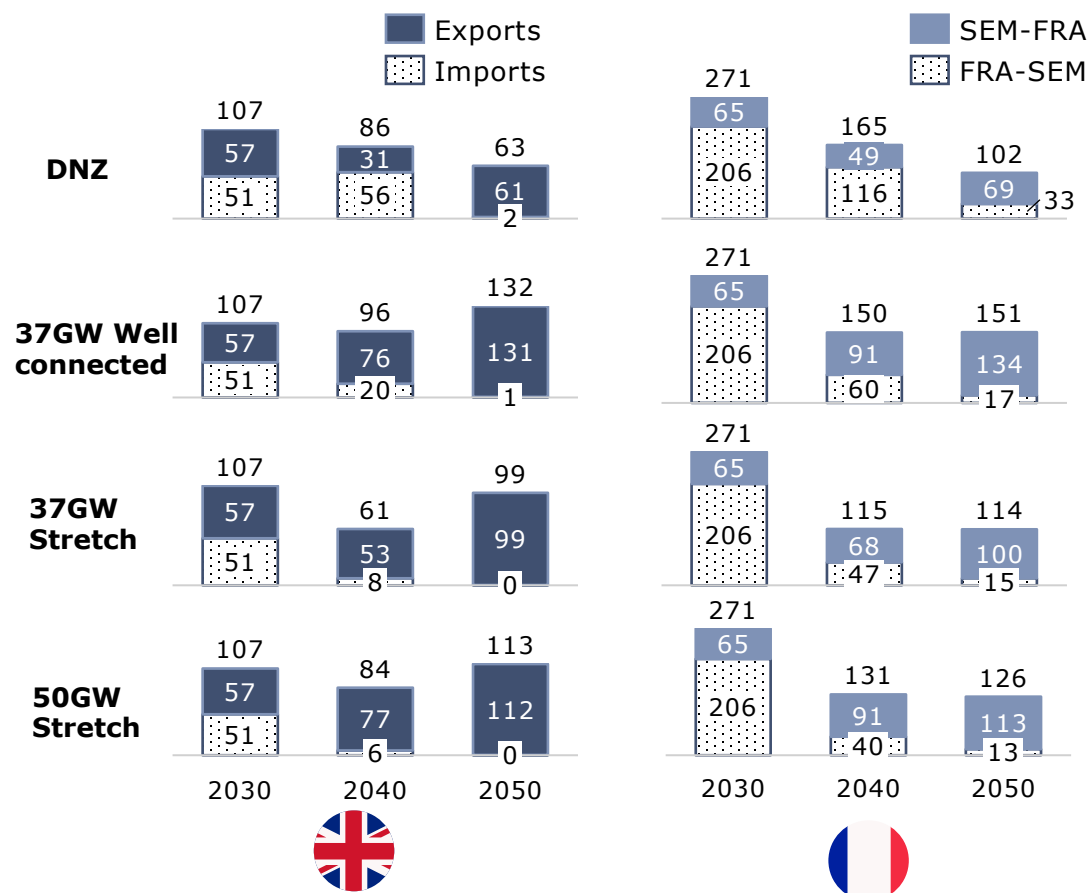
DISCUSSION

Reading the graph: The left panel shows the 37GW ORE pathway in shade of blue, whilst the right panel shows the 50GW pathway in shades of green. Each of the different shades of blue/green correspond to an IC pathway. The black lines indicate the equivalent result from the DNZ scenario.

- Maximum interconnector utilisation in this study is around 70%, as evidenced by the dark green bar in 2050 in the right hand side graph (i.e. 50GW ORE with DNZ levels of interconnection).
- Going from 12GW of electricity IC connecting the SEM to other markets in 2050 in the DNZ scenario to almost 19GW in the Stretch IC pathway only reduces IC gross utilisation by 5-6 points.
- The reason interconnector utilisation remains so high is because the majority of the additional ORE in the 37GW and 50GW ORE pathways is unable to be used domestically which in turn means most of this output is available to export.
- Considering peak demand excluding electrolysis is around 17GW across the SEM in 2050 and electricity IC capacity exceeds this, it is clear that achieving even this level of IC capacity will be challenging.

Congestion revenues are expected to evolve over time reflecting the level of renewable energy to export and reduce with more interconnection

AVERAGE CONGESTION RENT REVENUES PER IC (€M/GW/YEAR, REAL 2022)

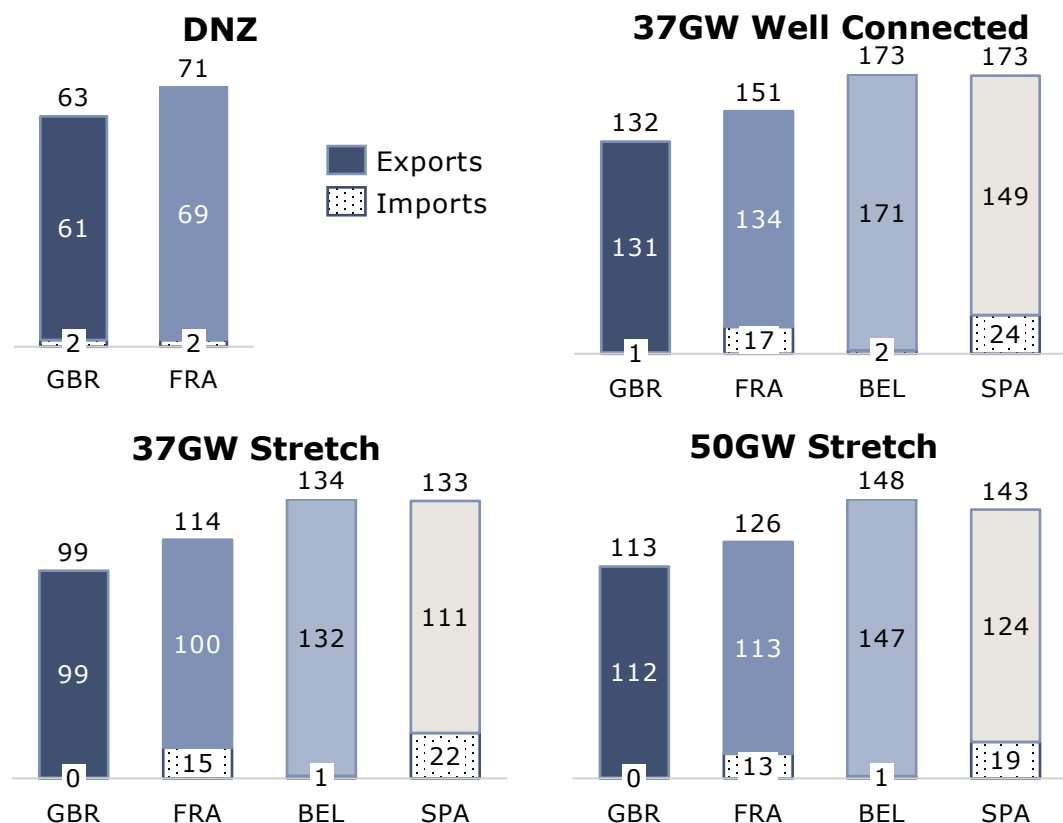


DISCUSSION

- 2030 is the same as the DNZ case for all scenarios as the DNZ is the starting point for the rest of the seven scenarios. The focus here is on 4 scenarios: DNZ, 37GW Well connected, 37GW Stretch, 50GW Stretch.
- Relative to the DNZ case, there is a significant increase in the average congestion rent by 2050 in the other scenarios. This is particularly the case for the solid blue parts of the bars, which represent the revenues from export from the SEM stemming from the increased offshore wind generation and cheaper prices.
- Comparing the 37GW Well Connected to the 37GW Stretch highlights the downward impact on average congestion rents of further increasing IC capacity. This is significant for both GB and France. In the case of France, in 2050 there is a decrease in revenues of roughly 25% (i.e. €114m in 37GW Stretch compared to €107m in 37GW Well Connected).
- Comparing the 37GW Stretch to 50GW Stretch indicates the export value of the extra wind at the highest level of assumed IC capacity. This indicates that there is a slight increase in average congestion rent revenues (e.g. for GB, an increase of around 10% by 2050).

Similar range of congestion revenues coming from exports are expected for the different connected countries with an upside for Belgium and Spain

AVERAGE CONGESTION RENT REVENUES PER GW IC IN 2050 (€M/GW, REAL 2022)

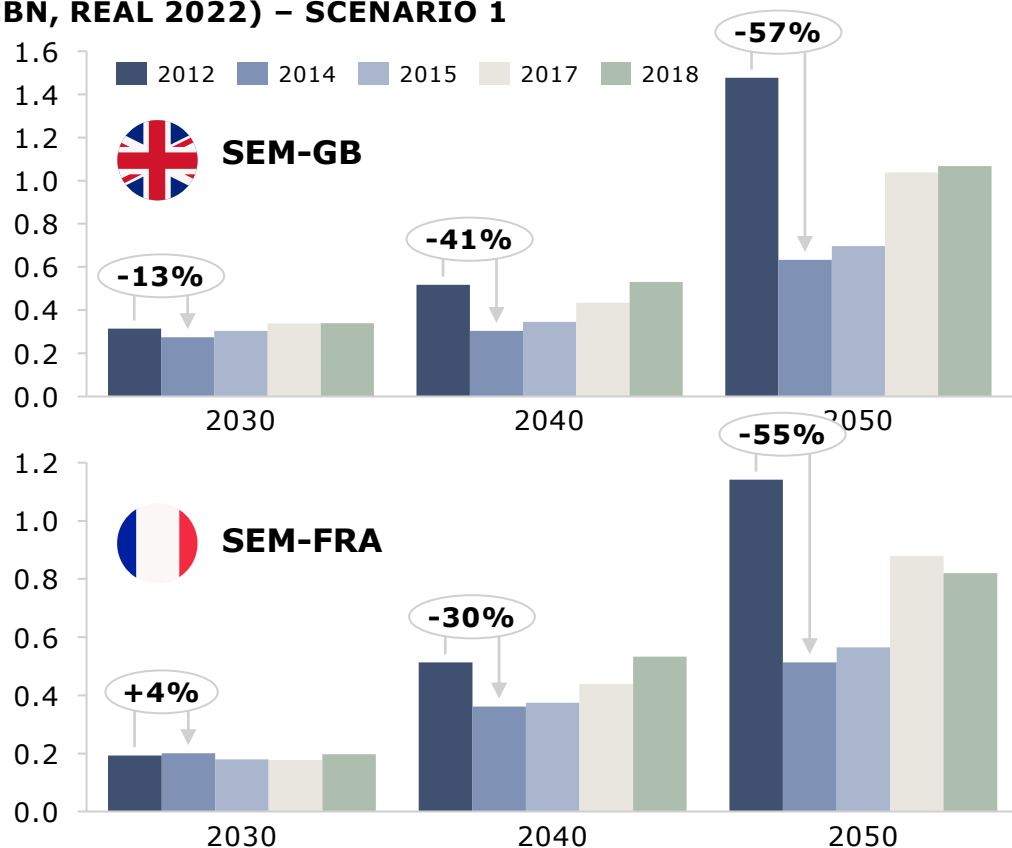


DISCUSSION

- The congestion rent values shown in the chart represent the average revenues per GW of IC capacity between the SEM and the connected country for 2050. In the DNZ IC assumptions, there are no interconnectors between Ireland and Belgium/Spain.
- Across all the countries and scenarios, the large majority of congestion revenues in 2050 comes from exports from Ireland linked to extra wind generation. The congestion rent value of exports from SEM is represented by the solid blue parts of the bars.
- The interconnection with France and Spain does display some congestion revenues coming from the import into SEM, linked to extra solar generation in these countries.
- Consistent patterns can be observed across the scenarios, with the average congestion rent revenues decreasing the greater the IC capacity i.e. from DNZ IC to Well Connected to Stretch. This stems from the fact that as IC capacity grows, price spreads decrease, which ultimately reduces the congestion rent potential of all IC.

Prices and congestion rent are heavily influenced by the weather year, with a ~50% drop in rents from weather year creating highest rent to the lowest

TOTAL IC CONGESTION RENT REVENUES IN THE 37GW WELL CONNECTED SCENARIO – SEM-GB AND SEM-FRA (€BN, REAL 2022) – SCENARIO 1



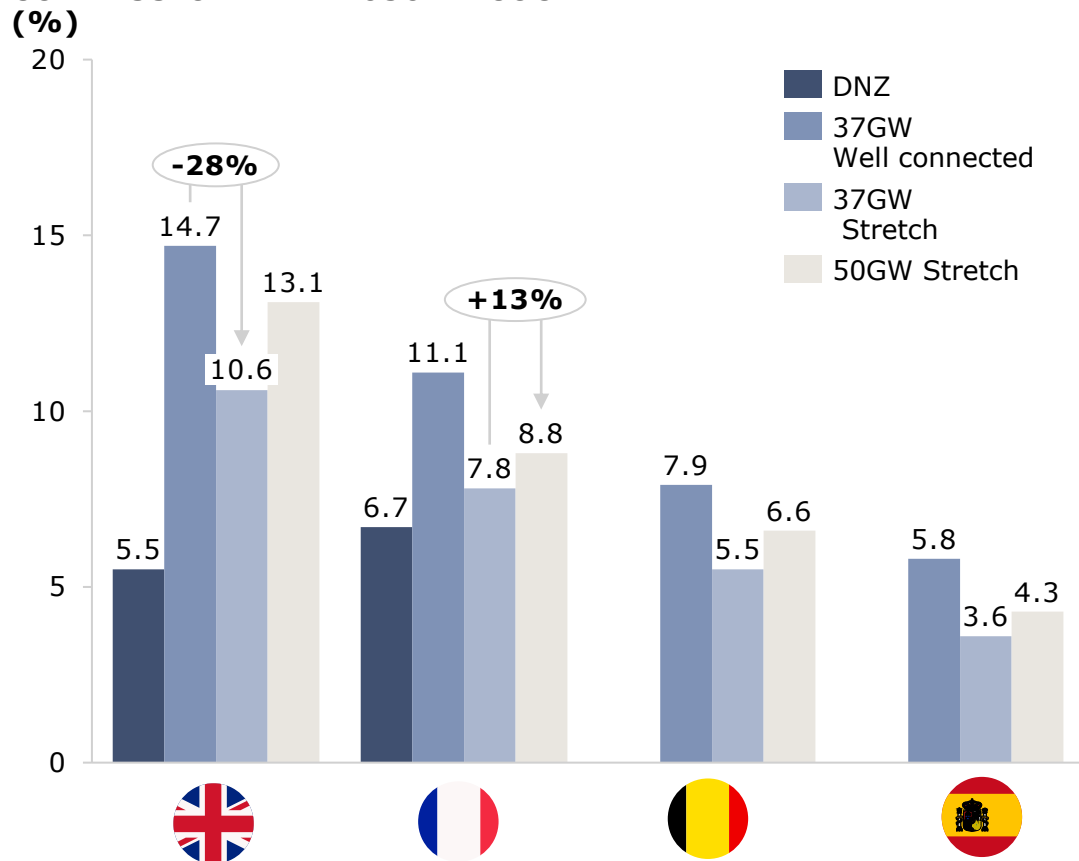
WEATHER YEAR VARIATION IN THE SEM

WY	WP	Wind LF	Solar LF	Hydro LF	Peak demand	Imports
Avg	100%	100%	100%	100%	100%	100%
		← Lowest			Highest →	
2012	107%	96%	96%	100%	101%	95%
2014	98%	95%	101%	100%	102%	108%
2015	89%	109%	102%	100%	97%	93%
2017	104%	99%	98%	100%	100%	98%
2018	102%	101%	104%	100%	99%	102%

Note: values between 2042, 2045, 2050, 2055 and 2060 are interpolated

Considering the investment needed, financial returns looks more promising for IC connecting to GB then France, with Belgium and Spain less attractive

AVERAGE INTERNAL RATE OF RETURN (IRR) OF IRISH IC COMMISSIONED IN 2050 BY COUNTRY

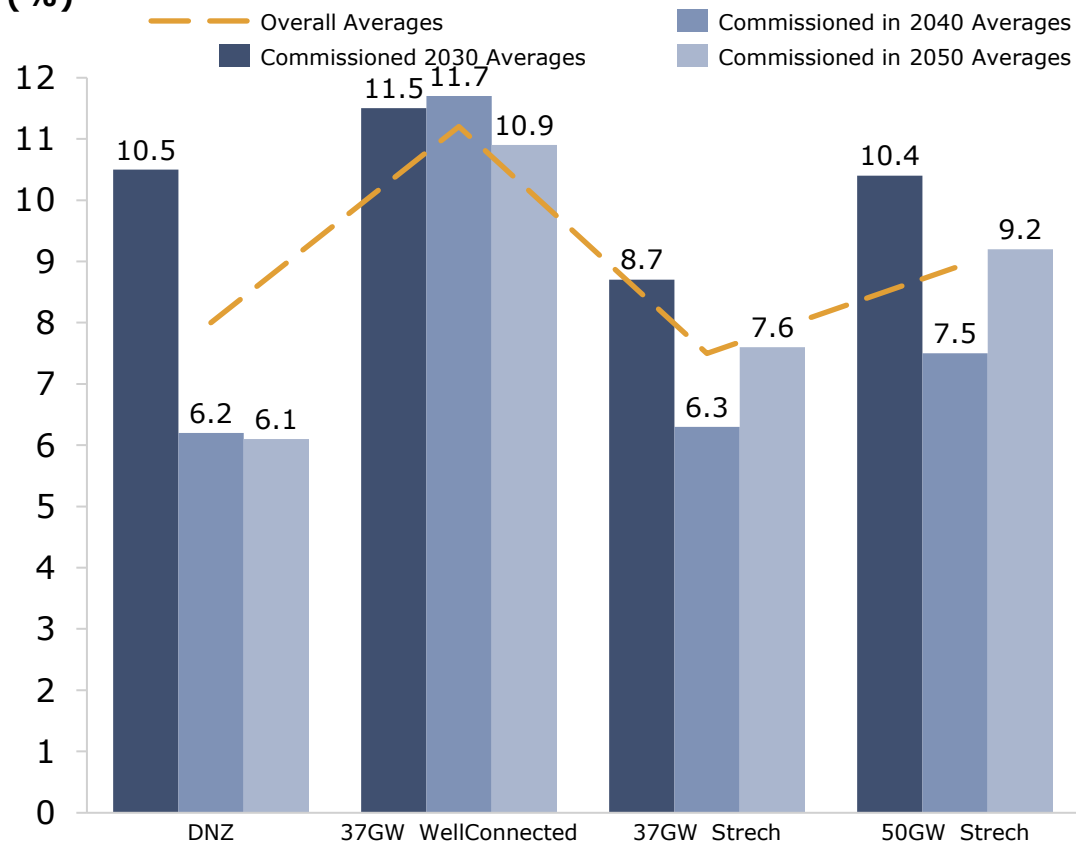


DISCUSSION

- The IRR reflects a combination of the IC congestion rents and the investment cost which varies significantly with the assumed cable distance between Ireland and the connected market. GB ICs have the highest IRRs in the 37GW/50GW+ scenarios as the congestion revenues are similar to the other markets but the CAPEX is significantly lower due to the shorter cable distance e.g. GB compared to Spain.
- In the DNZ case, only GB and France are connected to Ireland. For both markets, this case sees the lowest IRRs.
- For all connecting markets, the 37GW Well Connected case sees the largest IRRs
- Increasing interconnection, which is observed between the 37GW Well Connected and the 37GW Stretch, shows a substantial decrease in IRRs e.g. -28% for GB due to the cannibalisation effect of increased IC capacity reducing average congestion rents on all IC.
- In the 50GW Stretch scenario, additional offshore wind resources further push down SEM prices, which increases congestion revenues thereby increasing IRRs e.g. +13% for French IC.

Returns on IC investment look good overall in all scenarios, with significant variations depending on year commissioned and scenario

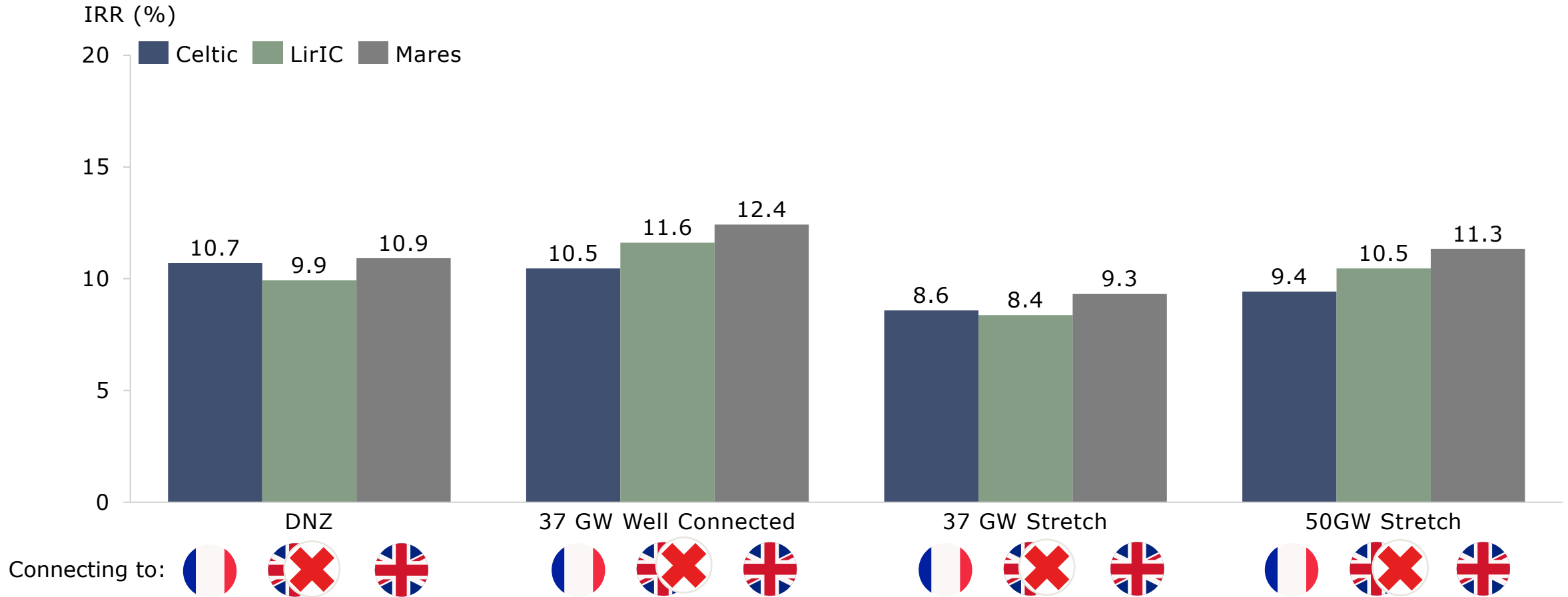
AVERAGE INTERNAL RATE OF RETURN (IRR) OF IRISH IC BY SCENARIO AND COMMISSIONED YEARS (%)



COMMENTARY

- In the DNZ case, limited amount of offshore wind to export from Ireland means that the IRRs in 2040-2050 becomes lower compared all the other scenarios.
- Among the four scenarios shown here, the 37GW Well Connected case presents the highest IRRs on average, potentially indicating a better balance in terms of the ratio between the available wind to export and the level of IC.
- In 2030, there is more congestion rent per IC as there is less interconnection and there is both revenues from export from and import to the SEM whereas by 2050, the revenues are concentrated on exports from SEM. Increased IC means there is a cannibalisation effect as the price spread with the connected market decreases - this effect is captured by comparing between the Well Connected and the Stretch 37GW pathways.

Projects starting in 2030 within the 37GW Well-Connected scenario generally exhibit the most favorable IRRs due to less cannibalization during the later years when compared to the Stretch scenario



For projects starting in 2040, Belgium and Spain interconnectors have the lowest IRRs owing to the highest expected CAPEX for these projects

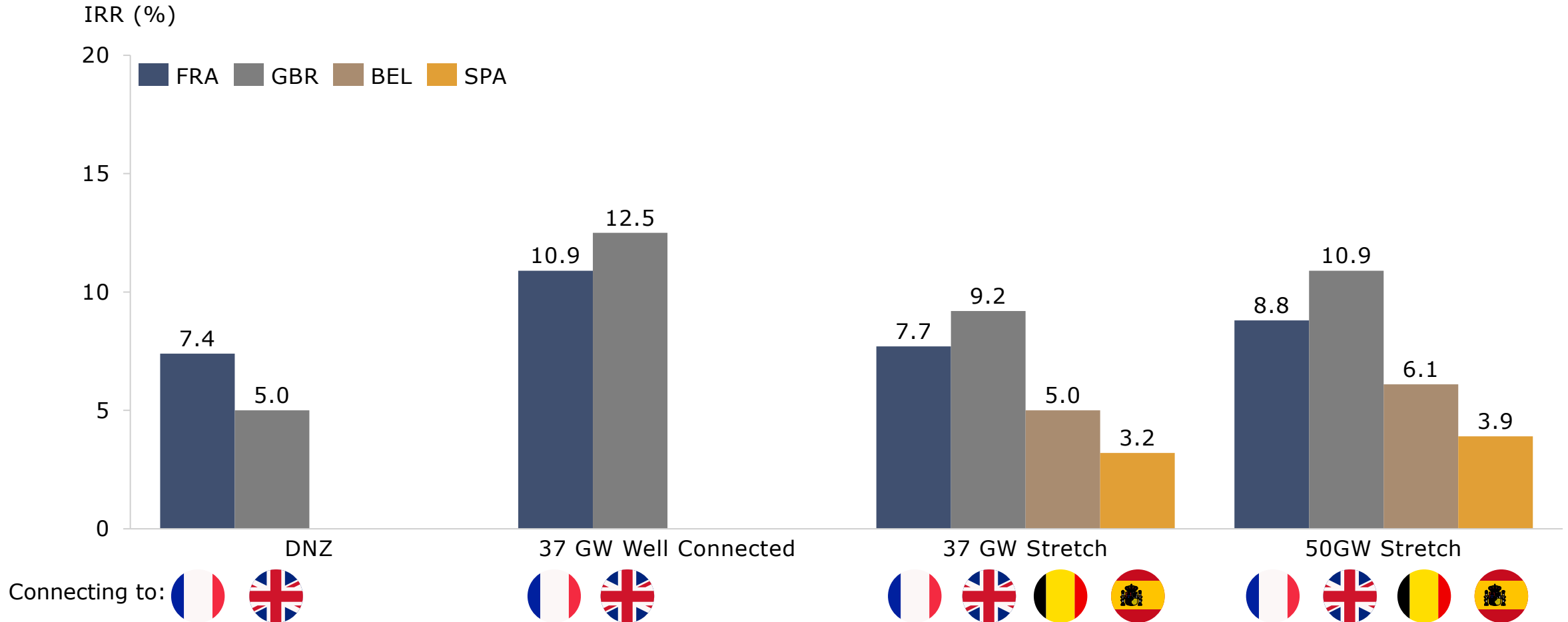
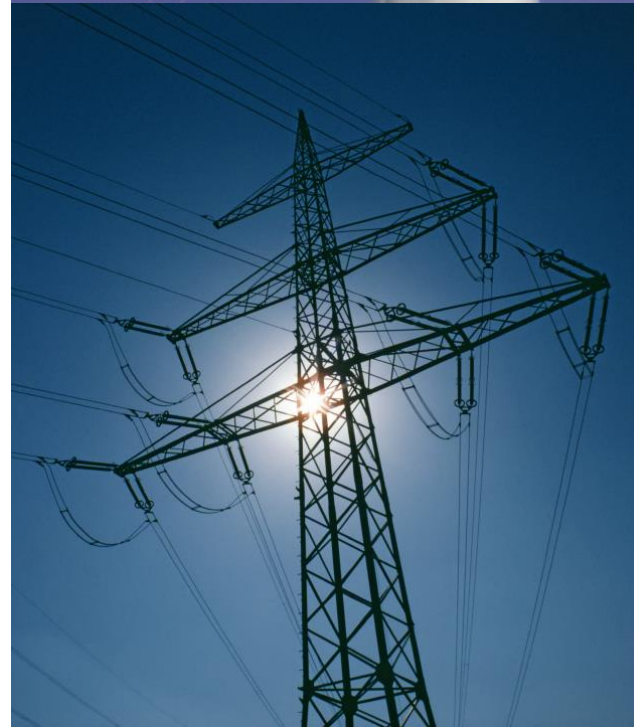


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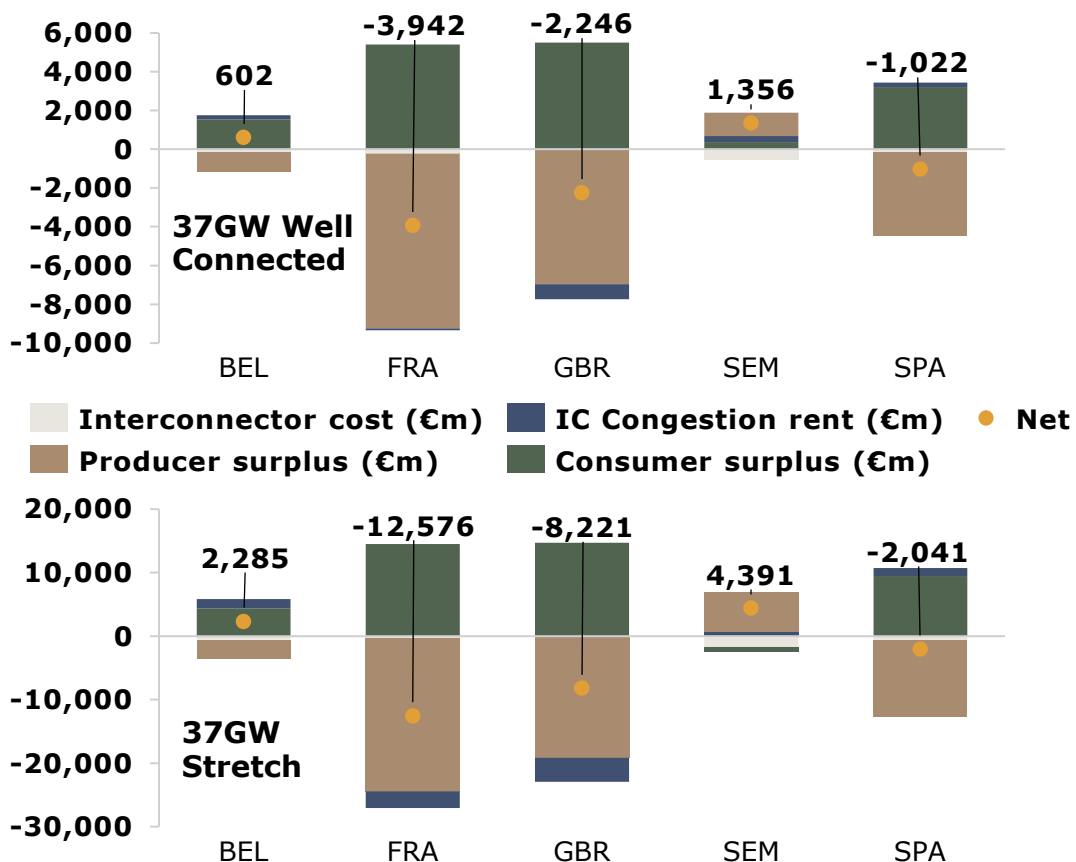
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SYSTEM IMPACTS

With 37GW ORE, the overall socio-economic welfare impacts of increasing IC are overall positive for Ireland and Belgium but negative overall

SOCIO-ECONOMIC WELFARE IMPACT COMPARED TO 37GW DNZ SCENARIO IN 2030-2055 (€M, REAL 2022 MONEY)



Note: 1) Contribution of off-grid ORE is included above. 2) Values shown on the chart represent Net SEW only

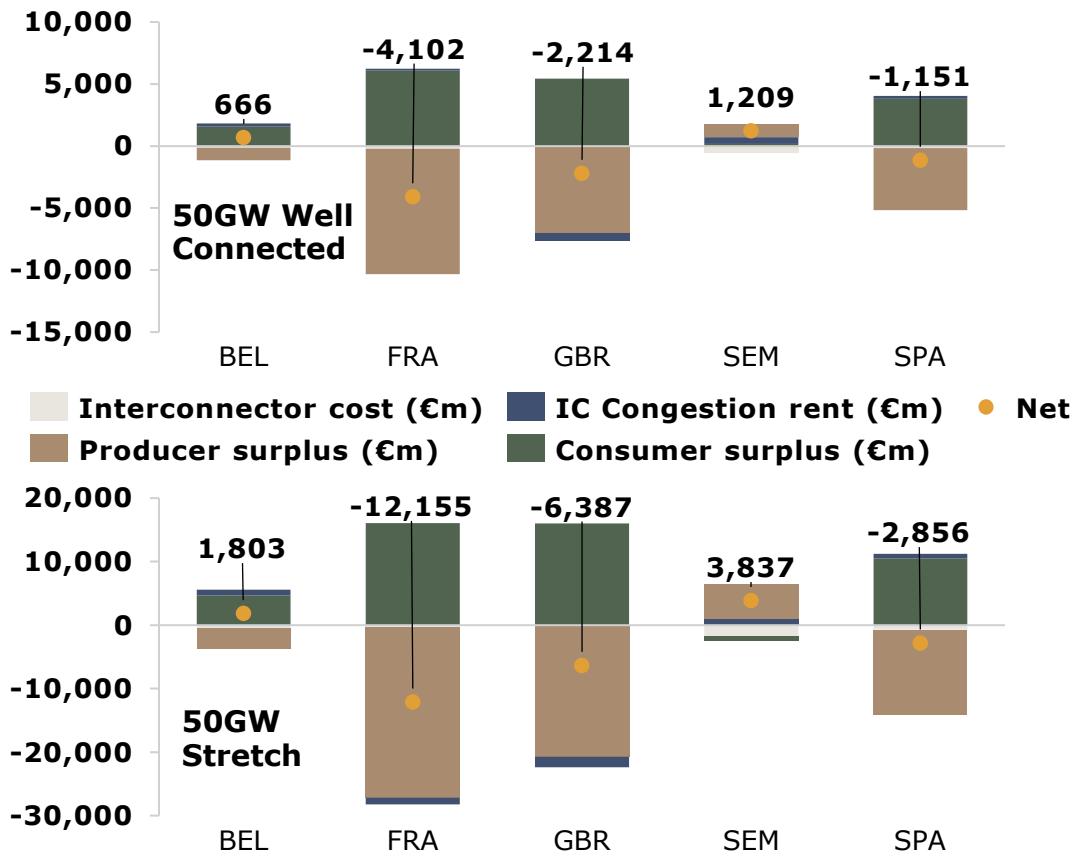
DISCUSSION

- Socio-Economic Welfare (SEW) impact analysis is a combination of different indicators, namely consumer surplus, producer surplus and IC congestion rent impacts, as well as IC cost. Positives value represent overall benefits for the country.
- Belgium and Ireland both have positive impacts overall, while the other countries are negatively impacted overall. This is consistent across both graphs and more amplified in the 37GW Stretch.
- While they have negative impacts overall, the connected markets all experience positive consumer surplus impact, however, in both 37GW Well Connected and 37GW Stretch scenarios.
- In comparison to the 37GW DNZ scenario, the upper left graph shows the SEW impacts of moving to the 37GW Well Connected scenario and the lower left graph shows the impacts of moving to the 37GW Stretch scenario.
- The calculations produce a net present value of the impacts over 25 years starting from 2030 with extrapolation between the modelled years 2030, 2040 and 2050. The IC cost represents the total CAPEX cost split 50:50 between the connected countries, with the cost divided over 20 years to get an annual cost. The congestion rent represents the total congestion rent revenues for connected markets split 50:50 between them. A discount rate of 4% is then applied to the period.

SYSTEM IMPACTS

Similarly, with 50GW ORE, the overall SEW impacts of increasing IC are overall positive for Ireland and Belgium but negative overall

SOCIO-ECONOMIC WELFARE IMPACT COMPARED TO 50GW DNZ SCENARIO IN 2030-2050 (€M, REAL 2022 MONEY)



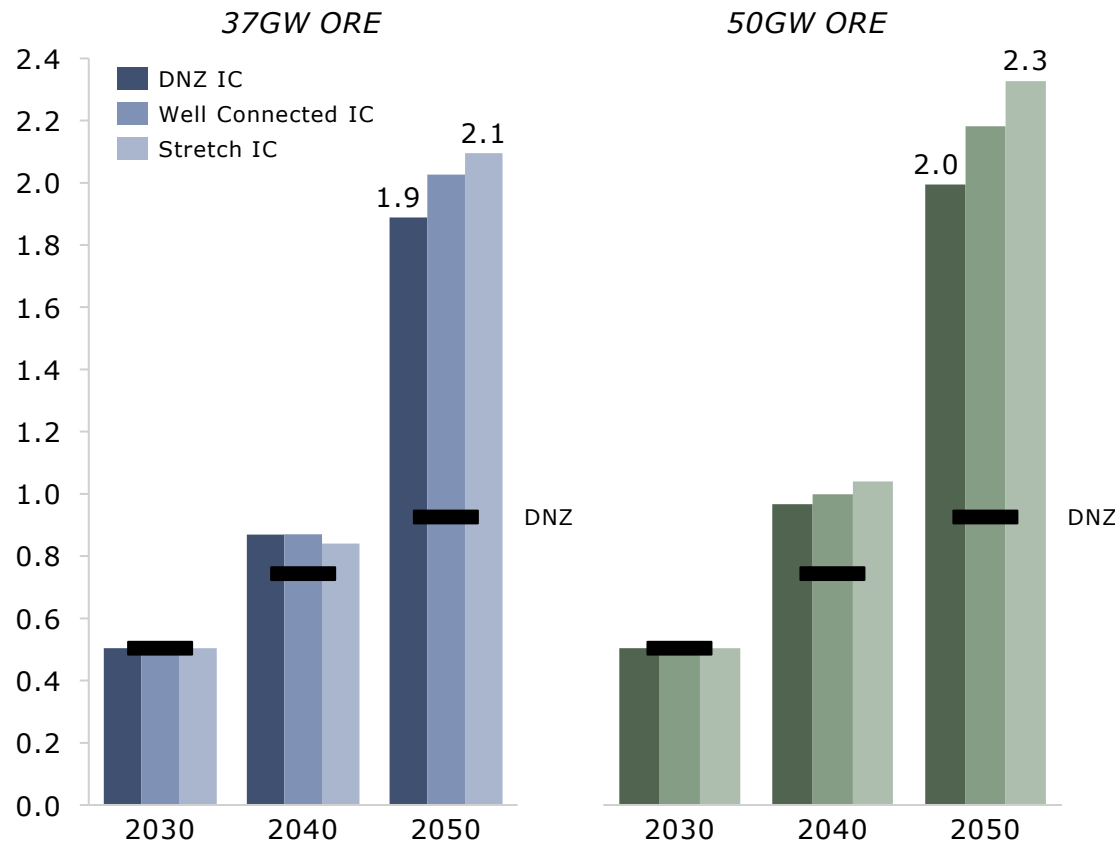
Note: 1) Contribution of off-grid ORE is included above. 2) Values shown on the chart represent Net SEW only

DISCUSSION

- Socio-Economic Welfare (SEW) impact analysis is a combination of different indicators, namely consumer surplus, producer surplus and IC congestion rent impacts, as well as IC cost. Positives value represent overall benefits for the country.
- Belgium and Ireland both have positive impacts overall, while the other countries are negatively impacted overall. This is consistent across both graphs and more amplified in the 37GW Stretch.
- While they have negative impacts overall, the connected markets all experience positive consumer surplus impact, however, in both 50GW Well Connected and 50GW Stretch scenarios.
- In comparison to the 50GW DNZ scenario, the upper left graph shows the SEW impacts of moving to the 50GW Well Connected scenario and the lower left graph shows the impacts of moving to the 50GW Stretch scenario.
- The calculations produce a net present value of the impacts over 25 years starting from 2030 with extrapolation between the modelled years 2030, 2040 and 2050. The IC cost represents the total CAPEX cost split 50:50 between the connected countries, with the cost divided over 20 years to get an annual cost. The congestion rent represents the total congestion rent revenues for connected markets split 50:50 between them. A discount rate of 4% is then applied to the period.

Total congestion revenues double in 37GW ORE compared to DNZ scenario and increase by 4-5 times between 2030 and 2050 to reach ~ €2bn per year

TOTAL CONGESTION RENT FROM IRISH INTERCONNECTOR (€ BILLIONS, REAL 2022 PRICES)



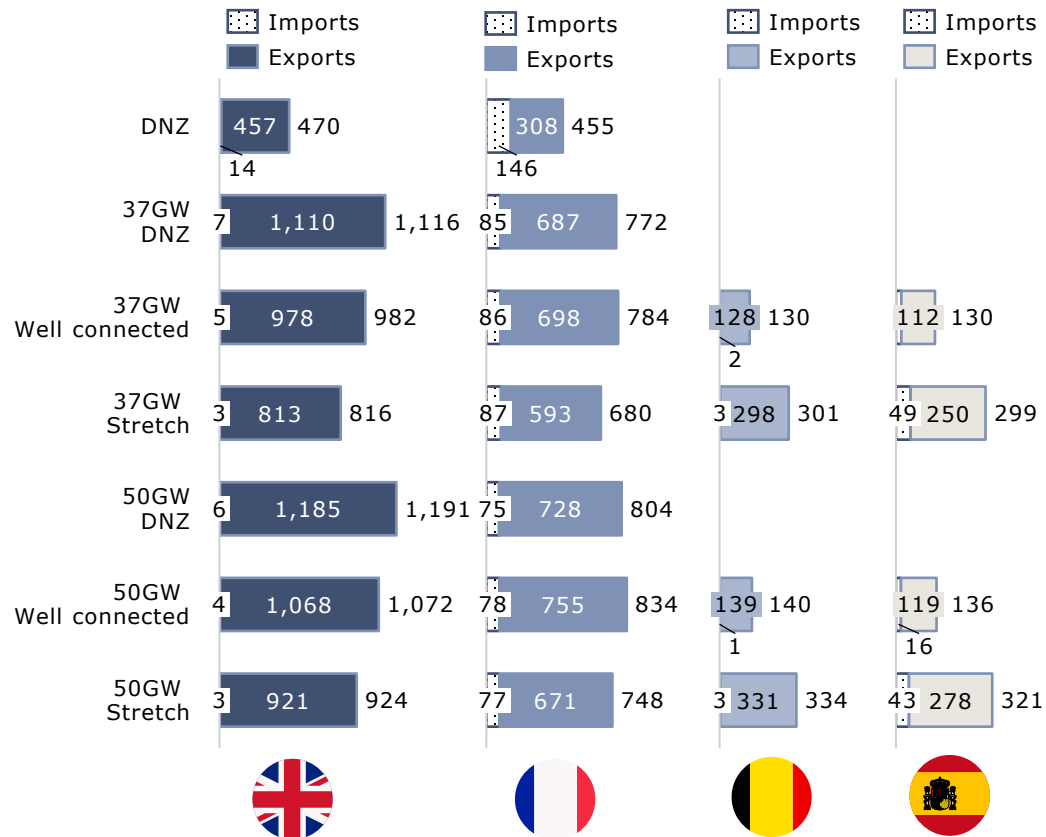
DISCUSSION

- The graph displays the total congestion rent which includes both revenues from Ireland to the connected country. There is an expectation that there would be a split of revenues between the two connected countries.
- Bringing additional wind combined with additional IC increases congestion revenues significantly compared to the DNZ case, with the biggest gap appearing in 2050 where there is twice as much total congestion revenue.
- Increasing IC capacity between the 37GW DNZ IC and Stretch IC cases slightly increases the total revenues by €0.2bn per year by 2050 thanks to additional flows. In the 50GW scenarios there is a slight increase to provide an additional €0.3bn per year by 2050 as there is more offshore wind output available to export.

SYSTEM IMPACTS

By 2050, most of the congestion rent revenues are expected to come from exporting to GB and France, with exports to Belgium and Spain also notable

TOTAL CONGESTION RENT REVENUES IN 2050 (€M, REAL 2022)



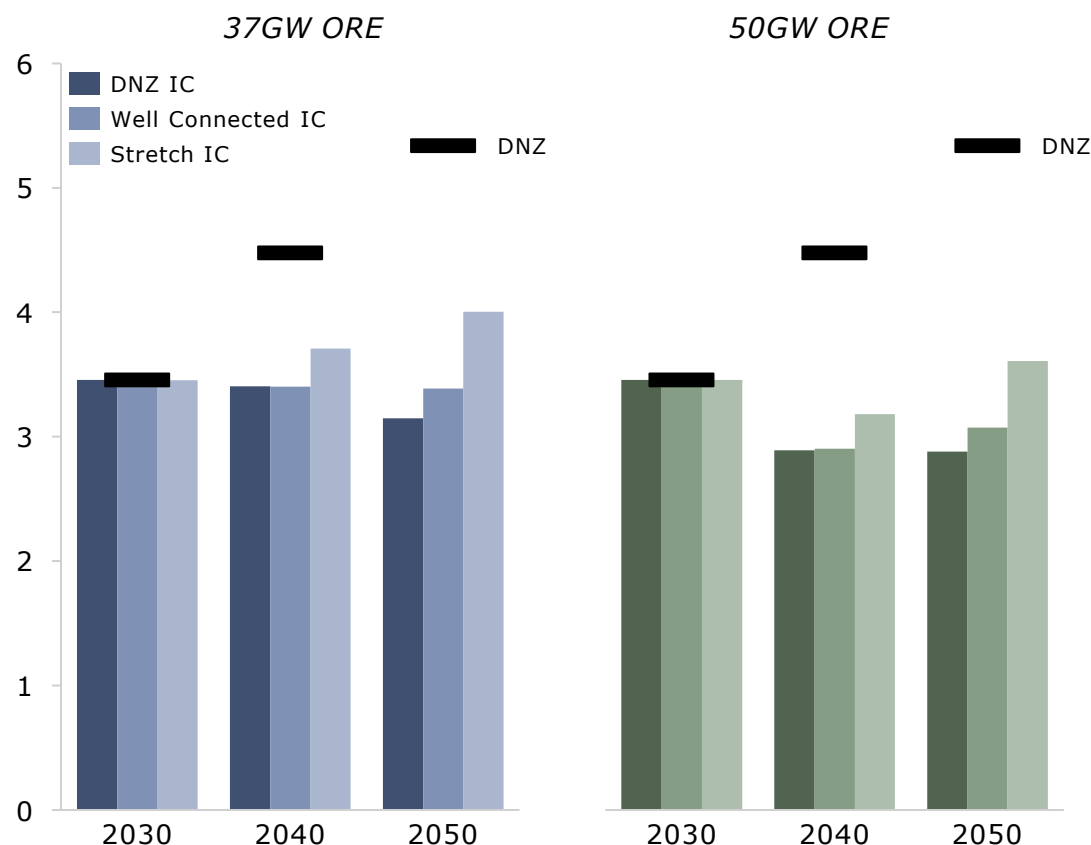
DISCUSSION

- The graphs show the total congestion revenues in 2050 in all the scenarios by connected country. GB and France have the highest IC capacity, while Belgium and Spain IC capacity is only present in the Well Connected and Stretch scenarios
- The coloured bars represent the export revenues i.e. Ireland to the connected country, which by 2050 represent the vast majority of the revenues. Revenues from imports into SEM are negligible for GB and Belgium, although more notable for France and Spain as they are still able to export some extra solar generation at times.
- In the Stretch scenarios, GB and France IC related overall congestion revenues decrease compared to the Well Connected equivalents despite the former having higher capacity. This indicates a cannibalisation effect linked to increased capacity and also more connection to Belgium and Spain, which lower the congestion rent revenues between GB/France and Ireland. This potentially suggests that a tipping point may exist between the Well Connected and Stretch scenario assumptions in terms of IC for France and GB.

SYSTEM IMPACTS

Wholesale price reductions translate into billions of euro of savings on the wholesale cost of meeting demand, but higher interconnection increases this

**SEM WHOLESALE COST OF MEETING DEMAND
(€ BILLIONS, REAL 2022 PRICES)**



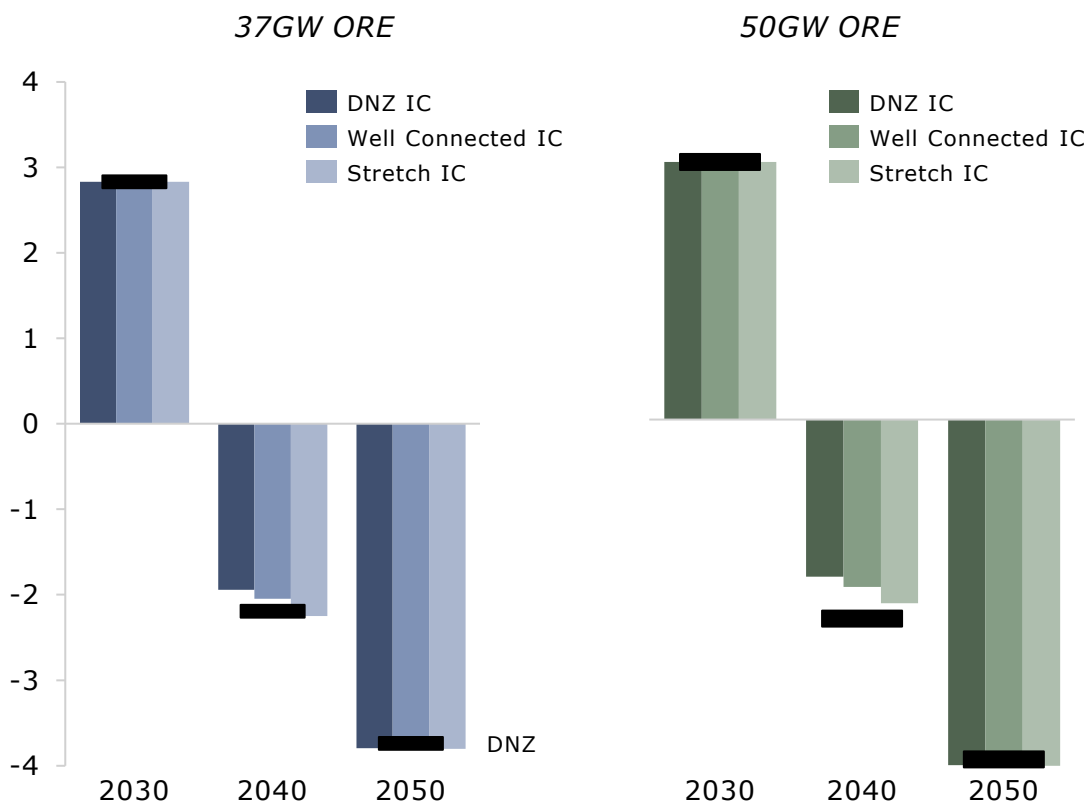
DISCUSSION

- Regardless of the level of interconnection, there are very significant savings in the cost of meeting demand in the 37GW ORE and 50GW ORE pathways.
- In the 37GW ORE pathway, savings are in the range of €0.75-1B per year in 2040 and €1.3-2.2B per year in 2050. These increase to €1.3-1.6B in 2040 in the 50GW ORE pathway and €1.7-2.5B in 2050 in the 50GW ORE pathway.
- In both 37GW and 50GW ORE pathways, increasing interconnection leads to higher wholesale costs of meeting demand. This is the case for the Stretch cases in 2040 and 2050 and also for the Well Connected cases in 2050.

SYSTEM IMPACTS

Increasing interconnection has limited impact on the power sector CO₂ emissions but does offer slight improvements

CARBON EMISSIONS FROM THE IRISH POWER SECTOR (MT CO₂)



Note: Contribution of off-grid ORE is included above.

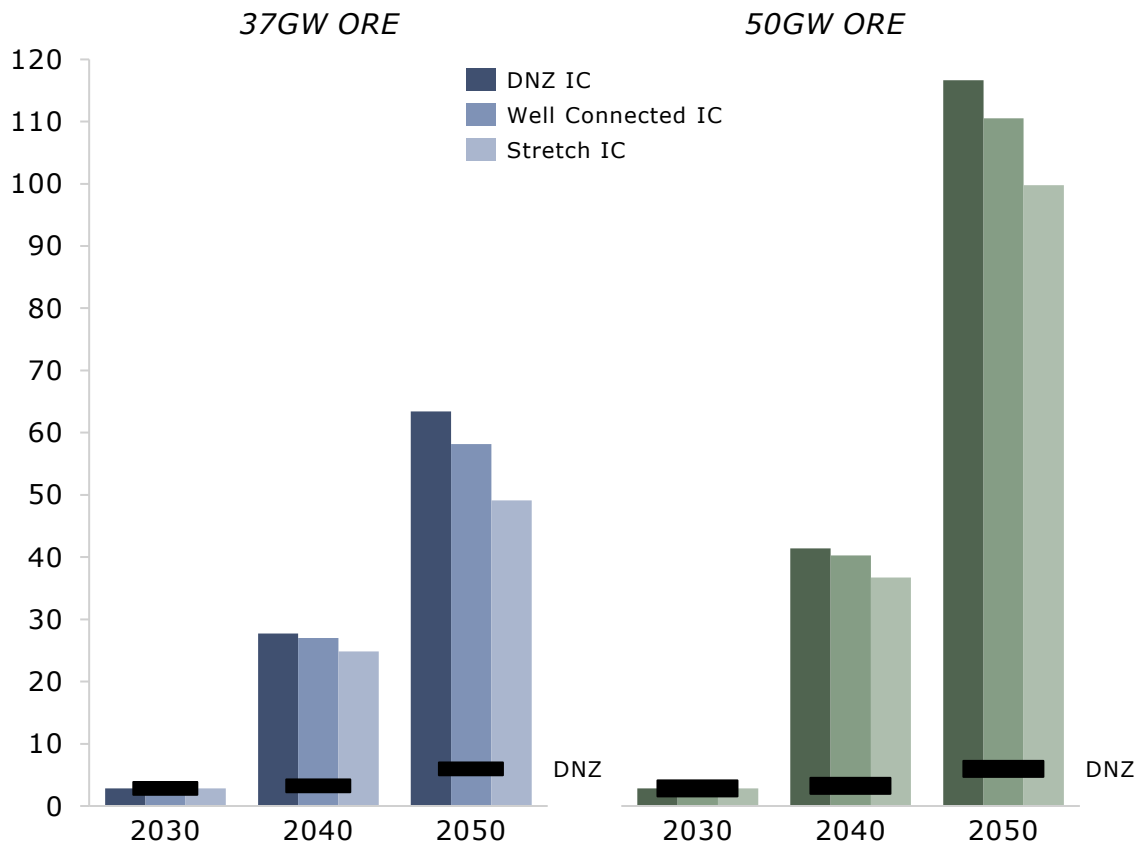
DISCUSSION

- The graph shows the CO₂ emissions calculated from the electricity power dispatch in Ireland. By 2040, emissions are already negative thanks to BECCs technology which have negative emissions and enable to go to net zero.
- Despite having higher wind generation and the same thermal capacity mix, there are lower emissions in 2040 in the DNZ scenario compared to the other scenarios. This is because wind generation is displacing some BECCS generation which has negative emissions.
- In the more interconnected cases, we can see that the emissions are slightly more negative in 2040, suggesting an additional benefit from the Irish power point of view. This is also the case for neighbouring countries benefiting from the extra renewables from Ireland which can displace some more carbon intensive technologies. By 2050, the interconnection increase barely affects the Irish power sector CO₂ emissions.

SYSTEM IMPACTS

Surplus energy production after electricity IC exports reaches >50TWh and >100TWh in the 37GW ORE and 50GW ORE pathways respectively

IRELAND ORE SURPLUS (TWH)



Note: Contribution of off-grid ORE is included above.

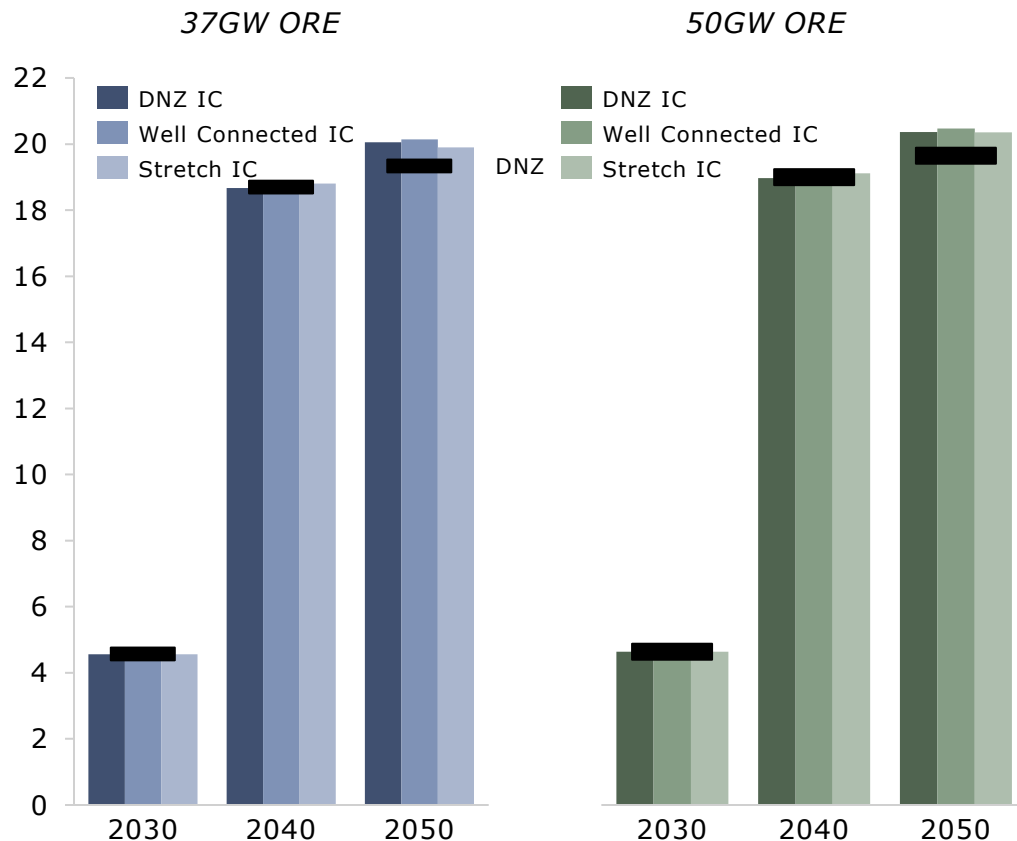
DISCUSSION

- After exporting as much energy as possible via electricity interconnectors, this study suggests the residual ORE surplus in the 37GW and 50GW ORE pathways is very substantial.
- In the 37GW ORE pathway, regardless of the amount of interconnection built, ORE surplus amounts to around double today's power demand in Ireland by 2050. Compared to expected 2050 domestic power demand of c.135TWh, ORE surplus is a little under half of annual demand.
- Turning to the 50GW ORE pathway, ORE surplus is 100TWh in the Stretch IC pathway, not far from projected 2050 domestic demand. To put it another way, the amount of ORE surplus would be sufficient to power Ireland on its own.
- Irish ORE surplus falls as electricity IC is added as some of the surplus can be sold in adjacent power markets.

SYSTEM IMPACTS

Increased interconnection has a very limited impact on security of supply with the Irish market already oversupplied by 2040

IRISH MINIMUM CAPACITY MARGIN/SECURITY OF SUPPLY (%)



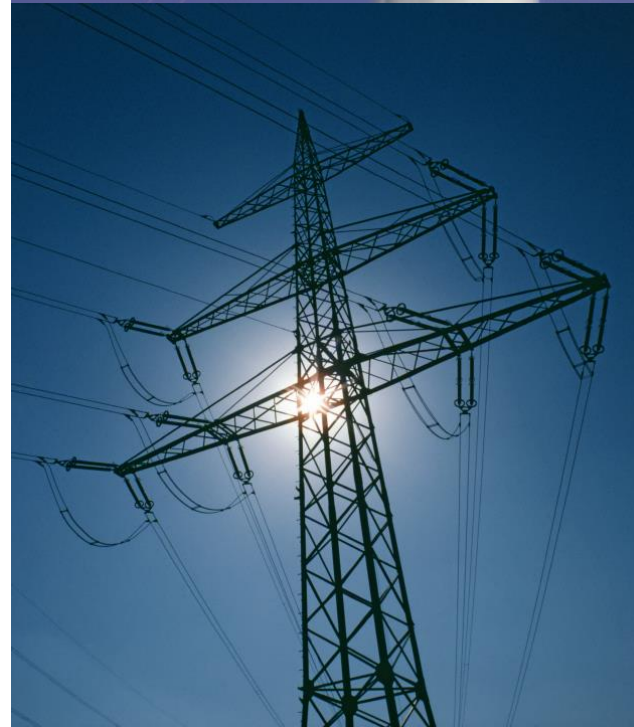
Note: Contribution of off-grid ORE is included above.

DISCUSSION

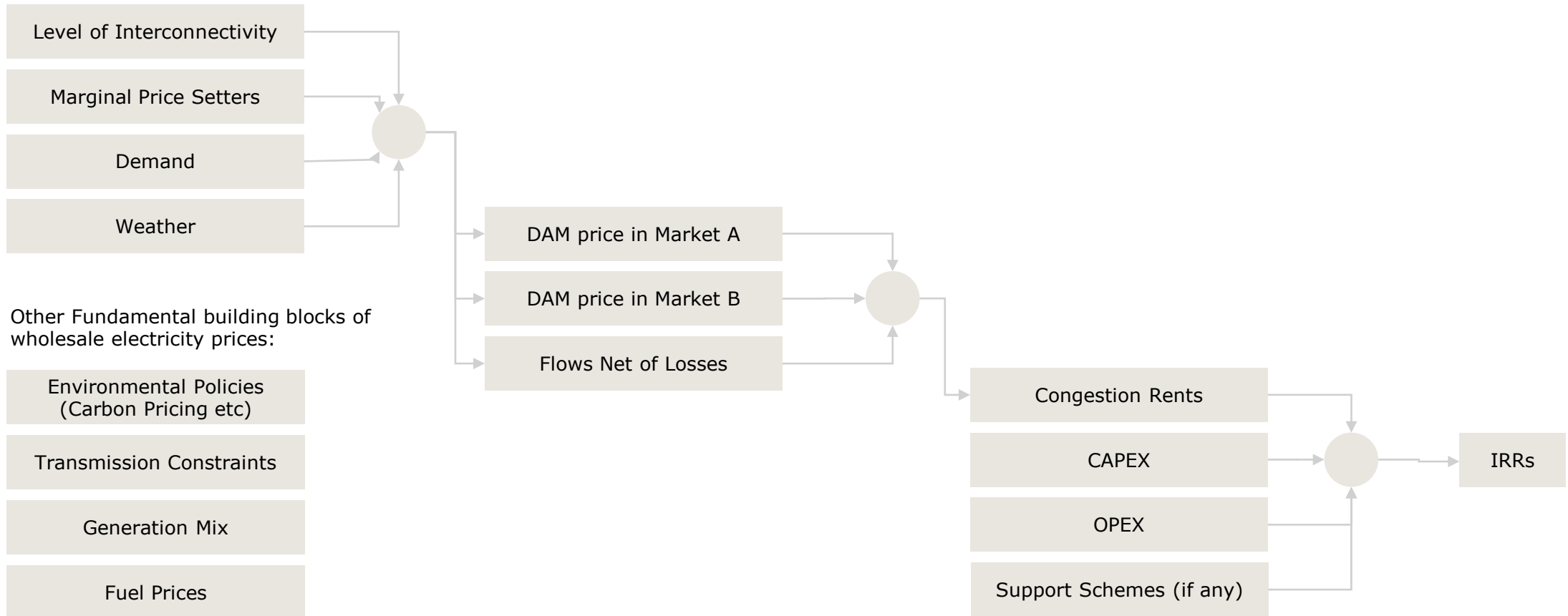
- The capacity margin reflects the level of security of supply which is calculated on an hourly level by looking at the difference between the local available capacity plus the available interconnection deducted by the local demand i.e. the lower the capacity margin, the tighter the system is either due to higher demand or lack of generation/interconnection available. The minimum capacity margin represents hence the tightest hour of the different weather years.
- In the different scenarios, we can see that the system becomes largely oversupplied by 2040 with more than 18% margin at the tightest hour.
- Increasing the interconnection provides little additional benefits for the security supply which is already very large in the DNZ.

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Fundamentals of the market, supply-demand dynamics and levels of cannibalization by other ICs, directly influences IC congestion rents, which, in turn, impact project IRRs



TYNDP data served as the foundational input to formulate a CAPEX and OPEX estimation model, essential for IRR calculations

CAPEX ESTIMATION METHODOLOGY

- TYNDP 2022 CAPEX, Capacity, and Length data were used as inputs to formulate a Capital Expenditure (CAPEX) estimation formula
- These CAPEX numbers were used as part of IRR calculations
- CAPEX (mEuro/GW) was plotted against Lengths (km) and a regressions analysis revealed the following model for CAPEX estimation
- $CAPEX (mEuros/GW) = 1.21 * Cable Length (km) + 494.3$

OPEX ESTIMATION METHODOLOGY

- A similar approach was taken for the OPEX estimation model; OPEX figures are taken from TYNDP 2022 for named projects
- OPEX (Euro/KW/year) was plotted against Capacity (MW) and a nonlinear regressions analysis was used to attain the OPEX
- According to the MaresConnect’s TYNDP factsheet, OPEX breakdown, more than 90% of the OPEX originates in dealing with the converter stations vs the cable

Capacity (MW)	OPEX (euro/kw/year)
750	13.9
1500	9
2250	6.9
3000	5.8

Source: ENTSOE TYNDP

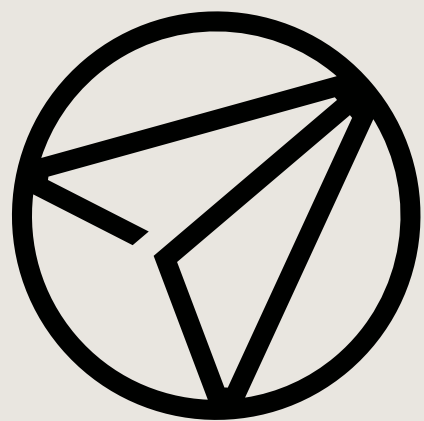
LENGTH ESTIMATION

- Average cable lengths from existing projects were rounded to establish representative cable length proxies for interconnecting projects
- For the case of Spain inspiration for the most likely route came from abandoned past TYNDP 2016 projects; Project 296 – Britib and Project 281 - ANAI: Abengoa Northern Atlantic Interconnection

	Lengths (Km)	CAPEX (mEuro/GW)
RoI-BEL	900	1583.3
RoI-GBR	200	736.3
RoI-FRA	500	1099.3
NIR-GBR	130	651.6
RoI-SPA	1200	1946.3

IRR CALCULATIONS

- The cashflow for the IRRs were based on Interconnector total congestion rents, with OPEX acting as a negative cashflow for 25 years
- The CAPEX was divided equally as a negative cashflow in the three years prior to the commissioning of an IC project



AFRY

ÅF PÖYRY



Offshore Renewables Surplus WS2 – Electricity Interconnection Qualitative Assessment Report

A report to the Department for the Environment, Climate and Communications

NOVEMBER 2023

AFRY is an international engineering, design and advisory company.

We support our clients to progress in sustainability and digitalisation.

We are 17,000 devoted experts within the fields of infrastructure, industry and energy, operating across the world to create sustainable solutions for future generations.

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The report contains projections that are based on assumptions that are subject to uncertainties and contingencies. Because of the subjective judgements and inherent uncertainties of projections, and because events frequently do not occur as expected, there can be no assurance that the projections contained herein will be realised and actual results may be different from projected results. Hence the projections supplied are not to be regarded as firm predictions of the future, but rather as illustrations of what might happen. Parties are advised to base their actions on an awareness of the range of such projections, and to note that the range necessarily broadens in the latter years of the projections.

AFRY and BVGA have been commissioned by DECC to provide an economic analysis of the potential for Offshore Renewable Energy (ORE) surplus

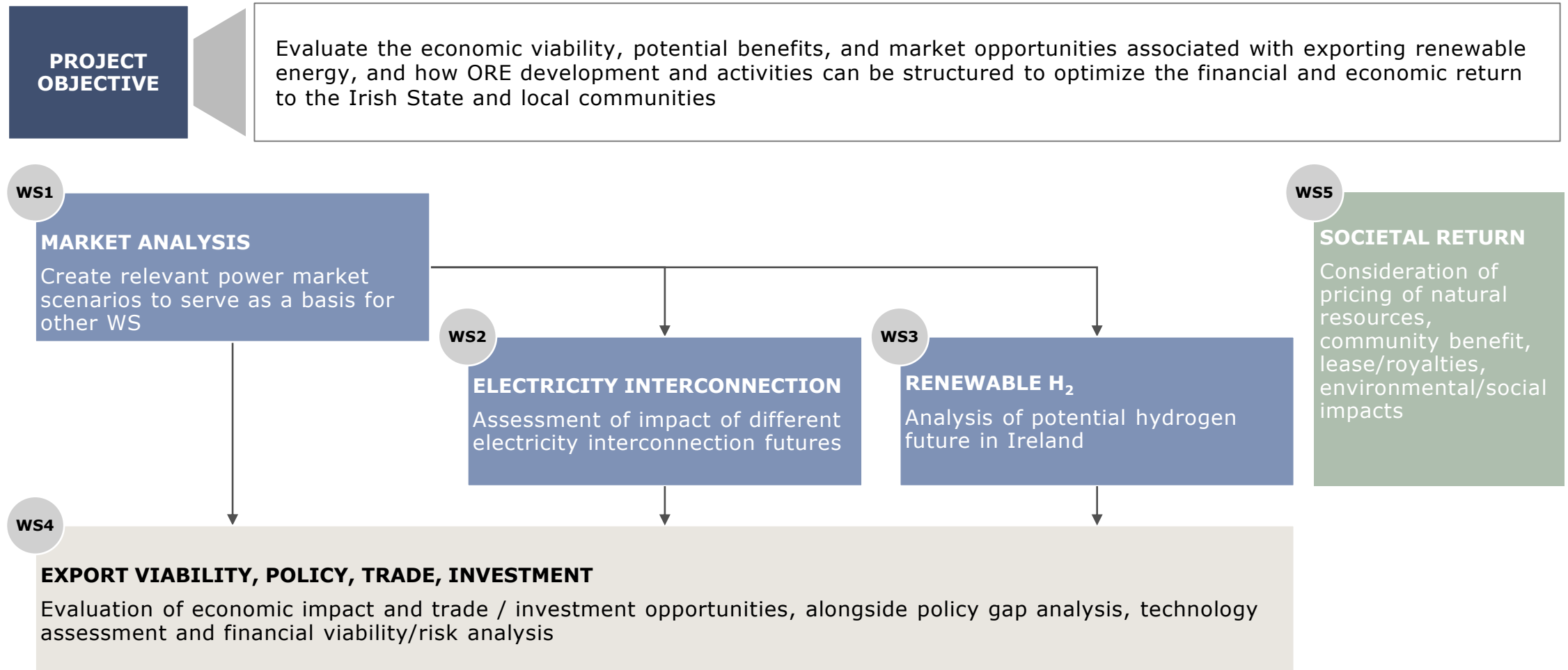
BACKGROUND

- Ireland has ambitious climate action targets for 2030 as well as a legally binding target of achieving net zero emissions by 2050.
- Offshore renewables are expected to play a key role in delivering on 2030 and 2050 targets.
- Furthermore, because of Ireland’s maritime endowment, there is potential to capture significantly more offshore renewable energy (ORE) than would be needed to satisfy domestic energy requirements.
- However, it is uncertain what the optimal use of any ORE surplus might be. More specifically, whether ORE surplus should be exported as electricity, hydrogen (or hydrogen derivative) or if instead it should be ‘refined’ and used to produce new value-added products and services domestically (perhaps data centres or green steel or green aluminium).
- Consequently, the Department of the Environment, Climate and Communications (“DECC” or “the Client”) has requested AFRY Management Consulting Limited (“AFRY”) and BVG Associates Limited (“BVGA”) provide an economic assessment of the potential for ORE surplus.

SCOPE

- The broad scope of work includes the following elements:
 - Market analysis
 - Financial analysis
 - Socioeconomic impact analysis
 - Policy and regulatory analysis
 - Risk analysis
- This will be delivered via 5 Workstreams (WS):
 - WS1 – Market Analysis
 - WS2 – Electricity Interconnection
 - WS3 – Renewable Hydrogen Development
 - WS4 – Export Viability, Policy Considerations, Trade and Investment Opportunities
 - WS5 – Optimised Financial and Economic Return to the State and Local Communities

This study has five discrete but interlinked Workstreams



WS2 is an extension from WS1 scenario framework with a focus on the interconnector aspect with this report considering the qualitative side

BACKGROUND

- The assessments of electricity interconnection, renewable hydrogen and economic impact require a view of the future energy sector both in Ireland and in Europe / Great Britain (GB).
- Areas of uncertainty include:
 - The level of domestic power and hydrogen demand
 - Fuel and carbon prices
 - The evolution of the capacity and generation mix
 - Power prices in the Irish Single Electricity Market (SEM) as well as neighbouring markets
 - Generation economics and the need (or lack thereof) for some form of support.
- Ultimately, the primary focus of WS1 is to create the scenarios of the Irish (and interconnected European) energy market in 2030, 2040 and 2050 that form the basis for analysis in subsequent WS.

SCOPE

- Workstream 2 has two main focus areas. First, based on the cases developed in Workstream 1, it considers on a quantitative basis, outcomes for the Irish electricity system and for electricity interconnection specifically under the cases examined. This allows for analysis of the impacts of different interconnector futures across the cases and the effects of the drivers behind the different cases on outcomes.
- Second, it considers on a qualitative basis issues relating to the regulatory and commercial models for progressing further interconnection. This includes for instance looking at the economic rationale for hybrid IC, regulatory funding models for IC and other potential revenues than the congestion rent.

KEY POINTS

Economic feasibility of IC projects must be viewed alongside the regulatory landscape to assess feasibility of future developments

ICs can access multiple revenue sources

Key Point: Congestion rent revenues are the prime source of remuneration. But other revenue sources are available such as via capacity mechanisms and provision of ancillary services

Regulatory Models for interconnection in Europe

Key Point: Three main forms of route to market exist for interconnectors in Europe. 1) TSO led projects with fully regulated revenues. 2) Private investor led projects with partially regulated revenues. 3) Private investor led projects with fully merchant revenues

Physical and Political Arrangements

Key Point: Several factors contribute to the complexity of project delivery. Longer routes, deeper sea depths, extensive use of the sea/seabed, and numerous maritime jurisdictions make project delivery more complex



Hybrid Interconnection

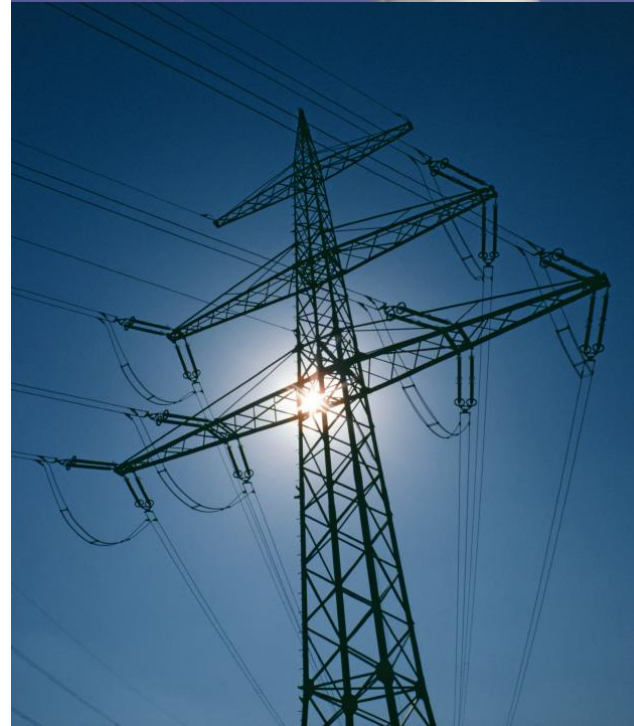
Key Point: Hybrid interconnectors, also known as Multi-Purpose Interconnectors (MPIs), offer several benefits such as boosting RES integration, operational synergies, lower capital costs, and reduced environmental impacts. EU Electricity Market reforms are aimed at supporting development of more MPIs by reducing risks for developers

Home Market / Offshore Bidding Zone

Key Point: Offshore bidding zones are emerging as the preferred market setup for hybrid interconnection due to potential for higher efficiency. However, there are risks particularly for OWFs who may receive lower prices

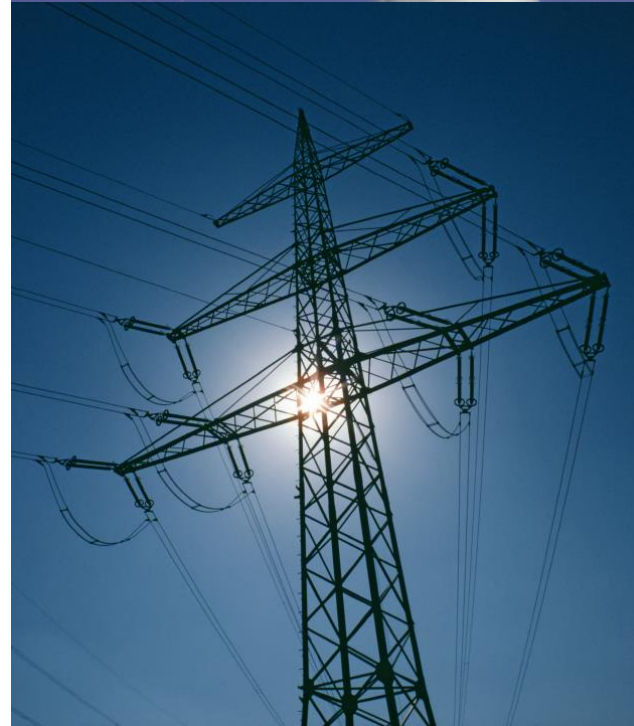
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PRACTICAL CONSIDERATIONS

The technical and practical complexities of ICs are influenced by cable distance, seabed characteristics and offshore jurisdictional arrangements

Cable Length & Voltage Levels

Subsea interconnectors can span long distances, and higher voltage levels may be required to reduce transmission losses. Longer cable lengths and higher voltages introduce additional technical complexities related to cable design, insulation and installation.

Submarine Cable Protection

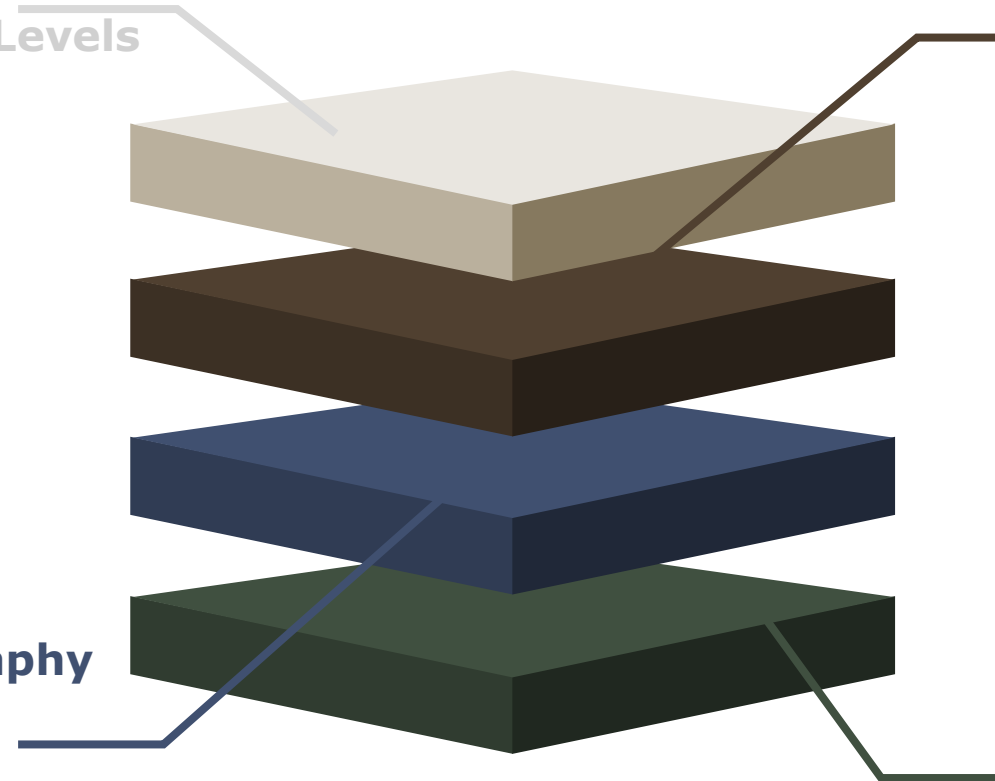
Protecting subsea cables from damage caused by factors such as ship anchors and fishing activities is imperative to maintain availability.

Depth & Subsea Topography

Installing subsea HVDC cables involves specialized vessels and equipment. Laying cables on the seabed, often at significant depths, requires careful planning and precise execution. Factors like seabed topography and existing infrastructure may complicate the installation process.

International Coordination

Coordinating with multiple countries, regulatory bodies, and stakeholders can add a layer of complexity in terms of permitting, regulatory compliance, and international agreements.



PRACTICAL CONSIDERATIONS

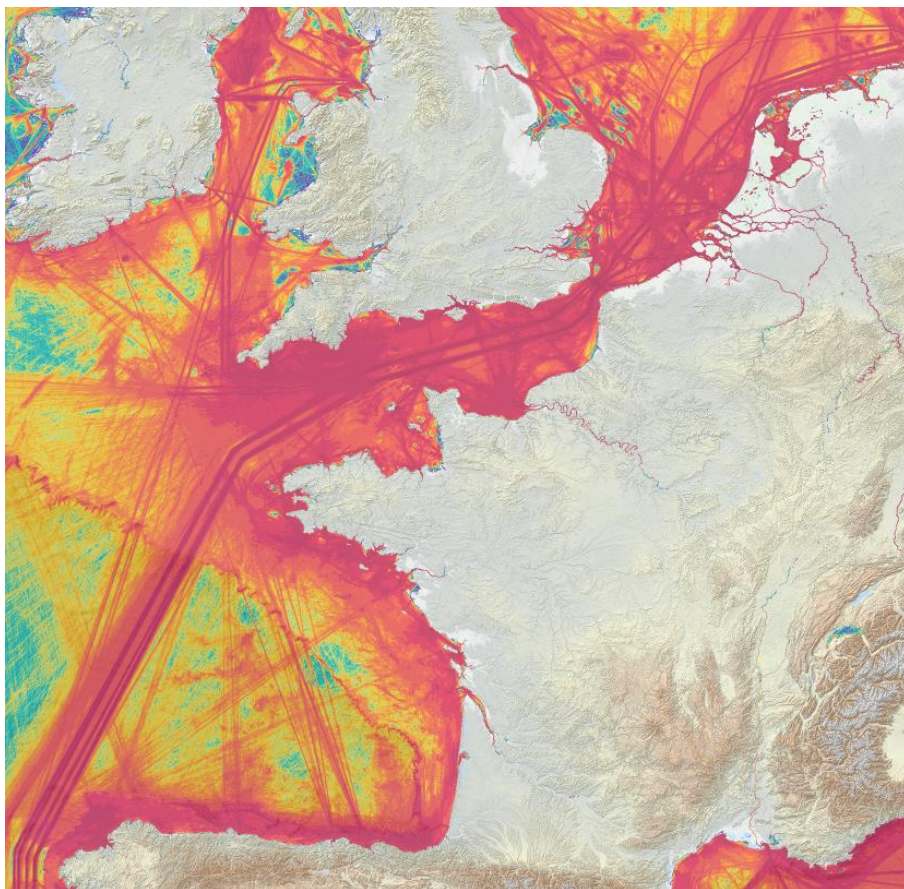
Interconnections face a number of technical and environmental complexities

	Cumulative Capacity by 2050 (MW)	Length	Depth	International Waters to be Crossed	Congestion	
BELGIUM	DNZ: 0 Well Connected: 750 Stretch: 2250	900 km	100 m (max)	GB, France, Belgium	<ul style="list-style-type: none"> The English Channel is one of the busiest waterways in the world, with a high volume of commercial shipping traffic, including cargo vessels, ferries, and tankers. There are several existing submarine cables and pipelines in the English Channel, which can contribute to congestion and potential cable damage. 	
GB	DNZ: 5500 Well Connected: 5500 Stretch: 6300	200 km	100 m (max)	GB	<ul style="list-style-type: none"> The Irish Sea experiences significant shipping traffic, including cargo vessels, ferries, and fishing vessels, although generally not to the same extent as the English Channel. The level of congestion can vary depending on the specific routes taken by ships and the time of year. 	
FRANCE	DNZ: 4500 Well Connected: 5200 Stretch: 6000	500 km	100-150 m (max)	GB, France	<ul style="list-style-type: none"> The Atlantic coast of France generally experiences lower shipping traffic compared to the English Channel. This region may have fewer existing submarine cables and pipelines, which could mean less congestion for new interconnectors. 	
SPAIN	DNZ: 0 Well Connected: 750 Stretch: 2250	1200 km	100-150 m (max)	GB, France, Spain	<ul style="list-style-type: none"> Fishing activity can still be a consideration, but it may be less intense than in the English Channel. 	

Sources: European Atlas of the Seas

Practical considerations like marine congestion can have a substantial impact on the feasibility and risk assessment of interconnector projects

MARINE TRAFFIC



Source: European Atlas of the Seas

COMMENTARY

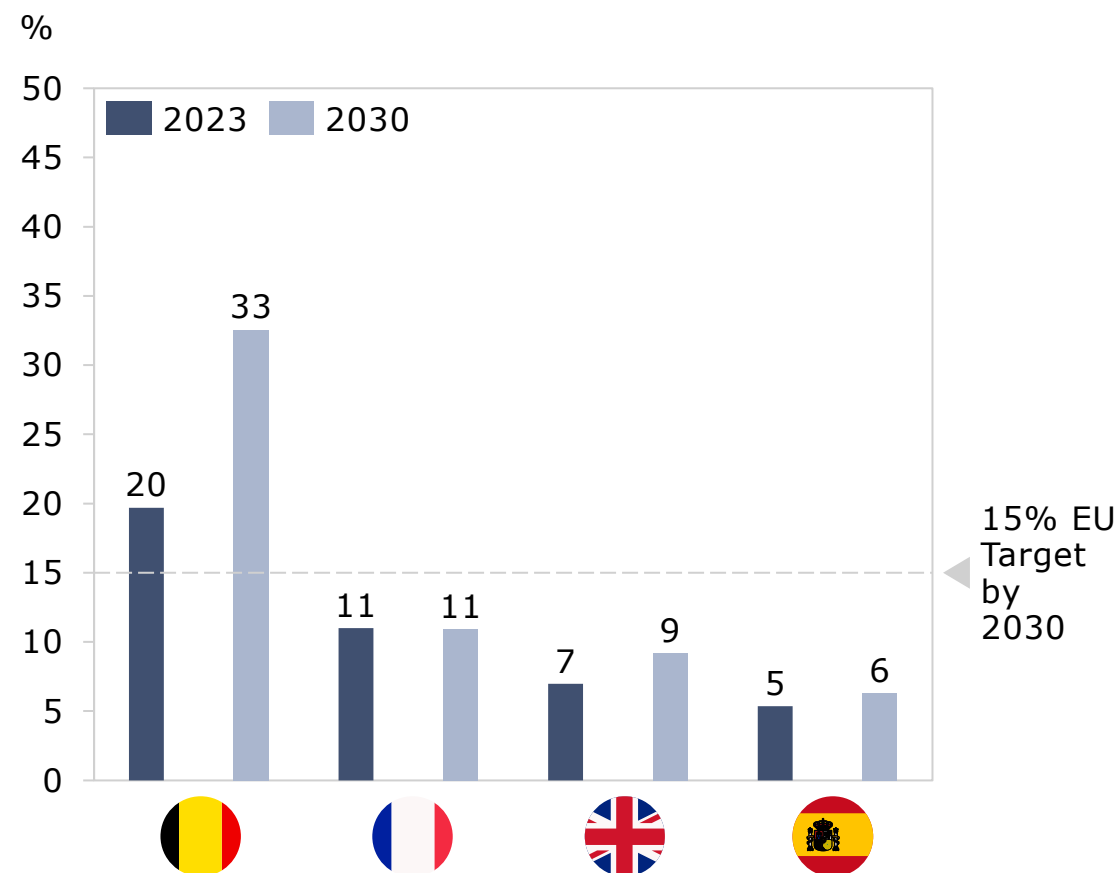
- Marine congestion can influence the choice of interconnector routes. Developers may need to identify routes that are less congested and where the risk of damage to the interconnector due to activities like shipping, fishing, or other marine operations is minimized. Route selection can significantly impact project feasibility and costs.
- Project timelines can be affected by marine congestion. Delays caused by congestion may result in increased project costs and financing challenges. Developers may need to adjust their schedules to work around periods of higher marine traffic.
- Engaging with local communities, industries, and other stakeholders is essential. Developers should communicate the potential impact of the interconnector on marine congestion and seek input from these stakeholders to address concerns and gain support.
- Understanding and assessing the risks associated with marine congestion is vital. Developers need to consider factors like the intensity of marine traffic, the frequency of maintenance required, and the potential for cable damage. Developing robust risk mitigation strategies is essential to ensure project feasibility.

Competitiveness can be looked at based on the number of other existing or actual interconnections in each country and relative to the EU IC target

COMMENTARY

- The European Union has established a goal of achieving a minimum of 15% interconnection capacity by 2030 to promote the connection of electricity production capacity among its member countries. This entails that each nation should establish the necessary electrical infrastructure, to enable the transmission of at least 15% of the installed electricity generation capacity within its borders to be shared with neighbouring countries.
- Based on AFRY analysis of announced IC projects and evaluation of the likelihood of the projects being commissioned by 2030, the chart shows the percentage of interconnector capacity of different countries vs their installed generation capacity by 2030.
- GB has a target of 18 GW of Interconnector Capacity by 2030 and based on its projected generation capacity by 2030 this amounts to 12%.
- Belgium's strong progress in surpassing the EU's interconnection targets and its ambitious aim to achieve double the EU targets by 2030 indicate a substantial commitment to enhancing interconnection within its energy landscape. As a result, any new interconnection projects will need to navigate a competitive environment, given the considerable interconnection developments already planned and in progress.
- GB, France, and Spain face the challenge of needing additional interconnection to meet their 2030 targets. However, in Spain's case, which lags significantly behind, achieving this target may be more attainable through interconnection with its immediate neighbours.

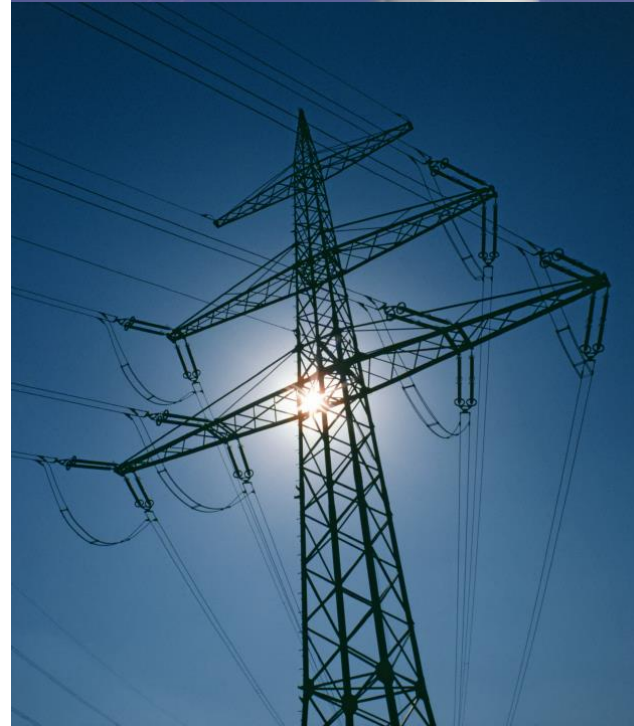
Ratio of cross border interconnector capacity / installed generation capacity 2023 and 2030 (%)



Sources: AFRY, ENTSO-E, Montel, 4C Offshore

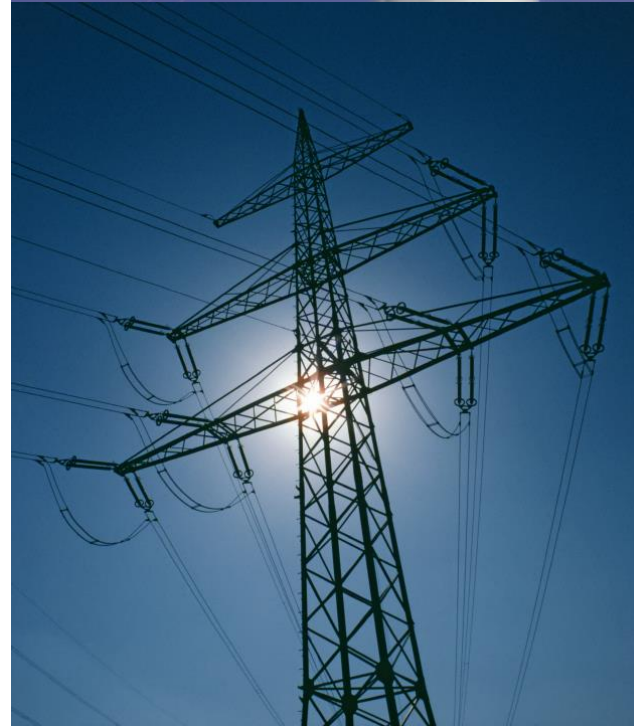
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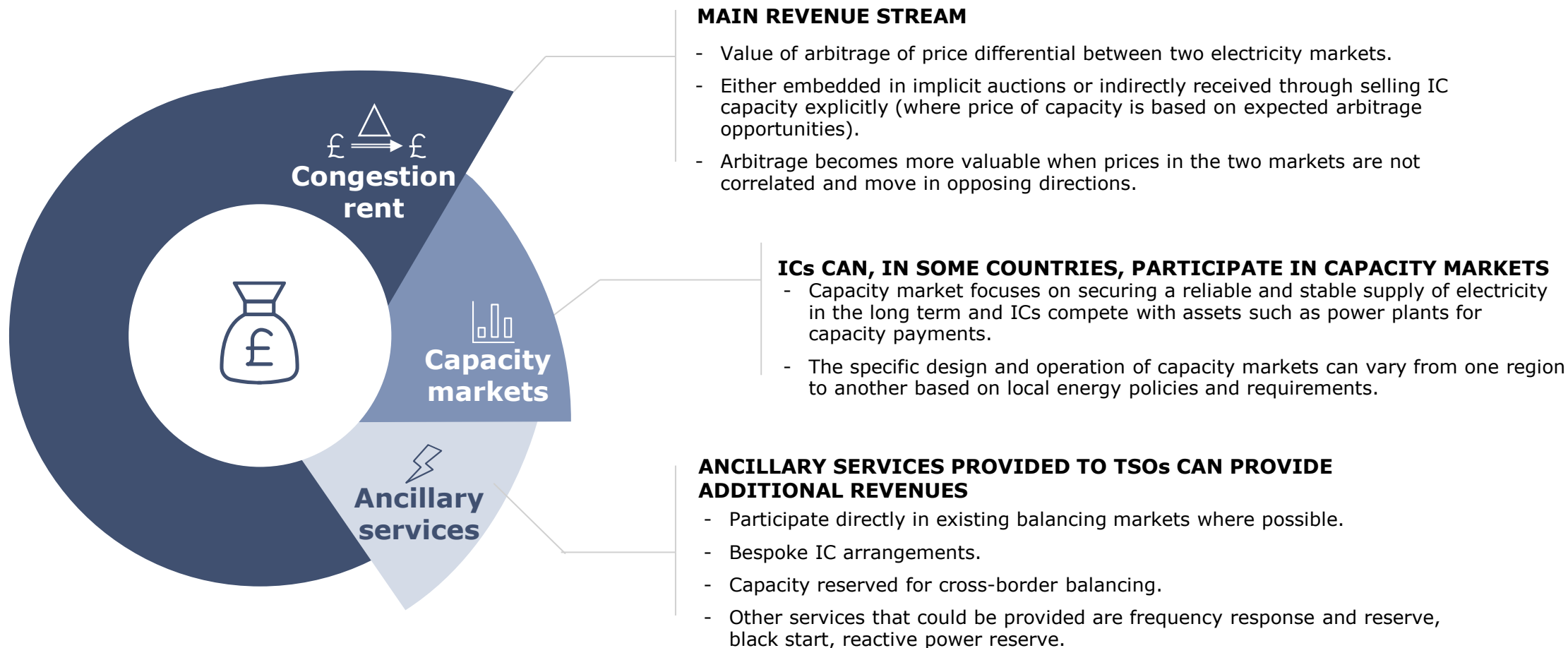


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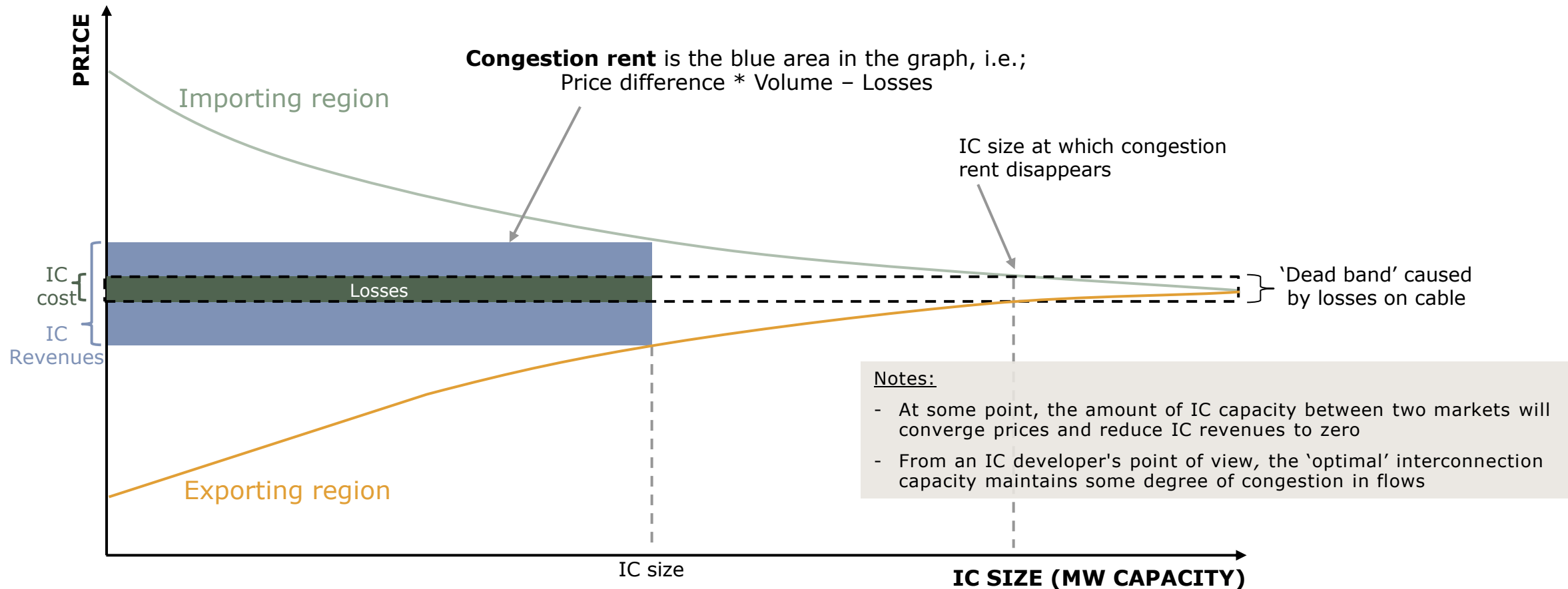


ICs can access a range of revenue streams depending on the market arrangements, however congestion rents are the main source of revenues

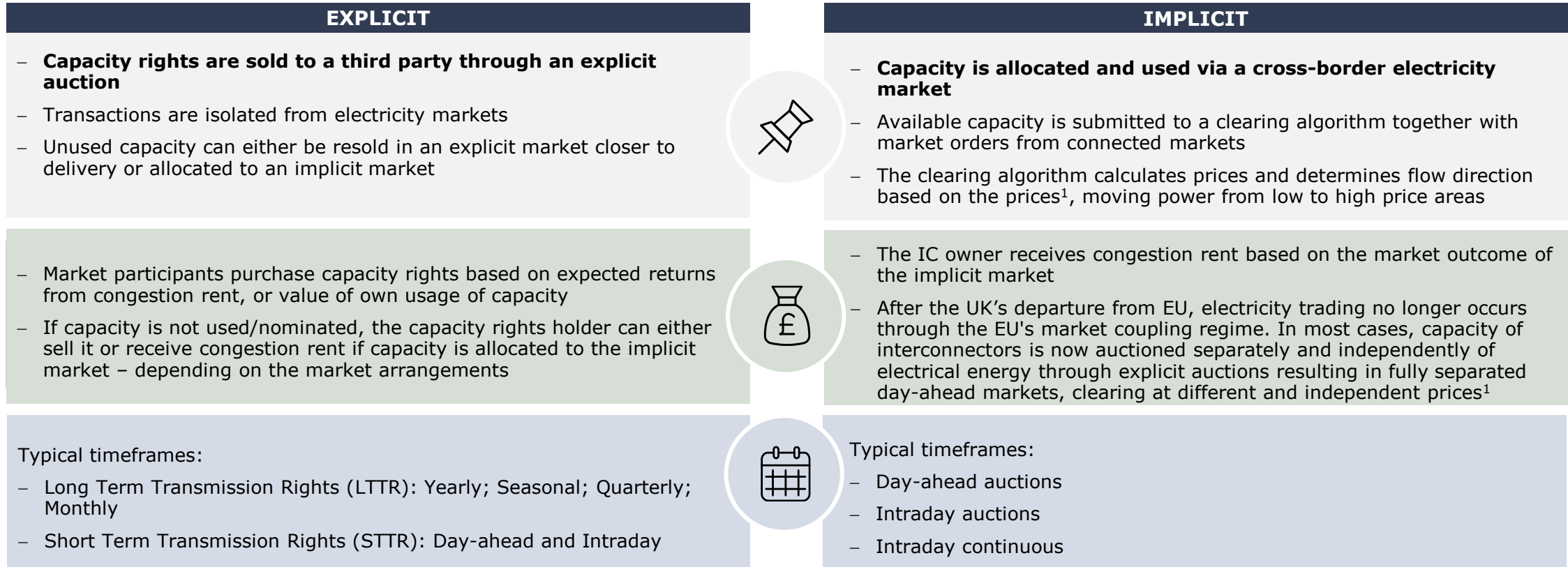


IC REVENUE STREAMS

Increase in Interconnector capacities reduces price spreads between markets ultimately reducing congestion rents



Congestion rent is realised by ICs through either explicit sale of capacity or allocation of capacity to an implicit market



A market can be entirely based on either explicit or implicit markets, or a combination of both.

1. This is a simplified explanation. The algorithms are usually sophisticated and include other factors such as ramping and losses etc.
Source: 1 GB Wholesale Electricity Market Arrangements. Department for Energy Security and Net Zero, 2023

IC REVENUE STREAMS

ICs are theoretically able to access revenues from capacity markets, depending on how the markets are regulated

- The aim of a **capacity market (CM)** is to ensure security of electricity supply in a competitive manner. This is achieved by providing a payment for reliable sources of capacity, alongside their electricity revenues, so resources are available when needed i.e. when the system is tight
- In contrast to an energy-only market, a capacity market compensates for the availability (readiness) to be instructed, not the actual energy produced



- ICs participate in Britain's capacity market auctions alongside generators, storage assets, and demand side response
- ICs are de-rated based on a mixture of historical and forward-looking analysis of likely flow direction during periods of high demand
- ICs can access 1-year contracts valued at the clearing price for their de-rated capacity
- Failure to meet capacity obligations during a system stress event leads to penalties
- Capacity market revenue is in addition to congestion rent as it is not necessary to hold back capacity

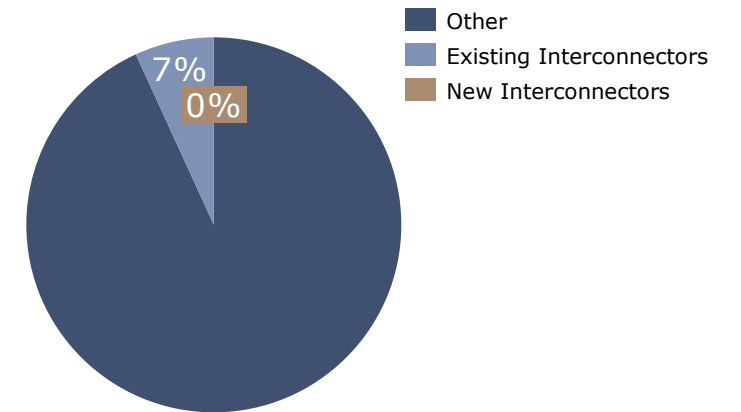


- The Irish Capacity Remuneration Mechanism (CRM) is a market mechanism implemented by the Irish government to ensure security of supply. The Single Electricity Market Operator (SEMO) issues Reliability Options (ROs) through an auction process, typically occurring at the 4 year ahead stage and subsequently the 1 year ahead stage
- Capacity providers that win in a capacity auction are entitled to receive ongoing capacity payments. These payments help finance the maintenance and development of electricity generation capacity. In exchange, successful participants have a responsibility to reimburse consumers when energy prices exceed a predetermined strike price for each capacity auction
- As of Aug. 2022, "circa 650MW of capacity procured through the auction processes since 2018 has withdrawn and has failed to deliver capacity to the electricity grid."¹



- New EU regulation no longer allows ICs direct access to this revenue stream (although this does not prevent direct IC participation in the GB's capacity market)
- There are ways to access revenues from capacity markets indirectly, i.e. ICs can sell IC capacity to third parties who can use it in the capacity markets

A total of 103 Capacity Market Units (6,167.95 MW derated) were successfully Awarded Capacity in the I-SEM 2024/2025 T-4 Capacity Auction²






Moyle and EWIC were awarded a total of 421 MW of capacity at 47,820 (EUR/MW) for 1 year

Source: 1 EirGrid notes publication of EY Report on Performance of the SEM Capacity Remuneration Mechanism, EirGrid, 2022, 2 SEM Capacity Market Final Capacity Auction Results 2024/2025 T-4 Capacity Auction, Eirgrid / SONI, 2021

IC REVENUE STREAMS

ICs can get revenue by providing ancillary services directly/indirectly, by reserving capacity for balancing and via bespoke services

ICs can technically offer ancillary services by adjusting imports and exports, rapidly ramping up or down to address frequency fluctuations, providing inertia support, and managing the injection or absorption of reactive power.

	EXPLANATION	HOW IT IS USED TODAY	CHALLENGES
 <p>Direct participation</p>	<ul style="list-style-type: none"> - The IC provides ancillary services directly via common balancing markets, alongside standard assets such as generators, storage assets and demand side response - Remunerated in line with the market rules 	<ul style="list-style-type: none"> - ICs are generally <i>not</i> eligible to participate in balancing markets competing on equal terms with other assets - GB: Eligible to provide ORPS and restoration - EU: Do not directly participate in common EU markets, but domestic services exists 	<ul style="list-style-type: none"> - Participating in frequency response and reserve markets is typically challenging, because of the impact it has on the connected market. Typically only used when it has an immaterial impact or no negative impact on the connected market
 <p>Reserve capacity</p>	<ul style="list-style-type: none"> - Reserving IC capacity for the balancing timeframe, allowing trading balancing services implicitly - IC receives congestion rent 	<ul style="list-style-type: none"> - GB: This option does not exist today. - EU: With the integrated balancing market platforms¹, TSOs can access ancillary services offered at the other side of the IC via a common pool of orders only constrained by the amount of IC capacity made available 	<ul style="list-style-type: none"> - Reserving capacity for the balancing market means the reserved capacity cannot be traded in preceding markets, such as the day-ahead. There is also a risk of reserved capacity for the balancing timeframe will not be used, when the earlier markets would otherwise have used it.
 <p>Bespoke services</p>	<ul style="list-style-type: none"> - Arrangements put in place to allow TSOs to use an IC for balancing purposes outside of the common marketplaces - IC owner or capacity-right holder usually remunerated by the TSO using the service 	<ul style="list-style-type: none"> - GB: ESO can adjust the flow in or out of GB by either limiting how much capacity is available to the market or directly adjusting the flow in cooperation with the TSO-counterparty. Also possible to adjust the flow via capacity-rights holders. - EU: Varies in the different countries 	<ul style="list-style-type: none"> - Adjusting flow in or out of a country impacts the connected area, hence it must be tightly regulated to avoid mis-use that could harm future cooperation. Also, it is challenging to compare cost/benefit against other alternative ancillary services.

1. MARI, PICASSO, TERRE and shared FCR markets

The provision of system services in the Irish market will undergo substantial changes once the current Regulated Arrangements expire

	DS3 Volume Uncapped up to 2025/2026	System Services Future Arrangements - Post DS3
Regulatory concept	Price regulation	Volume regulation
Procurement method	Eligibility criteria	Competitive
Volumes available	Uncapped	Capped
Price setting	Regulator determined	Market-based for balancing capacity Competitive auction for Fixed Contracts
Services procured	Frequency response: FFR Reserves: POR, SOR, TOR1, TOR2, RRS/RRD Ramping: 1hr, 3hr, 8hr Inertia: SIR Reactive power: SSRP Not yet procured: DRR, FPFAPR	As for DS3 but with scope for others, e.g.: – Congestion management – Damping – Oscillation – Ramping – Low carbon inertia
Contract duration	Up to 5 years / 6 years	Depends on product Hourly/Daily and more

EXTRACT OF THE PROVEN TECHNOLOGIES LIST

- There are currently 14 System Services products in Ireland
- There are two main categories of products: those addressing voltage control; and those address frequency control

	FFR	POR-TOR1	TOR2	RRS-RM8	SSRP / DRR	SIR	FPF APR
Interconnectors VSC	✓	✓	✓	✗	✓	✗	✓
Interconnectors LCC	✓	✓	✓	✗	✗	✗	✗

- The "Proven List" for DS3 System Services outlines technologies approved by TSOs for procurement.
- Being labeled as "proven" doesn't guarantee a service contract.
- Service providers must pass compliance assessments and meet performance standards.
- While a technology may be proven for multiple services, it can't provide all simultaneously, as some services depend on specific operational modes.

Source: AFRY, Source: EirGrid/SONI, DS3 System Services Proven Technologies List, 21 April 2022

Even if Black Start service seems to be available for ICs both in GB and SEM, it is highly uncertain what the payment to provide such service will be

Black Start (BS) is the procedure to recover from a total/partial shutdown of the transmission system which has caused an extensive loss of supply. BS is usually procured from plants able to start on-site auxiliary generator units, without reliance on external supply. Typical providers of BS service are thermal plants, but recently other technologies, including ICs, have been taken into consideration



BLACK START SERVICE FOR INTERCONNECTORS IN GB

- In Great Britain, National Grid has initiated selected Black Start service procurement through competitive tenders, with the first results published in November 2020 for the South West and the Midlands (delivery 2022-2027)
- Results of this procurement of Black Start service are not public data due to the nature of the service
- The Black Start Strategy and Procurement methodology 2021/2022 published in May 2021 confirms the willingness to reduce barriers to entry to interconnectors (alone or as a combined service)
- As such, there is evidence that an interconnector, upon meeting the technical requirements may provide black start service in GB, and the procurement process has recently moved to a competitive tender. The price procured with this service is unknown to date as this data is not published

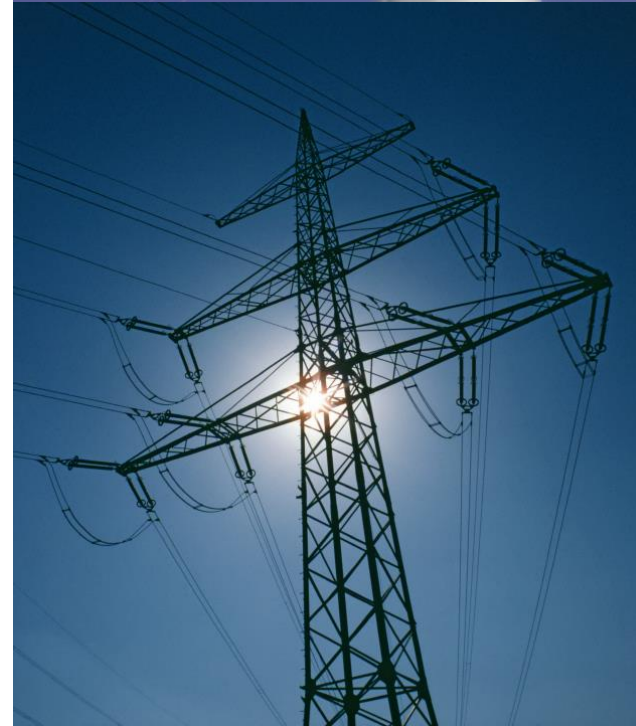


BLACK START SERVICE FOR INTERCONNECTORS IN SEM

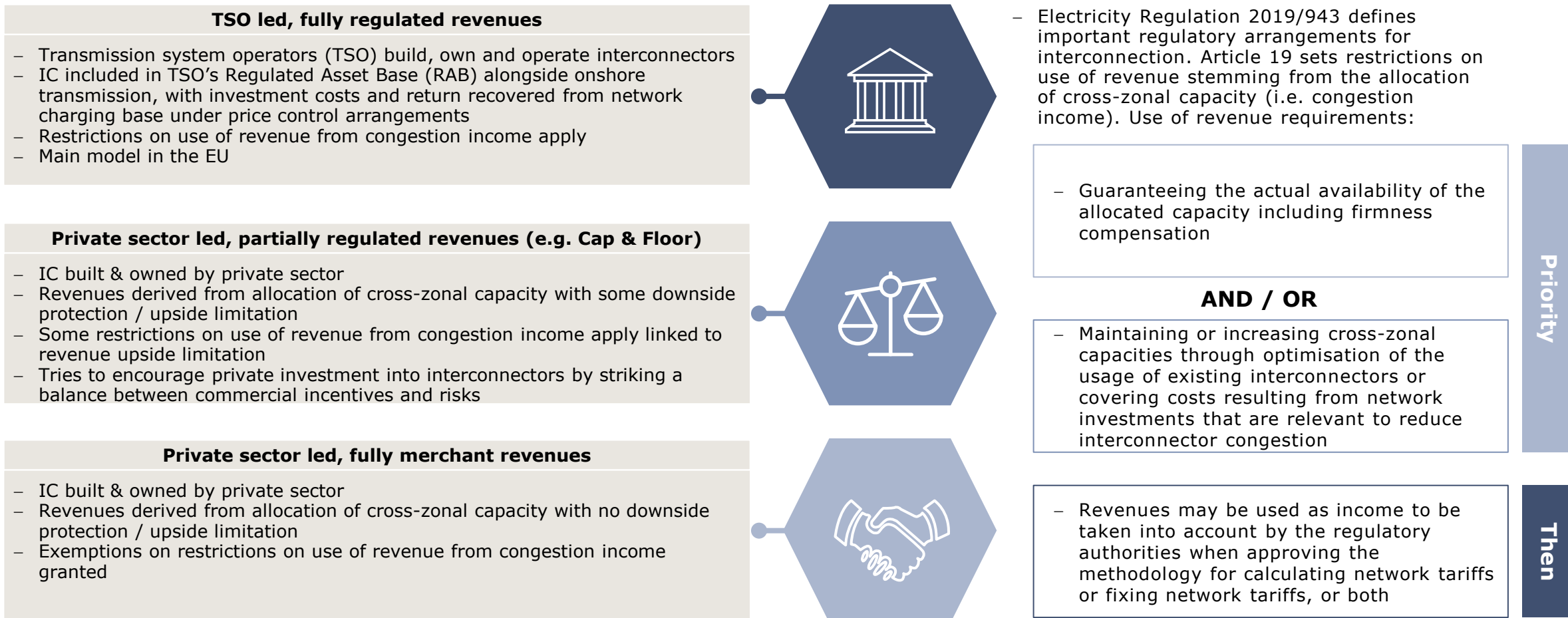
- In SEM, following EU 2016/1447, in Nov 2018, EirGrid published a consultation on the general application of technical requirements in line with Articles 11 to 50 of 2016/1447. The process led to the decision in March 2021
- On Black Start capability¹, the decision states that “*the relevant TSO may obtain a quote for Black Start capability from an HVDC system owner*”. EirGrid requested the TSO to obtain quotes based on system needs (approved by CRU). It is understood that Black Start can be procured, although not automatically allocated, from IC projects
- In the SEM, the recent published ancillary services statement of payment and charges shows that one IC (EWIC) received €81.63/hour for Black Start. This would represent 715 k€/year of revenues should the Black Start service be available every hour of the year in the SEM. However, the payment received by EWIC stated above may not correspond to the same payment for service provision by an IC in the future

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Three general revenue regulation models for interconnection stem from the ownership and exemption combinations (although there are exceptions)



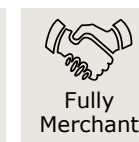
Note: The Cap and Floor regime is only currently available in GB and Ireland

REGULATORY MODELS

Three general revenue regulation models for interconnection stem from the ownership and exemption combinations (although there are exceptions)

IC type	Examples	Revenue
 <p>TSO IC with revenue regulation for IC with onshore assets</p>		<p>Regulated revenues</p>
 <p>Cap and Floor</p>		<p>Partially merchant revenues</p>
 <p>Merchant</p>		<p>Fully merchant revenues</p>

Notes: 1) Treatment of IFA as effectively a TSO asset is a function of its history. IFA2 has different treatment for GB and French components 2) Eleclink's revenues are not regulated, but it has a profit-sharing arrangement as a condition of its exemption, which requires 50% of profits above a certain level to be shared with RTE/NG ESO



Within the EU, for most Member States the main approach for interconnector development is through TSOs under a fully regulated regime

HIGHLIGHTS

- IC built & owned by TSO
- IC included in TSO's Regulated Asset Base (RAB) alongside onshore transmission, with investment costs and return recovered from network charging base under price control arrangements
- **Restrictions on use of revenue from congestion income apply**

STANDARD EU REGULATORY FRAMEWORK

- This is tailored for transmission system operators (TSOs). Given the unique characteristics of TSOs as natural monopolies, the compensation they receive for the use of capital is determined through regulatory processes and decisions made by regulatory authorities rather than through market-driven competition.
- Regulatory oversight is intended to balance the interests of TSOs, investors, and consumers in a fair and controlled manner.
- Regulations dictate how TSO's operate, the prices they can charge, and the quality of service they must provide.
- Even though TSOs are monopolies, they are still in competition for (equity and debt) investors and inadequate remuneration could hinder TSOs' ability to secure the necessary funding from investors to make essential infrastructure investments.
- Some examples of fully regulated interconnectors are;
 - **IFA**, a joint venture between the French Transmission Operator RTE and National Grid
 - **EWIC**, owned and operated by EirGrid

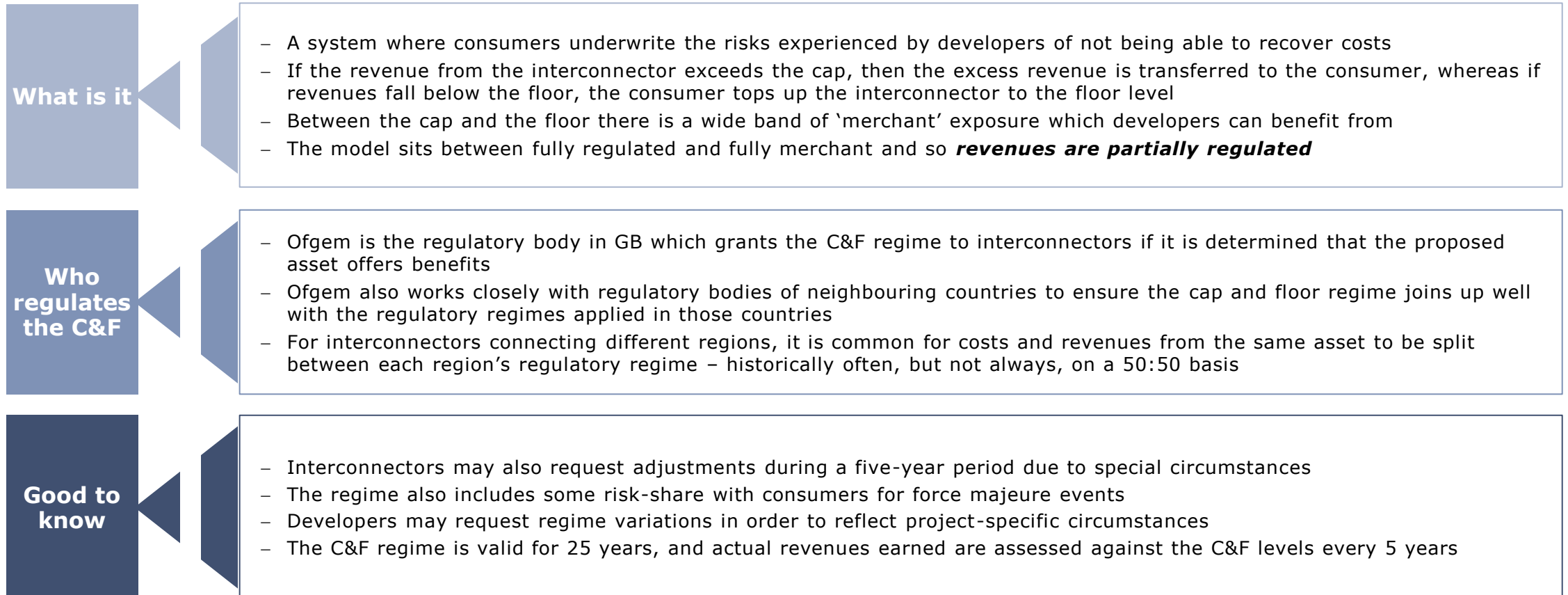
CALCULATING A RATE OF RETURN

- The CAPM methodology is utilized to calculate this rate of return, taking into account the level of risk associated with the investment, market conditions, and other relevant factors. It provides a widely accepted approach for assessing the equity remuneration in regulated sectors.
- The Regulatory Asset Base (RAB) is a financial measure which represents the total capital (money and assets) that a TSO has invested in its regulated business operations. The RAB is calculated to establish the foundation for determining the allowable remuneration or returns that TSOs can earn in their regulated activities.
- Presently, European TSO regulations primarily focus on two key forms of capital compensation regulation: Weighted Average Cost of Capital (WACC) and Return on Equity (RoE). These regulations also incorporate criteria for debt allowances, which can be determined based on either estimated or actual debt levels.
- The WACC is assessed by regulators using the CAPM methodology, which is applied to the RAB in some countries.

Sources: European Electricity Transmission Grids and the Energy Transition Why remuneration frameworks need to evolve, entsoe, 2021, Gautier, A. (2020). Merchant Interconnectors in Europe: Merits and Value Drivers

Ofgem designed the Cap and Floor regime to incentivise private investment in interconnector projects in GB

Features



Sources: Ofgem. (2021). Guidance – Interconnector Cap and Floor Regime Handbook. Ofgem. (2016). Cap and floor regime: unlocking investment in electricity interconnectors.

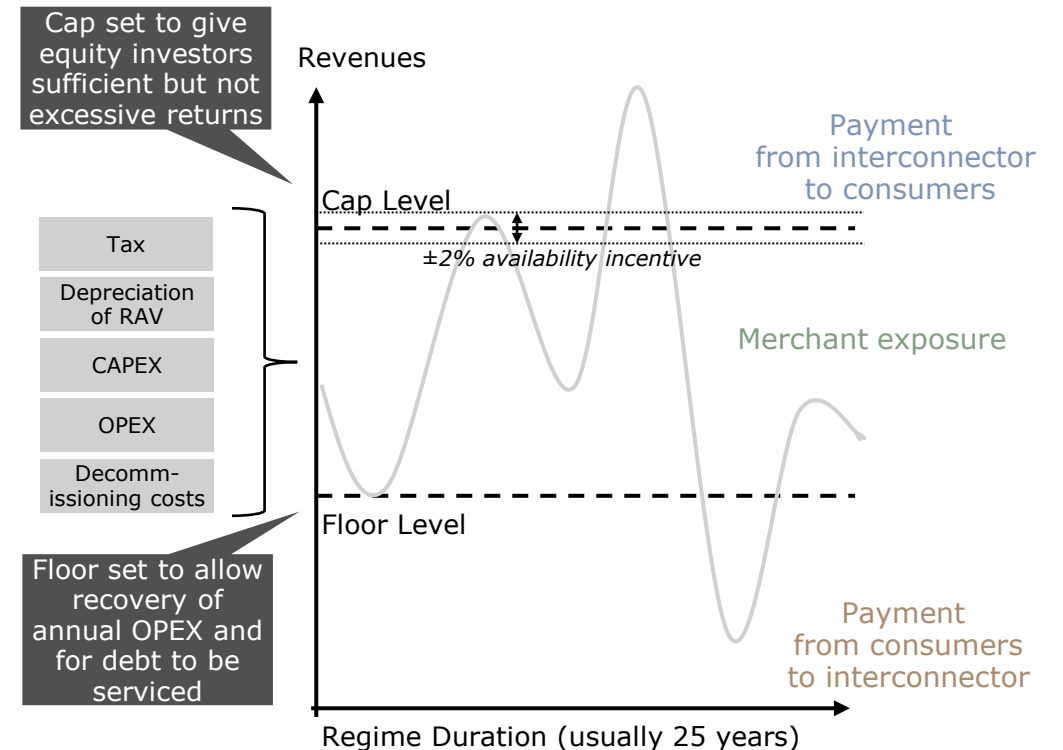
REGULATORY MODELS

The “Cap and Floor” revenue regulation model creates a merchant model within regulated bounds – leading example of ‘partially merchant’ model

CAP AND FLOOR OVERVIEW

- Projects that pass the **Initial Project Assessment (IPA)** (typically referenced against ‘system needs’) are granted a C&F regime in principle
- During the **Final Project Assessment (FPA)**, Ofgem assesses the efficiency of the project developer capital costs and preliminary cap and floor levels are decided. The final decision on granting the C&F regime is also finalised at this stage.
- The final levels of cap and floors are set at **Post Construction Stage (PCR)** once a review of the capital costs is conducted, and the efficiency of the operations and maintenance costs are assessed¹:
 - these are fixed (indexed) for the regime duration unless a reopener triggers including a review of the operating costs. The Cap and Floor levels are then profiled so that they are flat over time in real terms
 - there is an availability incentive applied to the cap level (1% change in the Cap for each percentage point deviation in availability from the target availability up to $\pm 2\%$)²
 - there is a minimum availability level of 80% for the application of the Floor
- Cap and floor levels are set ex-ante and remain fixed in real terms for the entire regime length

- The gap allowed between the cap and floor levels is created **by allowing different allowed rate of return on the project Regulated Asset Value (RAV)**
- For the Cap, the level of allowed return assumes 100% equity financing
- At the Floor, the allowed return is assuming debt financing



Note: (1) based on costs forecasts (2) the target availability level is set by Ofgem during FPA decision

REGULATORY MODELS

IC exemptions are carefully evaluated to balance regulatory flexibility and encourage investment while ensuring the stability of energy markets

HIGHLIGHTS

- IC built & owned by private sector
- Revenues derived from allocation of cross-zonal capacity with no downside protection / upside limitation
- **Exemptions from restrictions on use of revenue from congestion income granted**

OVERVIEW¹

- To encourage investments in infrastructure, Regulatory Authorities have the authority to grant exemptions to privately funded electricity interconnectors. These exemptions may include one or more of the following:
 1. Exemption from regulated third-party access (TPA)
 2. Relaxation of restrictions on the use of congestion revenues
 3. Relief from tariff regulation
 4. Exemption from ownership unbundling requirements
- As an example, ElecLink requested an exemption from all of the above provisions of European legislation for a period of 25 years
- The request was made to CRE and to Ofgem where ElecLink made the case that the "unique challenges of the project demonstrates the "specific nature of its Project and constituted a compelling case for ElecLink being treated as an exceptional case and being granted an exemption as provided in the regulations"⁴

REQUIREMENTS TO ACHIEVE EXEMPTION²

- According to the European Union Agency for the Cooperation Of Energy Regulators (ACER) to achieve exemption from National Regulatory authorities or ACER the interconnector project must prove:

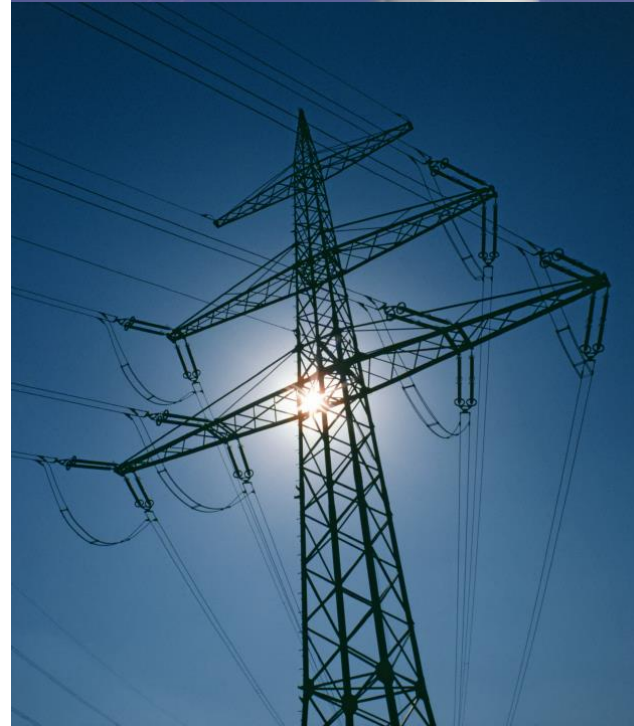
- 1** Enhances competition in electricity supply
- 2** The investment's risk level necessitates the exemption for it to proceed
- 3** The interconnection must be owned by a legally separate entity from the TSO in whose system it will be built
- 4** Must be built using private funds
- 5** The interconnection costs cannot be covered by usage fees from the connected transmission or distribution systems
- 6** The exemption does not harm the competition or the efficient functioning of the market or the regulated system

- In 2018 ACER published a decision in which it rejected exemptions for the AQUIND IC between France and GB. ACER's decision was based on the view that the AQUIND IC project does not fulfill the condition which necessitates that the level of investment risk is so high that the project would not proceed without an exemption³

Source: 1 Gautier, A. (2020), Merchant Interconnectors in Europe: Merits and Value Drivers, 2 Exemptions, ACER 2023 3 ACER Decision on the exemption request for the AQUIND interconnector, 2018 4 Final Joint Opinion of the Commission de regulation de l'énergie (France) and the Gas and Electricity Markets Authority (Great Britain) on ElecLink's exemption request

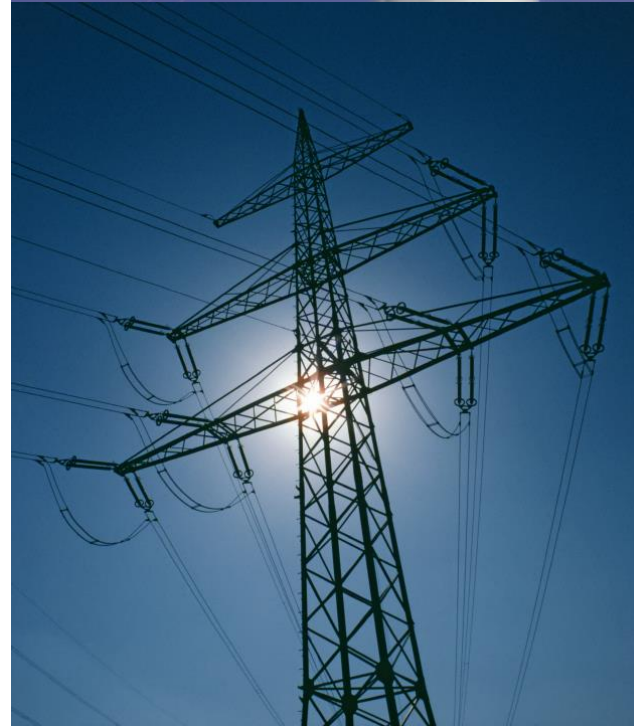
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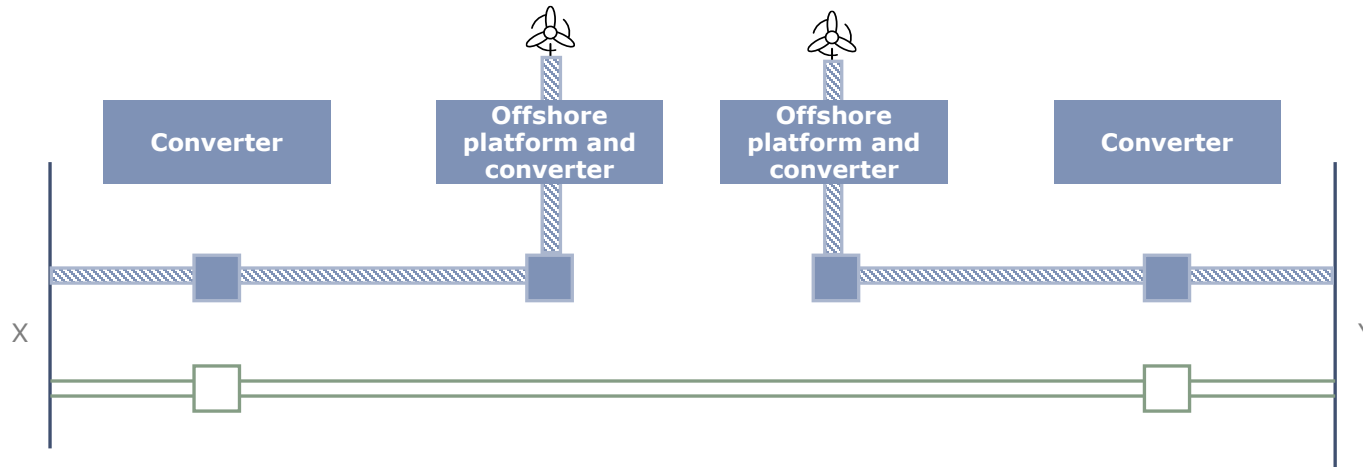
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Hybrid offshore transmission solutions combine cross-border interconnection with the transmission of offshore generation on shared-use assets

CONVENTIONAL

- Country X OWF and Country Y OWF connected radially to own market
- Point-to-point IC capacity connecting Country X and Country Y

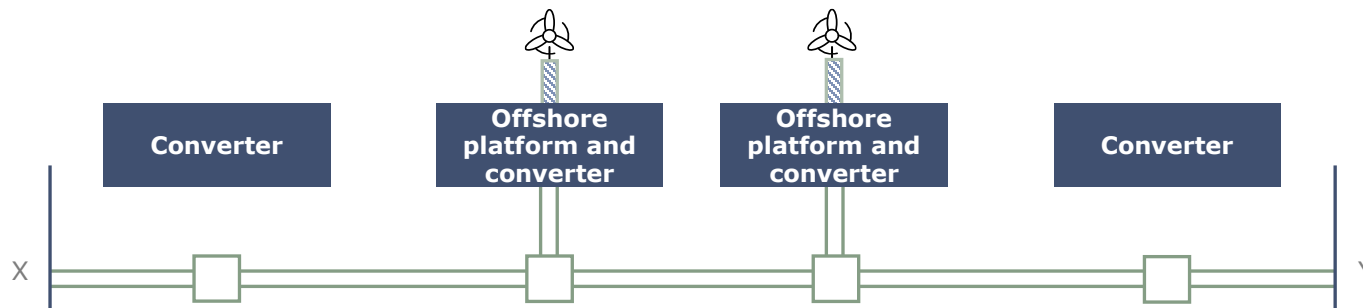


SINGLE USE TRANSMISSION ASSETS

i.e. discrete OWF transmission and interconnection assets

HYBRID OR MPI (EXAMPLE)

- Multi-use transmission provides connection and route to market for OWFs, while also providing market-to-market transmission capacity

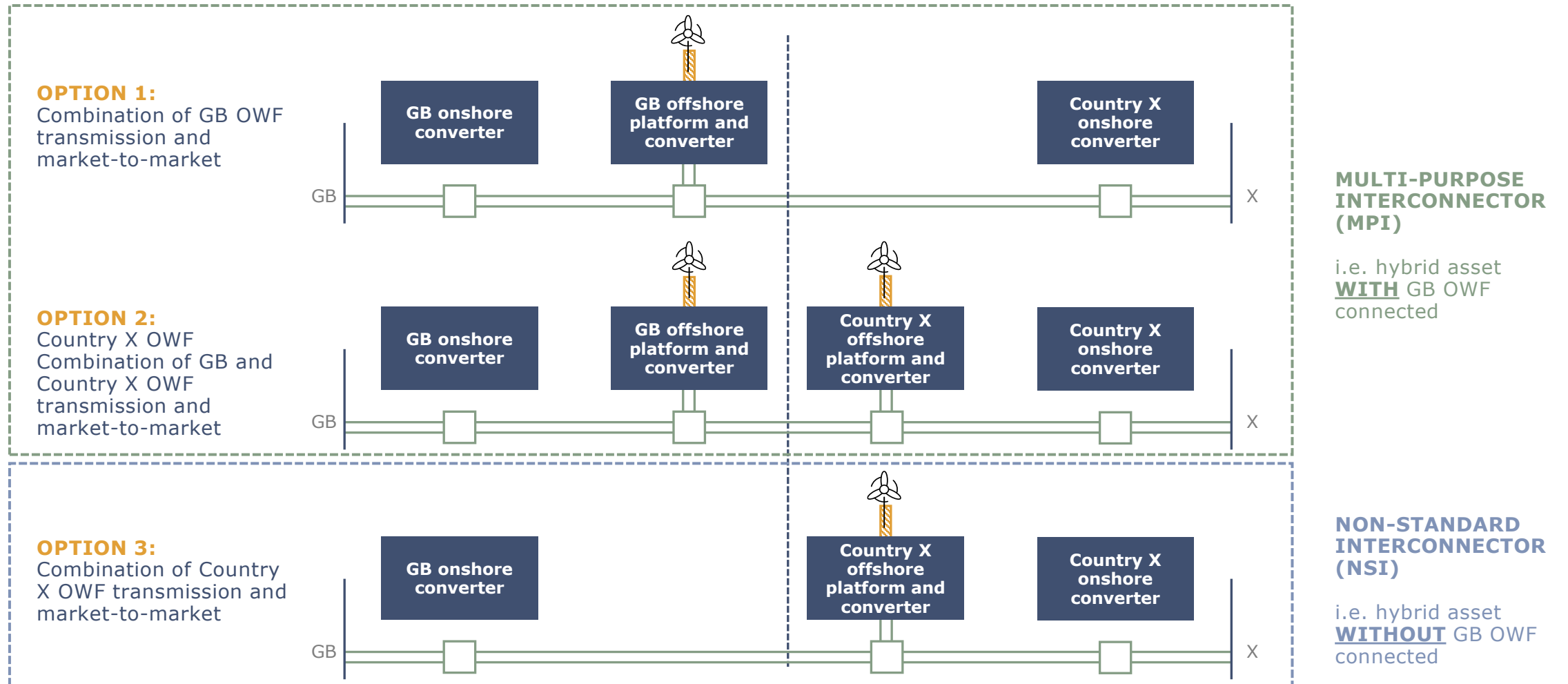


MULTI-USE TRANSMISSION ASSETS

i.e. shared assets for OWF transmission and interconnection

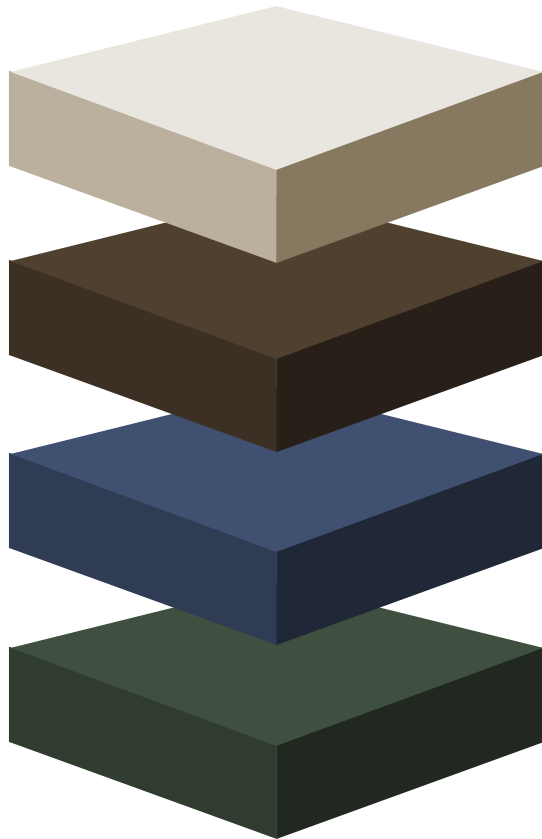
Note: Hybrid offshore transmission solutions are also known as Multi-purpose interconnectors or MPIs

In GB, Ofgem has developed the concept of “Offshore Hybrid Assets” as an umbrella term for hybrid offshore transmission, creating two distinctions



MPIs offer consumers advantages such as enhanced supply security, increased flexibility, and support for decarbonization efforts

BENEFITS OF CONVENTIONAL ICs



Security of Supply

They enhance energy reliability and security by allowing for the transfer of power between regions, ensuring a more stable energy supply

Prices

Can serve consumers by reducing electricity prices through increased competition and access to cheaper energy sources from interconnected regions

Grid Flexibility

Interconnection offers increased grid flexibility, as they enable the flow of electricity in response to demand and changing conditions.

Decarbonisation

Additionally, they facilitate the integration of renewable energy sources and contribute to decarbonization efforts by enabling the efficient sharing of clean energy across regions

SPECIFIC BENEFITS OF MPIs

- Multi-purpose interconnections (MPIs) build upon the advantages of point-to-point ICs, offering even more diverse and flexible ways to leverage benefits:

Capital Costs



Optimize transmission capacity, lowering capital costs by sharing infrastructure and reducing the need for multiple substations and extensive cabling in offshore wind projects

Environmental Impact



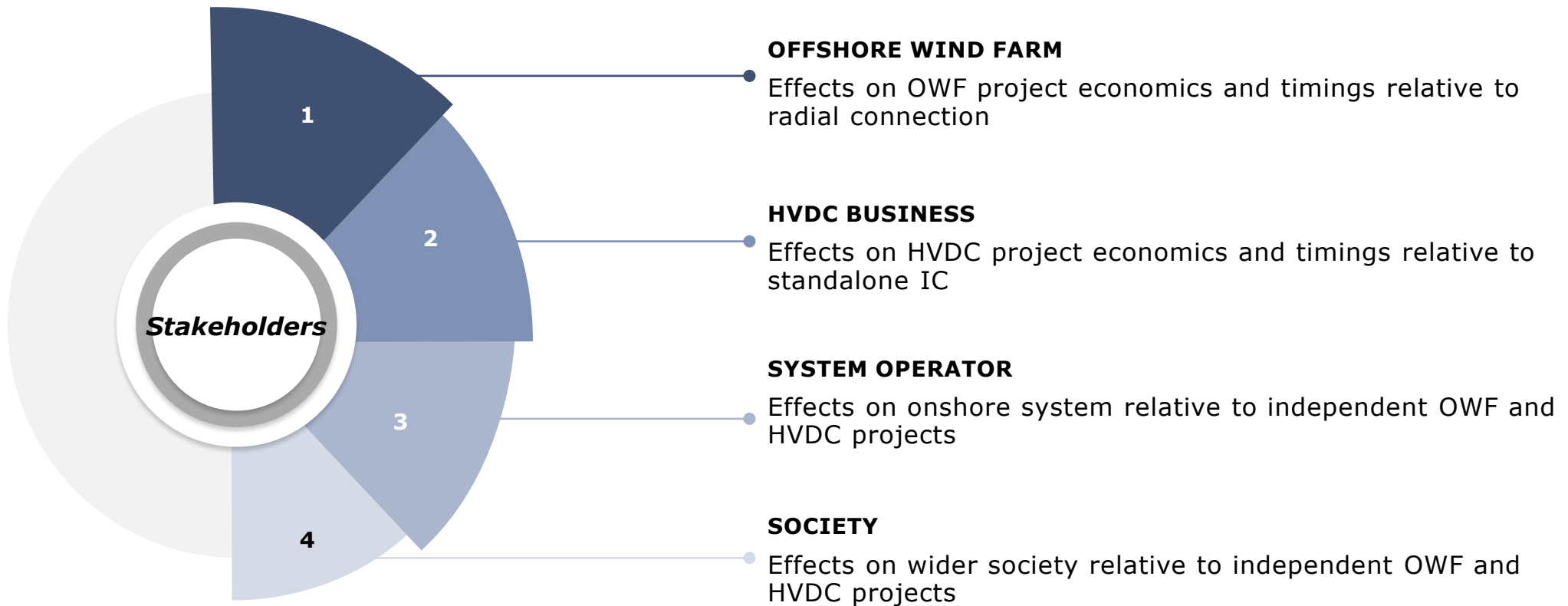
Can significantly lower environmental and community impacts. For example, MPI adoption may reduce the need for numerous landfall points and various new electricity assets, lessening cumulative concerns among local communities near coastal locations

RES Integration



Enable better integration of renewable wind energy into the grid by connecting to offshore wind generation. They create new routes for electricity imports while promoting domestic renewable energy generation for export during surplus production

Pros and cons of MPIs can be considered from the perspective of various stakeholders



MPIs come with pros and cons when examined from the viewpoints of various stakeholders, such as OWF owners, TSOs or IC owners

OFFSHORE WIND FARM

Potential pros	Potential cons
<ul style="list-style-type: none"> • Cost savings • Reduced planning, construction role • Reduced impact of connection scarcity 	<ul style="list-style-type: none"> • Uncertainty on access firmness • Increased risk given more meshed set-up

HVDC BUSINESS

Potential pros	Potential cons
<ul style="list-style-type: none"> • Cost savings • Increased use cases, future optionality 	<ul style="list-style-type: none"> • Reduced market-to-market availability and rent • Reliance on OWF project progression • Regulatory risks

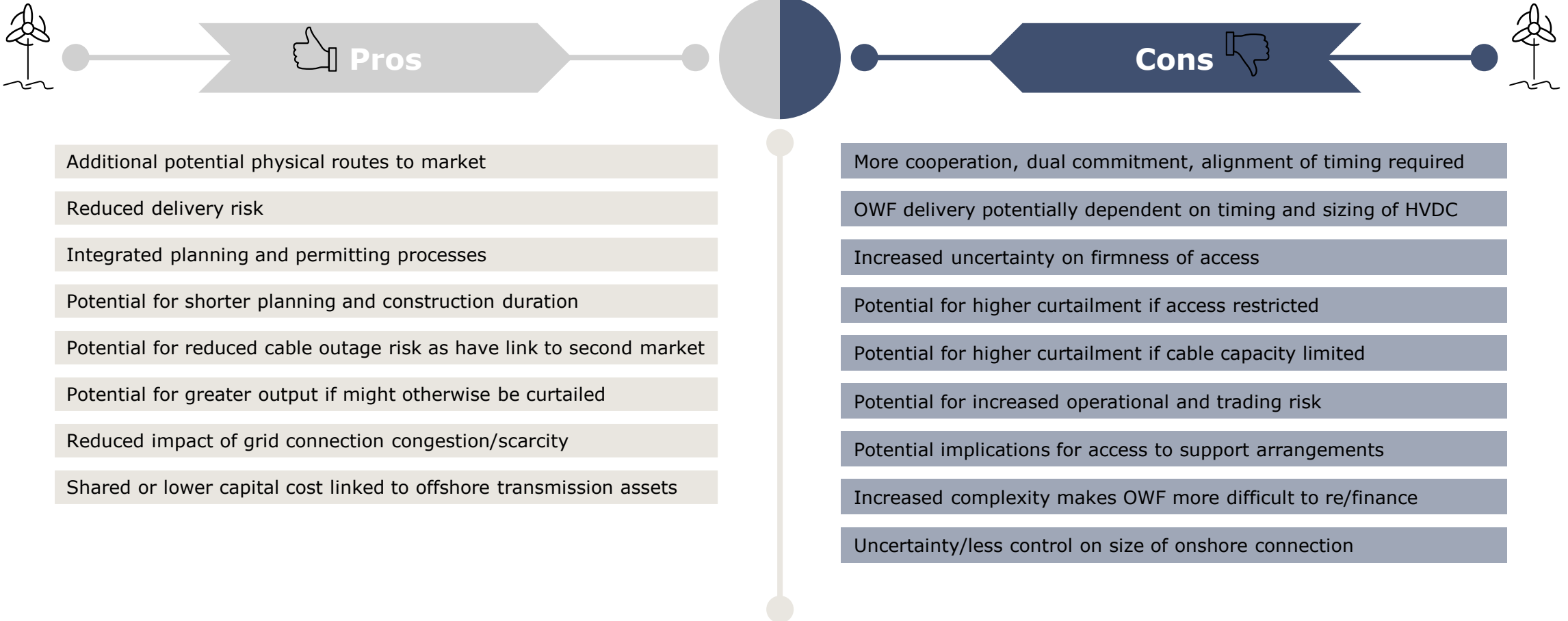
SYSTEM OPERATORS

Potential pros	Potential cons
<ul style="list-style-type: none"> • Reduced onshore build, reinforcement • Reduced onshore congestion 	<ul style="list-style-type: none"> • Increased scope for re-dispatch • Reduced scope for HVDC balancing services

SOCIETY

Potential pros	Potential cons
<ul style="list-style-type: none"> • Less cabling requirement • Less onshore construction disruption 	<ul style="list-style-type: none"> • Reduced construction jobs • Reduced investment

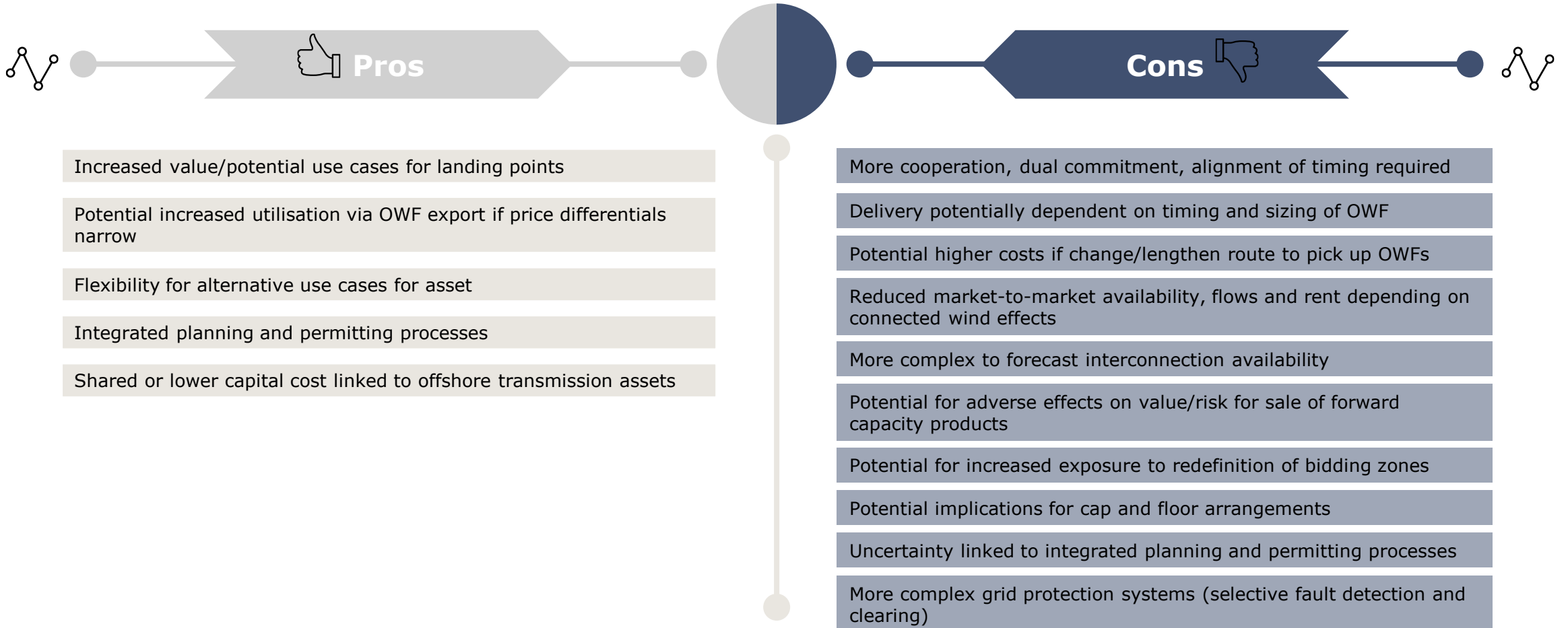
From the perspective of OWFs, MPIs offer increased market access but may pose challenges related to resource allocation and regulatory complexities



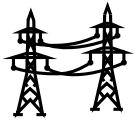
- Additional potential physical routes to market
- Reduced delivery risk
- Integrated planning and permitting processes
- Potential for shorter planning and construction duration
- Potential for reduced cable outage risk as have link to second market
- Potential for greater output if might otherwise be curtailed
- Reduced impact of grid connection congestion/scarcity
- Shared or lower capital cost linked to offshore transmission assets

- More cooperation, dual commitment, alignment of timing required
- OWF delivery potentially dependent on timing and sizing of HVDC
- Increased uncertainty on firmness of access
- Potential for higher curtailment if access restricted
- Potential for higher curtailment if cable capacity limited
- Potential for increased operational and trading risk
- Potential implications for access to support arrangements
- Increased complexity makes OWF more difficult to re/finance
- Uncertainty/less control on size of onshore connection

For IC owners, MPIs present revenue diversification opportunities but may entail operational complexities and regulatory uncertainty

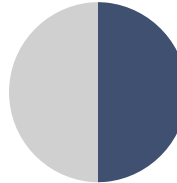


For TSOs, MPIs can help mitigate onshore grid congestion and reinforcement but may necessitate intricate coordination and planning with various stakeholders

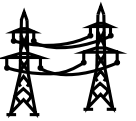


 **Pros**

- Reduced onshore planning and permitting requirements
- Reduced scale and costs of onshore reinforcement
- Reduced scale and costs of onshore congestion
- Reduced scale and costs of onshore investment given fewer landing sites

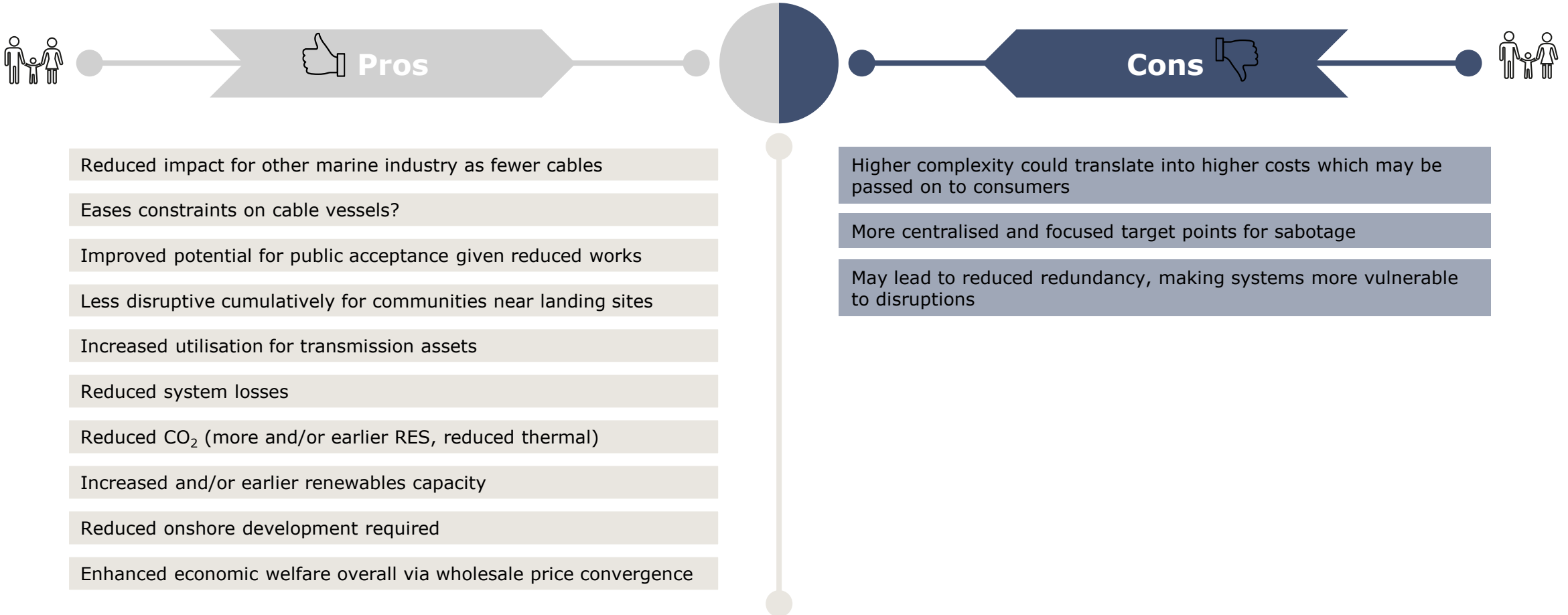


Cons 



- Potential scope for re-dispatch/countertrade to manage IC availability
- Potential implications for balancing costs if HVDC service provision restricted?
- Potential implications for connection fee income?
- Potential implications for existing planned reinforcements
- Introduction of potential resonance phenomena between converters
- Operational complexity

From a societal perspective, MPIs contribute to a more sustainable energy future and potentially lower electricity costs



MPIs offer potential cost savings compared to the combination of separate radially connected OWF and point-to-point interconnectors

OPTION 1 - STAND ALONE

Description	CAPEX	Calculations	Other Issues
In this option, the offshore wind farm connects to an offshore substation, and power is transmitted to Market 1 via a subsea cable (either AC or HVDC). Additionally, a separate point-to-point interconnector is constructed	Cost from the offshore substation to the shore: \$1 million per km + onshore connection cost	OWF: 1 billion Cables: \$1 million per km * 30 km = \$30 million + 3 million for onshore connection	Access to 1 market
	Distance from the offshore substation to the shore: 30 km		
	Cost of the point-to-point interconnector: \$500 m	Interconnector: \$500 million (including onshore connections)	Two separate permitting and planning processes
		Total = \$1.533 b	Higher environmental footprint

OPTION 2 - MPI

Description	CAPEX	Calculations	Other Issues
The offshore wind farm is connected to a multi-purpose interconnector that combines power export to both markets	Cost from the offshore substation to the shore: \$1 million per km + onshore connection cost	OWF: 1 billion Cables: \$1 million per km * 5 km = \$5 million	Access to 2 market
	Distance from the offshore substation to the MPI: 5 km		
	Cost of the point-to-point interconnector: \$500 m	Interconnector: \$500 million (including onshore connections)	Integrated planning and permitting process
		Total = \$1.505 b	Lower environmental footprint

Note: this is a worked example for illustrative purposes only, the numbers used are not based on any actual projects

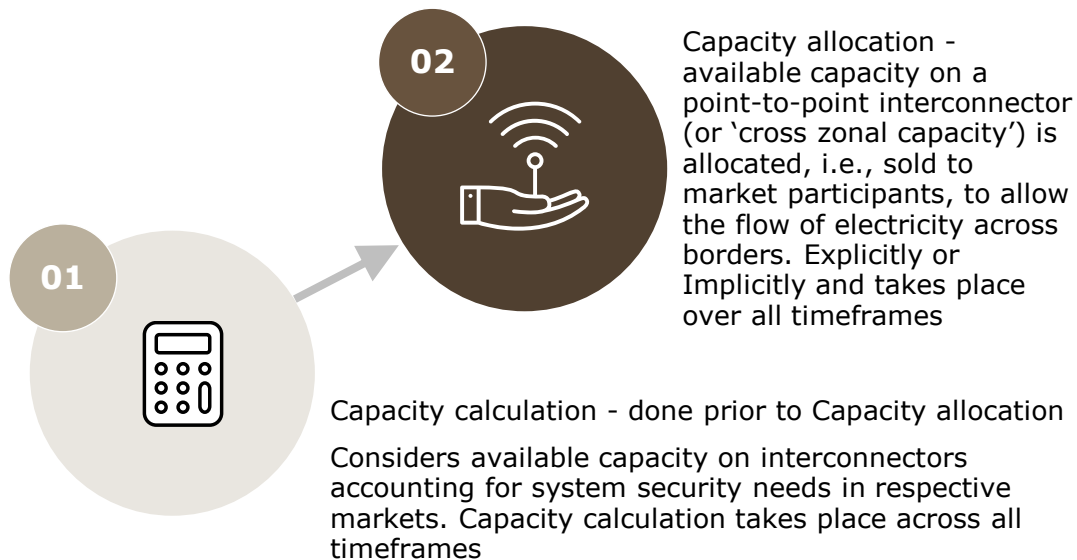
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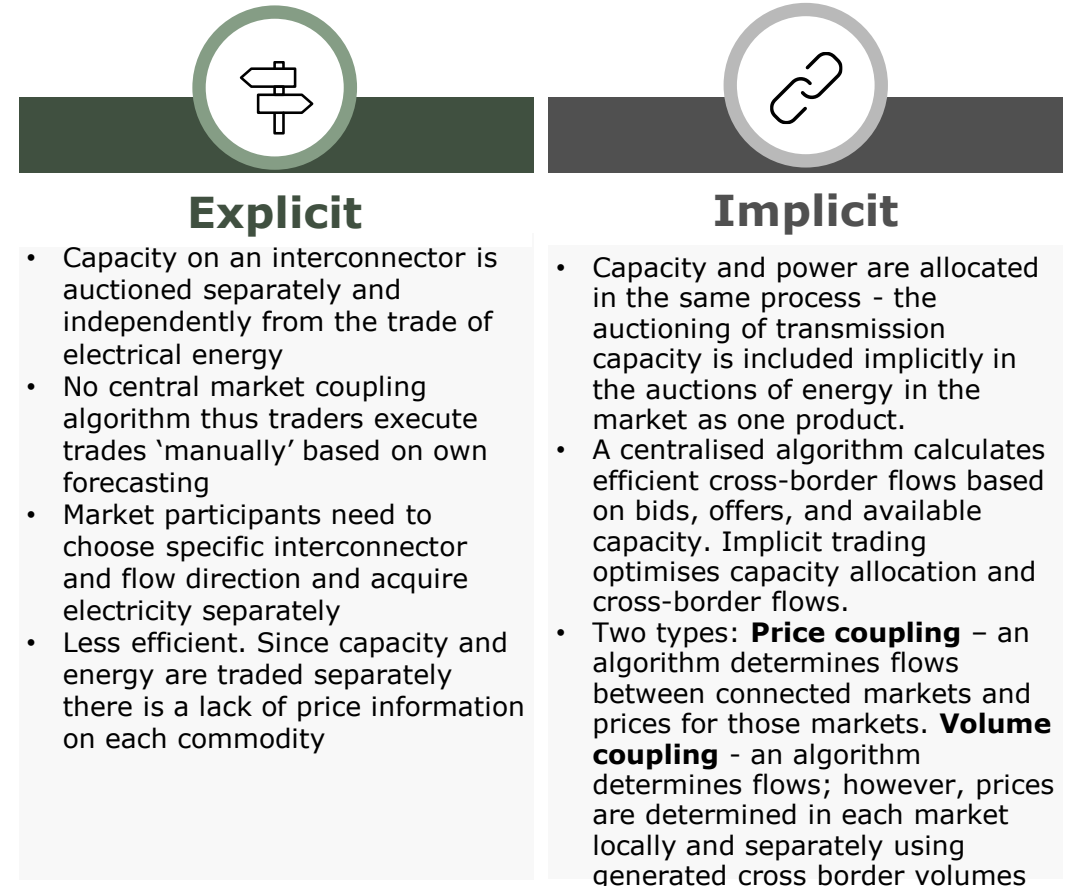


Likely that future trading arrangements for MPIs will be substantially based on existing features of cross-border market arrangements

CAPACITY ALLOCATION AND CAPACITY CALCULATION



EXPLICIT AND IMPLICIT TRADING (CAPACITY ALLOCATION)



Source: **1** Market Arrangements for Multi Purpose Interconnectors, Ofgem June 2023

Two models exist for operation of MPIs and connected windfarms

HOME MARKET (HM) MODEL

- The HM model is the current status quo and is similar to the model used for connecting offshore wind farms (OWFs) to the onshore grid.
- OWFs connected to Multi-Purpose Interconnectors (MPIs) will be considered part of their domestic or home bidding zone.
- Under the HM model, OWFs will have priority access to the MPI cable over cross-border capacity.
- This priority access ensures that OWFs are guaranteed a proportion of capacity on the MPI cable to transport their generated output to the domestic market.
- Due to the priority access and being part of the home bidding zone, OWFs will always bid into and receive the price of their domestic market.
- This holds true regardless of market forces and the direction of flows.

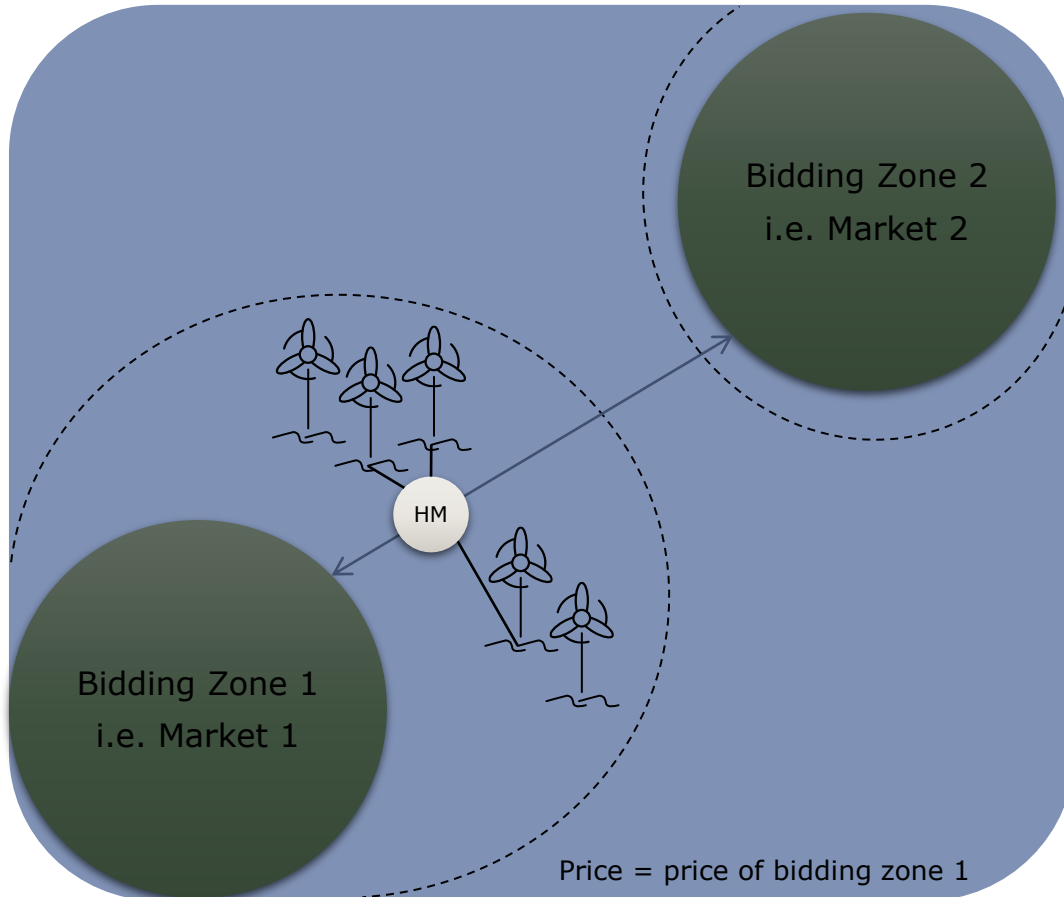
In summary, the HM model allows offshore wind farms connected to MPIs to have priority access to transmission capacity, ensuring they can transport their electricity to the domestic market and receive the price determined by that market, regardless of external factors.

OFFSHORE BIDDING ZONE (OBZ) MODEL

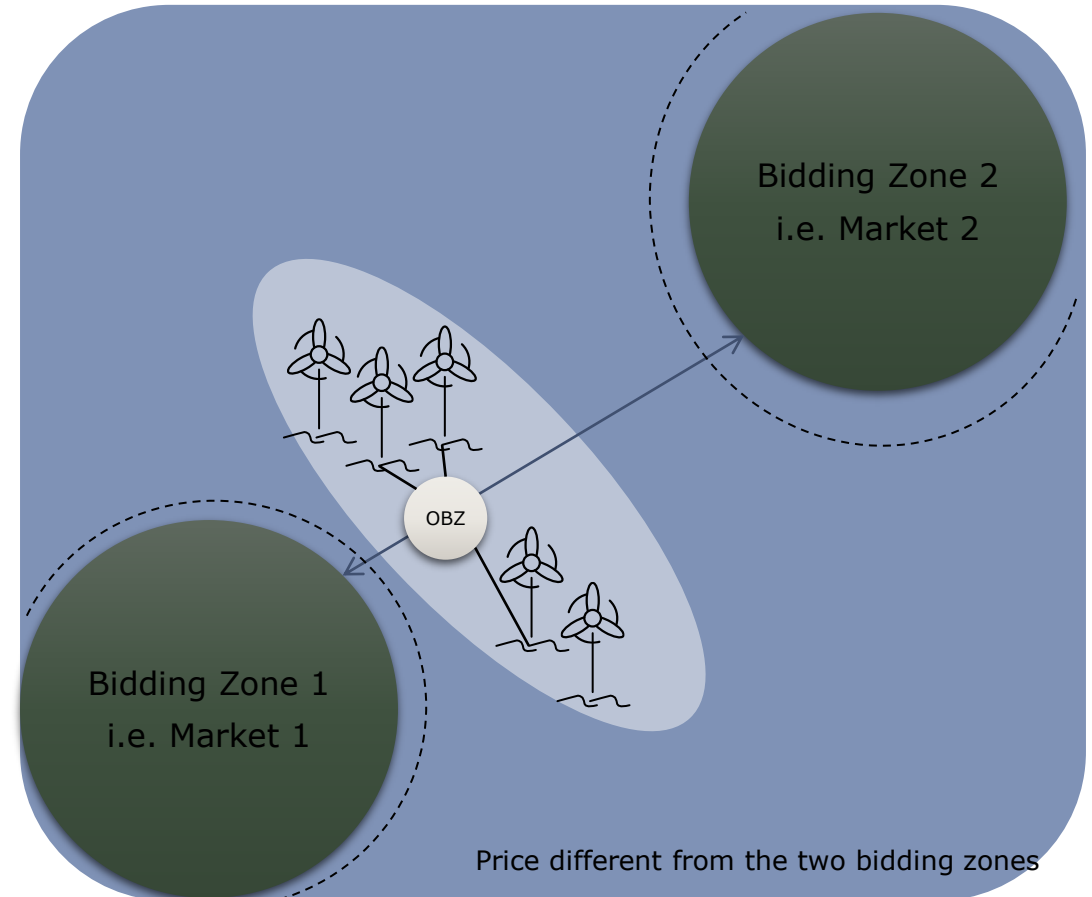
- Under the OBZ model, a separate bidding zone is created in the relevant jurisdiction for the OWF(s) connected to a single MPI.
- Instead of having priority access to cable capacity, the OWF will compete with bids/offers from other market players in onshore bidding zones for access to the cable that connects to all markets.
- Assuming implicit trading arrangements are in place, a central algorithm will match the bids and offers and dispatch the OWF to optimize the overall use of the MPI asset.
- As a result, the OWF is expected to usually receive the lowest price of the two onshore bidding zones to which it is connected.
- The central algorithm will match the OWF with the demand in the lower-priced zone, enabling the capacity of the cable to export supply from the lower-priced zone to the connected higher-priced zone.
- This approach mitigates forecast errors related to how much cable capacity is needed to export the OWF's generated electricity in a specific direction.
- The existence and use of a central algorithm will likely require a form of market coupling between GB and the EU.

The HM model is currently the status quo and is similar to the model used for current radial connections of OWFs to shore

HOME MARKET (HM) MODEL

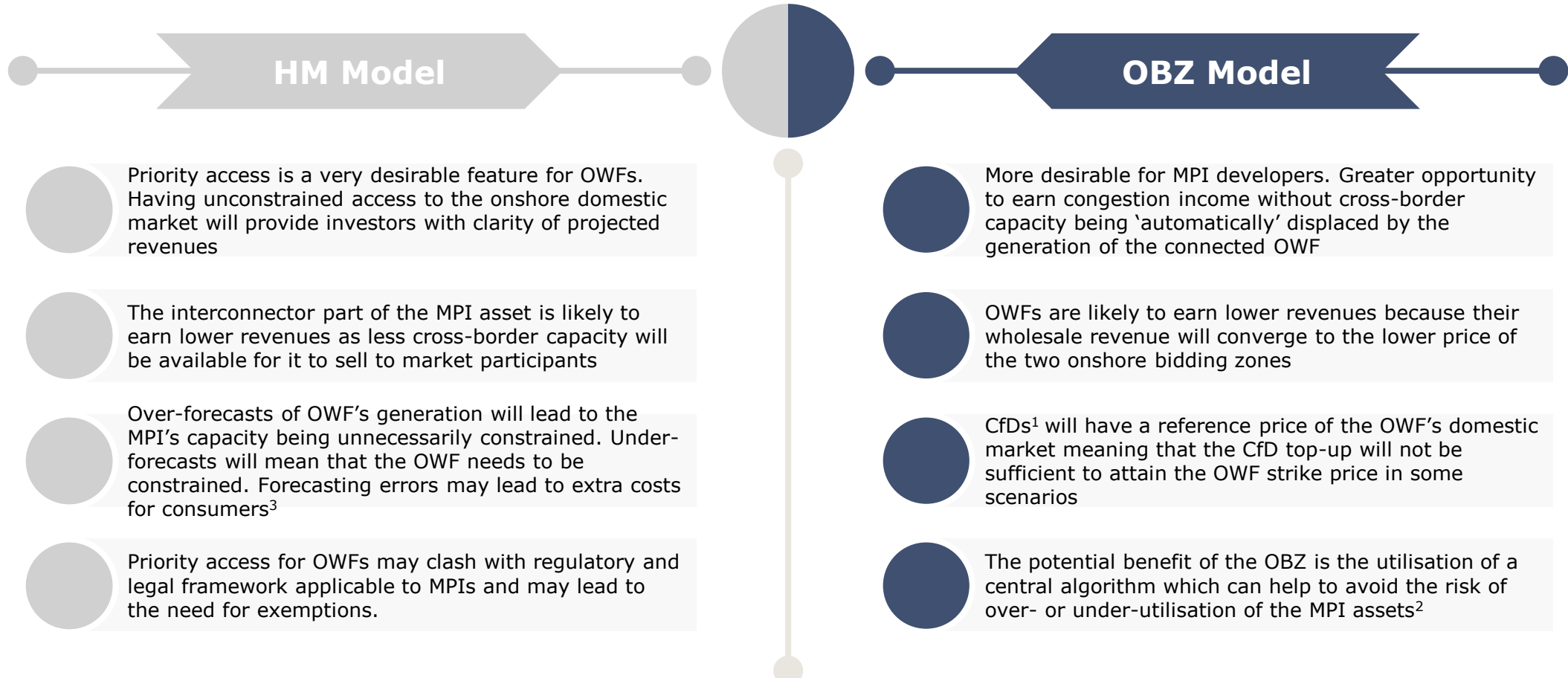


OFFSHORE BIDDING ZONE (OBZ) MODEL



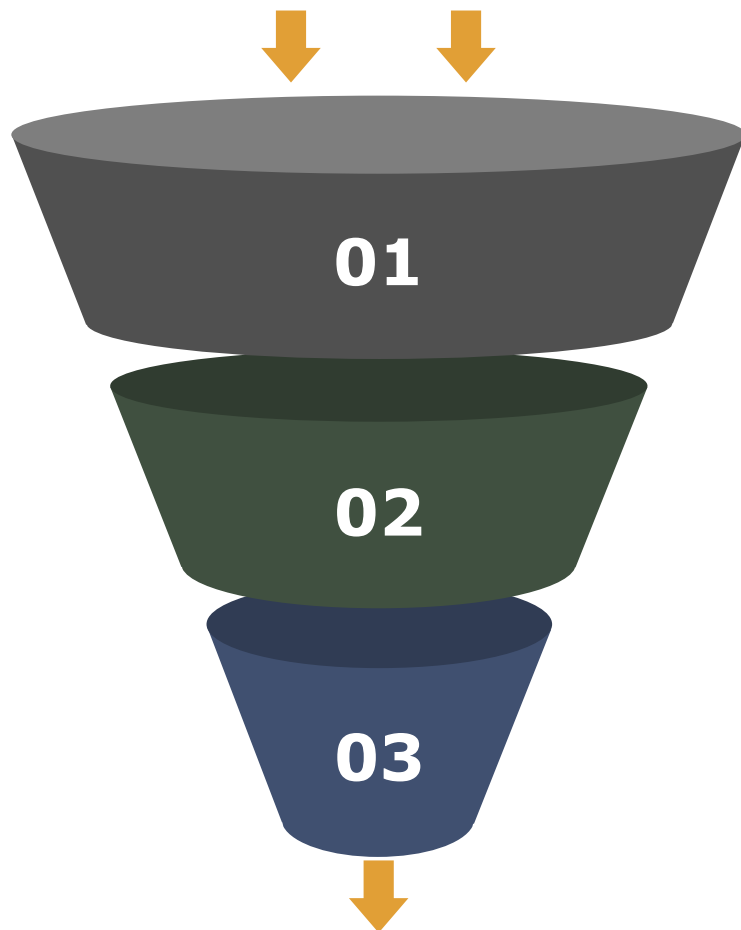
Source: 1 Market Arrangements for Multi Purpose Interconnectors, Ofgem June 2023

Both models come with various inherent benefits and risks



Note: **1** the eligibility and participation of MPI-connected OWF assets within the CfD scheme is still under consideration **2** this is on the assumption that implicit trading arrangements are in place **3** Detailed example of inefficiencies in the HM model provided on page 30 of the consultation

Examining HM and OBZ models qualitatively using market efficiency, consumer benefits and integration of renewables lenses favours OBZs



Market efficiency

- The OBZ model is better able to reflect the physical realities of all connected networks including MPI capacity. The HM model would potentially lead to inefficient cable usage, challenges in cost allocation and recovery, and the need for corrective actions, potentially affecting imported renewable generation. This is due to the OWF having priority access in a HM model.
- The OBZ arrangement considers competition throughout the network and optimally allocates resources using a centralized algorithm to ensure efficient cable utilization.


Consumer benefits

- HM Model is expected to result in remedial and imbalance costs due to forecast errors coupled with OWF priority access which ultimately will fall onto the consumer.
- The OBZ model, on the other hand, mitigates these constraints but introduces a revenue risk for the OWF.

Integration of renewables

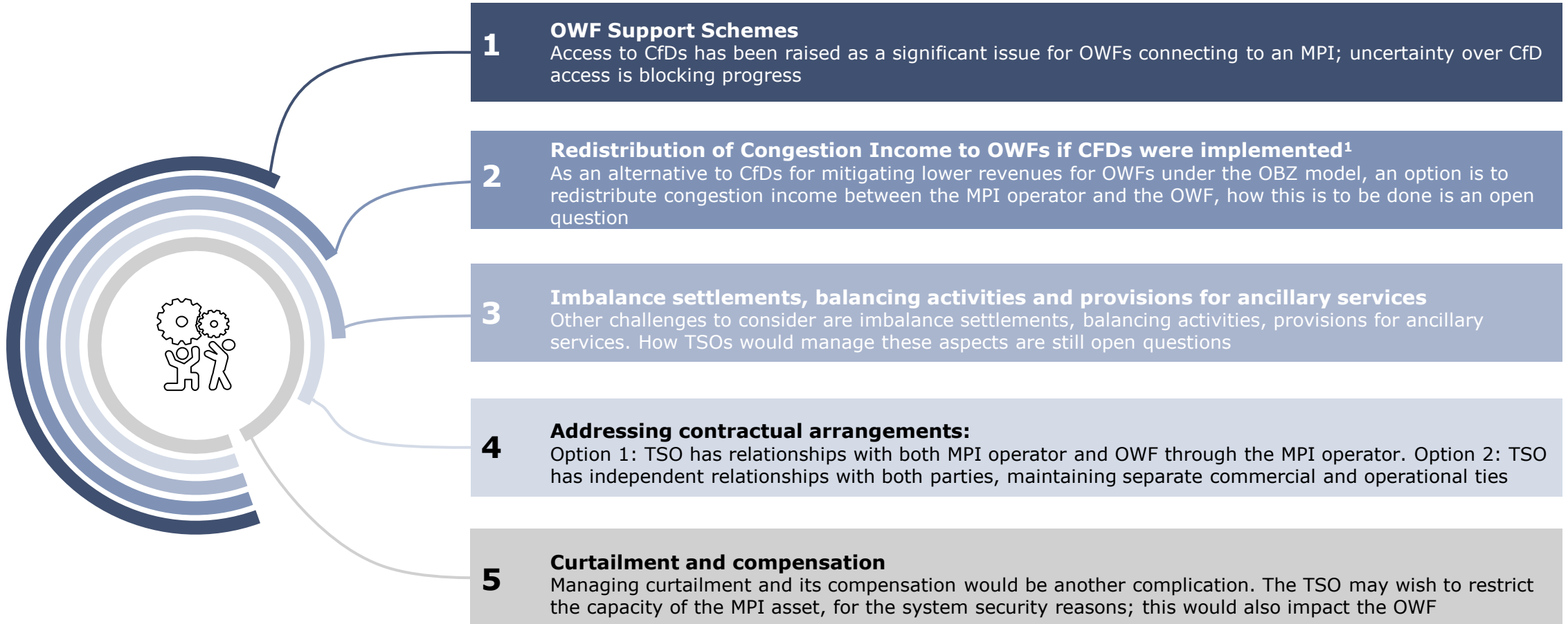
- The OBZ model is better able to reflect the realities of the entire network.
- Flows will be more efficient in reducing the need for curtailment of connected OWFs.
- Curtailment, possible under the HM, may lead to fossil fuel-based, generation to compensate for that curtailed OWFs.

After consulting various stakeholders, Ofgem determined that implicit trading & OBZ market arrangement is the most efficient solution for MPIs

 <p>Low to High Ranking</p>	Options	Description	Commentary
	1. Implicit trading & OBZ	<ul style="list-style-type: none"> - This option was identified by stakeholders as the most efficient solution for MPIs 	<p>The ranking presented in the table reflects Ofgem’s current thinking, and they believe it also reflects the broad consensus among the stakeholders.</p> <p><i>However, certain stakeholders argued that Option 4, would be preferable to Options 2 and 3 (i.e., the two HM options). In their view, the negatives associated with the HM model in terms of increased need for constraint management, outweighed the likely inefficiencies (i.e., increased flows against price direction and underutilisation of capacity) arising from trading over an MPI on the explicit basis.</i></p>
	2. Implicit trading & HM	<ul style="list-style-type: none"> - This option contains benefits of implicit trading, but inefficiencies and challenges of HM configuration remain, influencing the overall design. - Stakeholders argued that if there is an implicit trading available, it will be better to move to OBZ to realise full efficiency and benefits of that configuration. 	
	3. Explicit trading & HM	<ul style="list-style-type: none"> - This option was identified by stakeholders as a 'fallback arrangement' in the 'status quo' scenario where there is no implicit trading available. - Nevertheless, it was identified by stakeholders as slightly better than the last option but less efficient than the one above. 	
	4. Explicit trading & OBZ	<ul style="list-style-type: none"> - This option was identified by stakeholders as the least efficient combination of bidding zone configuration and trading arrangements. - This is due to operational complexities and inefficiencies of explicit trading which can be exacerbated under the OBZ. 	

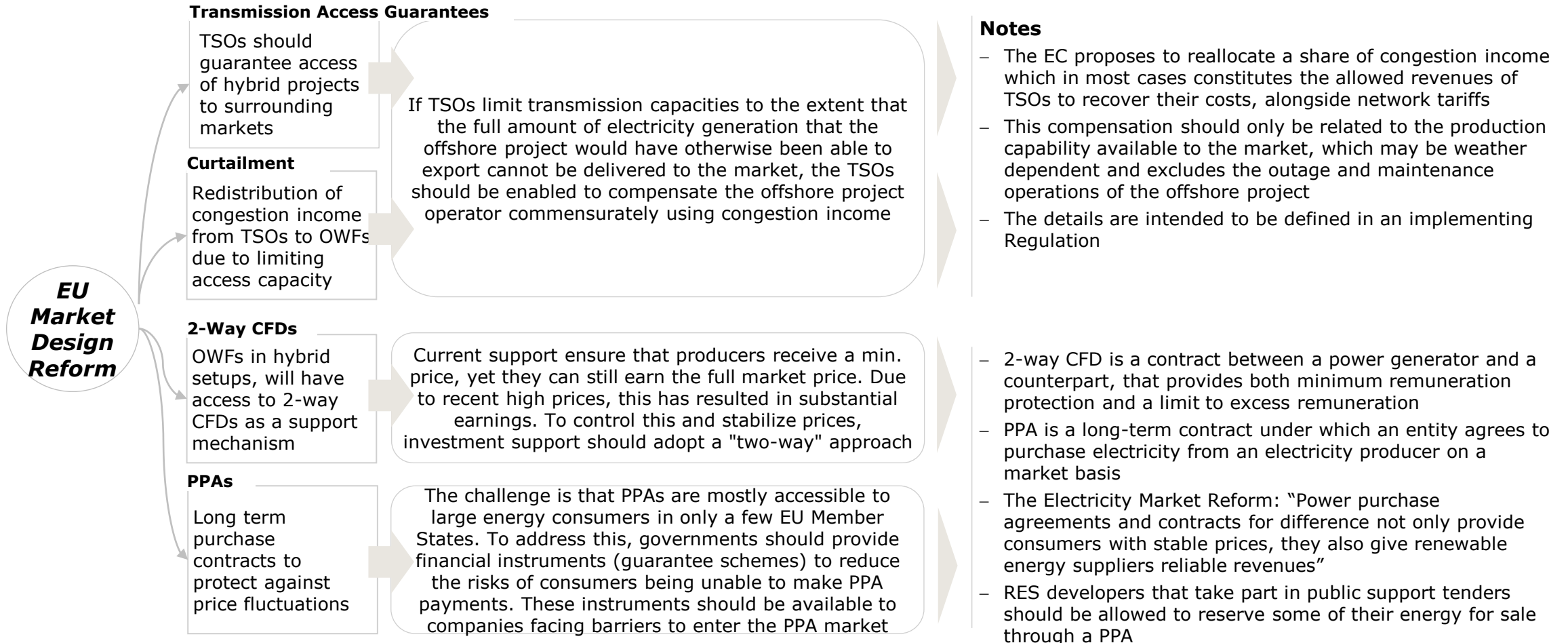
Source: 1 Market Arrangements for Multi Purpose Interconnectors, Ofgem June 2023

Apart from selecting the most efficient market arrangements questions remain about managing other critical aspects of MPIs



Note: ¹ In an OBZ model, OWFs receive the lowest price of the two bidding zones they are coupled with - In an exporting scenario a CfD will still function but not in an importing scenario
Source: Market Arrangements for Multi Purpose Interconnectors, Ofgem June 2023

In Oct-23, the EU Council reached an agreement on the proposal to amend the EU's Electricity Market Design; however, this is yet to be legally adopted



Source: Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulations

The Council of the EU has approved plans to compensate OWFs for lower prices due to OBZs by redistributing congestion income from TSOs to OWFs

EX-ANTE (VIA PRE-ALLOCATING FTRs)

What is it:

- Aims to redistribute the congestion income to OWFs through preferential (or potentially free) allocation of Financial Transmission Rights (FTRs) to the OWF by the MPI operator
- e.g. via auctions or direct allocation of a portion of FTRs.

ENTSO-E view:

- Ex-ante allocation of FTRs under preferential conditions would violate FCA Regulation
- LTTRs could either over- or under-compensate OWFs
- Will be difficult to determine exact volumes of FTRs to allocate
- That length of pay-out might be a point of concern (FTRs are usually auctioned one year ahead, while OWFs require long-term revenue stability)

- *FTRs are financial instruments or contracts that allow market participants to hedge or speculate on the price differences and congestion risks associated with the transmission of electricity across interconnectors. FTRs provide the holder with a financial entitlement or obligation based on the price spread between two different locations connected by the interconnector.*

EX-POST

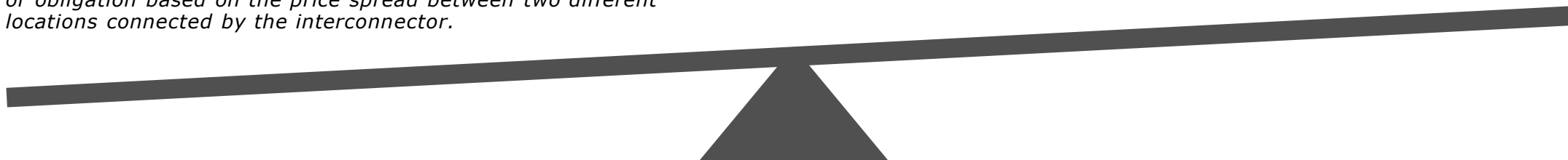
- Also explored in GB under the concept of Wind Adjusted Financial Transmission Rights (WAFTRs)

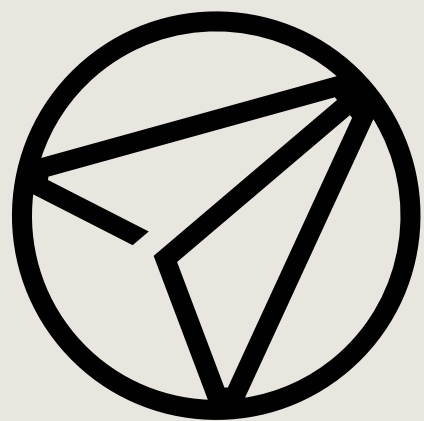
What is it:

- Ex-post approaches aim to redistribute congestion income directly to OWFs through re-allocation of the portion of congestion income equal to the difference between OWFs revenues in OBZ compared to HM configuration, based on actual generation. This is envisaged to be applied on top of a traditional CfD mechanism.

ENTSO-E view:

- “reallocating congestion income would potentially be based on arbitrary and non-market-based principles”.
- This approach will not be compatible with Article 19 of EU Electricity Regulation and Article 59 of Electricity Directive 2019/944 (no cross-subsidisation between transmission and other electricity activities)





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